THE EFFECT OF BREAKFAST ON COGNITIVE AND ACADEMIC PERFORMANCE IN SCHOOL CHILDREN

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The candidate confirms that the work submitted is her own, except where work which has formed part of jointly-authored publications has been included. The contribution of the candidate and the other authors to this work has been explicitly indicated below. The candidate confirms that appropriate credit has been given within the thesis where reference has been made to the work of others.

Chapter 4 is partly based on the jointly-authored publication:

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The candidate confirms that she was solely responsible for performing the literature searches and the synthesis of the evidence contained in this publication. The candidate wrote the first draft of the paper. The co-authors edited the paper for publication and provided advice on interpretation.

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Abstract

Breakfast is thought to be beneficial for cognitive and academic performance in school children. However, breakfast is the most frequently skipped meal, especially in adolescents. The overall aim of this thesis was, therefore, to elucidate the effects of breakfast consumption on the cognitive and academic performance of children and adolescents. This aim was addressed via two systematic research reviews (SRRs) and three research studies. The first SRR (SRR 1) reviewed the evidence from 54 studies examining the effects of breakfast on cognitive performance in children and adolescents and reported equivocal findings. SRR 1 also highlighted the methodological limitations of the existing research which might explain these mixed findings. These include a lack of research on adolescents, few ecologically valid breakfast manipulations or testing environments, small samples, insensitive cognitive tests and rare assessment of subjective state. Study 1 (n=226) aimed to address these issues by examining the acute effects of breakfast vs. no breakfast on cognitive performance and subjective state and task demand in adolescents (11-13 years). SRR 1 suggested that breakfast consumption vs. fasting has a short-term positive domain specific effect on cognition. Similarly, Study 1 showed the effects of breakfast consumption on cognitive performance were modest and specific to reaction time, but there were significant enhancements in subjective alertness, mood, motivation and concentration. The second SRR (SRR 2) reviewed the evidence from 25 studies examining the effects of breakfast on more ecologically relevant academic outcomes in children and adolescents. However, the paucity of studies and absence of studies in UK school children limited the ability to generalise the findings. Therefore, Studies 2 (n=292) and 3 (n=294) examined the association between habitual breakfast consumption frequency and academic performance outcomes used in the British school system; the Cognitive Abilities Test (CAT) and the General Certificate of Secondary Education (GCSE). SRR 2 revealed a consistent positive association between habitual breakfast consumption frequency and school grades in adolescents. In contrast, Study 2 found no association between habitual breakfast consumption frequency and CAT performance in 11-13 year olds. Methodological considerations were identified which could account for this discordance with previous research (SRR 2) and were applied in Study 3. Following adjustment for covariates, Study 3 concluded that rarely consuming breakfast on school days (≤1 school-day per week) predicted lower aggregated GCSE performance. Although further examination of the relationship between breakfast, cognitive and academic performance is needed, these findings from over 600 school children demonstrate that breakfast consumption has a subtle but significant effect on learning in school children.

List of publications and presentations from this thesis

Publications

Adolphus, K., Lawton, C. L., & Dye, L. (2013). The effects of breakfast on behaviour and academic performance in children and adolescents. *Frontiers in Human Neuroscience, 7*. doi: 10.3389/fnhum.2013.00425

Adolphus, K., Lawton, C. L., & Dye, L. (2015). The relationship between habitual breakfast consumption frequency and academic performance in British adolescents. *Frontiers in Public Health, 3,* doi: 10.3389/fpubh.2015.00068.

Abstracts

Adolphus, K., Lawton, C. L., & Dye, L. (2013). Breakfast consumption in 16-18 year olds: Current trends in consumption patterns and the associations with weight status. *Annals of Nutrition and Metabolism*; 63 (Suppl. 1), 1-1960

Adolphus, K., Lawton, C. L., & Dye, L. (2013). The effects of breakfast on in-class behaviour in children and adolescents. *Annals of Nutrition and Metabolism*; 63 (Suppl. 1), 1-1960

Presentations

Adolphus, K., Lawton, C. L., Asoko, H., & Dye, L. (2011). Does breakfast improve academic performance? The School of Education, University of Leeds, Research in Collaboration with Schools Conference, June, 2011,

Adolphus, K., Lawton, C. L., Asoko, H., & Dye, L. (2011). The acute effects of breakfast on cognitive performance and feelings of subjective state. University of Leeds Postgraduate Conference, October, 2011.

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Adolphus, K., Lawton, C. L., & Dye, L. (2013). The effects of breakfast on in-class behaviour in children and adolescents. Nutrimenthe conference, Spain, September 2013

Adolphus, K., Bhutter, M., & Clift, J (2013). Making the most of your ESRC studentship. ESRC PhD Student Conference, Westminster, London, 2013.

Adolphus, K., Lawton, C. L., & Dye, L. (2014). The impact of breakfast on academic performance, behaviour and cognitive performance in school children. British Psychological Society, Impact Portal, Podcast, August, 2014.

Adolphus, K., Lawton, C. L., & Dye, L. (2013). The effects of breakfast on classroom behaviour, cognitive and academic performance. Psychology Outreach Conference, Access and Community Engagement, University of Leeds, July 2013.

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List of Abbreviations

ACh	Acetylcholine
Actyl-CoA	Actyl-coenzyme A
AE	Adverse event
ANCOVA	Analysis of covariance
ANOVA	Analysis of variance
APA	The American Psychological Association
AUCi	Incremental Area Under Curve
BMI	Body Mass Index
BMI SDS	Body Mass Index standard deviation scores
BMR	Basal Metabolic Rate
BTEC	Business and Technology Education Council
CANTAB	CAmbridge Neuropsychological Test Automated Battery
CAT	Cognitive Abilities Test
CI	Confidence Intervals
COA	Continuity of Attention (factor scores)
CPM	Coloured Progressive Matrices task
CPT	Continuous Performance Task
CRT	Choice Reaction Time
df	Degrees of Freedom
EAL	English as an Additional Language
EEG	Electroencephalography
EFSA	The European Food Safety Authority
ERP	Event Related Potentials
FSM	Free School Meals
GCSE	The General Certificate of Secondary Education
GG	Greenhouse Geisser correction
GI	Glycaemic Index
GL	Glycaemic Load
GSA	Guideline Serving Amount
HBSC	Health Behaviour in School-age Children
HELENA	HEalthy Lifestyle in Europe by Nutrition in Adolescence
IPS	Institute of Psychological Sciences
IQ	Intelligence Quotient
LEA	Local Education Authority
LSM	Least Square Mean
MFFT	Matching Familiar Figures Test
NCHS	National Centre for Health Statistics

NHANES	National Health and Nutrition Examination Survey
NICE	National Institute of Clinical Excellence
NC	National Curriculum
OR	Odds Ratio
PAL	Paired Associates Learning test
POA	Power of Attention (factor scores)
QEM	Quality of Episodic Memory (factor scores)
RAVLT	Rey Auditory Verbal Learning Test
RCFT	Rey-Osterrieth Complex Figure Task
RCN	Royal College of Nursing
RCT	Randomised Controlled Trial
RDA	Recommended Daily Allowance
RNI	Reference Nutrient Intake
RTEC	Ready-to-eat cereal
RVIP	Rapid Visual Information Processing
SACN	Scientific Advisory Committee on Nutrition
SAS	Standard age scores
SBP	School Breakfast Program
SD	Standard deviation
SE	Standard error
SES	Socio-economic status
SM	Secondary Memory (factor scores)
SOM	Speed of Memory (factor scores)
SPSS	Statistical Package for the Social Sciences
SRR	Systematic Research Review
SRT	Simple Reaction Time
TEE	Total Energy Expenditure
UK	United Kingdom
VAS	Visual Analogue Scales
WHO	World Health Organisation
WISC	Wechsler Intelligence Scales for Children
WM	Working Memory (factor scores)
WPPSI	Wechsler Preschool and Primary Scale of Intelligence test
χ^2	Pearson’s Chi-squared

1 General Introduction and Thesis Aims

1.1 Benefits of breakfast consumption

Breakfast is generally accepted to be the most important meal of the day and is purported to confer a number of benefits for diet quality, health, cognitive and academic performance. Despite this, many people, especially adolescents, omit breakfast from the diet (Vereecken et al., 2009). Hence, it is important to evaluate the evidence for breakfast benefits and to consider the likely consequences of breakfast omission.

1.1.1 Breakfast and learning in children and adolescents: The focus of this thesis

There is a growing body of evidence that breakfast, relative to breakfast omission, and certain breakfast types, positively affects aspects of cognitive and academic performance (Adolphus, Lawton, & Dye, 2013; Hoyland, Dye, & Lawton, 2009). Nutrition is a particularly important environmental variable to consider in relation to cognitive and academic performance because it can be manipulated relatively easily. Breakfast has received particular attention in preference to other meals because it is consumed early in the day. Breakfast, therefore, has the potential to impact on the ability of school children to concentrate at school, which may benefit learning and academic performance (Bellisle, 2004).

Glucose is the main fuel for the brain and its capacity to store glucose as glycogen is limited. The brain relies on a constant supply of glucose for optimal functioning through the blood-brain barrier (Messier, 2004). Hence, much of the research on breakfast and learning stems from the belief that ingestion of breakfast improves cognitive function via increased glucose availability in the brain to fuel neuronal activity (Messier, 2004). Indeed, glucose-induced improvements in cognitive performance are well documented, such that healthy individuals consuming 25g of glucose perform better on cognitive function tasks relative to those given a placebo (Riby et al., 2006).

Children and adolescents have received particular attention in relation to the effects of breakfast for a number of reasons. Firstly, children and adolescents may be particularly vulnerable to the nutritional effects of breakfast on brain activity and associated cognitive and academic outcomes. Children have a higher brain glucose metabolism compared with adults. Positron emission tomography studies indicate that cerebral metabolic rate of glucose utilisation is approximately twice as high in children aged 4-10 years than adults. This higher rate of glucose utilisation gradually declines from age 10 and usually reaches adult levels by the age of 16-18 years (Chugani, 1998). Moreover, the longer overnight fasting period, due to higher sleep demands during childhood and adolescence can deplete glycogen stores overnight (Thorleifsdottir, Björnsson, Benediktsdottir, Gislason, & Kristbjarnarson, 2002). To maintain this higher metabolic rate, a continuous supply of energy derived from glucose is needed. Hence breakfast consumption may be vital in providing adequate energy for the morning. Childhood and adolescence are also important stages for cognitive development and intense learning at school (Casey, Galvan, & Hare, 2005; Luciana, 2003). Since children sometimes, and adolescents often, skip breakfast (see section 1.2) this may represent an important issue for cognitive and academic performance. Hence, the focus of this thesis is the examination of the effects of breakfast on learning in school children, with a specific focus on cognitive and academic outcomes.

1.1.1.1 Breakfast and cognitive performance

The first aim of this thesis was to examine the effects of breakfast relative to no breakfast, and breakfast composition, on cognitive performance in children and adolescents using systematic research review (SRR) methodology. The SRR performed is reported in Chapter 2. This SRR was conducted in order to update the findings of a previous systematic review published by Hoyland et al. (2009). In addition to addressing the first thesis aim, this SRR was also undertaken to highlight the limitations of the existing research which could be addressed in further experimental work presented in this thesis. Therefore, the outcomes of this SRR served to develop the second and third aims of this thesis which were; firstly to examine the acute effect of consuming breakfast vs. breakfast omission on cognitive performance in adolescents aged 11-13 years and secondly, to examine the acute effect of consuming breakfast vs. breakfast omission on subjective state (satiety, mood, alertness and motivation) in adolescents aged 11-13 years. These aims were addressed by the acute intervention study (Study 1) reported in Chapter 3. It was decided to focus this experimental work (Study 1, Chapter 3) on the acute, rather than the chronic effects, of breakfast consumption for a number of reasons. Many acute intervention studies reported in the SRR had small samples. Study 1 therefore aimed to achieve adequate statistical power and is the largest acute study performed in the UK to date. In addition, it was noted in the SRR (Chapter 2) that chronic interventions have inherent problems with attributing the effects of breakfast to breakfast consumption *per se* rather than the regime of providing breakfast at school.

Although the SRR (Chapter 2) did reveal some effects of breakfast type on cognitive performance and subjective state, it was decided to focus the subsequent experimental work (Study 1, Chapter 3) on the effects of breakfast consumption relative to breakfast omission, rather than a comparison of the effects of breakfast meals of differing composition or size. It was beyond the scope of the experimental work in this thesis to consider both types of comparison in a study of this size. Furthermore, it was deemed important to establish the effects of breakfast relative to fasting in Study 1 (Chapter 3) because the findings from existing research identified in the SRR (Chapter 2) were quite mixed. Hence there was scope to address certain methodological limitations which might account for these equivocal findings. For example, the SRR indicated a lack of research that included adolescents, ecologically valid breakfast manipulations and testing environments, large samples and sensitive cognitive tests. The SRR also drew attention to the need for more studies to assess aspects of subjective state, such as subjective feelings of mood, mental alertness, motivation and satiety, alongside cognitive performance because of the potential for subjective state to influence cognitive function (Dye & Blundell, 2002; Hetherington et al., 2013; Isaacs & Oates, 2008; Schmitt, Benton, & Kallus, 2005). These outcomes were considered important endpoints independently and both were therefore included as outcomes in the experimental work (Study 1, Chapter 3). Finally, the decision to focus on the effect of breakfast relative to no breakfast on cognitive performance was also based on the particularly high rate of breakfast skipping in adolescents (see section 1.2.2.4) and the paucity of research conducted on adolescent samples compared to research considering younger samples (i.e. children).

Adolescents were deemed an important target sample for Study 1 (Chapter 3) for a number of reasons. Firstly, adolescence involves a period of lifestyle change, including changes in, and increased control over, eating habits. Moreover, regular breakfast consumption during adolescence significantly predicts regular breakfast consumption during young adulthood (Merten, Williams, & Shriver, 2009). Therefore, adolescence may be an important time to establish regular breakfast consumption. Secondly, academic work during secondary school is often cognitively demanding and focussed towards the preparation for formal examinations and qualifications (e.g. the General Certificate of Secondary Education [GCSE]). Thirdly, adolescence is a period of rapid growth and increasing energy needs, highlighting the importance of adequate nutrition.

The experimental work (Study 1, Chapter 3) specifically targeted adolescents aged 11-13 years in order to address a lack of published studies in this age group highlighted by the SRR. Adolescents aged 11-13 years are in an important transitional period from primary to secondary school, since they are in the first two years of secondary education in the British school system. Interestingly, breakfast consumption data from school children in the United Kingdom (UK) has shown that the rate of breakfast skipping rises from 6% in primary school children to 20% in secondary school children (Hoyland, McWilliams, Duff, & Walton, 2012). Furthermore, other UK data indicates that the greatest decline in breakfast skipping occurs between school Year 6 (aged 10-11 years) and school Year 8 (aged 12-13 years) where breakfast skipping rises by 9% compared with only 3% during the period between Year 8 (aged 12-13 years) and Year 10 (aged 14-15 years; Balding, 2001). Therefore, adolescents aged 11-13 years represent an important age group because they may be particularly vulnerable to the negative consequences of skipping breakfast.

1.1.1.2 Breakfast and academic performance

The potential for breakfast to facilitate cognitive functions such as memory and attention could have some wider “real-life” impact for learning in the classroom and educational achievement. Furthermore, cognitive outcomes may be less influenced by other extraneous factors such as teaching quality. Although academic performance measures are perhaps more meaningful and educationally significant compared to objective measures of cognitive performance, investigation of the effect of breakfast on ecologically valid academic outcomes has been largely neglected by both reviews and primary research. Consequently, a fourth aim of this thesis was to examine the effects of breakfast and breakfast composition on academic performance in both children and adolescents. This aim was explored using SRR methodology and the resultant SRR is reported in Chapter 4. This SRR was undertaken to highlight areas for further research within the field of breakfast and academic performance. This SRR highlighted the need for further work within this field. The SRR also indicated that no study to date has examined a sample of school children from UK schools and hence no studies have included measures of academic performance that are used for assessment in the British school system. This gap in the literature was therefore addressed by the cross-sectional studies reported in Chapters 5 and 6 of this thesis. The fifth aim of this thesis was, therefore, to examine the association between habitual breakfast consumption frequency and Cognitive Abilities Test (CAT) performance in adolescents aged 11-13 years (Study 2, Chapter 5). Similarly, the sixth aim of this thesis was to examine the association between habitual school-day breakfast consumption frequency and GCSE performance in adolescents aged 16-18 years (Study 3, Chapter 6).

The SRR reported in Chapter 4 indicated that no study had examined the acute effects of breakfast on academic performance. Previous research had considered either cross-sectional associations between habitual breakfast consumption and academic performance or the effects of chronic breakfast interventions. Measures of academic performance usually assess content that is taught in schools over time rather than specific cognitive functions. Hence, it is unlikely that short term (same morning) improvements on academic performance following breakfast consumption will be apparent as this will also be dependent on prior learning. Instead, a plausible assumption is that the positive acute effects of breakfast on cognitive performance translate, with repeated consumption, to cumulative effects on academic performance in the longer term. It was, therefore, decided to focus the subsequent experimental work in this thesis, Study 2 (Chapter 5) and Study 3 (Chapter 6), on academic outcomes by considering cross-sectional associations between *habitual* breakfast consumption frequency and academic performance. This work did not consider the effects of a chronic breakfast intervention as this was not considered feasible or justifiable. A chronic intervention study would have required considerable resources. Furthermore, this would have necessitated preventing a group of adolescents from consuming breakfast for a long period of time which would be ethically contentious. Since there was no previous published evidence for an association between habitual breakfast consumption and academic performance in school children in the UK, it was deemed appropriate to establish some evidence for such an association which might inform the design and hypotheses of future well-controlled chronic intervention studies. It was acknowledged at the conception of these cross-sectional studies (Study 2, Chapter 5 and Study 3, Chapter 6) that the results would not allow any demonstration of cause and effect. Instead, they were conducted with a view to generating hypotheses which could then be tested more rigorously by future randomised controlled trials (RCT) or prospective cohort studies.

The cross-sectional studies in this thesis examined the relationship between habitual breakfast consumption frequency and academic performance in adolescent samples aged 11-13 years in Study 2 (Chapter 5) and 16-18 years in Study 3 (Chapter 6) but not in younger children. The literature on breakfast and academic performance is quite balanced across children and adolescents. However, it was decided to also focus the first cross-sectional study (Study 2, Chapter 5) on 11-13 year olds for the reasons discussed previously in relation to Study 1 (Chapter 3). Study 2 (Chapter 5) also presented an opportunity to analyse the CAT data collected as part of Study 1 and relate it to habitual breakfast consumption. Study 3 (Chapter 6) focussed on 16-18 year olds because these adolescents had already obtained GCSE grades, of interest because of the importance of these outcomes for future employment and educational trajectories.

The cross-sectional studies, Study 2 (Chapter 5) and Study 3 (Chapter 6), in this thesis examined the association between academic performance and habitual breakfast consumption frequency (e.g. 5 days per week) not composition (e.g. macro or micronutrient content). These cross-sectional studies focussed on habitual breakfast consumption frequency in order to examine the influence of this behaviour pattern (i.e. consuming vs. not consuming breakfast) on the cognitive performance outcomes assessed in Study 1 (Chapter 3).

1.1.2 The benefits of breakfast consumption for maintaining a healthy body weight

Along with the reported benefits of breakfast on cognitive and academic performance, breakfast consumption is associated with a variety of advantageous health-related factors. For example, much evidence has shown a consistent favourable relationship between body weight indices and breakfast consumption. Frequency of breakfast intake has been shown to inversely correlate with Body Mass Index (BMI) in a dose-response manner in adolescents (Timlin, Pereira, Story, & Neumark-Sztainer, 2008). In 11-13 year old British adolescents, breakfast consumers had significantly lower BMI z-scores than breakfast skippers (Coppinger, Jeanes, Hardwick, & Reeves, 2012). Skipping breakfast is also associated with increased odds of being obese in British adolescents (Harding, Teyhan, Maynard, & Cruickshank, 2008). Two recent systematic reviews have also confirmed this association, concluding that children and adolescents who habitually consume breakfast have a lower likelihood of being overweight or obese (de la Hunty, Gibson, & Ashwell, 2013; Szajewska & Ruszczynski, 2010).

It is likely that breakfast consumption acts as a proxy for a healthy lifestyle. This notion is supported by studies reporting an association between breakfast consumption and increased physical activity levels, indicated by several different physical activity indices in children and adolescents. These indices include cardio-respiratory fitness (Sandercock, Voss, & Dye, 2010), daily accelerometry-derived levels of moderate to vigorous physical activity (Corder et al., 2014) and sedentary behaviour (Santaliestra-Pasias et al., 2014). However, this positive association is not consistently reported. A number of studies observe no association (Lyerly, Huber, Warren-Findlow, Racine, & Dmochowski, 2014; Utter, Scragg, Ni Mhurchu, & Schaaf, 2007).

1.1.3 The benefits of breakfast consumption for meeting nutrient requirements

Regular breakfast consumption is also associated with many positive diet-quality indices. Children and adolescents who habitually consume breakfast are more likely to have favourable macronutrient intakes including higher intakes of dietary fibre, total carbohydrate and lower total fat intake (Deshmukh-Taskar et al., 2010). Evidence also suggests that daily micronutrient intakes are higher in breakfast consumers compared with breakfast skippers (Affenito et al., 2013; Deshmukh-Taskar et al., 2010). Consumption of ready-to-eat cereal (RTEC), in particular, is associated with better micronutrient intake. Intakes of iron, B vitamins (folate, thiamine, riboflavin, niacin, vitamin B_6 and vitamin B_{12}) and Vitamin D are all higher in school children who regularly eat RTEC compared to those who do not (Gibson, 2003). Additionally, supporting evidence from biomarkers of nutrient intake shows that folate, riboflavin and vitamin B^{12} status are positively associated with RTEC consumption (Gibson, 2003). Regular breakfast consumption is also associated with higher fruit and vegetable intake in adolescents (Pedersen, Meilstrup, Holstein, & Rasmussen, 2012). Other health-related factors less frequently associated with breakfast skipping include increased likelihood of tobacco smoking and alcohol consumption in adolescents (Keski-Rahkonen, Kaprio, Rissanen, Virkkunen, & Rose, 2003).

1.2 Trends in breakfast consumption

1.2.1 Prevalence of breakfast consumption: A subsidiary focus of this thesis

A subsidiary focus of this thesis was to examine the nature of breakfast eating in school children in the UK and to extend previous work by including more in-depth descriptions of breakfast intake and by differentiating between school-day and weekend breakfast eating. This included frequency, food type, macronutrient and micronutrient content, and the contribution to population reference nutrient intakes (RNIs). This aim was addressed by Study 3 (Chapter 6). Several observational studies have reported that between 20–30% of children and adolescents skip breakfast, although there is a considerable amount of variation in the intake figures reported between studies. The variety of definitions of what constitutes breakfast or being a breakfast consumer (e.g. consuming breakfast 7 days/week, 5 days/week, or on a dietary survey day) contributes towards this variation. There is also relatively little research on the extent of breakfast skipping in British school children and extrapolation from studies conducted elsewhere is problematic. However, there are a small number of recent surveys which have been conducted in British school children. In a representative sample of British school children aged 5-15 years, 14% did not eat anything for breakfast on the morning of the survey (Hoyland et al., 2012). More recent data has demonstrated that 18% of British adolescents aged 11-18 years reported not eating breakfast on the day of survey (Mullan et al., 2014). This is consistent with Lattimore & Halford's (2003) observation a decade earlier that 19% of British 11-16 year olds reported that they had skipped breakfast on the day of survey.

A slightly higher prevalence of breakfast skipping was reported in a representative sample of over 10,000 children and adolescents from the1999-2006 US National Health and Nutrition Examination Survey (NHANES), with 20% of 9-13 year olds and 31% of 14-18 year olds reporting skipping breakfast on the day of dietary recall (Deshmukh-Taskar et al., 2010). Similarly, The Healthy Lifestyle in Europe by Nutrition in Adolescence (HELENA) study also reported a high rate of breakfast skipping such that 38% of European adolescents aged 13-17 years agreed with the statement 'I often skip breakfast' (Hallström et al., 2011). The Health Behaviour in School-age Children (HBSC) study also reported similarly high rates of breakfast skipping in 11-15 year olds from 41 countries. The proportion of adolescents reporting that they habitually ate breakfast (7 days per week) ranged from 33%-75% between the countries included in the study (Vereecken et al., 2009).

1.2.2 Socio-demographic differences in breakfast consumption

There is also evidence that breakfast consumption differs according to socio-demographic characteristics such as gender, age, ethnicity, and socio-economic status (SES). These socio-demographic factors were therefore taken into consideration in all of the empirical studies presented in this thesis.

1.2.2.1 Gender

It is fairly consistently reported that female adolescents are more likely to skip breakfast than male adolescents. The HELENA study showed that significantly fewer European adolescent boys agreed that they 'often skip breakfast' compared to girls (33% vs. 42% respectively; Hallström et al., 2011). Similarly, the HBSC study indicated that girls had lower odds of habitually eating breakfast in 33/41 investigated, including the UK (Vereecken et al., 2009). Lattimore and Halford (2003) also observed that female adolescents were more likely to skip breakfast than males on the day of reporting (67% vs. 33% respectively). Gender differences have also been reported in American 15 year olds, with more females skipping breakfast than males (23% vs. 14%, respectively; Nicklas, Reger, Myers, & O'Neil, 2000).

In female adolescents, breakfast is often skipped as a strategy to lose weight (Boutelle, Neumark-Sztainer, Story, & Resnick, 2002). Female adolescents who were dieting were three times more likely to skip breakfast than non-dieting female adolescents (Lattimore & Halford, 2003). Interestingly, this gender difference did not occur in school children of primary school age (Deshmukh-Taskar et al., 2010; Hoyland et al., 2012). In 2012, the prevalence of breakfast skipping in British primary school children (5-11 years) was equal across genders (6% for males and females). However in secondary school children (11-15 years), a considerably larger proportion of females (26%) than males (15%) skipped breakfast (Hoyland et al., 2012).

1.2.2.2 Socio-economic status

The evidence that SES is associated with breakfast eating is very consistent, such that school children from higher SES backgrounds are more likely to eat breakfast than school children from lower SES backgrounds. This relationship exists for a range of SES indicators including parental education level (Delva, O'Malley, & Johnston, 2006; Hallström et al., 2012; Hallström et al., 2011; Øverby, Stea, Vik, Klepp, & Bere, 2011), parent occupation (Keski-Rahkonen et al., 2003), material affluence (Vereecken et al., 2009), receipt of Free School Meals (FSM; Moore et al., 2007), and area-level deprivation indices (Hoyland et al., 2012; Utter et al., 2007).

1.2.2.3 Ethnicity

There is also good evidence that breakfast consumption varies across ethnic groups. Analysis of the Scottish cohort (>16,000 adolescents) of the HBSC study indicated that being white was associated with lower odds of skipping breakfast relative to non-white ethnic backgrounds (Levin & Kirby, 2012). In British 11-13 year olds, black Caribbean, black African and Indian adolescents were more likely to skip breakfast than white adolescents (Harding et al., 2008). Several US studies also show similar patterns. The 1999-2006 NHANES indicated that a significantly lower proportion of white children and adolescents (9-18 years) were breakfast skippers compared to black and other non-white/mixed ethnicity children and adolescents (Deshmukh-Taskar et al., 2010). Similar ethnic differences were reported in American 9-10 year old girls, with white girls reporting more frequent breakfast consumption than black girls. Interestingly, these ethnic differences decreased during adolescence, due to the increasing number of white adolescent girls skipping breakfast (Affenito et al., 2005). In an analysis of over >100,000 American 13-18 year olds, there were significant differences in the proportion of white and non-white adolescents frequently eating breakfast, which consistently showed that more white adolescents than non-white adolescents ate breakfast frequently (Delva et al., 2006).

1.2.2.4 Age

There is also a consistent trend for breakfast skipping to increase with age during childhood and adolescence. The HBSC study also observed that older adolescents (13 and 15 years) relative to younger adolescents (11 years) had lower odds of regular breakfast consumption which was consistent across 40/41 countries included in the study (Vereecken et al., 2009). Devla et al. (2006) also showed the same pattern in American adolescents, with breakfast skipping increasing between the ages of 13-18 years. Similarly, breakfast skipping increased with each year in 9-19 year old American girls (Affenito et al., 2005).

1.3 Definition of children and adolescents

It is difficult to define childhood and adolescence. The World Health Organisation (WHO) and the American Psychological Association (APA) have defined 'adolescence' as youth generally aged between 10-18 years and 'children' as <10 years (APA, 2002; WHO, 2012). In contrast, the Royal College of Nursing (RCN) do not accept chronological age thresholds for the onset of adolescence because of the variation in the onset and end of biological, emotional and socio-behavioural transitions between individuals. Hence the RCN define adolescents as "any young person in a process of transition between childhood and adulthood" (RCN, 2013, p.4). For the purpose of this thesis, children and adolescents are defined in accordance with the WHO and APA definitions, but with a distinction between primary and secondary school children in the UK. This distinction represents an important transitional period to all school children. Hence, for the purposes of the studies described in this thesis, 'children' are considered to be aged 4-10 (primary school age) and 'adolescents' are considered to be aged 11-18 years (secondary school age).

1.4 Summary of thesis aims

The overall aim of this thesis was to examine and elucidate the effects of breakfast consumption on the cognitive and academic performance of children and adolescents aged 4-18 years. This overall aim can be subdivided into more specific aims relating to the effects of breakfast on cognitive performance (Aims 1-3, see section 1.4.1) and the effects of breakfast on academic performance (Aims 4-6, see section 1.4.2). A subsidiary aim (Aim 7) was to examine the nature of breakfast consumption in adolescents aged 16-18 years (Study 3, Chapter 6). Table 1.1 summarises how the SRRs and the empirical work presented within Chapters 2-6 of this thesis map onto these specific aims.

1.4.1 Aims 1-3: Breakfast and cognitive performance

1. To systematically review the effects of breakfast vs. no breakfast and breakfast composition on cognitive performance in children and adolescents (SRR 1, Chapter 2).
2. To examine the acute effect of consuming breakfast vs. breakfast omission on cognitive performance in adolescents aged 11-13 years (Study 1, Chapter 3)

3 To examine the acute effect of consuming breakfast vs. breakfast omission on subjective state feelings (satiety, mood, alertness motivation) in adolescents aged 11-13 years (Study 1, Chapter 3)

1.4.2 Aims 4-6: Breakfast and academic performance

4 To systematically review the effects of breakfast vs. no breakfast and breakfast composition on academic performance in children and adolescents (SRR 2, Chapter 4).

5 To examine the association between habitual breakfast consumption frequency and academic performance (CAT performance) in adolescents aged 11-13 years (Study 2, Chapter 5)

6 To examine the association between habitual school-day breakfast consumption frequency and academic performance (GCSE performance) in adolescents aged 16-18 years (Study 3, Chapter 6)

Table 1.1: Study title, research method, sample, breakfast comparison and main outcome variable for each of the main aims addressed in this thesis

Aim	**Chapter, study title**	**Research method**	**Sample**	**BF comparison**	**Main outcomes**
1	Chapter 2 **SRR 1**	SRR	Children & adolescents	BF vs. no BF & BF composition	Cognitive performance
2 & 3	Chapter 3 **Study 1**	Acute intervention	Adolescents (11-13 years)	BF vs. no BF	Cognitive performance
4	Chapter 4 **SRR 2**	SRR	Children & adolescents	BF vs. no BF & BF composition	Academic performance
5	Chapter 5 **Study 2**	Cross-sectional study	Adolescents (11-13 years)	Habitual BF consumption frequency	Academic performance
6 & 7	Chapter 6 **Study 3**	Cross-sectional study	Adolescents (16-18 years)	Habitual BF consumption frequency	Academic performance

Abbreviations: BF: breakfast

2 A SYSTEMATIC RESEARCH REVIEW OF THE EFFECT OF BREAKFAST ON COGNITIVE PERFORMANCE IN CHILDREN AND ADOLESCENTS

Statement of Contribution

The candidate confirms that she was solely responsible for developing and performing the literature searches and the synthesis of the evidence contained in this chapter. The candidate was solely responsible for writing the chapter and the production of all data extraction tables. Supervisors provided editing and proof-reading assistance with the chapter.

2.1 Introduction

There are four relatively recent published reviews of the effect of breakfast on school children's cognitive performance (Grantham-McGregor, 2005; Hoyland et al., 2009; Pollitt & Mathews, 1998; Rampersaud, Pereira, Girard, Adams, & Metzl, 2005). These reviews all arrive at the conclusion that breakfast consumption is more beneficial than skipping breakfast for cognitive outcomes and that the observed effects are more apparent in children who are undernourished. The most recent, and only systematic review was conducted by Hoyland et al. (2009) who identified 45 studies (within 41 papers) of the effects of breakfast on objectively measured cognitive performance in the period from 1950-2008. This chapter provides an updated SRR of the literature investigating the relationship between breakfast consumption and cognitive performance in children and adolescents in order to address the first aim of this thesis (see Chapter 1).

2.2 SRR aims

The aim of the review reported in this chapter was to systematically evaluate the literature examining the effects of breakfast on cognitive performance in children and adolescents. The review also aimed to consider the methodological challenges when examining the effects of breakfast on cognitive function. The effects of acute and chronic breakfast interventions are considered along with naturalistic observations of the association between habitual breakfast consumption and cognition function.

2.3 Search strategy and search terms

Databases searched were: Ovid MEDLINE, Pubmed, Web of Science, the Cochrane Library, EMBASE and PsychINFO for articles. The following search terms were used: (‘breakfast’ OR ‘breakfast program*’) AND (‘cogniti*’ OR ‘memory’ OR ‘attention OR ‘visual-spatial’ OR ‘visuo-spatial’ OR ‘recall’ OR ‘recognition’ OR ‘problem solving’ OR ‘reaction time’ OR ‘vigilance’ OR ‘executive function’ OR ‘reasoning’ OR ‘psychomotor’) AND (child* OR adolescent*). The reference lists of existing reviews and identified articles were examined individually to supplement the electronic search. Additionally, an inventory of existing references obtained from on-going citation alerts was examined. Appendix 9.1 provides a detailed description of the searches and selection process. Studies are limited to cognitive outcomes in children and adolescents aged 18 years or less (N.B. some samples included individuals aged up to 20 years but the mean age of the sample was <18 years) and to articles published in English in peer-reviewed journals.

2.3.1 Overview

This literature search identified 54 studies published in 52 articles which examined the effect of breakfast on cognitive function in children and adolescents. Thirty-four studies considered the acute effect of a single breakfast meal where performance was typically assessed within 4 hours post-ingestion. These studies were further categorised into those employing breakfast vs. no breakfast comparisons (n=24) or comparisons of breakfast type (n=15). However, it is important to note that some studies examining the effect of breakfast vs. no breakfast also examined comparisons of breakfast type (n=5).The effect of chronic breakfast interventions on cognition was evaluated in 11 studies. Chronic intervention studies were all evaluations of breakfast provision at school as school breakfast programs (SBPs). Performance was commonly assessed at one follow-up period following an intervention duration ranging from 1 month to 3 school years. Chronic interventions were all SBP vs. no SBP comparisons; no chronic SBP study compared school breakfast meals that differed in composition. The association between habitual breakfast consumption and cognitive performance was examined in 9 cross-sectional studies. In these observational studies, associations were examined between habitual breakfast consumption frequency or composition defined by consumption on the morning of testing (i.e. Breakfast: yes/no) or on a weekly intake basis (i.e. Breakfast intake on ≥5 days a week/< 5 days per week). Most studies were US or UK based (14 and 15 studies respectively), with the remaining studies carried out in various developed and developing countries including Australia (3 studies), Peru (3 studies), India (2 studies), Jamaica (2 studies) and Iran (2 studies).

Tabulated results are shown in separate tables according to the intervention or assessment of breakfast: Table 2.1 summarises acute intervention studies; Table 2.2 summarises chronic intervention studies; Table 2.3 summarises observational studies. A summary of the overall findings of the 54 studies reviewed in this chapter according to each cognitive domain is shown in Table 2.4. In addition, appendices 9.2-9.13 provide supporting information to identify the individual studies which demonstrate positive, negative and/or no effects of, or associations with, breakfast.

In the 15 acute intervention studies that compared different breakfast meal types, 7 were comparisons of the Glycaemic Index (GI) or Load (GL) of breakfast foods or meals. GI is an index of the blood glucose raising potential of carbohydrate-rich foods, usually having an energy content of >80 % from carbohydrate, and hence provides a measure of carbohydrate quality (Brouns et al., 2005). It is defined as the incremental area under the 2-hour blood glucose curve (AUCi) following 50g of available carbohydrate expressed as a percentage of the AUCi following 50g of a reference food, usually glucose or white bread (Foster-Powell, Holt, & Brand-Miller, 2002). Consumption of low GI foods produces a more stable postprandial glycaemic response than high GI foods. High GI foods produce a rapid rise in blood glucose, to a high level, followed by a rapid decline. Low GI foods elicit a lower increase in blood glucose, but a slow decline resulting in a prolonged net increase of blood glucose concentrations above fasting levels. GL represents both the quality and quantity of carbohydrate in a serving (GI x amount of carbohydrate/100; Foster-Powell et al., 2002). Given that both the quality and the quantity of carbohydrate in a food serving are important determinants of the glycaemic response, GL is a better predictor of the glycaemic response and predicts blood glucose in an approximately linear manner (Brand-Miller et al., 2003). The studies that focus on GL, rather than GI do so because it is more accurately associated with glycaemic response. Five of the 7 GI/GL studies used concomitant blood glucose measures to confirm the associated glycaemic response following high and low GI or GL conditions.

An additional 3 studies did not explicitly compare the GI or GL of different breakfast foods or meals, but the macronutrient composition differed across conditions such that the effects were described in terms of differences in glycaemic responses. The remaining 5 studies attempting to differentiate the effect of breakfast meal types included comparisons of breakfast meals differing in energy (2 studies), high carbohydrate vs. high protein comparisons (2 studies) and comparisons of the distribution of energy across the morning by the provision of a mid-morning snack compensated or not by a reduced energy breakfast (1 study).

The breakfast manipulations were varied, but a commonality was the use of foods/meals that were carbohydrate-rich. Most studies included RTECs or breads in combination with other foods including milk, sweet and fat spreads, fruit, fruit juice, yoghurt and cheese. Macronutrient composition of the test meals varied widely between the studies. The energy loads of the breakfast manipulations were also wide-ranging from 95 Kcal – 600 Kcal with a mean energy load of 225 Kcal. In acute intervention studies, the breakfast manipulations were typically fixed energy (31/34) rather than ad-libitum (3/34). Of course, acute studies comparing different breakfast types require fixed breakfast manipulations to ensure that these only differ in terms of the nutrient component under test. In chronic SBP intervention studies, meals were always ad-libitum as per usual protocol within these programs. Also of note, 6 acute studies employed breakfast meals which were based on government SBPs already in existence.

Studies were conducted in school children aged between 3-20 years (pooled sample size: n=26,378). Thirteen studies were carried out in adolescents (≥11 years) and 20 studies were carried out in children (<11 years). Twenty-one studies included both children and adolescents, although 16 of these included children aged 11 years and younger (e.g. 8-11 years), and hence these samples consisted of mostly children. Most (41/54) studies were carried out in well-nourished school children of both sexes. Thirteen studies were conducted in mixed samples of well- and undernourished school children. This SRR assumed that the school children in these studies were well-nourished since they were described as healthy and BMI was within the normal range. Stunting (below -1-2 standard deviations [SD] height-for-age), wasting (below -1-2 SD weight-for-height) and underweight (below -1-2 SD weight-for-age) were typically used as indicators of undernourishment using the US National Centre for Health Statistics (NCHS) reference or the more recent WHO standards. Where SES was specified, studies were conducted in school children of a range of SES backgrounds: 10 studies included low SES school children, 7 studies included mid-high SES school children and 9 studies included school children from mixed SES backgrounds.

Acute intervention studies employed both randomised and non-randomised crossover and parallel-groups designs. Most acute studies employed crossover designs (25/34) of which 18 were randomised and 6 were non-randomised, but order of treatment was counterbalanced. The remaining study (Conners & Blouin, 1987) did not report randomisation or counterbalancing. Eight studies employed parallel-groups designs, of which 7 were randomised. In acute studies, 18 studies were school-based and 15 studies were laboratory based and the remaining 1 study did not report the study location. Control groups were usually fasted but some studies attempted to include placebo controls, such as very low energy conditions (e.g. a 60g orange, sugar free drinks or jelly). These are not true placebos, but may control for the extra attention given to children and adolescents during breakfast. Of the 11 chronic SBP studies 5 were non-randomised matched school comparison studies, 1 was a non-randomised matched participant comparison study, 4 were randomised controlled trials and the remaining study was a before-and-after SBP study. Control conditions were usually breakfast at home or no breakfast, depending on participants' usual breakfast intake.

A variety of cognitive domains were examined using an extensive assortment of both computerised and 'pen-and-paper' tasks. Within this review, the cognitive tasks are grouped into seven broad categories according to the cognitive domain assessed: Memory (verbal, visual-spatial, phonological working), attention, reaction time, psychomotor function, visual perception, executive function, global function. This is broadly based on the taxonomy employed by previous reviews in relation to nutrition and cognitive function (de Jager et al., 2014; Hoyland, Lawton, & Dye, 2008). Typically, the studies reviewed investigated several aspects of post-ingestion cognitive performance using a battery of cognitive tasks and hence many studies are discussed more than once. Within the acute studies, the temporal distribution of the cognitive tasks across the morning was highly variable and ranged from +10 minutes to +210 minutes post-breakfast. Some studies (13/34) tracked post-breakfast performance across the morning at various time points usually shortly after breakfast (e.g. +60 minutes), in the mid-morning (e.g. +120-180 minutes) and late-morning (e.g. +210 minutes). However, many acute studies (21/34) included only one post-intervention testing period. Further, 25 studies did not include a baseline (pre-breakfast) test session.

2.3.2 Memory

Cognitive tasks assessing memory are divided into verbal (2.3.2.1), visual-spatial (2.3.2.2) and working memory (2.3.2.3).

2.3.2.1 Verbal memory: Overview

This domain captures short or immediate and long term recall and recognition of information presented and encoded in verbal format (de Jager et al., 2014; Wesnes & Brooker, 2011). Twenty-one studies took measures of verbal memory (11 studies measured immediate verbal memory; 1 study measured delayed verbal memory; 9 studies measured both), most commonly by free word recall tasks in immediate and/or delayed contexts (see Table 2.1-Table 2.3 and Appendices 9.2 and 9.3 respectively). Other tasks included cued word recall, free word recall with selective reminding, word recognition, free and cued story recall, sentence recall and object name recall in immediate and delayed contexts.

2.3.2.1.1 Acute intervention studies: Comparisons of the effects of breakfast vs. no breakfast on verbal memory

Comparisons of the effects of breakfast relative to no breakfast on verbal memory (immediate and/or delayed) were made in 10 acute intervention studies (see Table 2.1 and Appendices 9.2 and 9.3). Two crossover studies demonstrated no significant facilitation of immediate and delayed story recall following a 350 Kcal oatmeal or RTEC breakfast relative to no breakfast in American 9-11 year olds (experiment 1) and 6-8 year olds (experiment 2; Mahoney, Taylor, Kanarek, & Samuel, 2005). Similarly, a crossover study reported that consumption of a 95 Kcal confectionary snack provided as breakfast compared to a low energy placebo drink matched for sweetness had no effect on immediate story recall in American males aged 9-12 years (Busch, Taylor, Kanarek, & Holcomb, 2002). In German adolescents, consumption of a 476 Kcal school breakfast had no effect on three tests of immediate verbal memory: cued recall of factual text, recognition of previously learnt Turkish vocabulary and object name recall (Widenhorn-Müller, Hille, Klenk, & Weiland, 2008). In the above four studies, the school children were well-nourished and from mid-high SES backgrounds. Additionally, assessments were made on one occasion within the first hour of consumption (+15-60 minutes post breakfast). However, Simeon and Grantham-McGregor (1989) also found no facilitation, by breakfast or no breakfast, of immediate cued story recall in the late-morning (+180 minutes post breakfast) in stunted or previously undernourished 9-11 year olds. Maffeis et al. (2012) also reported that consumption of breakfast had no effect on word recall with selective reminding in the late-morning (+180 min post breakfast) relative to baseline in obese 9-10 year olds. However, under fasting conditions, word recall with selective reminding significantly increased across the morning at +180 minutes post intervention relative to baseline in this sample.

A crossover study compared the effects of two varieties of RTEC and a glucose drink relative to fasting on verbal memory in British school children aged 9-16 years (Wesnes, Pincock, Richardson, Helm, & Hails, 2003). There was a general decline in performance across the morning but RTEC consumption reduced the decline in “Quality of Episodic Memory” (QEM) factor scores across the morning relative to no breakfast. QEM factor scores reflect accuracy scores on immediate and delayed free word recall, delayed word recognition and a visual memory task (Wesnes, Ward, McGinty, & Petrini, 2000). Ingestion of the glucose drink relative to fasting did not benefit QEM factor scores. There was also no effect of condition on “Speed of Memory” (SOM) factor scores, which reflect reaction times on delayed word recognition, two working memory tasks and a visual memory task. Individual task performance was not reported, making it difficult to partial out the effects of breakfast on specific verbal memory tasks. However, it was reported that performance on individual cognitive tasks showed a similar pattern of effects as the factor scores and of note, immediate word recall showed the strongest effect of breakfast condition. This suggests that consumption of breakfast facilitated the ability to store and retrieve verbal information, but not the speed at which the information was retrieved (Wesnes et al., 2000). Similarly, a recent school-based crossover study observed an enhancement of delayed free word recall following a low GI RTEC relative to fasting in British adolescents aged 13-15 years who were non-habitual breakfast consumers (Defeyter & Russo, 2013). Following breakfast consumption, performance increased relative to baseline and decreased under fasting conditions. Interestingly, the significant facilitation of breakfast was only apparent under conditions of greater cognitive load (i.e. when the to-be-remembered words could not be categorised).

Two studies took measures of verbal memory following breakfast or no breakfast using the Rey Auditory Verbal Learning Test (RAVLT). Israeli adolescents aged 11-13 years were tested on two occasions using the RAVLT (immediate and delayed free word recall and recognition) and the Logical Memory subtest of the Wechsler Memory Scale (story recall; Vaisman, Voet, Akivis, & Vakil, 1996). At test 1, participants who reported consuming breakfast at home had superior immediate free word recall compared to those who skipped breakfast, but there was no effect on any other parameters of the RAVLT or story recall ability. At test 2, participants received either a school breakfast or no breakfast, but were permitted to consume breakfast at home. Those who consumed a school breakfast had superior mean learning (mean recall across 5 trials plus recall on trial 5 only), less retroactive interference, better delayed word recognition on the RAVLT and superior story recall relative to those who ate breakfast at home or no breakfast. Delayed recall was significantly better following breakfast at school vs. no breakfast. Conversely, no significant differences on RAVLT immediate mean recall (across 5 trials) were found in American adolescents aged 14 years who received a US government school breakfast (424 Kcal) or a very low calorie control (12 Kcal; Cromer, Tarnowski, Stein, Harton, & Thornton, 1990).

2.3.2.1.2 Acute intervention studies: Comparisons of the effects of different breakfast types on verbal memory

Nine studies investigated the effect of different types of breakfasts on verbal memory (immediate and/or delayed; see Table 2.1 and Appendices 9.2 and 9.3). Mahoney et al. (2005) observed no effect on immediate and delayed story recall following an oatmeal breakfast compared to an isocaloric RTEC breakfast in 9-11 year olds (experiment 1) and 6-8 year olds (experiment 2). The oatmeal had more protein and fibre and less sugar relative to the RTEC, and whilst not explicitly compared or reported, the oatmeal had a lower GI than the RTEC (GI: 66 vs. GI: 75-80 respectively; calculated by Benton et al., 2007).

Wesnes et al. (2003) compared two RTECs that differed in complex carbohydrate content and a glucose drink. There was a significant main effect of breakfast condition on QEM factor scores but the lack of statistical post-hoc tests precludes firm conclusions about which breakfast conditions were statistically different from others. However, the pattern of results showed that there was little difference in performance between the two RTEC conditions, but both RTECs reduced the decline in QEM factor scores relative to a glucose drink which provided a similar amount of carbohydrate (38.5g). Again, whilst the GI of the conditions was not explicitly compared, the glucose drink had a higher GI (GI: 100) than the two RTEC conditions (GI: ≈74, Foster-Powell et al., 2002). However, it should be noted that although the GI of these RTECs is considered high, each would have produced a more dampened glycaemic response relative to the glucose drink (Foster-Powell et al., 2002; Henry, Lightowler, & Strik, 2007).

Support for a low GI breakfast facilitation effect was demonstrated in a crossover study of British 6-11 year olds which explicitly compared the effects of a low GI RTEC (GI: 42) vs. high GI RTEC (GI: 77) on the same verbal memory tests and factor scores as Wesnes et al. (2003) (Ingwersen, Defeyter, Kennedy, Wesnes, & Scholey, 2007). The low GI RTEC functioned to reduce the decline in Secondary Memory (SM) factor scores (referred to as QEM in Wesnes et al., 2003) relative to baseline significantly more than the high GI RTEC immediately following breakfast (+10 minutes post breakfast) and mid-morning (+130 minutes post breakfast). Consistent with Wesnes et al. (2003), there was no effect on SOM factor scores.

Smith and Foster (2008) also compared the effects of a high GI RTEC (GI: 77) relative to a low GI RTEC (GI: 30) on the California Verbal Learning Test (CVLT) performance in Australian 14-17 year olds and observed contradictory findings to those of Ingwersen et al. (2007). Free and cued recall was assessed immediately following word presentation, following a short (+40 minutes post word presentation) and long delay (+80 minutes post word presentation) corresponding to +20, +60 +100 minutes post breakfast respectively. The task was modified by imposing divided attention at the time of encoding by the use of a simultaneous motor task. There was no effect of condition on raw cued and free recall scores. However, relative to the number of words freely recalled at the short delay, fewer words were forgotten after the long delay following consumption of the high GI RTEC compared with the low GI RTEC.

Three studies examined breakfast meals differing in GL on verbal memory. There was no effect on immediate and delayed object name recall following three breakfasts of high (GL: 18), medium (GL: 12) and low GL (GL: 3) in British school children aged 5-7 years from a school in an economically disadvantaged area (Benton, Maconie, & Williams, 2007). Although meals were intended to be isocaloric, actual intake across conditions varied which could explain the lack of effects. However, regression analysis indicated that lower GL was predictive of better immediate verbal recall of objects. Two studies demonstrated no clear effect of isocaloric GL manipulations on immediate word recall in Australian 10-12 year olds (Brindal et al., 2012; Brindal et al., 2013). Glycaemic responses were confirmed via continuous glucose monitoring. Brindal et al. (2012) found no difference between high (GL: 33) medium (GL: 24) and low (GL: 18) GL drinks provided at breakfast on immediate word recall despite significant differences in glycaemic response. In the second study, Brindal et al. (2013) observed a positive effect of a low GL (GL: 5) drink relative to a high GL (GL: 35) and very high GL (GL: 65) drink in girls only.

The effects of both breakfast GI and GL on immediate and delayed verbal memory were examined in British 11-14 year olds (Micha, Rogers, & Nelson, 2011). The four breakfast conditions were: low GI-high GL, high GI-high GL, low GI-low GL and high GI-low GL. Immediate and delayed verbal memory was not related to either breakfast GI or GL.

2.3.2.1.3 Chronic intervention studies: The effects of SBPs on verbal memory

Three chronic studies showed no facilitation of immediate verbal memory in primary school children (see Table 2.2 and Appendix 9.2). A cluster RCT evaluated the effect of the Welsh Primary School Free Breakfast Initiative on immediate verbal memory in 9-11 year olds (Murphy et al., 2011). Compliance with the intervention was variable. Intention-to-treat analysis indicated no significant differences in word recall in intervention vs. control schools at 1-year follow up. Per-protocol analysis indicated no significant differences in word recall in schools that had set up SBPs vs. control schools. The results also showed the intervention had no impact on breakfast eating, which may explain the lack of effects. The proportion of children eating breakfast everyday remained unchanged whilst the proportion of children eating breakfast at home decreased, suggestive of a shift in consumption from at-home to at-school.

A secondary analysis of this trial data investigated whether SES (as indicated by FSM status) modulated the effect of the intervention on verbal memory (Moore et al., 2014). SES did not significantly interact with the effects of the intervention on immediate word recall. However, immediate word recall was significantly poorer in children in receipt of FSMs. Worobey and Worobey (1999; experiment 1) also showed that a 6-week SBP had no effect on immediate word recall, relative to baseline where participants consumed breakfast at home, in American 3-5 year olds.

2.3.2.1.4 Cross-sectional studies: The association between habitual breakfast frequency and verbal memory

Two cross-sectional studies demonstrated an association between habitual breakfast consumption frequency or composition and verbal memory (immediate and/or delayed; see Table 2.3 and Appendices 9.2 and 9.3). Eating breakfast >4 days/week significantly predicted better recall of sentences in Indian adolescents aged 11-13 years, a third of whom were undernourished (Gajre, Fernandez, Balakrishna, & Vazir, 2008). Cross-sectional associations between the GI and GL of typical breakfast meals consumed on the morning of testing and both immediate and delayed verbal memory were examined in British 11-14 year olds (Micha, Rogers, & Nelson, 2010). Adolescents were classified into groups according to the GI and GL of their breakfast: Low GI-high GL, high GI-high GL, low GI-low GL and high GI-low GL. A high GI breakfast across high and low GL groups was associated with better immediate verbal memory, but there was no effect on delayed verbal memory.

2.3.2.2 Visual-spatial memory: Overview

Visual-spatial memory describes short and long term recall and recognition of visual or spatial information (de Jager et al., 2014). It includes visual memory, which is the ability to recall or correctly identify or reproduce a visually presented image, such as a picture, an object, a scene, or a face. It includes spatial memory, which is memory for routes and sequential information and memory for object locations or positioning (de Jager et al., 2014; Postma, Jager, Kessels, Koppeschaar, & van Honk, 2004). This domain also includes measures of spatial working memory. Spatial working memory relies on the temporary storage and manipulation of a limited amount of visual-spatial information in the “visual-spatial sketch pad” within the multi-component working memory system (Baddeley, 2000; Baddeley & Hitch, 1974). Working memory is discussed separately (see section 2.3.2.3) in relation to phonological working memory. Twenty studies (see Table 2.1-Table 2.3 and Appendices 9.4 and 9.5) took measures of visual-spatial memory including picture recognition, object location recall, memory for routes, memory for sequences of objects and recall of geometric figures in immediate and/or delayed contexts (12 studies measured immediate visual-spatial memory; 1 study measured delayed visual-spatial memory; 7 studies measured both).

2.3.2.2.1 Acute intervention studies: Comparisons of the effects of breakfast vs. no breakfast on visual-spatial memory

Comparisons of the effects of breakfast relative to no breakfast were made in 13 acute studies (Table 2.1). Busch et al. (2002) found no facilitation of immediate recall of the location of words in a map task following a confectionary snack vs. no breakfast in males aged 9-12 years. Similarly, null effects of breakfast relative to fasting were observed on immediate recall of sequences of geometric shapes in obese 9-10 year olds (Maffeis et al., 2012). In American habitual breakfast consumers aged 8-10 years, consumption of a 350 Kcal breakfast relative to fasting did not enhance performance on two visual-spatial memory tasks: One Card Learning (immediate picture recognition) and Paired Associates Learning (PAL; immediate recall of picture locations; Kral et al., 2012).

Two crossover studies by Mahoney et al. (2005) used a similar map task to that used by Busch et al. (2002) and also the Rey-Osterrieth Complex Figure Task (RCFT) where participants copy then recall a complex drawing. Copy accuracy provides a measure of visual perception and visual-spatial constructional ability (discussed in section 2.3.6) and recall in immediate and delayed contexts provides a measure of visual memory (Fernando, Chard, Butcher, & McKay, 2003). Mahoney et al. (2005) observed better immediate map recall following consumption of oatmeal relative to no breakfast in 9-11 year olds (experiment 1) and 6-8 year olds (experiment 2). However, there was no effect of breakfast on immediate and delayed recall on the RCFT in both studies. In a parallel groups study, Vaisman et al. (1996) measured visual memory using the Benton Visual Retention Test which requires participants to reproduce a series of complex drawings after a short delay (10-15 seconds). At test 1, there was no difference in performance in participants who self-reported eating breakfast at home compared to participants who had skipped breakfast. At test 2, participants who consumed a school breakfast performed better relative to those who ate breakfast at home or no breakfast. Positive effects on immediate recall of a route and immediate picture recall were also observed in adolescents aged 13-20 years following a school breakfast, although effects were specific to male adolescents only (Widenhorn-Müller et al., 2008).

Wesnes et al. (2003) reported a positive effect of two varieties of RTEC relative to no breakfast on QEM factor scores, which included accuracy scores on a delayed picture recognition task. There was no effect of SOM factor scores, which included reaction times on a delayed picture recognition task and a spatial working memory task. There was also no effect on Working Memory factor scores (WM) which included accuracy scores on a spatial working memory task. More recently, the same visual-spatial memory tasks as those used by Wesnes et al. (2003) were employed in a randomised crossover study in 9-11 year olds (Amiri et al., 2014). There was no difference in performance on both measures of visual-spatial memory following breakfast relative to fasting.

Four crossover studies measured visual-spatial memory +180 minutes post breakfast using the Hagen Central Incidental Task which assesses memory for sequences of pictures (Pollitt, Cueto, & Jacoby, 1998; Pollitt, Leibel, & Greenfield, 1981; Pollitt, Lewis, Garza, & Shulman, 1982; Simeon & Grantham-Mcgregor, 1989). Six pictures are shown consecutively with a drawing of an animal and an object (e.g. armchair) and participants are told to pay attention to the animal only as objects are incidental to the task. Following a short delay, participants are shown a picture of the animal only and must recall the serial position (central scores). Participants are then required to recall the matching object associated with the animal (incidental scores), with higher scores reflecting ineffective cognitive strategy (Pollitt et al., 1998; Pollitt et al., 1981). Across the four studies, the effects of breakfast varied. Pollitt et al. (1998; experiment 1) and Pollitt et al.(1981) observed no effect of breakfast on recall of the serial position of all animal pictures, however there was better recall for the serial position of the last animal picture following no breakfast compared with breakfast. Pollitt et al. (1998; experiment 1) and Pollitt et al. (1982) observed higher incidental recall scores (indicative of poorer performance) following no breakfast vs. breakfast. This was said to be indicative of poorer discrimination between relevant and irrelevant stimuli (Pollitt et al., 1998; Pollitt et al., 1982). Simeon and Grantham-McGregor (1989) observed no effects of breakfast on central or incidental recall scores. It should be acknowledged that because of learning effects, the analyses of incidental scores were restricted to the first testing occasion and therefore comparisons were between-groups on this parameter.

2.3.2.2.2 Acute intervention studies: Comparisons of the effects of different breakfast types on visual-spatial memory

Eight acute studies made comparisons between the effects of breakfast meals which differed in composition on visual-spatial memory (Table 2.1). Mahoney et al. (2005) reported no difference in recall of items on a map task following oatmeal relative to RTEC in 9-11 and 6-8 year olds (experiment 1 and 2 respectively). Both experiments by Mahoney et al. (2005) found no difference in the effects of RTEC relative to oatmeal consumption on immediate and delayed recall on the RCFT. Superior QEM factor scores were observed following consumption of two RTECs relative to a glucose drink (Wesnes et al., 2003). The same factor score (termed SM) was facilitated by consumption of a low GI RTEC relative to a high GI RTEC at +10 and +130 minutes post breakfast in 6-11 year olds (Ingwersen et al., 2007). In both studies, there was no effect of different breakfasts on SOM or WM factor scores. Amiri et al. (2014) used the same visual-spatial memory tasks as Wesnes et al. (2003) and Ingwersen et al. (2007) to compare the effects of two isocaloric breakfasts which were either high carbohydrate or high protein and matched for fat. There was no difference in performance on both measures of visual-spatial memory following the high carbohydrate vs. high protein breakfast. Benton et al. (2007) also reported no effects on immediate and delayed recall of the location of objects following breakfast meals differing in GL.

Two studies compared the effect of breakfast size and the provision of a mid-morning snack on visual-spatial memory (Michaud, Musse, Nicolas, & Mejean, 1991; Muthayya et al., 2007). Michaud et al. (1991) observed that immediate recall of the locations of boxes was better following consumption of a higher energy breakfast relative to habitual breakfast in French adolescents aged 13-20 years. Muthayya et al. (2007) took measures of immediate and delayed picture recognition following three conditions of 840 Kcal distributed differently across breakfast (standard or small); snack or no snack; lunch (standard or small).The sample was stratified as high or low SES. The pattern of results showed a decline in immediate and delayed picture recognition across the morning in all conditions which was reduced by consumption of a mid-morning snack. In low SES children, the decline in immediate and delayed picture recognition at +150 minutes post breakfast (soon after consumption of the mid-morning snack) relative to baseline was reduced following the two conditions which included a mid-morning snack relative to the no snack condition. In high SES children, the decline in immediate and delayed picture recognition at +150 minutes post breakfast (soon after consumption of the mid-morning snack) relative to baseline was reduced only in the standard breakfast and mid-morning snack condition relative to the no snack condition. However, there was no effect of consumption of either a small or standard breakfast on immediate and delayed picture recognition at +30 minutes (which was pre mid-morning snack).

2.3.2.2.3 Chronic intervention studies: The effects of SBPs on visual-spatial memory

Two chronic intervention studies examined the effect of SBPs on visual-spatial memory in samples in which a proportion of the school children were undernourished. Both demonstrated mixed results (Table 2.2). Cueto and Chinen (2008) examined the effects of a 3-year mid-morning SBP on immediate picture recognition in Peruvian 11 year olds, two thirds of whom were undernourished. The investigators compared school children who had consumed breakfast at home (control group) to school children who had consumed a mid-morning school breakfast in addition to breakfast at home (intervention group). The SBP was delivered in two types of schools: multiple or full-grade schools. Multiple-grade schools include children of different ages within the same class and are associated with more poverty, undernourished children and lower achievement than full-grade schools. Significantly higher picture recognition was observed in multiple-grade intervention schools compared to multiple-grade control schools at post intervention. Picture recognition performance was worse following the SBP in full grade intervention schools compared to full grade control schools, but the difference was not significant.

More recently, a matched school comparison study compared the effects of a 1-year SBP compared to no SBP on PAL test from the CANTAB test battery in two primary schools in Malawi (Nkhoma et al., 2013). The sample consisted of participants from very low SES backgrounds, almost half of whom were undernourished. The SBP provided a daily 100g ration of porridge providing 350 Kcal, however this ration was reduced by 25% (87 Kcal) for the majority of the intervention due to economic pressures. There was no effect of the intervention on visual-spatial memory. Further, changes in weight and height were not significantly different between children in the SBP school vs. non SBP school although there was a significantly greater increase in mid-upper arm circumference (proxy measure of malnutrition) in the SBP school relative to the non-SBP school. The reduction in portion size may have reduced potential cognitive benefits from the SBP. Further, the authors also noted that some families reduced food provision for children attending the SBP which may have accounted for the lack of significant effects.

2.3.2.2.4 Cross-sectional studies: The association between habitual breakfast frequency and visual-spatial memory

One internet based study (Table 2.3) observed that self-reported breakfast consumption on the day of cognitive testing was associated with superior delayed picture recognition performance relative to breakfast omission in British primary and secondary school children (Wesnes, Pincock, & Scholey, 2012).

2.3.2.3 Phonological working memory: Overview

Working memory is the temporary storage of a limited amount of information in the service of a complex cognitive activity (Baddeley, 2000; Baddeley & Hitch, 1974). This cognitive domain includes measures of phonological working memory. This is the temporary storage and manipulation of speech coded information and is reliant on the “phonological loop” component of the working memory model proposed by Baddeley and Hitch (1974). Twenty-six studies took measures of phonological working memory (see Table 2.1-Table 2.3 and Appendix 9.6). Measures included digit span (forwards and backwards), serial subtractions by threes and sevens, *n*-back, the Sternberg item-recognition paradigm and mental calculation tasks.

2.3.2.3.1 Acute intervention studies: Comparisons of the effects of breakfast vs. no breakfast on phonological working memory

Sixteen studies included a breakfast and no breakfast condition (Table 2.1). Consumption of breakfast relative to no breakfast did not improve performance on the *n*-back task in 8-10 year olds (Kral et al., 2012). Similarly, Wesnes et al. (2003) and Amiri et al. (2014) observed no effect of breakfast relative to fasting on performance of a Sternberg-like numeric working memory task (indicated by WM factor scores). No effects of breakfast relative to no breakfast were observed on digit span forwards and backwards performance in 9-12 year old males (Busch et al., 2002). There was also no facilitation of digit span performance following breakfast compared with no breakfast in 9-11 year olds (Pollitt et al., 1982). Similarly, experiment 2 by Mahoney et al. (2005) also observed no effect of oatmeal and RTEC consumption vs. no breakfast on digit span forwards and backwards in 6-8 year olds. However, in experiment 1 by Mahoney et al. (2005) digit span backwards was improved following consumption of oatmeal relative to no breakfast in 9-11 year olds. However, this effect was specific to girls only. Two American studies showed positive effects of breakfast on mental calculation performance in school children aged 8-11 years (Conners & Blouin, 1982; Pivik, Tennal, Chapman, & Gu, 2012).

Three crossover studies investigated the effects of breakfast vs. no breakfast on working memory under conditions of varying cognitive load. Defeyter and Russo (2013) compared a low GI RTEC relative to no breakfast on serial subtraction tasks requiring adolescents to count backwards in threes (low cognitive load) or sevens (high cognitive load). There was a significant effect of breakfast, such that accuracy on both tasks increased post breakfast consumption relative to baseline but decreased following no breakfast. However, the cognitive load of the task did not interact with the effects. Reaction times on the Sternberg paradigm were facilitated by an ad libitum breakfast relative to no breakfast in British adolescents aged 12-15 years, an effect which was specific to high cognitive load trials (Cooper, Bandelow, & Nevill, 2011). Response times improved across the morning (from +20 minutes and +140 minutes post breakfast) following breakfast relative to no breakfast. However, this pattern of effects was reversed in low cognitive load trials, with reaction times improving more across the morning under fasting conditions relative to breakfast consumption. In contrast to Defeyter and Russo (2013), the majority (90%) of the adolescents were habitual breakfast consumers. Conversely, a second study by the same authors observed that consumption of low and high GI breakfast meals relative to no breakfast had no effect on low and high cognitive load trials of the Sternberg paradigm in British 12-14 year olds (Cooper, Bandelow, Nute, Morris, & Nevill, 2012).

Four studies included children of varied nutritional status (Chandler, Walker, Connolly, & Grantham-McGregor, 1995; Cueto, Jacoby, & Pollitt, 1998; López et al., 1993; Simeon & Grantham-Mcgregor, 1989). Two studies reported positive effects of breakfast consumption relative to fasting on working memory in undernourished children, with no effects in well-nourished children (Cueto et al., 1998; Simeon & Grantham-Mcgregor, 1989). Two studies showed no effects of a school breakfast, relative to no breakfast, on digit span forwards performance in both well- and undernourished children (Chandler et al., 1995; López et al., 1993). However, Chandler et al. (1995) allowed participants in both conditions to consume breakfast at home which may have obscured the effects. Moreover, López et al. (1993) assigned participants to condition based on habitual breakfast intake such that only participants who usually ate breakfast were assigned to the breakfast condition which is an obvious bias.

2.3.2.3.2 Acute intervention studies: Comparisons of the effects of different breakfast types on phonological working memory

Eleven studies assessed phonological working memory following different breakfast types (Table 2.1). Three studies found no effect of consumption of breakfasts differing in GI, complex carbohydrate or protein using the same Sternberg-like numerical working memory task (indicated by WM factor scores; Amiri et al., 2014; Ingwersen et al., 2007; Wesnes et al., 2003). Similarly, two recent studies found no difference in digit span backwards performance following breakfasts differing in GL, despite large differences in blood glucose AUCi (Brindal et al., 2012; Brindal et al., 2013). There was also no difference in digit span forwards and backwards performance following consumption of a higher protein school breakfast relative to a usual high carbohydrate school breakfast in American 4-11 year olds (Morrell & Atkinson, 1977). Similarly, mental calculation performance in 10 year old Danish and Swedish children was not differentially affected by breakfast meals which were either high or low energy (Wyon, Abrahamsson, Jartelius, & Fletcher, 1997).

Two studies demonstrated positive effects of specific breakfast types. Mahoney et al. (2005) observed that in girls, digit span backwards was significantly better following consumption of oatmeal relative to RTEC in 9-11 year olds and 6-8 year olds (experiment 1 and 2 respectively). Two studies demonstrated positive effects of specific breakfast types in terms of GI and GL, however the results were contradictory. Micha et al. (2011) observed that high GI breakfast meals facilitated serial subtractions performance compared to low GI meals, an effect which was consistent across high and low GL. Following consumption of high GI and high GL meals, associated blood glucose concentrations were higher immediately before cognitive testing (+90 minutes post breakfast) and salivary cortisol concentrations were higher before and after cognitive testing (+90 and +140 minutes respectively) compared to low GI and low GL meals. Conversely, Cooper et al. (2012) reported that response times improved more across the morning (from +30 minutes to +120 minutes post breakfast) on the Sternberg paradigm following a low GI vs. high GI breakfast, matched for energy and macronutrient content. Response times were markedly quicker +120 minutes after a low GI vs. high GI breakfast. Further, accuracy was better maintained across the morning following a low GI breakfast, but declined following a high GI breakfast, under conditions of greater memory load only. The low GI condition was associated with lower blood glucose concentrations at +120 minutes post breakfast relative to the high GI condition.

2.3.2.3.3 Chronic intervention studies: The effects of SBPs on phonological working memory

Three chronic studies examined phonological working memory (Table 2.2). Worobey and Worobey (1999; experiment 1) showed that digit span performance in 3-5 year olds did not change significantly following a 6-week SBP, relative to baseline, when breakfast was consumed at home. Similarly, no effects on digit span performance were reported in a RCT comparing the effects of a 1 month SBP vs. no SBP providing a 600 Kcal breakfast to a sample of undernourished and well-nourished Peruvian school children (Jacoby, Cueto, & Pollitt, 1996). However, school children who participated in a 6-week SBP providing 267 Kcal showed greater improvement in digit span performance from pre to post intervention compared to school children in control schools (Richter, Rose, & Griesel, 1997).

2.3.2.3.4 Cross-sectional studies: The association between habitual breakfast composition and phonological working memory

Micha et al. (2010) observed that a low GI-high GL breakfast was associated with superior serial subtractions by sevens performance relative to any other GI and GL group (see Table 2.3).

2.3.3 Attention: Overview

This domain refers to the ability to sustain performance on an attention demanding task over an extended period of time or the ability to focus on relevant stimuli and ignore competing irrelevant stimuli (de Jager et al., 2014). Attention was the most frequently investigated cognitive domain in relation to the effects of breakfast. Thirty-six studies included measures of attention, typically using continuous performance tasks ([CPTs];

see Table 2.1-Table 2.3 and Appendices 9.7-9.8). CPTs require participants to sustain attention on a particular form of continuous stimuli and respond only to target stimuli. Tests of attention included the Rapid Visual Information Processing (RVIP) task, which was developed from the Bakan vigilance task (Bakan, 1959). The RVIP task requires participants to respond to a target string of digits (e.g. “3, 5, 7”) within a rapidly presented continuous stream of digits (e.g. usually 100 digits per minute). Digit vigilance tasks, where participants are required to respond to a single target digit within a rapidly presented stream of digits were also frequently employed. Categoric search tasks were also included in the studies reviewed. These require participants to detect a target stimulus (e.g. digit, letter) presented simultaneously amongst non-target stimuli. Examples of categoric search tasks included in the studies reviewed were letter, digit, and word cancellation tasks and the d2 test of attention (requires the participant to detect the letter “d” marked with two small dashes). More complex attention tasks included were digit-symbol substitution tasks where participants are required to replace digits with symbols according to a digit-symbol code within a fixed time period.

2.3.3.1 Acute intervention studies: Comparisons of the effects of breakfast vs. no breakfast on attention

Nineteen acute intervention studies examining attention outcomes included breakfast and no breakfast conditions (see Table 2.1). Four studies found no effects of breakfast compared to breakfast omission on attention in adolescents (Cromer et al., 1990; Defeyter & Russo, 2013; Dickie & Bender, 1982; Widenhorn-Müller et al., 2008). Performance on the d2 test of attention was not facilitated by a 476 Kcal school breakfast relative to no breakfast (Widenhorn-Müller et al., 2008). There was also no benefit to digit vigilance performance following a 424 Kcal school breakfast relative to a very low calorie control (Cromer et al., 1990). RVIP performance was also not facilitated by consumption of a 162 Kcal low GI RTEC breakfast relative to no breakfast (Defeyter & Russo, 2013). Dickie and Bender (1982; experiment 2) observed null effects of breakfast relative to no breakfast on categoric search performance in 16-17 year olds. Participants were randomised to either continue consumption of their usual boarding school breakfast (500 kcal) or to omit breakfast.

A further four studies demonstrated no positive effects of breakfast on attention in younger school children aged 6-11 years. Pollitt et al. (1981) observed no effect of a 535 Kcal breakfast on performance on a variant of the digit vigilance task. The task involved presentation of a continuous stream of pictures, rather than digits, requiring a response to a predefined target picture. Consistent findings were observed by Pollitt et al. (1998) on a CPT; however the author did not report details of the type of task. Consumption of a common Iranian high carbohydrate breakfast impaired “Power of

Attention" (POA) factor scores, which included response times on digit vigilance, relative to no breakfast in girls (Amiri et al., 2014). Mahoney et al. (2005; experiment 2) found no effect of breakfast consumption relative to no breakfast on measures of visual attention and auditory attention (RVIP variants) in 6-8 year olds.

Four studies investigating effects of large breakfast meals in children of varied nutritional status demonstrated mostly null findings. Two studies showed that consumption of a 510-520 Kcal breakfast did not benefit categoric search performance in well-nourished and undernourished 8-10 year olds (Chandler et al., 1995; Cueto et al., 1998). López et al. (1993) also reported that a 394 Kcal breakfast did not facilitate performance on a task requiring responses to target geometric shapes within a continuous stream of shapes. In contrast, Simeon and Grantham-McGregor (1989) reported that consumption of a 590 Kcal breakfast improved digit-symbol substitution performance in undernourished children, an effect which was not observed in well-nourished children.

Seven studies demonstrated positive effects of breakfast consumption on attention in well-nourished children and adolescents. In experiment 1 (9-11 year olds) by Mahoney et al. (2005), there was no effect of breakfast vs. no breakfast on a visual CPT, however significantly fewer false alarms were made on an auditory CPT following oatmeal and RTEC relative to no breakfast. This effect was only demonstrated in the first 3.3 minutes of the 10 minute task. Conversely, Busch et al. (2002) observed that performance on the same visual CPT used by Mahoney et al. (2005) was facilitated by a lower energy breakfast intervention relative to no breakfast in 9-12 year old males.

Accuracy on a visual CPT was improved following consumption of breakfast relative to fasting in 9-11 year olds (Conners & Blouin, 1982). Pivik and Dykman (2007) showed that response times rather than accuracy outcomes on the Go/No-Go task were superior following breakfast vs. no breakfast in 8-11 year olds who were habitual breakfast consumers. Similarly, consumption of two RTECs relative to fasting reduced the decline in POA factor scores, which included response times on digit vigilance, across the morning in 9-16 year olds (Wesnes et al., 2003). There was no effect on "Continuity of Attention" (COA), which included accuracy scores on digit vigilance (Wesnes et al., 2003). Cooper et al. (2012) observed that response times on the Flanker Task improved more across the morning (+30 to +120 post breakfast) following a low GI breakfast relative to no breakfast in adolescents aged 12-14 years. Maffeis et al. (2012) showed that consumption of breakfast had a positive effect on performance on Conners' CPT relative to no breakfast in obese children. The pattern of results showed that performance under fasting conditions significantly declined at +180 minutes post-intervention relative to baseline but there was no change in performance following breakfast.

2.3.3.2 Acute intervention studies: Comparisons of the effects of different breakfast types on attention

Comparisons of the effects of different breakfast types on attention were made in thirteen studies (see Table 2.1). Two studies showed a low GI breakfast facilitated accuracy on attention tasks relative to a high GI breakfast. The first study reported that the decline in “Accuracy of Attention” factor scores (including accuracy scores on digit vigilance; referred to as COA by Wesnes et al. 2003) was significantly reduced +130 minutes after consumption of a low GI RTEC relative to a high GI RTEC (Ingwersen et al., 2007). There was, however, no effect on “Speed of Attention” factor scores (which included reaction times on digit vigilance; referred to as POA by Wesnes et al. 2003).The second study showed accuracy on incongruent (more difficult) trials of the Flanker task was better maintained across the morning (+30 to +120 post breakfast) following a low GI breakfast relative to an isocaloric high GI breakfast (Cooper et al., 2012). Conversely, Micha et al. (2011) observed that high GI breakfast meals were associated with superior accuracy on a categoric search task, an effect which was consistent across high and low GL meals.

Three studies showed no effects of breakfasts differing in GL on attention tasks. Brindal et al. (2012; 2013) reported null findings on an attention switching task while Benton et al. (2007) reported no main effect of GL on the Paradigm of Shakow. However, Benton et al. (2007) reported that low GL meals predicted fewer lapses of attention, indicated by a response time exceeding 1000ms, on more difficult trials of the attention task.

Four studies made comparisons of breakfast meals which differed in macronutrient composition. In 9-11 year olds, consumption of a common Iranian high carbohydrate breakfast impaired POA factor scores relative to a high protein breakfast (Amiri et al., 2014). However, this effect was apparent in girls only. Wesnes et al. (2003) found consumption of two types of RTECs reduced the decline in POA factor scores across the morning relative to a glucose drink. However, despite compositional differences in the amount complex carbohydrate in each RTEC, performance was similar following consumption of both RTECs. Similarly, experiment 1 by Mahoney et al. (2005) demonstrated no difference in performance on an auditory and visual CPT following consumption of oatmeal compared with RTEC in 9-11 year olds. However, experiment 2 (Mahoney et al., 2005) demonstrated that consumption of oatmeal relative to RTEC resulted in better accuracy on an auditory CPT in 6-8 year olds but there were no differences on the visual CPT.

The final three studies compared breakfast meals which differed in size and/or a mid-morning snack. There was no effect of breakfast size or mid-morning snack on RVIP performance in 7-9 year olds (Muthayya et al., 2007). No effect of breakfast size was found on categoric search performance in 10 year olds (Wyon et al., 1997) but performance was worse following consumption of a higher energy breakfast relative to habitual breakfast consumption in 13-20 year olds (Michaud et al. 1991).

2.3.3.3 Chronic intervention studies: The effects of SBPs on attention

Five studies evaluated the effect of SBPs on attention, with only one study showing positive effects which were specific to undernourished children (see Table 2.2). Children who participated in a 6-week SBP showed greater improvements in accuracy on a categoric search task from pre to post intervention compared to children in control schools without a SBP (Richter et al., 1997). Digit-symbol substitution performance does not seem to be affected by chronic breakfast interventions, even in undernourished school children (Jacoby et al., 1996; Richter et al., 1997; Cueto & Chinen, 2008). There was also no effect on auditory attention following an 8-month SBP in American 8-11 year olds from low SES backgrounds (Lieberman et al., 1976). RVIP performance was not facilitated by a 1-year SBP relative no SBP in undernourished and well-nourished Malawian children (Nkhoma et al., 2013).

2.3.3.4 Cross-sectional studies: The association between habitual breakfast frequency, composition and attention

Four cross-sectional studies examined the association between habitual breakfast consumption frequency or composition and attention (see Table 2.3). Eating breakfast >4 days/week significantly predicted better categoric search performance in adolescents (Gajre et al., 2008). Self-reported breakfast consumption on the morning of testing was related to better digit vigilance accuracy compared with those who skipped breakfast (Wesnes et al., 2012). However, Dickie and Bender (1982; experiment 1) found that self-reported breakfast consumption on the morning of testing did not affect categoric search performance in British adolescents. Micha et al. (2010) observed that self-reported consumption of a low GI-high GL breakfast was associated with superior accuracy on a categoric search task relative to any other GL and GI group (Table 2.3).

2.3.4 Reaction time: Overview

Reaction time refers to how quickly and accurately a participant can respond to a pre-defined stimulus. Reaction time can reflect motor speed (movement time) and processing or decision time. Ten studies used Simple Reaction Time (SRT) and Choice Reaction Time (CRT) paradigms to measure reaction time (see Table 2.1 and Table 2.3 and Appendix 9.9). SRT tasks measure simple reaction time to a single predetermined stimulus in a single predetermined location following varying inter-stimulus intervals. The CRT task uses a similar paradigm, but involves the delivery of multiple types of stimuli (e.g. "X" or "T") or delivery of a single stimulus type in multiple locations and requires the participant to make one of a number of responses according to the type of stimulus. Reaction or response time is frequently used as an outcome variable in many tests of cognitive function. In these instances, reaction time reflects time taken to perform more complex functions. The studies described below all employed SRT and CRT to visual stimuli and were, therefore, direct measures of reaction time (Dye & Blundell, 2002). It should also be acknowledged that SRT and CRT tasks involve an attention component such that participants are required to direct and sustain their attention during the task in order to process the relevant stimuli efficiently. Therefore, these tasks may be referred to as attention tasks in some studies (de Jager et al., 2014).

2.3.4.1 Acute intervention studies: Comparisons of the effects of breakfast vs. no breakfast on reaction time

Six studies employed SRT and CRT following breakfast or no breakfast (see Table 2.1). Three studies observed no facilitation of SRT and CRT performance in well and undernourished school children (Cueto et al., 1998; Defeyter & Russo, 2013; Kral et al., 2012). Cooper et al. (2011) observed that accuracy on a SRT was better following consumption of an ad-libitum breakfast relative to no breakfast in adolescents. This effect was not found for response times and confined to more difficult trials. However, one study reported that enhancement effects of breakfast on SRT and CRT tasks were specific to response times (POA factor scores) rather than accuracy (COA factor scores) in school children (Wesnes et al., 2003). Amiri et al. (2014) observed opposing effects of breakfast consumption according to gender. In boys, CRT performance was impaired under fasting conditions relative to consumption of a high carbohydrate or high protein breakfast. In girls, a high carbohydrate breakfast impaired SRT and CRT performance relative to fasting. However, it is unclear if these effects relate to response times or task accuracy.

2.3.4.2 Acute intervention studies: Comparisons of the effects of different breakfast types on reaction time

Five studies compared the effects of different breakfast types on SRT and CRT (see Table 2.1). Two studies found no effect of breakfasts differing in GL on SRT and CRT performance (Brindal et al., 2012; Brindal et al., 2013). Wesnes et al. (2003) also found no effect on POA or COA factor scores following two types of RTEC differing in complex carbohydrate. However, both RTECs reduced the decline in POA factor scores across the morning relative to a glucose drink providing a similar amount carbohydrate. In contrast, Ingwersen et al. (2007) observed that a low GI RTEC relative to a high GI RTEC facilitated “Accuracy of Attention” factor scores (referred to as COA by Wesnes et al. 2003), but there was no effect on “Speed of Attention” (referred to as POA by Wesnes et al. 2003). Amiri et al. (2014) observed that consumption of a high carbohydrate breakfast resulted in the largest decline in SRT and CRT performance at +30 and +120 minutes post breakfast compared with a high protein breakfast, an effect which was specific to girls only.

2.3.4.3 Cross-sectional studies: The association between habitual breakfast frequency and reaction time

Wesnes et al. (2012) observed that school children who self-reported that they ate breakfast on the morning of testing demonstrated higher POA factor scores (reaction times on SRT, CRT and digit vigilance) relative to those who skipped breakfast (Table 2.3).

2.3.5 Psychomotor function: Overview

Measures of motor control and co-ordination were used in four studies (see Table 2.1-Table 2.3 and Appendix 9.10). Tests included either finger tapping tasks or grooved peg board tasks.

2.3.5.1 Acute intervention studies: Comparisons of the effects of breakfast vs. no breakfast on psychomotor function

Kral et al. (2012) reported that consumption of RTEC relative to no breakfast had no effect on performance of a chase task, requiring 8-10 year olds to follow a rapidly moving target (Table 2.1).

2.3.5.2 Acute intervention studies: Comparisons of the effects of different breakfast types on psychomotor function

Only one study compared different breakfast types on psychomotor performance. Muthayya et al. (2007) found no effect of breakfast size or the addition of a mid-morning snack on finger tapping performance in 7-9 year olds (Table 2.1).

2.3.5.3 Chronic intervention studies: The effects of SBPs on psychomotor function

Only one chronic study examined psychomotor performance (Worobey & Worobey (1999; experiment 2). They reported that performance on the grooved peg board was significantly faster following a 6-week SBP relative to a control group who consumed breakfast at home (Table 2.2).

2.3.5.4 Cross-sectional studies: The association between habitual breakfast frequency and psychomotor function

One study examined cross-sectional associations between habitual breakfast frequency and finger tapping performance (Baldinger, Krebs, Muller, & Aeberli, 2012). The results showed no association between finger tapping performance and habitual breakfast frequency in Swiss children aged 7- 10 years (Table 2.3).

2.3.6 Visual perception: Overview

Fourteen studies employed measures which assess visual perception (see Table 2.1 and Table 2.2 and Appendix 9.11) such as Kagen's Matching Familiar Figures Test (MFFT). The MFFT is a visual match-to-sample task where participants match a target picture from a choice of six highly alike pictures with no specified time limit. The MFFT test is also used to assess impulsive responding and provides an index of reflection-impulsivity (Kagan, Lapidus, & Moore, 1978; Simeon & Grantham-Mcgregor, 1989). Pattern match and stimulus discrimination tasks, similar to the MFFT, were also used. These require visual match-to-sample of geometric figures. Other tests included the Same or Different task, where participants indicate if two highly alike pictures are the same or different and the RCFT copy trial which measures visual-spatial constructional ability, combining perception with a motor response (Fernando et al., 2003).

2.3.6.1 Acute intervention studies: Comparisons of the effects of breakfast vs. no breakfast on visual perception

Nine acute studies compared the effects of breakfast and no breakfast conditions on visual perception (Table 2.1). Three studies used the RCFT copy trial. Mahoney et al. (2005; experiment 1) found RCFT copy accuracy was significantly better following oatmeal or RTEC relative to no breakfast in 9-11 year olds. In experiment 2 in 6-8 year olds, the effect differed according to gender. Girls showed better copy accuracy when fasted than after RTEC but the reverse pattern was found in boys. Conversely, Busch et al. (2002) showed no effect of a confectionary snack compared to no breakfast on RCFT copy accuracy in 9-12 year old boys.

Five studies used the MFFT and demonstrated mixed findings. Simeon and Grantham-McGregor (1989) observed that wasted children who were also stunted and/or previously hospitalised for malnutrition were faster and made fewer errors on the MFFT following breakfast, but there was no difference in non-wasted children. Conversely, healthy control children showed superior performance under fasting conditions than following breakfast. These effects were specific to easy trials of the task. The positive effects of breakfast consumption on MFFT error scores found in two other studies were also confined to easy trials and to participants with an Intelligence Quotient (IQ) below the median of the IQ distribution of the sample in well-nourished school children (Pollitt et al., 1998; Pollitt et al., 1981). In contrast, Pollitt et al. (1982) demonstrated that fewer errors were made on harder trials of the MFFT following breakfast relative to fasting, but there was no effect of condition on easier trials and effects were not moderated by IQ in school children. Cromer et al. (1990) showed no effect of breakfast consumption on MFFT performance, but this was most likely because of a ceiling effect observed. One further study showed positive effects of breakfast consumption relative to fasting on a stimulus discrimination task similar to the MFFT in undernourished children (Cueto et al. 1998). Conversely, in well-nourished children, breakfast consumption adversely affected performance relative to fasting (Cueto et al. 1998).

2.3.6.2 Acute intervention studies: Comparisons of the effects of different breakfast types on visual perception

Four studies compared the effects of different breakfast meals in acute intervention trials (Table 2.1). Two studies observed no effect of breakfasts differing in GL on a visual inspection task (Brindal et al., 2012; Brindal et al., 2013). Mahoney et al. (2005) reported no significant differences in RCFT copy accuracy following oatmeal and RTEC breakfasts in 9-11 year olds (experiment 1) and 6-8 year olds (experiment 2).

2.3.6.3 Chronic intervention studies: The effects of SBPs on visual perception

There were three chronic intervention studies (Table 2.2). Worobey and Worobey (1999; experiment 1 and 2) observed positive effects following a 6 week SBP on a Pattern Match and Same or Different task in 3-5 year olds. However, there was no effect of the intervention on the MFFT. Lieberman et al. (1976) found no effect of an 8-month SBP vs. no SBP on RCFT copy accuracy in 8-11 year olds.

2.3.7 Executive function: Overview

Executive function includes higher-order complex cognitive processes (Elliott, 2003). The term usually encompasses functions such as planning, generating strategies, problem solving, response inhibition and set-shifting (Elliott, 2003; Wesnes & Brooker, 2011). Fourteen studies included tests of executive function (see Table 2.1-Table 2.3 and Appendix 9.12). These included the Stroop task, verbal fluency tasks (letter and categoric fluency), the Trail Making Test and the Mazes subtest of the Wechsler Preschool and Primary Scale of Intelligence test (WPPSI).

2.3.7.1 Acute intervention studies: Comparisons of the effects of breakfast vs. no breakfast on executive function

Eight acute studies compared the effects of breakfast and no breakfast (Table 2.1). Three studies used the Stroop task in British adolescents. Cooper et al. (2011) found that accuracy on both the incongruent and congruent trials of the Stroop task decreased across the morning (+20 to +140 minutes post breakfast) but the decline was reduced following an ad libitum school breakfast relative to no breakfast. Subsequently, Cooper et al. (2012) found that response times on the incongruent trials of the Stoop task improved more across the morning (+30 to +120 minutes post breakfast) following a low GI breakfast than no breakfast. Conversely, Defeyter and Russo (2013) reported no effect of breakfast relative to no breakfast on response times and accuracy of the Stroop task irrespective of trial type. One further study in adolescents observed no effects of breakfast consumption compared to no breakfast on a reasoning task (Dickie & Bender, 1982; experiment 2).

Three studies included undernourished children. Two studies demonstrated that categoric verbal fluency was facilitated by breakfast consumption in children who were undernourished but there was no effect on performance in well-nourished children (Chandler et al., 1995; Simeon & Grantham-McGregor, 1989). However, López et al. (1993) did not observed a positive effect of breakfast consumption on a “Domino task” requiring non-verbal reasoning in undernourished children. One further study in well-nourished children by Kral et al. (2012) also observed no facilitation of a visual-spatial problem solving task by breakfast consumption.

2.3.7.2 Acute intervention studies: Comparisons of the effects of different breakfast types on executive function

Three acute studies comparing breakfast meals varying in composition showed positive effects of specific breakfast types, but the results were contradictory (Table 2.1). Accuracy on incongruent and congruent trials of the Stroop task was better maintained across the morning (+30 to +140 minutes post breakfast) following a low GI breakfast relative to an isocaloric high GI breakfast in adolescents (Cooper et al., 2012). In contrast, Micha et al. (2011) reported that consumption of a high GI-high GL breakfast facilitated performance on the Stroop task relative to low GI-high GL, high GI-low GL and low GI-low GL breakfasts. However, letter fluency was significantly improved following consumption of the low GI vs. high GI breakfast which was consistent across high and low GL conditions. The study also included a non-verbal reasoning task (matrices task) on which no effect of either breakfast GI or GL was detected. Wyon et al. (1997) observed that verbal reasoning performance was better following a higher energy breakfast than participants' habitual breakfast. However, deviation from habitual breakfast energy intake did not affect categorical verbal fluency.

2.3.7.3 Chronic intervention studies: The effects of SBPs on executive function

Three chronic intervention studies demonstrated positive effects of SBPs following chronic interventions ranging between 6 weeks to 1 year (Table 2.2). Nkhoma et al. (2013) investigated the effects of a 1-year SBP relative to no SBP on the CANTAB Intra-Extra Dimensional Shift task, which requires rule acquisition and reversal. There was a significant effect of the intervention on rule acquisition (early trials of the task). At follow up, the SBP children showed a greater decrease in errors on trials before the set-shift relative to baseline than the non-SBP children. There was no effect of the intervention on errors on trials succeeding the set-shift, suggesting that rule learning, but not the ability to update and change responses when rules are changed, was facilitated by breakfast.

A cluster-RCT evaluated the impact of a 1-year SBP relative to no SBP on performance on the Reitan Trail Making Test in British primary and secondary schools within deprived areas of the UK (Shemilt et al., 2004). However, the trial suffered substantial contamination between treatment arms. Further, two thirds of schools in the intervention condition did not continuously operate a SBP between baseline and both following ups (+3 month and +12 month). Intention-to-treat analysis indicated that the time taken to complete the task was significantly shorter in primary intervention schools relative to primary control schools at +3 month follow-up. However, the effects had dissipated at +12 month follow-up, most likely due to the reported contamination. Further, there was no effect on performance in secondary intervention schools at either follow-up. Per-protocol analysis of SBP attendees compared with non-attendees at +12 month follow-up indicated no difference in Trail Making Test performance in both primary and secondary school children.

Worobey and Worobey (1999; experiment 1) investigated the effects of a 6-week SBP relative to baseline (breakfast at home) on performance on two tasks of executive function: the Embedded Figures Test and the Mazes subtest from WPPSI. The Embedded Figures Test assesses non-verbal reasoning. The WPPSI Mazes test requires participants to solve a series of complex mazes. There was no effect of the SBP on the Embedded Figures Test, however, relative to baseline when participants consumed breakfast at home, performance on the Mazes task was significantly better following the SBP. Dietary intake data indicated that energy intake at breakfast was similar during the SBP relative to breakfast at home however, a higher percentage of energy was consumed as carbohydrate during the SBP compared to breakfast consumed at home.

2.3.7.4 Cross-sectional studies: The association between habitual breakfast composition and executive function

One cross-sectional study by Micha et al. (2010) demonstrated that consumption of high GL breakfasts, which were either high or low GI, were associated with better performance on a non-verbal reasoning task relative to low GL breakfasts. However, there was no association between breakfast GI or GL and performance on the Stroop task or letter fluency task (Table 2.3).

2.3.8 Global function: Overview

Tests of global cognitive function assess multiple domains of cognitive function. They are usually employed to reflect general ability or intelligence (de Jager et al., 2014; Isaacs & Oates, 2008). Nine studies employed measures of global cognitive function as outcome measures (see Table 2.1-Table 2.3 and Appendix 9.13). Global function tasks were intelligence tests such as the Wechsler Intelligence Scales for Children (WISC) which comprise of a variety of subtests and provide IQ scores. Many studies which examine specific cognitive domains use single subtests from these global function batteries. Raven's Coloured Progressive Matrices task (CPM), a non-verbal IQ test (de Jager et al., 2014; Isaacs & Oates, 2008) was also used to assess global function. Four of the 8 cross-sectional studies included in this review examined the association between habitual breakfast intake and cognitive function using global function tests. However, only 3 of the 34 acute intervention studies used a global function test as an outcome measure. Global cognitive function tests were usually employed in acute trials as a screening measure, or to account for baseline differences in IQ across study conditions, or to include IQ as covariate in the analysis.

2.3.8.1 Acute intervention studies: Comparison of the effects of breakfast vs. no breakfast on global function

Three crossover studies showed no benefit of breakfast consumption relative to fasting on global cognitive function +180 minutes post breakfast in school children aged 9-11 years (Cueto et al., 1998; Pollitt et al., 1998; Pollitt et al., 1982; Table 2.1). Further, Cueto et al. (1998) observed that performance on the Peabody Picture Vocabulary test was better under fasting conditions than following breakfast consumption, an effect specific to well-nourished children.

2.3.8.2 Chronic intervention studies: The effects of SBPs on global function

Two chronic intervention studies examined the effects of SBPs on Raven's CPM scores (Table 2.2). Mean IQ scores from Raven's CPM were higher following a 3-

month intervention providing 250ml 2.5% fat milk at breakfast relative to matched control schools with no intervention (Rahmani et al., 2011). This effect was only apparent in boys. The study also examined performance pre- and post-intervention on the WISC, but there was no effect on verbal, non-verbal and overall IQ scores. There was no difference in Raven's CPM performance between a school that had received an 8-month SBP relative to a matched control school with no intervention (Lieberman et al., 1976).

2.3.8.3 Cross-sectional studies: The association between habitual breakfast frequency, composition and global function

Four cross-sectional studies examined the association between habitual breakfast consumption and global function (Table 2.3). Two studies demonstrated opposing findings regarding Raven's CPM performance. The first study found no association between breakfast intake frequency and Raven's CPM IQ scores in Malaysian 4-6 year olds (Nasir et al., 2012). However, the second study found a significant association between frequency of breakfast intake and Raven's CPM IQ scores in Iraqi 7-8 year olds (Ghazi, Isa, Aljunid, Tamil, & Abdalqader, 2012). Children who were regular breakfast eaters were more likely to have high IQ scores (>75th percentile) compared with children who were irregular breakfast eaters. However, it was not clear how "regular" breakfast consumption was defined.

The association between breakfast consumption and IQ scores from the WPPSI was examined in a cohort of 5-6 year old Chinese children (Liu, Hwang, Dickerman, & Compher, 2013). Often/always eating breakfast (≥4 days/week) was associated with higher verbal and full IQ scores, relative to less frequent consumption, following adjustment for confounders. However, performance IQ scores (visual-spatial subtests) were not significantly associated with breakfast consumption. The authors suggested that the specific facilitation of verbal IQ scores but not performance IQ scores was not due to breakfast *per se* but to the potential social interaction and "meal time discussions" during breakfast which may have expanded vocabulary or facilitated comprehension of stories.

The association between habitual breakfast composition and WISC IQ scores was examined in Japanese school children aged between 5-16 years (Taki et al., 2010). Following adjustment for confounders, participants who habitually ate white rice for breakfast had higher full IQ and perceptual organisation index (visual-spatial subtests) scores compared to those who habitual ate white bread for breakfast. There was no effect on verbal IQ scores. The GI of Japanese white rice is lower than white bread (68 vs.100), which suggests that habitual intake of lower GI breakfast foods and the accompanying more stable and sustained glycaemic response, may be associated with higher IQ scores. However, the rice breakfast meals were lower in fat than the bread breakfast meals, which could also account for the findings.

Table 2.1: Tabulation of studies investigating the acute effect of breakfast on cognitive performance

Authors	Design	Sample	BF intervention	Cognitive measures	Reported results
Amiri et al. (2014)	Acute study. Randomised crossover design. 1-week washout.	n=51 aged 9-11 years. Male:47% Female:53% Well-nourished. Iran.	Three conditions: Fixed isocaloric BF of differing macronutrient content and no BF. 1. High CHO BF 2. High PRO BF 3. No BF	CT: baseline, +30 mins, +120 mins post BF. CDR battery Reaction time: SRT, CRT Attention: Digit vigilance Working memory: Numeric working memory task (Sternberg-like) Visual-spatial memory: Delayed picture recognition, spatial working memory task	CRT: Poorer performance following no BF vs. high CHO and high PRO in boys. SRT, CRT, power of attention (SRT, CRT and digit vigilance factor score): General decline in performance in girls following high CHO BF. No other effects of BF on CT.
Benton et al. (2007)	Acute school-based study. Randomised crossover design. BF administered during a 4-week school BF club.	1 primary school. n=19 mean age: 6 years 10 months (range: 5 years 11 months-7 years 8 months). Male: 47% Female: 53% Low SES school. UK.	Three conditions: Ad libitum BF of differing GL, designed to be isocaloric but intake varied. 1. HGL: 25g Cornflakes, 115 ml semi-skimmed milk, 2 teaspoons sugar, 1 waffle, 1 tablespoon syrup. Mean intake: GL:18, 196Kcal, 4.7g PRO, 1.7g fat, 33.9g CHO 2. MGL: 60g scrambled egg, 1 slice bread, 10g jam, 8g low-fat spread, 125g yoghurt. Mean intake: GL:12, 168Kcal, 8.9g PRO, 5.2g fat, 21.7g CHO 3. LGL: 30g ham, 40g cheese, 1 slice linseed bread, 8g low-fat spread. Mean intake: GL:3, 157Kcal, 10.8g PRO, 10.2g fat, 5.7g CHO	CT: +140-210 min post BF. Verbal memory: Immediate and delayed object name recall from British Ability Scale. Visual-spatial memory: Immediate and delayed object location recall Attention: Paradigm of Shakow (respond to visual stimulus after auditory warning)	ANOVA: no main effect of BF condition on all CT measures. Correlations: Significant negative correlation between immediate verbal memory and BF GL. Significant negative correlation between BF GL and CHO intake and attention (difficult final trials only). Significant positive relationship between fat intake and attention (difficult final trials only). Regression: Lower GL BF predicted better immediate verbal memory. PRO, fat, CHO did not predict verbal memory. Lower GL BF predicted better attention (difficult final trials only).

Table 2.1 continued

Authors	Design	Sample	BF intervention	Cognitive measures	Reported results
Brindal et al. (2012)	Acute lab-based study. Randomised crossover design. 3 consecutive days.	n=39 mean age ± SD: 11.6 ± 0.7 years (range: 10-12). Male: 67% Female: 33% Well-nourished. Australia.	Three conditions: Fixed isocaloric BF (311Kcal) of differing GL. 1. HGL:70g white bread, 10g margarine, 5 g vegemite/low sugar jam, 200ml juice drink (GL:33, 7g PRO, 9g fat, 50g CHO) 2. MGL:100g low fat yoghurt, 20g full fat cheese, 35g white bread, 5g vegemite/low sugar jam, 100ml juice drink (GL:24, 14g PRO, 9g fat, 45g CHO) 3. LGL:100ml full fat milk, 100g low fat yoghurt, 20g cheese, 35g white bread, 5g vegemite/low sugar jam (GL:18, 18g PRO, 10g fat, 38g CHO) BG monitored.	CT: baseline, +60, +120, +180 min post BF. Reaction time: Composite score of reaction times across 3 tasks: SRT, CRT, and odd-man-out reaction time Attention: Attention switching task, letter cancellation Verbal memory: Immediate free word recall based on RAVLT word lists Working memory: Digit span backwards from WISC Visual perception: Visual inspection time task	No significant effects of BF GL on all CT measures despite significant difference in BG response.
Brindal et al. (2013)	Acute lab-based study. Randomised crossover design. 3 consecutive days.	n=40 mean age ± SD: 11.6 ± 0.1 years (range: 10-12). Male: 48% Female: 52% Well-nourished. Australia.	Three conditions: Fixed isocaloric drink (263Kcal) of differing in Gl. 1. VHGL: Glucose drink. GL:65, 0g PRO, 0g fat, 65g CHO 2. HGL: Glucose drink with 200ml whole milk. GL:35, 7g PRO, 8g fat, 42g CHO 3. LGL: Glucose drink with 400ml whole milk. GL:5, 13g PRO, 15g fat, 19g CHO BG monitored.	CT: baseline, +60, +120, +180 min post BF. Reaction time: Composite score of reaction times across 3 tasks: SRT, CRT, and odd-man-out reaction time Attention: Attention switching task, letter cancellation Verbal memory: Immediate free word recall based on RAVLT word lists Working memory: Digit span backwards from WISC Visual perception: Visual inspection time task	No significant main effects of drink GL on all CT measures despite significant difference in BG response. Verbal memory: Significant sex x condition interaction. Post hoc test indicated girls recalled significantly more words following LGL or HGL drink compared with glucose drink. Opposite pattern in boys, but not statically significant.

Table 2.1 continued

Authors	Design	Sample	BF intervention	Cognitive measures	Reported results
Busch et al. (2002)	Acute lab-based study. Crossover design. Counter-balanced. 1-week washout.	n=21 males aged 9-12 years. Well-nourished. USA.	Two conditions: Fixed BF vs. no BF. 1. BF: 25g confectionary snack (95Kcal, 0g PRO, 1.1g fat, 22g simple CHO) 2. No BF: Aspartame sweetened drink matched for sweetness (0Kcal)	CT: +15 min post BF. Attention: CPT (visual) Visual-spatial memory: Map task (immediate recall) Visual perception: Rey Complex Figure task (copy accuracy) Verbal memory: Story recall, (immediate recall) Working memory: Digit span forwards and backwards	CPT: Significantly higher hit rate, lower miss rate and lower false alarms after BF vs. no BF. No other significant effects of BF on CT.
Chandler et al. (1995)	Acute school-based study. Randomised crossover design. 2-week washout.	4 schools. n=197 aged 8-10 years. Male: 51% Female: 49% Stratified by nutritional status: Underweight: n=97, mean age ± SD: 9.7 ± 0.9 years Normal: n=100, mean age ± SD: 9.1 ± 0.8 years Low SES. Jamaica.	Two conditions: Fixed BF vs. No BF. BF also consumed at home before school. 1. School BF:68g bread, 28g cheese, 225ml chocolate milk (520Kcal, 21.3g PRO) 2. Low energy control: 60g orange (18Kcal, 0.3g PRO)	CT: between 0900-1200hrs. Attention: Letter cancellation Working memory: Digit span forwards Executive function: Verbal fluency (categorical fluency).	BF*nutrition group interaction: Underweight children generated significantly more words on verbal fluency task following BF vs. no BF, but no change in normal weight. No other significant effects of BF on CT.
Conners & Blouin (1982)	Acute lab-based study. Crossover design.	n=10 aged 9-11 years. Well-nourished. USA.	Two conditions: Fixed BF vs. no BF 1. BF: RTEC, milk, sugar, egg, juice, toast 2. No BF	CT: 0950, 1100, 1210hrs Attention: CPT (visual) Working memory: Mental calculation task EEG recoding	CPT: Significantly less errors following BF vs. no BF at all time points across morning. Mental Calculation: Significantly better performance at 1100hrs following BF vs. no BF. No other significant effects of BF on CT. Significant reduction in amplitude of evoked potentials following BF vs. no BF.

Table 2.1 continued

Authors	Design	Sample	BF intervention	Cognitive measures	Reported results
Cooper et al. (2011)	Acute school-based study. Randomised crossover design. 1-week washout.	5 secondary schools. n=96, mean age ± SD: 13.2 ± 1.2 years (range: 12-15). Male: 50% Female: 50% 90% habitual BF consumers. Well-nourished. UK.	Two conditions: Ad libitum BF vs. no BF. 1. BF: Choice of RTECs, muesli, semi-skimmed milk, bread, fat spreads, jam, yoghurt, fruit and fruit juices. Mean intake: Male: 589Kcal, 14.0g PRO, 10.7g fat, 107.6g CHO. Female: 406Kcal, 9.3g PRO, 8.2g fat, 72.8g CHO 2. No BF BG monitored.	CT: +20, +140 min post BF. Tasks differed in difficulty Reaction time: SRT (two difficultly levels) Executive function: Stroop task (two difficultly levels) Working memory: Sternberg paradigm (three difficulty levels)	SRT: BF*time*difficulty interaction: Significantly better accuracy following BF vs. no BF at +20 mins on more difficult trials. No effect of BF on response times. Stroop: BF*time interaction: Accuracy better maintained across morning following BF vs. no BF on both versions. No effect of BF on response times. Sternberg: BF* time*difficulty interaction: Response times faster across morning following BF vs. no BF on more difficult trials. Response times faster across morning following no BF vs. BF on easier trial. No effect of BF on task accuracy. Significantly higher BG following BF vs. no BF across morning.
Cooper et al. (2012)	Acute school-based study. Randomised crossover design. 1-week washout.	2 secondary schools. n=41 mean age ± SD: 12.8 ± 0.4 years (range: 12-14). Male: 44% Female: 56% Well-nourished. UK.	Three conditions: Fixed isocaloric BF (420Kcal) differing in GI and no BF. 1. HGI: 55g cornflakes, 42g white bread, 6g margarine, 216g 1% fat milk (GI:72,14.3g PRO, 7.2g fat, 75g CHO) 2. LGI: 217g 1% fat milk, 75g Muesli, 150g apple (GI:48,15.5g PRO, 6.4g fat, 75g CHO) 3. No BF BG and insulin monitored.	CT: +30, +120 min post BF. Tasks differed in difficulty. Executive function: Stroop task (two difficulty levels) Selective attention: Flanker task (two difficulty levels) Working memory: Sternberg Paradigm (three difficulty levels)	Stroop task: BF*time*difficultly interaction: Response times improved across morning following LGI vs. no BF on difficult version. BF*time interaction: Greater decrease in accuracy across morning following HGI vs. LGI. Sternberg: BF* time* interaction: Response times improved more across morning following LGI vs. HGI on all versions. BF*time*difficulty interaction: Accuracy better maintained across morning following LGI vs. HGI on difficult trial. Flanker task: BF* time* interaction: Response times improved more across the morning following LGI vs. no BF on both versions. BF* time*difficulty interaction: Accuracy better maintained across morning following LGI vs. HGI and no BF on difficult trials.

Table 2.1 continued

Authors	Design	Sample	BF intervention	Cognitive measures	Reported results
Cromer et al. (1990)	Acute lab-based study. Randomised independent groups design.	n=34 mean age ± SD: 14.2 ± 0.4 years. Mid-high SES. Well-nourished. USA.	Two conditions: Fixed BF vs. no BF following overnight stay. 1. BF: Government school BF. 60g doughnut, 236g chocolate milk, 118g orange juice (424Kcal, 11.5g PRO. 14.1g fat, 63.9g CHO) 2. Low energy control: 236g sugar-free drink, ½ cup of sugar-free jelly (12Kcal, 1.6g PRO, 0g fat, 1.6g CHO) BG monitored	CT: +60, +240 min post BF Verbal memory: Immediate free word recall from RAVLT Attention: Digit vigilance Visual perception: MFFT	No significant effect of condition on all CT measures. Ceiling effects observed on MFFT. No difference in BG between BF conditions and no correlation between BG and CT performance. Significantly more habitual BF eaters (≥5/days per week) in control group (81%) vs. BF group (45%)
Cueto et al. (1998) also in Pollitt et al. (1996) (Study 1) and Pollitt et al.1998 (Exp 3)	Acute lab-based study. Randomised crossover design. 1-week washout.	n=54 males. Stratified by nutritional status: Nutritionally at risk: n=23, mean age ± SD: 10.3 ± 0.7 years Not at risk: n=31, mean age ± SD: 10.4 ± 0.7 years. Low SES Peru.	Two conditions: Fixed BF vs. no BF following standardised evening meal and overnight stay. 1. Government school BF: 80g cake, 50g milk-like drink (510Kcal, 14.4g PRO, 12.1g fat, 81.9g CHO). Fortified with Fe, Vit A +C. 2. Low energy control: Sugar and caffeine free carbonated drink BG monitored.	CT: +180 min post BF. Attention: Digit cancellation Global function: Raven's Coloured Progressive Matrices, Peabody Picture Vocabulary test. Reaction time: CRT Working memory: Sternberg paradigm Visual perception: Stimulus discrimination	Nutritionally at risk: Significantly poorer performance on Sternberg paradigm and stimulus discrimination following no BF vs. BF. Nutritionally not at risk: Better performance following no BF vs. BF on Peabody Picture Vocabulary test and stimulus discrimination task. No other significant effects of BF on CT. BG was not significantly associated with test performance in both nutritional groups under both conditions.
Defeyter & Russo (2013)	Acute school-based study. Crossover design. Counterbalanced. 1-week washout.	1 secondary school. n=40 mean age ± SD: 14.2 ± 0.5 years (range: 13-15). Male: 48% Female: 52% BF skippers. Low SES. Well-nourished. UK.	Two conditions. Fixed BF vs. no BF. 1. 35g LGI RTEC: Kellogg's All-Bran, 125ml skimmed milk (162Kcal, 9.4g PRO, 1.2g fat, 22.7g CHO) 2. No BF	CT: baseline, +135 min post BF. High and low cognitive load versions of tasks. Order counterbalanced. Verbal memory: Delayed free word recall Reaction time: CRT Attention: RVIP Executive function: Stroop task Working memory: Serial subtractions by 3s and 7s	Word recall: Significantly better recall following BF vs. no BF on high cognitive load version of task only. Serial 3's and 7's: Significantly better working memory following BF vs. no BF. Cognitive load of task did not interact with effect. No other significant effects of BF on CT.

Table 2.1 continued

Authors	Design	Sample	BF intervention	Cognitive measures	Reported results
Dickie & Bender (1982) Exp 2	Acute school-based study. Randomised independent groups design.	4 boarding schools. Investigation 1: n=55 mean age: 17 years Investigation 2: n=53 mean age 16.2 years Mid-high SES. Well-nourished. UK.	Two conditions: Ad libitum BF vs. no BF. 1. Usual boarding school BF: ≈500Kcal 2. No BF	CT: +195 min post BF Investigation 1: Attention: Letter cancellation Investigation 2: Executive function: Sentence-Picture verification task (reasoning task)	No significant effects of BF on all CT measures
Ingwersen et al. (2007)	Acute school-based study. Crossover design. Counterbalanced. 2 consecutive days.	1 primary school. n=64 mean age: 9.3 years (range: 6-11). Male: 40% Female: 60% Well-nourished. Mixed SES. UK.	Two conditions: Fixed BF of differing GI. Not isocaloric. 1. HGI: 35g Kellogg's Coco Pops (GI: 77, 133Kcal, 1.6g PRO, 0.9g fat, 29.8g CHO) and 125ml semi-skimmed milk 2. LGI: 35g Kellogg's All-Bran (GI: 42, 98Kcal, 4.9g PRO, 1.6g fat, 16.1g CHO) and 125ml semi-skimmed milk	CT: baseline +10, +70 +130 min post BF. CDR battery Verbal memory: Immediate and delayed free word recall, delayed word recognition Reaction time: SRT, CRT Attention: Digit vigilance Working memory: Numeric working memory (Sternberg-like) Visual-spatial memory: Delayed picture recognition, spatial working memory	Significantly better secondary memory (delayed word and picture recognition, immediate and delayed word recall factor score) following LGI vs. HGI at +10 and +130 min but not +70 min. Significantly better accuracy of attention (SRT, CRT, digit vigilance factor score) following LGI vs. HGI at +130 mins. No effect of BF on speed of attention, speed of memory and working memory factor scores.
Kral et al. (2012)	Acute lab-based study. Randomised crossover design. 1-week washout.	n=21 mean age ± SD: 9.2 ± 0.8 years (range: 8-10). Male: 29% Female: 71% Habitual BF consumers. Well-nourished. USA.	Two conditions: Fixed BF vs. no BF. 1. BF: 32g RTEC (choice of 3) 192g 1% fat milk, 60g banana, 187g orange juice (≈350Kcal, 9.9g-12.4g PRO, 3.3g-5.1g fat, 68.0-69.1g CHO) 2. No BF	CT: baseline and +45, +90 +135 min post BF Cogstate battery. Visual-spatial memory: PAL, one card learning task (immediate recall), Working memory: One back task (n-back) Psychomotor function: Chase task Executive function: Groton maze learning task Reaction time: SRT, CRT	No significant effects of BF on all CT measures.

Table 2.1 continued

Authors	Design	Sample	BF intervention	Cognitive measures	Reported results
López et al. (1993)	Acute school-based study. Independent groups design.	12 primary schools. n=279 mean age ± SD: 10.3 ± 0.5 years (range: 8-10). Male: 48% Female: 52% Stratified by nutritional status: Normal: n=106 Underweight: n=73 Stunted: n=100 Low SES. Chile.	Two conditions: Fixed BF vs. no BF. 1. BF: 2 cakes, 200ml flavoured milk (394Kcal; 6g PRO) 2. No BF	CT: +60 min post BF Executive function: Domino task Attention: Attention task (response to target geometric figures within continuous stream) Working memory: Digit span	No significant effects of BF on all CT measures.
Maffeis et al. (2012)	Acute lab-based study. Randomised crossover design. 1-week washout.	n=10 median age: 9.6 years (range: 9-10). Male: 40% Female: 60% Well-nourished (obese). Italy.	Two conditions: Fixed BF vs. no BF. 1. BF: 200ml full fat milk, 32g bread, 25g marmalade (295Kcal, 9.6g PRO, 8.8g fat, 44.9g CHO) 2. No BF (water) Blood samples: BG, insulin, glucagon, ghrelin, peptide YY, GLP-1 monitored. Indirect calorimetry: REE, meal induced thermogenesis and macronutrient oxidation.	CT: baseline, +180 min post BF. Attention: Conners' CPT Verbal Memory: Immediate free word recall with selective reminding within TOMAL word selective reminding subtest Visual-spatial memory: Visual sequential memory subtest within TOMAL (memory for sequences of geometric shapes; immediate recall).	CPT: Fasting induced a significant decrease in performance; no change in performance following BF. Selective reminding: Fasting induced a significant increase in word recall; no change in performance following BF. No other significant effects of BF on CT. Decrease in CPT performance was significantly associated with reduced in CHO oxidation.

Table 2.1 continued

Authors	Design	Sample	BF intervention	Cognitive measures	Reported results
Mahoney et al. (2005) Exp 1	Acute school-based study. Crossover design. Counterbalanced. 1 day a week for 3 consecutive weeks.	1 private primary school. n=30 aged 9-11 years. Male: 50% Female: 50% 52% habitual BF consumers. Mid-high SES. Well-nourished. USA.	Three conditions: Fixed isocaloric BF of differing macronutrient content and no BF. 1. 43g Oatmeal, ½ cup skimmed milk (360Kcal, 4g PRO, 2g fat, 32g CHO) 2. 36g RTEC, ½ cup skimmed milk (350Kcal, 1g PRO, 1.5g fat, 30g CHO) 3. No BF	CT:+60 min post BF Visual-spatial memory: Map task (immediate and delayed recall), Rey Complex Figure task (immediate and delayed recall) Visual perception: Rey Complex Figure task (copy accuracy) Working memory: Digit span forwards and backwards Attention: CPT (auditory and visual) Verbal memory: Story recall (immediate and delayed recall)	Map task: Significantly better immediate recall following oatmeal BF vs. no BF. Digit span backwards: Girls performed significantly better following oatmeal vs. RTEC and no BF. Rey complex copy: Significantly better copy accuracy following both oatmeal and RTEC vs. no BF. CPT auditory: Fewer false alarms following oatmeal and RTEC vs. no BF early in task. No other significant effects of BF on CT.
Mahoney et al. (2005) Exp 2	As Mahoney et al. (2005) Exp 1	1 private primary school. n=30 aged 6-8 years. Male: 50% Female: 50% 64% habitual BF consumers. Mid-High SES. Well-nourished. USA.	As Mahoney et al. (2005) Exp 1	As Mahoney et al (2005) Exp 1 with modifications for younger participants.	Map task: Significantly better immediate recall following oatmeal BF vs. no BF Digit span backwards: Girls performed significantly better following oatmeal vs. RTEC Rey complex copy: Boys had significantly better copy accuracy following RTEC vs. no BF. Significantly better copy accuracy for girls after no BF vs. RTEC. CPT auditory: More hits following oatmeal vs. RTEC with intermediary performance following no BF. Fewer misses following oatmeal or no BF vs. RTEC. No other significant effects of BF on CT.

Table 2.1 continued

Authors	Design	Sample	BF intervention	Cognitive measures	Reported results
Micha et al. (2011)	Acute school-based study. 2x2 factorial design. Randomised crossover and independent groups design. Independent groups: HGL vs. LGL Crossover: HGI vs. LGI. 2-week washout.	5 secondary schools. n=74 mean age ± SD: 12.6 ± 0.1 years (range: 11-14). Male: 50% Female: 50% Mixed SES Well-nourished. UK.	Two independent groups (differing GL) with crossover conditions (differing GI) within each group. Fixed BFs. HGL (GL:41-55): 1. LGI: 66g muesli, 200ml milk, 245ml juice, 7g table sugar (GI:48, 470Kcal, 14g PRO, 7.1g fat, 86.6g CHO) 2. HGI: 55g cornflakes, 300ml milk, 200ml juice, 7g table sugar. (GI:61, 470Kcal, 14g PRO, 5.3g fat, 90.4g CHO) LGL (GL:21-28): 1. LGI: 40g muesli, 250ml milk, 5g table sugar. (GI:48, 281Kcal, 12.5g PRO, 6.4g fat, 43.2g CHO) 2. HGI: 30g cornflakes, 300ml milk, 5g table sugar. (GI: 61, 276Kcal, 12g PRO, 5.1g fat, 45.2g CHO) BG, salivary cortisol monitored.	CT: +103 min post BF. Verbal memory: Immediate and delayed free word recall Executive function: Stroop task Executive function: Matrices task (reasoning ability), verbal fluency task (letter fluency) Attention: Digit cancellation Working memory: Serial subtractions by 7s	Verbal fluency task: Significantly higher number of words following LGI BF vs. HGI BF Stroop task: Significantly faster completion following HGI-HGL BF Digit cancellation: Significantly higher number correct following HGI BF vs. LGI BF. Serial 7s: Significantly higher number correct following HGI BF vs. LGI BF No other significant effects of BF GI/GL on CT. Higher BG before CT following HGL and GI vs. LGL and GI BF. Higher cortisol before and after CT in HGI vs. LGI meals.
Michaud et al. (1991)	Acute school-based study. Randomised (by school) crossover design. 2-week washout.	n=319 mean age ± SD: 16.1 ± 1.3 years (range: 13-20) Male: 47% Female: 53% Well-nourished. France.	Two conditions: 1. Habitual BF 2. Higher energy BF than habitual BF. Stratified by extra energy consumed: • + 0-99Kcal • + 100-199Kcal • + 200-299Kcal • + 300-399Kcal • + ≥ 400Kcal	CT: 1100 hrs Visual-spatial memory: Scale test (immediate recall for location of boxes) Attention: Word cancellation	Visual-spatial memory: Significant increase in recall following additional energy BF vs. habitual BF. Attention: Significantly worse word cancellation performance following additional energy BF vs. habitual BF.
Morrell & Atkinson (1977)	Acute school-based study. Randomised independent groups design.	n=52 aged 4-11 years. Well-nourished. USA	Two conditions: Fixed BF. 1. Usual school BF: Fruit juice, RTEC or bread, milk, chocolate or syrup or sweet roll. Meat, fish, poultry, cheese or egg: approx. 11g PRO 2. High PRO, low CHO school BF: Unsweetened juice, pink, frankfurter, hamburger, burritos: approx. 24g PRO	CT: Late morning Working memory: Digit span forwards and backwards from WISC	No significant effects of BF on working memory.

Table 2.1 continued

Authors	Design	Sample	BF intervention	Cognitive measures	Reported results
Muthayya et al. (2007)	Acute lab-based study. Randomised crossover design. 1-week washout.	n=69 aged 7-9 years. Stratified by SES: Low SES: n=34, mean age ± SD: 7.6 ± 0.6 years. 32% wasted, 21% stunted. Male: 44%, Female: 56% High SES: n=35, mean age ± SD: 7.6 ± 0.6 years. Well-nourished. Male: 63%, Female: 37% India.	Three conditions. Ad- libitum BF of differing energy content with/without mid-morning snack. BF: chapatti and potato curry. Mid-morning snack: Mango flavoured bar. 1. Small BF (187Kcal) + mid-morning snack (153Kcal) + standard lunch (500Kcal) 2. Standard BF (340Kcal) + mid-morning snack (153Kcal) +small lunch (347Kcal) 3. Standard BF (340Kcal) + standard lunch (500Kcal)	CT: baseline, +30, +150 min post BF. Visual-spatial memory: Immediate and delayed picture recognition Psychomotor function: Finger tapping Attention: RVIP	LSES: Raw scores: Significantly better immediate picture recognition accuracy +150 minutes following condition 2 vs. 3. No effect of condition to delayed picture recognition raw scores. Change scores: Decline in accuracy on immediate picture recognition at session 3 relative to baseline was significantly smaller following condition 1 and 2 vs. 3. Decline in accuracy on delayed picture recognition at session 3 relative to baseline significantly smaller following condition 1 and 2 vs. 3. HSES: Raw scores: No effect of condition to immediate and delayed picture recognition. Change scores: Decline in accuracy on immediate picture recognition at session 3 relative to baseline was significantly smaller following condition 2 vs. 3. Increase in false alarms on delayed picture recognition at session 3 relative to baseline was significantly smaller following condition 2 vs. 3. No other significant effects of BF on CT.
Pivik & Dkyman (2007)	Acute lab-based study. Randomised independent groups design.	n=60 aged 8-11 years Male: 50% Female: 50% Habitual BF consumers. Well-nourished. USA.	Two conditions: Fixed BF vs. no BF following standardised evening meal and overnight stay. 1. BF: Based on US SBP. ¾ cup RTEC, 227ml 2% fat milk, one slice white bread, ½ cup applesauce (340Kcal, 14g PRO, 6g fat, 57g CHO). 2. No BF BG monitored.	CT: baseline, +40 min post BF. Attention: Go/No-Go task EEG recording during task.	Significant increase in reaction time relative to baseline for no BF group only; No change in BF group. No effect on task accuracy, but presence of ceiling effect. Increased alpha wave synchronisation in no BF group.

Table 2.1 continued

Authors	Design	Sample	BF intervention	Cognitive measures	Reported results
Pivik et al. (2012)	Acute lab-based study. Randomised independent groups design.	n=81 mean age ± SD: 9.78 ± 0.8 years (range 8-11). Male: 46% Female: 54% Habitual BF consumers. Well-nourished. USA.	Two conditions: Fixed BF vs. no BF following standardised evening meal and overnight stay. 1. BF: Based on US SBP. ¾ cup RTEC, 227ml 2% fat milk, one slice white bread, ½ cup applesauce (340Kcal, 14g PRO, 6g fat, 57g CHO) 2. No BF BG monitored.	CT: baseline, +40 min post BF. Working memory: Mental calculation task EEG recording during task	Significant increase in accuracy following BF relative to baseline; no change in no BF group. Significant increase in response time in no BF group relative to baseline; no change in BF group EEG: Increased high theta and high and low alpha band activity in no BF group vs. BF group. Increased delta and lower theta activity in left frontal recordings in no BF vs. BF group indicating increased region specific activity for working memory.
Pollitt et al. (1998) Exp 1	Acute lab-based study. Randomised crossover design.1-week washout.	n=32 aged 9-11 years Male: 28% Female: 72% Well-nourished. USA.	Two conditions: Fixed BF vs. no BF following standardised evening meal and overnight stay. 1. BF: 535Kcal, 15g PRO, 20g fat, 75g CHO 2. No BF BG monitored.	CT: +180 min post BF Visual-spatial memory: HCIT (memory for sequences of objects and animals; immediate recall; immediate recall) Attention: CPT Visual perception: MFFT Global function: Peabody Picture Vocabulary test (used as covariate and outcome).	MFFT: Low IQ school children made significantly more errors on easy trials following no BF vs. BF. Decrease in BG associated with more errors. HCIT: Recall of last object significantly better following no BF vs. BF. Incidental score better following no BF vs. BF (analysis on first day of testing only) No other significant effects of BF on CT.
Pollitt et al.(1981)	Acute lab-based study Randomised crossover design.1-week washout.	n=34 mean age 10 years 4 months (range: 9-11). Male: 35% Female: 65% Well-nourished. USA.	Two conditions: Fixed BF vs. no BF following standardised evening meal and overnight stay 1. BF: Waffles, syrup, margarine, orange juice, milk (535Kcal, 15g PRO, 20g fat, 75g CHO) 2. No BF BG monitored	CT: +180 min post BF Visual-spatial memory: HCIT (memory for sequences of objects and animals; immediate recall). Attention: CPT (visual) Visual perception: MFFT	MFFT: Significantly more errors on easy trials following no BF vs. BF for school children with lower IQ only. Decrease in BG associated with more errors. HCIT: Significantly better recall of last item following no BF vs. BF. No other significant effects of BF on CT.

Table 2.1 continued

Authors	Design	Sample	BF intervention	Cognitive measures	Reported results
Pollitt et al.(1982) Also Politt et al 1998 Exp 2	Acute lab-based study. Randomised crossover design.1-week washout.	n=39 mean age 10 years 4 months (range: 9-11). Male: 51% Female: 49% Well-nourished. USA.	Two conditions: Fixed BF vs. no BF following standardised evening meal and overnight stay 1. BF: 448Kcal, 12g PRO, 16g fat, 65g CHO. No details of type food provided. 2. No BF	CT: +180 min post BF Visual-spatial memory: HCIT (memory for sequences of objects and animals; immediate recall). Working memory: Digit span, xylophone tapping Visual perception: MFFT Global function: Slossum Intelligence Scale (used as covariate and outcome)	MFFT: Significantly more errors following no BF vs. BF on difficult levels only. No interaction with IQ. HCIT: Significantly higher incidental scores following no BF vs. BF (analysis on first day of testing only) No other significant effects of BF on CT.
Simeon & Grantham McGregor (1989)	Acute lab-based study. Randomised crossover design.1-week washout.	n=90 aged 9-10.5 years. Stratified by nutritional status: Stunted: n=30 Previously undernourished: n=30 Control/well-nourished: n=30 Effect of wasting also considered. Low SES. Jamaica.	Two conditions: Fixed BF vs. no BF following standardised evening meal and overnight stay. 1. BF: based on Jamaican government SBP. 105g Nutribun, 242g Milk,25g cheese (590Kal, 29g PRO, 12g fat, 91g CHO) 2. Low energy control: 185ml Aspartame sweetened tea	CT: +180 min post BF Working memory: Digit span forwards and backwards, mental calculation task from WISC Executive function: Verbal fluency (categorical fluency). Verbal memory: Cued story recall (immediate recall) Attention: Coding test (digit-symbol substitution) from WISC Visual-spatial memory: HCIT (memory for sequences of objects and animals; immediate recall). Visual perception: MFFT	Stunted/previously undernourished/wasted: BF*nutrition group interaction indicated worse performance on verbal fluency, coding, digit span backwards and forwards and MFFT (easy trials) following no BF vs. BF. Well-nourished: BF*nutrition group interaction indicated better performance on calculation task and MFFT following no BF vs. BF. No other significant effects of BF on CT.

Table 2.1 continued

Authors	Design	Sample	BF intervention	Cognitive measures	Reported results
Smith & Foster (2008)	Acute lab-based study. Randomised independent groups design.	n=38 mean age ± SD: 15.6 ± 0.9 years (range: 14-17). Male: 50% Female: 50% Mostly habitual BF consumers: average 0.8 days/week skipped BF. Well-nourished. Australia	Two conditions: Fixed BF differing in GL. 1. LGI: 30g Kellogg's All-Bran RTEC, 125 ml semi-skimmed milk (GI:30, 218Kcal, 12.7g PRO, 4.8g fat, 26.3g CHO) 2. HGI: 30g cornflakes RTEC 125 ml semi-skimmed milk (GI:77, 232Kcal, GI:77, 10.4g PRO, 4g fat, 37g CHO) BG monitored.	CT:+20, +60, +100 min post BF Verbal memory: Immediate, short and long delay free and cued word recall from CVLT Concomitant motor task to increase task demands.	No significant effects of BF GI on raw recall scores. Relative to the number of words recalled at the short delay, significantly less words were forgotten after the long delay following HGI RTEC vs. LGI RTEC. No significant effects of BF GI on BG.
Vaisman et al. (1996)	Acute school-based study. Randomised independent groups design.	5 primary schools. n=569 aged 11-13 years. Male: 51% Female: 49% Test 1 (baseline): n=491 Test 2 (post-intervention): n=503 Mixed SES Israel.	Test 1 (baseline): Two conditions: Self-reported BF on morning of test. 1. BF at home 2. No BF Typical breakfast: biscuits, chocolate milk and a small portion of RTEC. Test 2 (post-intervention): Three conditions: Fixed school BF intervention for 14-days vs. BF at home or no BF. 1. School BF: 30g sugared cornflakes, 200ml 3% fat milk (≈263Kcal, 7g PRO, 38g CHO, 8g fat) 2. BF at home 3. No BF Chronic intervention but analysis assessed acute effects of BF.	CT: +30 min post school BF and +120 min post BF at home Verbal memory: Immediate and delayed free word recall and recognition from RAVLT, story recall within Wechsler Memory Scale Logical Memory subtests Visual-spatial memory: Benton Visual Retention Test (immediate recall)	Test 1: RAVLT: significantly better immediate recall following self-reported BF at home vs. no BF. No other significant effects of BF on CT. Test 2: RAVLT: Significantly better mean learning, best learning, retroactive inhibition and recognition following school BF vs. no BF and BF at home. Significantly better delayed recall and temporal order following school BF vs. BF at home. Story recall: Significantly better recall following school BF vs. no BF and BF at home. Benton Visual Retention: Significantly better performance following school BF vs. no BF and BF at home.

Table 2.1 continued

Authors	Design	Sample	BF intervention	Cognitive measures	Reported results
Wesnes et al. (2003)	Acute lab-based study. Randomised crossover design. 4 consecutive days.	n=29 aged 9-16 years. Male: 48%, mean age: 12.1 years. Female: 52%, mean age: 12.3 years. Well-nourished. UK.	Four conditions: Fixed BF of differing macronutrient content and no BF. Not isocaloric. Ad libitum water. 1. 45g Nestlé Shreddies, 125ml semi-skimmed milk (38.3g CHO, 25.2g complex CHO) 2. 30g Nestlé Cheerios, 125ml semi-skimmed milk (28.7g CHO,16g complex CHO) 3. 330ml orange flavoured drink (38.3g glucose) 4. No BF	CT: baseline +30, +90, +150 +210 min post BF CDR battery. Verbal memory: Immediate and delayed free word recall, delayed word recognition Reaction time: SRT, CRT Attention: Digit vigilance Working memory: Numeric working memory (Sternberg-like) Visual-spatial memory: Delayed picture recognition, spatial working memory	Significant main effects of BF condition to power of attention (SRT, CRT, digit vigilance factor score) and quality of episodic memory (delayed word and picture recognition, immediate and delayed word recall factor score). No post-hoc tests, but observed decline in cognitive performance during morning in no BF and glucose drink condition which was reduced by two cereal BF conditions. No effect of BF to on continuity of attention, speed of memory and working memory factor scores.
Widenhorn-Müller et al. (2008)	Acute school-based study. Randomised crossover design. 1-week washout.	1 boarding school. n=104 mean age ± SD: 17.2 ± 1.6 years (range: 13-20). Male: 52% Female: 48% 88% habitual BF consumers. Mid-high SES Well-nourished. Germany.	Two conditions: Fixed BF vs. no BF. Water and unsweetened peppermint tea provided ad libitum in both conditions. 1. BF: 60g wholegrain bread 28g butter, 20g chocolate spread, 30g jam (476Kcal) 2. No BF	CT: +45 min post BF. Attention: d2 Test of Attention Visual-spatial memory: Trail route (immediate recall), Logos task (picture recognition; immediate recall) Verbal memory: Turkish vocabulary, cued recall of factual text, object recall, telephone numbers (all immediate recall)	Significant effect of BF on visual-spatial memory in males, but observed order effects. No other significant effects of BF on CT.

Table 2.1 continued

Authors	Design	Sample	BF intervention	Cognitive measures	Reported results
Wyon et al. (1997)	Acute school-based study. Randomised independent groups design.	5 primary schools. n=195 n=165 completed aged 10 years. Male:44% Female: 56% Well-nourished. Denmark and Sweden.	Two conditions: Ad libitum BF at home of differing energy content. High energy BF: Male: 100g bread, 10g margarine, 28g cheese, 20g ham, 300 ml 3% milk, 20g cornflakes, 100g apple, 200ml juice (Mean intake: 536Kcal) Female: 50g bread, 10g margarine, 20g ham, 300 ml 1.5% milk, 20g cornflakes, 100g apple, 200ml juice (Mean intake: 434Kcal) Low energy BF: Male: 50g Bread, 10g margarine, 24g jam, 500ml cordial (Mean intake: 170Kcal). Female: 30g Bread, 10g margarine, 24g jam, 500ml cordial (Mean intake: 121Kcal)	CT: late morning Working memory: Mental calculation and multiplication task Attention: Digit cancellation Executive function: Grammatical reasoning, verbal fluency (categorical fluency).	Significantly higher scores on grammatical reasoning task after high energy BF vs. low energy BF. No other significant effects of BF on CT.

Abbreviations: ANOVA: Analysis of variance, BG: Blood glucose, BF: Breakfast, CDR: Cognitive drug research, CHO: Carbohydrate, CPT: Continuous performance test, CT: Cognitive testing, CRT: Choice reaction time, CVLT: California Verbal Learning Test, EEG: Electroencephalography, GI: Glycaemic index, GL: Glycaemic load, GLP-1: Glucagon-like peptide-1, Fe: Iron, HCIT: Hagen Central Incidental Task, HGI/L: High Glycaemic index/load, Kcal: Kilocalorie, LGI/L: Low Glycaemic index/load, MFFT: Matched Familiar Figures Test, MGI/L: Medium Glycaemic index/load, PAL: Paired associates learning, PRO: Protein, RAVLT: Rey Auditory Verbal Learning Test, RDA: Recommended daily allowance, REE: Resting energy expenditure, RTEC: Ready to eat cereal, RVIP: Rapid Visual Information Processing, SBP: School breakfast program, SD: Standard deviation, SES: Socio-economic status, SRT: Simple reaction time, TOMAL: Test of memory and learning, VHGI/L: Very high Glycaemic index/load, WISC: Wechsler intelligence scale for children

Table 2.2: Tabulation of studies investigating the effect of chronic interventions on cognitive performance

Authors	Design	Sample	BF intervention	Cognitive measures	Reported results
Cueto & Chinen (2008)	SBP evaluation. Independent groups design. Compared matched schools with SBP (11 schools) vs. No SBP (9 schools). Multiple and full grade schools. 3 year intervention	20 primary schools. n=590 SBP: n=300, mean age ± SD: 11.87 ± 1.77. Male: 51.7%, Female: 48.3% Control: n=290 mean age ± SD: 11.87 ± 1.90. Male: 49.7%, Female: 50.3% Comparable nutrition status: 66-69% of school children ≤-2 SD height-for-age NCHS Low SES Peru.	Two conditions: 1. Free mid-morning SBP: BF during school break time at 1000-1100 hrs. Milk-like beverage and 6 biscuits (600 Kcal, 19.5g PRO, 20g fat, 60% RDA for various micronutrients, 100% RDA for iron). 2. Control: No BF/BF at home Compliance: 82% consumed all of BF. Consumed BF mid-morning following BF at home.	CT: +3-years. Administered after BF at ≈1100 hrs. Attention: Coding test (digit-symbol substitution) from WISC Visual-spatial memory: Picture recognition (immediate recall)	Significantly better picture recognition in multiple-grade intervention schools compared to multiple-grade control schools at post intervention. No other significant effects of BF on CT.
Jacoby et al. (1996) also reported in Pollitt et al 1996 (Study 2)	SBP evaluation. Cluster RCT. Independent groups design. 5 intervention schools, 5 control schools, 1 month intervention.	10 Primary school. n=352. Intervention: n=201, mean age ± SD: 136.2 ± 18 months. Male: 46%, Female: 54% Control: n=151, mean age ± SD: 138.9 ± 20 months. Male: 53%, Female: 47% Normal, underweight and stunted school children. Low SES Peru.	Two conditions, SBP. 1. SBP: Milk-like beverage and 6 biscuits (600Kcal, 19.5g PRO, 60% RDA for various micronutrients and 100% RDA iron. 2. Control: No SBP, wait list control	CT: baseline, +1 month. Attention: Digit cancellation, Coding test (digit-symbol substitution) from WISC Working memory: Digit span from WISC	No significant difference between intervention vs. control schools on all CT measures.
Lieberman et al. (1976)	SBP evaluation. Independent groups design Compared matched school with SBP vs. no SBP. 8-month intervention.	2 primary schools. n=617 aged 8-11 years SBP: n=294 Control: n=323 Well-nourished Low SES USA	Two conditions 1. SBP: “Traditional” hot BF designed to provide ≈ 1/4 of the RDA for 9-10 year olds. Based on foods from USDA SBP in addition to eggs, meat or meat alternatives. 2. Control: No SBP 60% attendance rate at SBP.	CT: baseline +8 months Global function: Raven’s Coloured Progressive Matrices Visual perception: Rey Complex Figure task (copy accuracy) Auditory attention: Listening task.	No significant differences on all measures in intervention vs. control schools.

Table 2.2 continued

Authors	Design	Sample	BF intervention	Cognitive measures	Reported results
Moore et al. (2014)	As Murphy et al. (2011). Secondary analysis to assess impact of SBP on SES inequalities.	As Murphy et al (2001). Included additional SES measures using data linkage. SES measures: School-level: 1. % whole school entitled to FSM 2. % participants in school entitled to FSM Individual level 3. Y/N FSM entitlement	As Murphy et al. (2011).	As Murphy et al. (2011).	School level analysis: FSM entitlement did not significantly interact with the effects of the intervention on word recall. Individual level analysis: FSM entitlement did not significantly interact with the effects of the intervention on word recall. Main effect of FSM entitlement on word recall, word recall was significantly poorer in school children in receipt of FSM.
Murphy et al. (2011)	SBP evaluation. Clustered RCT. Independent groups design 56 control schools, 55 intervention schools. 1 year intervention.	111 primary schools. Subsample of 1 Year 5 and 1 Year 6 class in each school for cognitive assessment. n=4123 at baseline n=4112 at follow-up aged 9–11years. Control: n=2063 Intervention: n=2049 Well-nourished. Mixed SES UK.	Two conditions: 1. SBP: Welsh Primary School Free BF Initiative: Low-sugar RTEC, milk, bread, fruit. Considered nutritionally balanced. 2. Control: No SBP, wait list control Compliance: 41% attended SBP 1 day/week and 30% attended 5 days/week. 10 schools randomised to intervention did not set up SBP.	CT: baseline, +4 months, +1 year. Administered between 0900-1100hrs in groups of ≈40 participants. Verbal memory: Immediate free word recall.	ITT: No significant differences in word recall in intervention vs. control schools. No difference in prevalence of BF skipping in intervention vs. control schools. PP: No significant differences in word recall in schools that had set up SBP vs. control schools.
Nkhoma et al. (2013)	SBP evaluation. Independent groups design. Compared matched school with SBP vs. No SBP. 1 school year intervention	2 primary schools. n=226 at baseline n=190 at follow up mean age ± SD: 6.6 ± 0.5 years (range: 6-8) Male: 50% Female: 50% Underweight: 25% Stunted: 42% NCHS reference. Low SES Malawi.	Two conditions: 1. SBP:100g micronutrient-fortified porridge (350Kcal). Reduced ration by 25% due to government funding cut (263Kcal, 11-103% of RNI of various micronutrient. 2. Control: No BF/BF at home	CT: baseline, +1-year. CANTAB battery. Visual-spatial memory: PAL (immediate recall) Attention: RVIP Executive function: Intra-extra dimensional set shift (rule acquisition and reversal).	Significantly less errors on set shift task at follow-up in SBP vs. no SBP. No other significant effects of BF on CT. Significant increase in mid-arm circumference between baseline and follow-up in SBP; no change in no SBP.

Table 2.2 continued

Authors	Design	Sample	BF intervention	Cognitive measures	Reported results
Rahmani et al. (2011)	SBP evaluation, Independent groups design. Compared matched schools with SBP vs. No SBP. 3 month intervention	4 single-sex primary schools. n=469 Male: 49% mean age ± SD: 7.9 ± 0.8 years. Female: 51% mean age ± SD: 7.5 ± 0.9 years. Iran.	Two conditions: 1. SBP: 250ml 2.5% fat milk at 0930 hrs 2. Control: No milk	CT: baseline +3 months. Global function: Raven's Coloured Progressive Matrices and WISC	Boys in intervention group performed significantly better on Raven's post intervention compared with control group. No effect in girls. Multiple t-tests conducted on outcomes at baseline and post intervention (within and between groups).
Richter et al. (1997)	SBP evaluation. Independent groups design. Compared matched school with SBP vs. no SBP. 6-week intervention	2 primary schools. n=108. Intervention vs. control schools poorly matched. Control: n=55 well-nourished children mean age ± SD: 8.3 ± 0.8 years from inner city school. Mid SES. Intervention: n=53 undernourished school children mean age ± SD: 10.5 ± 1.9 years from rural school. Low SES. South Africa.	Two conditions: 1. SBP:30g cornflakes, 100ml semi-skimmed milk, banana (≈267Kcal, 7.2g PRO, 2.5g fat, 54g CHO) 2. Control: No SBP	CT: baseline, +6 weeks. Attention: Letter cancellation, Coding test (digit-symbol substitution) from WISC Working memory: Digit span from WISC	Digit span and letter cancellation: Mean change scores significantly higher in intervention vs. control group.
Shemilt et al. (2004)	SBP evaluation. Clustered RCT. Independent groups design. 24 intervention schools, 19 control schools. 1 year intervention.	43 primary and secondary schools. Subsample of n=200 per school. n=5837 at baseline n=3894 at follow up Control: n=2372, mean age ± SD: 10.13 ± 3.93 years. Male: 52%, Female: 48%. Intervention: n=3465, mean age ± SD: 9.59 ± 2.96 years. Male: 49%, Female: 51%. Well-nourished. Mixed SES UK.	Two conditions: 1. Funding for free SBP. 2. Control: No funding for SBP Contamination between treatment arms: 72.2% of pupils in intervention and 77.0% of pupils in control had SBP at their school. Evoked PP analysis: School children classified as: 1. Non-attendees: Never attended SBP 2. Attendees: Attended SBP at least once	CT: baseline, +3 months, +12 months. Executive function: Reitan Trail Making Test Part A (primary school children) and Part B (secondary school children)	ITT: Time taken to complete Trail Making Test Part A was significantly shorter in the intervention vs. control at +3 month follow-up. No other significant effects of BF on CT. PP: No significant differences in trail making between attendees vs. non-attendees. Adjusted for: school type, baseline outcome measure, gender and eligibility for FSMs.

Table 2.2 continued

Authors	Design	Sample	BF intervention	Cognitive measures	Reported results
Worobey & Worobey (1999) Exp 1	SBP evaluation. Pre-post intervention design. 6-week intervention.	1 preschool. n=12 aged 3 years 10 months to 5 years 2 months. Mid SES. Well-nourished. USA.	Two conditions: 1. Pre intervention (baseline): BF at home. Intake record by parents. Mean intake: 275Kcal 2. Intervention: SBP: 1 serving milk, 1 serving fruit/ vegetable/ fruit juice, 2 servings of bread and meat. Mean intake: 262Kcal.	CT: baseline, +6 weeks. Visual perception: same or different task, pattern match Executive function: Mazes task from WPPSI, Embedded figures task (nonverbal reasoning) Verbal memory: Verbal memory scale from MSCA (free word recall; immediate recall) Working memory: Numeric memory scale from MSCA (digit span forwards and backwards)	Significantly improved performance on mazes, pattern match, same or different task after SBP BF compared with baseline (BF at home). No other significant effects of BF on CT.
Worobey & Worobey (1999) Exp 2	SBP evaluation. Independent groups design. Compared participants attending SBP vs. no SBP. 6-week intervention.	1 preschool n=16 SBP: n=9 aged 3 years 11 months to 4 years 6 months. Control (BF at home): n=7 aged 3 years 10 months to 4 years 5 months. Mid SES. Well-nourished. USA	As in Worobey & Worobey (1999) Exp 1 but addition of control group. Two conditions 1. SBP: Mean intake: 158Kcal. 2. Control: BF at home. Intake record by parents. Mean intake: 212Kcal	CT: baseline, +6 weeks. Visual perception: Same or different task, cookie hunt task (pattern match), MFFT. Psychomotor function: Animal pegs (place pegs in correct animal locations) from WPPSI	Animal pegs: Both SBP and control group improved significantly from baseline to follow up. Follow-up scores significantly faster in SBP vs. control. MFFT: Both SBP and control group improved significantly from baseline to follow up. Cookie task: Significant decline in performance from baseline to follow up in control group; no change in SBP group. Same/different task: SBP improved significantly from baseline to follow up; no change in control group. Follow-up scores significantly higher in SBP vs. control. No other effects of BF on CT.

Abbreviations: BF: Breakfast, CANTAB: Cambridge Neuropsychological Test Automated Battery, CHO: Carbohydrate, CT: Cognitive testing, FSM: Free school meals, IG: Independent groups, ITT: Intention to treat, Kcal: Kilocalorie, MFFT: Matched Familiar Figures Test, MSCA: McCarthy Scales of Children's Abilities, NCHS: National Centre for Health Statistics PAL: Paired associates learning, PP: Per protocol, PRO: Protein, RCT: Randomised control trial, RDA: Recommended daily allowance, RNI: Reference nutrient intake, RTEC: Ready to eat cereal, RVIP: Rapid Visual Information Processing, SBP: School breakfast program, SD: Standard deviation, SES: Socio-economic status, WISC: Wechsler intelligence scale for children, WPPSI: Wechsler preschool primary scale of intelligence

Table 2.3: Tabulation of observational studies investigating associations between breakfast and cognitive performance

Authors	Design	Sample	BF assessment	Cognitive measures	Reported results
Baldinger et al. (2011)	Cross-sectional survey study.	Primary school children. n=656 aged 7-10 years. Well-nourished. Switzerland.	Questionnaire to assess BF eating frequency. BF intake classified as: 1. Almost Always 2. Sometimes 3. Almost never 4. Only on weekends	Psychomotor function: Finger tapping	No association between BF and finger tapping performance.
Dickie & Bender (1982) Exp 1	Cross-sectional survey study	3 secondary schools. n=487 stratified by age: Mean age 12.5 years: n=227 Mean age 15.3 years: n=260 Well-nourished. UK.	Questionnaire to assess BF intake on morning of CT. 1. BF 2. BF+ mid-morning snack 3. No BF or mid-morning snack 4. No BF	CT: Pre and post lunch Attention: Letter cancellation	No significant effects of self-report BF on attention.
Gajre et al. (2008)	Cross-sectional survey study.	School children. n=379 aged 11-13 years. Male: ≈55% Female: ≈45% Underweight: 20.8% Stunted: 38.5% NCHS reference. India.	Questionnaire to assess BF eating frequency and type. BF defined as first eating occasion of the morning before school. BF intake classified as: 1. Regular: >4 days/ week 2. Irregular: 2-3 days/ week 3. Never BF composition not reported.	CT: between 0900-1100 hrs. Attention: Letter cancellation Verbal memory: Immediate recall of sentences	ANOVA indicated that regular BF group had significantly better letter cancellation scores compared to no BF group. Regression analysis indicated that regular BF significantly predicted letter cancellation and sentence recall scores. Lack of adjustment for confounders: Stepwise regression technique used.
Ghazi et al. (2012)	Cross-sectional survey study.	5 primary schools n=529 aged 7-8 years Male: 52% Female: 48% Below weight-for-age: n=64 Well-nourished: n=465 Mixed SES Iraq	Questionnaire to assess BF frequency. Completed by parents. BF defined as food eaten between 0600-1000 hours. BF intake classified as: 1. Regular BF 2. Irregular BF/no BF	CT: Administered by parents/self-administered Global function: Raven's Coloured Progressive Matrices Scores dichotomised: 1. High >75th percentile 2. Low ≤75th percentile	Significant association between Raven's scores and BF intake. BF skippers were more likely to have low Raven's scores vs. BF eaters. Lack of adjustment for confounders: Pearson's χ^2 used for analysis.

Table 2.3 continued

Authors	Design	Sample	BF assessment	Cognitive measures	Reported results
Liu et al. (2013)	Cross-sectional survey study. Part of China Jintan Child Cohort Study.	Pre-school children n=1269 aged 5-6 years. Male: 55% Female: 45% Well-nourished. China.	Questionnaire, 1-item to assess BF frequency. Completed by parents. BF intake classified as: 1. Always: ≥6 days/week 2. Often: 4-5 days/week 3. Sometimes:2-3 days/ week 4. Rarely: 0-1 days/week Responses dichotomised: 1. Often/always (≥4 days/week) 2. Sometimes/rarely (<4 days/week)	Global function: WPPSI Three scores calculated: 1. Verbal IQ (Information, Vocabulary, Comprehension, mental calculation, Similarities subtest) 2. Performance IQ (Block design, Geometric design, Mazes, Picture completion, Object assembly subtests) 3. Full score IQ (All subtests)	ANOVA indicated that verbal, performance and full IQ scores were significantly higher for often/always BF consumption vs. sometimes/rarely BF consumption. Regression (adjusted analysis): Often/always BF consumption predicted higher verbal and full IQ scores. Adjusted for: gender, current living location, parental education and occupation, primary child caregiver.
Micha et al. (2010)	Cross-sectional survey study.	Two secondary schools n=60 mean age ± SD: 13 ± 0.1 years (range 11-14) Male: 40% Female: 60% Habitual BF consumers. Well-nourished. UK.	Interview to assess type and amount of food consumed for BF on day of testing. BF intake classified as: HGL (GL:43-44): 1. LGI: GI: 53, 502Kcal, 17.9g PRO, 14g fat, 81.2g CHO 2. HGI: GI: 68, 379Kcal, 12.6g PRO, 9.3g fat, 65.2g CHO LGL (GL:31-23): 3. LGI: GI: 58, 272Kcal, 10.2g PRO, 11.3g fat, 34.5g CHO 4. HGI: GI: 64, 240Kcal, 9.7g PRO, 7.7g fat, 35.4g CHO Median spilt for GI and GL. BG monitored	CT: +90-120 mins post usual BF. If additional snack was eaten (>10g CHO) CT +90 mins post-snack Tasks: As Micha et al. (2011)	Immediate word recall: HGI associated with better recall. Matrices: HGL associated with better performance. GL*Gender interaction. Girls: LGL associated with better performance. Boys: HGL associated with better performance. Digit cancellation: HGL and LGI associated with better performance. GI*gender interaction. Girls: LGI associated with better performance. Serial 7s: HGL and LGI BF associated with better performance. Adjusted for: gender, SES, age, height, weight, BMI, Hb and BG levels, 'happy' mood score before the CT tests and time between BF and the first CT test
Nasir et al. (2012)	Cross-sectional survey study.	Preschool children n=1933 aged 4-6 years Male: 48% Female: 52% Majority well-nourished. Underweight: 8% Stunted: 8.4% Mixed SES Malaysia	Questionnaire to assess BF frequency. Completed by parents. BF intake classified as: 1. BF eaters: ≥5 days/week 2. BF skippers: <5 days/ week	Global function: Raven's Coloured Progressive Matrices	No difference in cognitive performance in BF eaters vs. BF eaters. Independent samples t-test used for analysis: No significant difference found so not entered into final hierarchical regression model with adjustment for confounders.

Table 2.3 continued

Authors	Design	Sample	BF assessment	Cognitive measures	Reported results
Taki et al. (2010)	Cross-sectional survey study.	School children. n=290 aged 5.6-18.4 years Male: 50% Female: 50% Well-nourished. Mix SES Japan	Questionnaire to assess BF staple type. Parents completed for participants aged ≤10 years. BF intake classified as: 1. Rice BF (Japanese boiled white rice): n=152. GI:68 2. Bread BF (white bread): n=87. GI:100 3. Mixed BF (rice and bread): n=51	Global function: WAIS for participants aged ≥16 years. WISC for participants aged <16 years. Seven scores calculated: 1. Verbal IQ 2. Performance IQ 3. Full scale IQ 4. Verbal comprehension index 5. Perceptual organization index 6. Processing seed index 7. Working memory index MRI scanning.	Rice BF group had significantly higher full scale IQ and perceptual organization index scores vs. bread group. Rice BF group had significantly higher global grey matter ratio[a] vs. bread and both BF group. Rice BF group had significantly larger regional grey matter volume in the left superior temporal gyrus and bilateral caudate nuclei vs. bread group. Bread BF group has significantly larger regional grey matter volume in bilateral orbitofrontal gyri and the right precentral gyrus vs. rice BF group. Adjusted for: age, gender, SES, habitual BF frequency, number of BF side dishes.
Wesnes et al. (2012)	Cross-sectional survey study.	32 primary and secondary schools. n=1386 aged 6-16 years. Male: 48%, mean age ± SD: 11.1 ± 2.3 years. Female: 52%, mean age ± SD: 11.8 ± 2.5 years. Well-nourished. UK.	Online questionnaire to assess BF intake on day of testing. BF intake classified as: 1. BF 2. No BF. BF intake data collected during an initiative to promote BF consumption	CT: between 0742-1233 hrs. Self-administered via website. Reaction time: SRT, CRT Attention: Digit vigilance Visual-spatial memory: Delayed picture recognition	Significantly faster power of attention response times (SRT, CRT, digit vigilance factor score) in BF eaters vs. no BF. More discernible for females. Significantly lower response speed variability (SRT, CRT, digit vigilance factor score) in BF eaters vs. no BF. Significantly more correct hits and less false alarms on digit vigilance task BF eaters vs. no BF. Significantly better sensitivity to correct targets and faster responses on picture recognition in BF eaters vs. no BF.

[a] Grey matter volume percentage divided by intracranial volume

Abbreviations: ANOVA: Analysis of variance, BG: Blood glucose, BF: Breakfast, BMI: Body mass index, CHO: Carbohydrate, CT: Cognitive testing, CRT: Choice reaction time, GI: Glycaemic index, GL: Glycaemic load, Hb: Haemoglobin, Kcal: Kilocalorie, NCHS: National Centre for Health Statistics, PRO: Protein, SD: Standard deviation, SES: Socio-economic status, SRT: Simple reaction time, WAIS: Wechsler adults intelligence scale, WISC: Wechsler intelligence scale for children, WPPSI: Wechsler preschool primary scale of intelligence, χ^2: Chi Squared

Table 2.4: Summary of findings of the effects of breakfast on each cognitive domain

Cognitive domain	Acute interventions		Chronic interventions	Habitual BF studies	
	BF vs. NO BF	BF type vs. BF type	SBPs	Frequency	Composition
Immediate verbal memory	2/9	4/9	0/3	1/1	1/1
Delayed verbal memory	3/5	3/7	0/0	0/0	0/1
Combined verbal memory	3/10	5/9	0/3	1/1	1/1
Immediate visual-spatial memory	6/13	2/8	1/2	0/0	0/0
Delayed visual-spatial memory	1/4	3/7	0/0	1/1	0/0
Combined visual-spatial memory	7/13	4/8	1/2	1/1	0/0
Phonological working memory	7/16	4/11	1/3	0/0	1/1
Attention	8/19	8/13	1/5	2/3	1/1
Reaction time	3/6	3/5	0/0	1/1	0/0
Psychomotor function	0/1	0/1	1/1	0/1	0/0
Visual perception	7/9	0/4	2/3	0/0	0/0
Executive function	4/8	3/3	3/3	0/0	1/1
Global function	0/3	0/0	1/2	2/3	1/1

Key: No. of studies with positive effect/no. of studies in which test was applied

2.4 Interim summary of findings

A summary of the findings of this SRR is shown in Table 2.4. These findings can be summarised as follows:

2.4.1 Acute effects of breakfast vs. no breakfast (24 studies)

- There was evidence that breakfast consumption was more beneficial than breakfast skipping. However, findings were not consistent.
- 20/24 studies that included a fasting condition reported a positive effect of breakfast consumption on at least one cognitive task.
- Many studies also reported null findings. 19/24 studies reported no effects of breakfast on at least one cognitive task.
- Very few studies observed a detrimental effect of breakfast consumption. Only 6/24 studies reported a negative effect of breakfast relative to fasting on at least one cognitive task.
- Effects were demonstrated across a range of energy loads (95 Kcal – 590 Kcal) and a range of breakfast foods.
- In mixed samples of well and undernourished children, nutritional status influenced the relationship between breakfast and cognitive performance.
- There was also some evidence that higher cognitive load tasks were more sensitive to the effects of breakfast, but findings were not consistent.
- The evidence suggests that certain cognitive domains are more reliably facilitated by the consumption of breakfast than others (Table 2.4). However, some domains were more frequently examined than others.
- Overall, attention (8/19 studies), working memory (7/16 studies) and immediate visual-spatial memory (6/13 studies) were most frequently facilitated by breakfast consumption (Table 2.4).
- Visual perception (7/9), executive function (4/8 studies), reaction time (3/6 studies) and delayed verbal memory (3/5 studies) also seemed sensitive to the effects of breakfast but fewer studies examined these domains.

2.4.2 Acute effects of breakfast type (15 studies)

- Firm conclusions cannot be made regarding the acute effects of breakfast composition. There are fewer studies comparing breakfast type than those which compare breakfast with no breakfast and these demonstrate inconsistent findings.
- To add to the complexity of the evidence, breakfast conditions differed unintentionally in other nutrients or characteristics.

- Where positive effects occurred, attention (8/13 studies) and immediate verbal memory (4/9 studies) were most consistently facilitated by type of breakfast (Table 2.4).
- The evidence generally suggested that breakfast foods or meals which were lower in GI (6/7 which compared GI explicitly or indirectly) were associated with better cognitive performance. The evidence for facilitation from low GL breakfast meals was insufficient and inconsistent (2/4 of which compared GL) despite GL being a better predictor of glycaemic response (Brand-Miller et al., 2003).

2.4.3 Chronic interventions (11 studies)

- There is insufficient evidence to support a consistent effect of SBPs on cognitive performance.
- 10/11 chronic SBPs interventions failed to demonstrate a positive effect on at least one cognitive measure. Attention appeared to be particularly insensitive to the effects of chronic SBP interventions (1/5 studies showed a benefit)
- 6/11 SBP studies reported a positive effect on at least one cognitive task. The positive effects of SBPs were most consistent on tasks assessing executive function (3/3). However, this should be interpreted with caution due to the lack of consideration of other cognitive domains.

2.4.4 Habitual breakfast consumption: Frequency and composition (9 studies)

- Few studies employed cross-sectional designs to examine the association between habitual breakfast consumption and cognitive outcomes, precluding firm conclusions.
- The evidence was fairly consistent across the small amount of studies available. 5/7 studies demonstrated that habitual breakfast consumption (frequency and quality) was related to cognitive function.
- The evidence demonstrated fairly consistently that the frequency of habitual breakfast consumption was positively related to cognitive function. Associations were most consistent for global measures of cognitive function (2/3) and attention (2/3).
- The composition of habitual breakfast consumption was also related to cognition in 2 studies. Both studies suggested that habitual consumption of lower GI breakfast meals was associated with superior cognitive performance.

2.5 Discussion

2.5.1 Principal findings

The present SRR indicates that there is some evidence that breakfast consumption has a transient beneficial effect on cognitive function compared to breakfast omission. However, this finding is not consistent across all studies. It is more difficult to make conclusions about the acute effects of breakfast composition and the chronic effects of SBP interventions as there are fewer studies and these largely report inconsistent findings. Particularly, SBPs seem to have limited effects on cognitive outcomes, but this may be partly attributed to the difficulties in executing these typically large, pragmatic trials. There is a small amount of evidence suggesting that habitual breakfast consumption is related to cognitive function but again, conclusions are limited due to the small amount of studies available and the greater influence of other confounders. Previous reviews (Hoyland et al., 2009; Pollitt & Mathews, 1998) support the most consistent finding that consumption of breakfast relative to breakfast skipping facilitates cognition in the short-term.

2.5.1.1 Effect of breakfast manipulations on specific cognitive domains

The evidence suggests that certain cognitive domains are more reliably facilitated by the acute consumption of breakfast relative to fasting than others (Table 2.4). Attention, working memory and immediate visual-spatial memory were most frequently associated with positive effects of breakfast consumption relative to fasting. To a lesser degree, visual perception, executive function, reaction time and delayed verbal memory appeared to show consistent effects of breakfast but findings were less conclusive due to there being fewer published studies. There was also some evidence that specific cognitive modalities were more susceptible to facilitation by specific breakfast types and by chronic intervention, but the evidence is insufficient and inconsistent. In acute studies which compared breakfast type, a low GI breakfast (see section 2.5.1.3) was most consistently associated with positive effects on attention and immediate verbal memory (Table 2.4). Positive effects of SBPs were most consistently demonstrated on tasks assessing executive function (Table 2.4). In studies reporting associations between habitual breakfast consumption frequency and type, fractionation of effects was less apparent with 3 of the 7 studies reporting effects on global function tasks (Table 2.4). In addition to the fractionation of effects on specific cognitive modalities, there were also instances where effects were specific to certain tasks and parameters within tasks, although the weight of the evidence was insufficient to draw firm conclusions. For example, some studies suggested that enhancement effects of breakfast on reaction time tasks (SRT, CRT) are specific to response times rather than accuracy, with other studies showing the reverse pattern.

The variable findings for particular cognitive domains should be interpreted in conjunction with an appreciation of the imbalance of research effort across cognitive domains. This means that some modalities appear consistently facilitated by breakfast consumption, but the paucity of research across multiple domains precludes this conclusion. Moreover, tests used within domains also vary between studies and may not reflect the same underlying cognitive process. Nevertheless, the evidence at present does suggest that breakfast does not exert global effects across cognitive domains. This is also similar to the domain specific effects of glucose ingestion on cognitive function which has some relevance given that most breakfast manipulations were carbohydrate-rich (Hoyland et al., 2008; Riby et al., 2006). Although children and adolescents rarely consume pure glucose for breakfast, the carbohydrate component (usually polysaccharides e.g. starch) in most of the breakfast manipulations is digested and absorbed into the bloodstream as glucose. However, the rate at which glucose is absorbed into the blood stream following ingestion of polysaccharides will be different to that following ingestion of pure glucose. Glucose is a monosaccharide which is absorbed rapidly into the blood stream from the small intestines whereas polysaccharides elicit a dampened glycaemic response (Dye, Lluch, & Blundell, 2000). Furthermore, the polysaccharide component of breakfast is usually digested and absorbed in the presence of other macronutrients (i.e. protein, fat) and fibre.

When interpreting the finding that certain cognitive domains may be more sensitive to the effects of breakfast than others, it should be acknowledged that cognitive functions are not discrete; they overlap. Many of the tests employed by the studies reviewed are considered valid measures of the cognitive processes they purport to test. However, they also require efficient functioning of other processes (Schmitt et al., 2005). This is particularly true for tests of executive function. Higher-order executive function processes can also influence or control more basic cognitive functions such as attention and memory (Wesnes & Brooker, 2011). Tests of executive function can, therefore, assess numerous aspects of cognitive function (Wesnes & Brooker, 2011). For example, the Stroop task also measures selective attention and so some researchers refer to this as a test of attention. Hence, changes in executive function may also reflect changes in other aspects of cognitive function. Many tasks that assess visual-spatial memory include a verbal component. Two studies used a map task to assess immediate recall of object name locations (Busch et al., 2002; Mahoney et al., 2005). Although this is a spatial memory task, it has a verbal component, and therefore success on the task is determined by both spatial and verbal memory.

Similarly, there are many different conceptualisations regarding how different tasks might be classified within specific cognitive domains. Indeed, different authors may classify the same task under different cognitive domains. This was evident in the studies reviewed in relation to working memory. Tasks included were purported to measure working memory but some of the tasks were simple span tasks which require participants to only immediately recall items, arguably a of measure short-term memory (Cowan, 2008; Gathercole & Alloway, 2006). Complex span tasks add a secondary processing task (e.g. mathematical operation or re-sequencing or unrelated task) requiring participants to remember items during an on-going task. For example, forwards digit span involves the auditory presentation of random sequences of digits for immediate verbal recall. Because the task does not include an additional processing task or manipulation of the to-be-remembered information, it has been argued that it does not tap into working memory (Gathercole & Alloway, 2006). The classification of tasks within this review was adapted from previous reviews concerned with the effects of nutrition on cognitive performance, to allow comparability of the findings (de Jager et al., 2014; Hoyland et al., 2008). However, the conclusions that could be drawn would likely differ if tasks were classified in a different manner.

The large number of null findings should also be considered when interpreting the findings. Significant positive findings for a particular cognitive domain in some studies were coupled with null effects in other studies. Moreover, where positive effects occurred, there were instances where effects were only apparent under specific conditions such as more difficult trials of the task, or in a specific subgroup of the sample under study. However, detrimental effects of breakfast consumption on cognition were very rarely reported. The evidence is therefore not unanimous across studies. The failure to detect an effect in some studies but not others may be a result of true lack of effect. However, it may be due to task insensitivity (de Jager et al., 2014). Across studies that assessed the same cognitive domain, a wide range of tests were used and only a limited amount of tests detected effects. This may be because some tasks were not sensitive enough to detect differences in performance induced by breakfast manipulations which are likely to be subtle. Indeed, the majority of studies did not state that cognitive test choice was driven by previous evidence showing the task to be sensitive to nutritional manipulations. This suggests that the rationale behind the choice of cognitive tasks is paramount; and tests should be chosen on the basis of their sensitivity to nutrient intervention. Another factor which may account for the inconsistent findings is the evidence for enhancement effects on certain parameters within tasks. This suggests that breakfast may facilitate a specific component of performance on a particular cognitive task. Therefore, a limited analysis of performance on a task (e.g. only accuracy) may result in null findings. Finally, the large methodological variation between the studies reviewed, as shown in Tables 2.1-2.3 may have also contributed to the inconsistent findings. These include differences in breakfast manipulation, timing of cognitive testing, testing environment and the sample recruited.

2.5.1.2 The timing of the effects of breakfast on cognition across the morning

Within acute studies, the timing of effects of breakfast manipulations on cognitive performance was inconsistent. Positive effects were noted at many time points across the morning from immediately post-ingestion (+10 minutes) to late morning (+210 minutes). It is difficult to determine when effects are most apparent because of the range of assessment timings. Moreover, many studies did not include appropriate post-hoc comparisons to confirm when statistical differences in performance occurred across conditions. However, effects of breakfast consumption relative to fasting appeared most commonly in the mid-late morning (~180 minutes post breakfast). This may be when performance decrements in fasted conditions become apparent, allowing for greater discrimination between conditions. In the studies that tracked performance across the morning with multiple testing sessions, performance often declined across the morning from baseline, in the early morning, to the final test session, in the late morning, in both breakfast and fasting conditions. However, breakfast consumption functioned to reduce this decline in performance rather than enhance performance above baseline levels.

2.5.1.3 Breakfast composition and cognitive performance

There were few studies which compared the effects of different breakfast meals on cognitive function. Of the few studies which made comparisons of different breakfast types on cognition, the findings were mixed preventing conclusions regarding the effect of breakfast type on cognition. Moreover, in acute intervention studies comparing breakfast to breakfast omission, effects were demonstrated across a range of breakfast manipulations and energy loads, suggesting that breakfast composition may be unrelated to cognition. A recent SRR of the effects of breakfast composition on cognitive performance in school children and adults also concluded that the evidence to date is insufficient to make firm conclusions (Edefonti et al., 2014).

Within the limited data comparing breakfast type, the evidence generally suggested that lower GI breakfasts may facilitate immediate verbal memory and attention relative to higher GI breakfasts. This was noted in both acute studies (Ingwersen et al., 2007; Mahoney et al., 2005; Micha et al., 2011; Wesnes et al., 2003) and also studies of habitual breakfast consumption composition (Micha et al., 2010; Taki et al., 2010). There were also suggestions that high GI conditions (glucose drink) were associated with a greater decline in performance in the late morning relative to fasting (Wesnes et al., 2003). This may be because following a high GI food, blood glucose concentrations rise rapidly causing a concomitant high insulin response resulting in a rapid disposal of blood glucose to levels lower than fasting concentrations (Foster-Powell et al., 2002). Taken together, this suggests that breakfast foods or meals that elicit a glycaemic response characterised by less oscillating glucose concentrations and a more sustained blood glucose concentration above fasting concentrations may facilitate verbal memory and attention. This also suggests that the post-prandial blood glucose profile may mediate the effects of breakfast on cognitive performance. However, it is not possible to confirm whether the low GI conditions were followed by the expected low glycaemic response, and if this was associated with cognition, as concomitant blood glucose measures were not always taken in studies which reported such effects (Ingwersen et al., 2007; Wesnes et al., 2003).

In studies which utilised continuous blood glucose monitoring, the evidence indicated that large differences in postprandial glycaemic responses elicited by high and low GL conditions were apparent in the absence of any cognitive performance effects (Brindal et al., 2012). Moreover, some evidence indicated that cognitive effects were apparent when blood glucose concentrations had returned to baseline, suggesting that effects of GI or GL manipulations on cognitive performance are not related to blood glucose concentrations in a close temporal manner. Moreover, there was also evidence that positive effects on cognitive performance occurred at times when blood glucose concentrations were actually lower in the low GI than high GI condition, questioning the suggestion that low GI foods may elicit better cognitive performance through a more prolonged blood glucose concentration above fasting levels (Cooper et al., 2012). Many studies also reported effects at times when post-prandial blood glucose concentrations are likely to have returned to baseline in both high and low GI conditions (Cooper et al., 2012; Ingwersen et al., 2007; Wesnes et al., 2003). These temporal relationships suggest that other factors associated with ingestion of these low GI breakfast meals, rather than glucose response per se, may mediate the effects on cognitive performance. Alternatively, cognitive performance could be related to blood glucose levels, but not in a tightly, temporally coupled manner.

Currently available evidence suggests that breakfast GI rather than GL is more strongly associated with cognitive performance. Similarly, a recent SRR concluded that GL was inconsistently associated with cognitive performance in school children and adults (Gilsenan, de Bruin, & Dye, 2009). However, conclusions are limited because most previous research has examined breakfast manipulations differing in GI, rather than GL. In addition, a key limitation of many studies is that breakfast conditions often differed in other characteristics that were not intended to be manipulated. For example, GI manipulations were often not isocaloric, had different carbohydrate loads across conditions and GL was not controlled for. To test if GI specifically is responsible for the effects, the nutritional (e.g. fat, protein, carbohydrate) composition of the meals should matched or similar and only the carbohydrate source should be varied and GL should be controlled for (Edefonti et al., 2014). Hence findings cannot be reliably attributed to either GI or GL. Nevertheless, the evidence does suggest that GL is less reliably associated with cognition than GI. In the 4 studies that investigated breakfast meals which differed in GL, the findings were less consistent than manipulations of GI (2/4 showed effects). This may be because GL can be modulated by reducing the GI of the carbohydrate of the meal and/or by reducing the carbohydrate load by replacing it with protein or fat. In two studies that did not find an effect of a low GL condition on cognitive function, the low GL conditions were also relatively low in carbohydrate and did not sustain blood glucose concentrations above fasting levels for longer than +60 minutes (Brindal et al., 2012; Brindal et al., 2013). Hence, maintaining the carbohydrate load across conditions, but reducing the GI of the carbohydrate in the low GL condition might have had different effects on cognition and may have sustained the blood glucose concentrations over a longer period. Hence, some authors argue that both GI and GL should be used in conjunction to best describe the glycaemic response of a food/meal and to accurately attribute effects on cognitive function (Micha et al., 2010, 2011).

The facilitation of cognitive function from low GI breakfast foods/meals was not consistent. Some studies reported an advantage of high GI breakfasts on cognitive function. Smith and Foster (2008) demonstrated that fewer words were forgotten after a long delay (+100 minutes) in a verbal memory task following consumption of the high GI RTEC vs. low GI RTEC. Although there were no significant differences in blood glucose measures taken at +10, +50 and +90 minutes post breakfast between GI conditions, the authors speculated that the additional glucose availability provided by the high GI RTEC at the time of encoding (+20 minutes post breakfast), when blood glucose levels were expected to peak, facilitated the reduction in forgetting. However, during the time of encoding and the assumed concomitant blood glucose peak in the high GI condition, immediate word recall was also assessed and was not facilitated by the high GI RTEC. This questions the appealing notion that high blood glucose concentrations during encoding facilitate recall.

2.5.1.4 Interaction of socio-demographic characteristics, breakfast and cognitive function

There was some evidence that advantageous effects of breakfast on cognition may be more apparent in undernourished children. In acute studies that included mixed samples of well and undernourished children, 4/5 suggested that positive effects of breakfast were specific or greater in children who were undernourished (Chandler et al., 1995; Cueto et al., 1998; Muthayya et al., 2007; Simeon & Grantham-Mcgregor, 1989). However, this could not be directly attributed to nutritional status in the study by Muthayya et al. (2007) as effects were more apparent in children who were low SES, only a third of whom were undernourished. One acute study did not find an effect of breakfast consumption in a sample of well and undernourished children, but noted that stunted children made more errors on an attention task relative to non-stunted children (López et al., 1993). Findings from chronic intervention studies also suggested that effects were more apparent in undernourished children (Cueto & Chinen, 2008; Nkhoma et al., 2013; Richter et al., 1997). One chronic intervention study showed effects in a sample which included severely undernourished children but did not analyse the interaction between nutritional status and the effects of the intervention on performance (Nkhoma et al., 2013). However, the beneficial effects on cognitive performance coincided with changes in anthropometric indicators of nutritional status (mid-upper arm circumference). Effects may be more demonstrable in undernourished children because these children also performed more poorly on the cognitive tasks (Ghazi et al., 2012; López et al., 1993; Nasir et al., 2012) and therefore had greater room for improvement.

The present review found little evidence that other socio-demographic characteristics moderated the relationship between breakfast and cognitive function. There was inconsistent evidence regarding interactions between breakfast and gender. Seventeen of the 25 studies that investigated whether effects of breakfast were influenced by gender reported similar effects across genders. The effects of breakfast differentially affected males and females in 8 studies, usually on one particular measure or parameter only. Further, there were no consistent trends (e.g. greater effects in females or males). Effects were also demonstrated across different ages, but most studies were conducted in children, precluding firm conclusions about the effects in adolescents. The effects in adolescents may be different. The rate of glucose utilization in the brain gradually declines from age 10 and usually reaches adult levels by the age of 16–18 years (Chugani, 1998). Furthermore, adolescence involves a period of rapid development, growth and lifestyle change which is also coupled with changing eating habits and increased control over eating habits. It is therefore likely that children and adolescents differ in their response to breakfast relative to fasting. There were some indications that baseline IQ modified the relationship between breakfast and cognitive performance such that the effects of breakfast were greater in, or specific to, school children with lower IQs (Pollitt et al., 1998; Pollitt et al., 1981), however the interaction was not reported in all studies that included IQ as a covariate (Jacoby et al., 1996; López et al., 1993; Pollitt et al., 1982; Simeon & Grantham-Mcgregor, 1989).

2.5.2 Methodological considerations

2.5.2.1 Breakfast manipulation

There was a considerable amount of variability with regard to the type of breakfast manipulation. The energy loads of the breakfast manipulations were also wide-ranging and were often not driven by a clear rationale. Although, higher energy (>500 Kcal) breakfast manipulations which were also fortified with large amounts of micronutrients were more common in studies carried out in developing countries in samples including undernourished children (Chandler et al., 1995; Cueto & Chinen, 2008; Cueto et al., 1998; Jacoby et al., 1996; Simeon & Grantham-Mcgregor, 1989). In acute intervention studies, the breakfast manipulations were typically fixed rather than ad-libitum. Fixed breakfast interventions require participants to consume a standardised breakfast in order to reduce variability in response but often assume that a prescribed portion size and type of breakfast is suitable for all participants. Further, such breakfasts may not be representative of participants' normal breakfast size and type and therefore have low ecological validity. Fixed interventions are particularly questionable in studies which include samples of school children of a wide age range and it is likely that the selected portion size is not suitable for all such participants (e.g. Wesnes et al., 2003; Widenhorn-Müller et al., 2008). Further, compliance to the breakfast manipulation in terms of the amount consumed was rarely reported. Ad-libitum breakfast manipulations allow participants to choose a breakfast that is palatable and suitable for them in terms of portion size. This should therefore better reflect the participants' usual eating habits. This is also important given that deviation from habitual intake can adversely affect cognitive performance (Lloyd, Green, & Rogers, 1994; Wyon et al., 1997).

2.5.2.2 Variability in study designs

There was a considerable amount of inter-study variability with regard to the types study designs employed by the studies included in this review. Studies considered both the acute effects of a single breakfast meal and the effects of a chronic breakfast intervention within SBPs. The latter studies are not a true test of breakfast *per se*. In SBP studies, food consumed before school was not recorded in both conditions and fasting requirements were not prescribed. Hence, participants in the non-SBP conditions often consumed breakfast at home. Further, compliance to the intervention in terms of whether or not the SBP breakfast was consumed was not always stated.

Rather, studies usually described compliance in terms of attendance rates. Hence, these comparisons are more strictly a test of the SBP regimen. Similarly, studies that examined cross-sectional associations between habitual breakfast consumption and cognitive performance provide no indication of causality or temporality.

Acute intervention studies permit greater isolation of the effects of the breakfast; however these studies are not without limitations. Compliance to the fasting requirements before and following breakfast/no breakfast was not always reported. Further, evening food intake was also not reported or controlled for, which may be particularly important in studies comparing breakfast meals differing in GI and GL, because evening intake can influence glycaemic responses the following morning (Lamport, Hoyle, Lawton, Mansfield, & Dye, 2011). However, 8 laboratory acute studies did include an overnight stay and hence a monitored overnight fasting period. On the contrary, a difficulty with well controlled laboratory-based studies is the potential for behaviour change due to the novel environment. The Hawthorne effect may be present such that participants may be motivated to perform well on the cognitive tasks simply because they are under investigation (McCarney et al., 2007). School-based studies have the advantage of aligning with the participants' normal, familiar environment and daily routine, providing ecologically valid evidence. In addition, during the test morning, the participants are cognitively taxed by their school lessons. In contrast, in laboratory studies, the intervals between study measures provide opportunities to heighten boredom, or produce systematic alterations in mood and behaviour. This highlights the trade-off between experimental control (precision) and ecological validity (naturalness). A further limitation was that many studies lacked large representative samples and it was unclear if many of the studies were sufficiently powered to detect an effect.

2.5.3 Potential Mechanisms of action for breakfast benefits

Despite the methodological differences and mixed results reported, the findings from the studies reviewed allow for speculation on the physiological and behavioural mechanisms involved in the observed short-term cognitive effects of breakfast consumption. The physiological mechanisms described below are primarily concerned with the processes by which ingestion of carbohydrate, and subsequent changes in glycaemia, influence cognitive function, given that most of the breakfast manipulations were carbohydrate based. The underlying mechanisms by which carbohydrate may facilitate cognitive performance are speculative and multiple. Further, it is likely that these mechanisms do not operate exclusively; several could act in combination to underlie the short-term facilitation effects observed by consumption of carbohydrate at breakfast (Gibson, 2007).

2.5.3.1 Brain glucose availability

The first and most simplistic mechanism is that ingestion of carbohydrate will improve cognitive function via increased glucose availability in the brain to directly fuel neuronal activity (Gibson, 2007; Messier, 2004). Raising blood glucose levels may impact brain function by increasing availability of glucose and therefore neuronal uptake of glucose. However, this mechanism seems unlikely because changes in peripheral blood glucose do not relate to changes in neuronal glucose uptake in the brain (Messier, 2004). Glucose enters the brain extracellular fluid via the blood-brain barrier through GLUT-1 glucose transporters (Mergenthaler, Lindauer, Dienel, & Meisel, 2013). Brain extracellular glucose levels fluctuate with blood glucose levels such that brain extracellular glucose levels are approximately 20-30% of the blood glucose levels (Messier, 2004). However, fluctuations in brain extracellular glucose levels do not affect neuronal glucose uptake because there are intermediary processes in the brain which regulate neuronal uptake of extracellular glucose, which are driven by neuronal activity, not brain extracellular glucose concentrations (Gibson, 2007; Messier, 2004). The preferential process which transports glucose in the extracellular fluid to neurons is mediated via astrocytes which are located between the capillaries of the blood-brain barrier and neuronal synapses (Tsacopoulos & Magistretti, 1996). Once glucose is transported into the brain extracellular fluid, it is transported into astrocytes via GLUT-1 transporters and stored as glycogen or metabolised into lactate. In response to neuronal activity, glycolysis of glucose takes place within astrocytes to form lactate which is transported back into the extracellular fluid to be taken up as an energy substrate by neurons (Tsacopoulos & Magistretti, 1996). Thus, astrocytes function as a buffering system, regulating availability of glucose in the extracellular space for neurones in response to neuronal activity and also contain glycogen stores to prevent large fluctuations in glucose availability (Gibson, 2007). This mechanism may explain why there is dissociation between changes in blood glucose concentrations and changes in cognitive performance, such that effects occur when blood glucose levels have returned to baseline. Hence, increased blood glucose levels as a result of carbohydrate intake appear insufficient to have an impact on brain function, even though brain extracellular glucose levels fluctuate with blood glucose.

An alternative hypothesis is that increased blood glucose availability in the brain may facilitate cognition via a more localised mechanism by facilitating glucose uptake specifically in regions where extracellular glucose levels are decreased (Smith et al., 2011). This mechanism is based on findings that increased neuronal glucose uptake driven by active neurons during demanding cognitive tasks leads to a local deficit in extracellular glucose which is rate-limiting for glucose transfer to neurones (Messier, 2004). This suggests the possibility that carbohydrate or glucose ingestion increases the localised availability of brain glucose during conditions of increased cognitive demand and therefore neuronal activity, during which localised extracellular glucose levels would be otherwise depleted. This also suggests that the capacity for astrocytes to store glycogen is small and limited (Messier, 2004). In vivo microdialysis in rats has shown that hippocampal extracellular glucose levels fluctuate depending on cognitive demand (McNay, Fries, & Gold, 2000). During completion of a more demanding spatial working memory task, extracellular hippocampal glucose levels fell 30% below baseline compared with 11% during a less demanding spatial working memory task (McNay et al., 2000). In rats administered glucose, hippocampal extracellular glucose remained at baseline levels and performance on the more difficult task was better in comparison to rats administered saline or no treatment. This suggests that normalisation of hippocampal extracellular glucose is associated with improved cognition. However, this does not explain why cognitive effects are apparent when blood glucose levels have returned to baseline following consumption of a carbohydrate breakfast. Furthermore, it fails to explain the inverted-U shape relationship between glucose and memory, with 25g of glucose considered optimal for facilitation (Hoyland et al., 2008; Riby et al., 2006).

2.5.3.2 Insulin

It has also been suggested that secondary metabolic events induced by carbohydrate ingestion, such as changes to concentrations of neurotransmitters and hormones may mediate changes to cognition (Gibson, 2007; Messier, 2004; Smith et al., 2011). Insulin has also been suggested to mediate the association between carbohydrate ingestion and cognitive performance. This counter-regulatory hormone is involved in glucose homeostasis and is released in response to increased blood glucose in order to reduce circulating glucose by promoting uptake into cells (either for storage or glycolysis). Insulin crosses the blood-brain barrier and insulin receptors are located in the brain (Plum, Schubert, & Bruning, 2005). Further, administration of insulin intranasally has been shown to facilitate cognitive performance in adults (Shemesh, Rudich, Harman-Boehm, & Cukierman-Yaffe, 2012). It therefore seems plausible that glucose-mediated insulin delivery to the brain may facilitate cognitive performance following ingestion of carbohydrate.

2.5.3.3 Cortisol

There was some evidence that cortisol may mediate the association between breakfast and cognitive performance (Micha et al., 2011). Cortisol levels as a result of the combination of carbohydrate consumption and an arousing situation (cognitive testing) may interact to bring about effects on cognitive performance (Micha et al., 2011). Cortisol is released via the hypothalamic-pituitary-adrenal axis in response to stressful situations, such as cognitive testing (Gibson, 2007). Additionally, cortisol receptors are abundant in the hippocampus, a brain region implicated in memory. As with glucose, there is evidence for an inverted-U shape relationship between cortisol and cognitive performance, particularly for memory (Abercrombie, Kalin, Thurow, Rosenkranz, & Davidson, 2003). Ingestion of glucose can interact with a stressful task and provoke a greater cortisol response (Kirschbaum et al., 1997) which in-turn has dose-dependent and bidirectional effects on cognitive function (Gibson, 2007). This may account for cognitive effects being most apparent at times when post-prandial blood glucose levels have returned to, or below, baseline values, but when differences in cortisol are likely to occur (i.e. during cognitive testing). However, this amplification of the cortisol response seems to be specific to carbohydrate (as glucose) rather than other macronutrients such as protein or fat (Gonzalez-Bono, Rohleder, Hellhammer, Salvador, & Kirschbaum, 2002). Furthermore, it should be noted that breakfast ingestion alone would not stimulate cortisol release in absence of a stressful or demanding task.

2.5.3.4 Acetylcholine

Other suggested mechanisms involve the excitatory neurotransmitter acetylcholine (ACh) based on the fact that synthesis of ACh requires glucose. Glucose is critical for the production of actyl coenzyme A (Actyl-CoA), a precursor of ACh (Messier, 2004; Smith, Riby, Eekelen, & Foster et al., 2011). Particular attention has been given to the association between glucose, ACh and memory. This mechanism suggests that enhancement of memory occurs because of increased ACh synthesis through increase availability of Actyl-CoA driven by an increase in the availability of glucose. In vivo microdialysis in rats indicated that ACh output in the hippocampus increased by 50% during completion a spatial working memory task relative to baseline (Ragozzino, Unick, & Gold, 1996). The administration of glucose relative to saline increased ACh by a further 50% which also enhanced performance on the task. This suggests that ACh is a potential mediator of the effects of glucose or carbohydrate ingestion on cognitive performance. However, this does not explain why certain glucose doses that are assumed to raise extracellular glucose do not improve memory. For example very high doses of glucose are not associated with enhanced memory nor increased hippocampal extracellular Ach (Ragozzino et al., 1996).

2.5.3.5 Neural activity

Some studies included in this review included concurrent electroencephalography (EEG) measures during cognitive testing which suggest that breakfast may influence cognitive function via effects on neural activity. Pivik et al. (2012) investigated the effects of breakfast on EEG activity in frontal and parietal brain regions during mental calculation tasks. Under fasting conditions, response times worsened at +40 minutes relative to baseline, but the breakfast group showed no changes in response times. The cognitive effects were coupled with increased frontal-parietal theta band activity in fasting participants relative to fed participants. Frontal theta activity has been reported to have a major role in working memory functions (Sauseng, Griesmayr, Freunberger, & Klimesch, 2010). Increased theta activity in frontal brain regions has been suggested to reflect the active maintenance of task relevant information and suppression of task irrelevant information in working memory tasks. Increased theta band activity in frontal brain regions has also been shown during the retention period in Sternberg-like working memory tasks (Jensen & Tesche, 2002; Raghavachari et al., 2001). The increased theta band activity is sustained until the retrieval of information in Sternberg-like memory tasks (Jensen & Tesche, 2002). Further, theta band activity increases with higher working memory loads or mental effort in Sternberg-like tasks (Jensen & Tesche, 2002). In this context, the associated EEG effects under fasting conditions are indicative of increases in brain activity that serve to enhance working memory performance; however, this was in the absence of improved working memory performance. This implies that fasting school children applied greater mental effort to the task in a compensatory effort to maintain performance at baseline levels. In school children who consumed breakfast, increases in task accuracy in the absence of increased brain activity associated with working memory performance during the task suggests that neural processes involved in working memory were more efficient, which may have facilitated performance. In support, performance on a CPT was improved following consumption of breakfast, which was coupled with a reduction in the amplitude of event related potentials (ERPs), relative to fasting in 9-11 year olds (Conners & Blouin, 1982). A recent review of the glucose facilitation effect on memory has also suggested that glucose may facilitate memory via decreasing the cognitive resources required for memory indicated by a reduction in amplitudes of ERPs (Smith et al., 2011).

2.5.3.6 Subjective state and cognitive performance

As well as physiological mechanisms, breakfast may affect cognitive performance indirectly through changes in feelings or subjective state (e.g. mood, alertness) caused by the consumption of breakfast. The searches performed for this SRR identified a small body of evidence which evaluated the effect of breakfast on feelings or subjective state alongside cognitive function. Subjective state, such as mood, is an important outcome in its own right, but it is also suggested that mood can influence cognitive function (Dye & Blundell, 2002; Hetherington et al., 2013; Hoyland et al., 2009; Schmitt et al., 2005). Hence, in the studies reviewed, subjective state outcomes were considered as primary endpoints of the breakfast manipulation but also as potential mediators or confounders that may influence cognitive function. For example, Micha et al. (2010; 2011) regarded mood measures taken immediately prior to cognitive testing as dependant variables but also as potential intermediates/ explanatory variables in the pathway between breakfast consumption and cognitive function. The studies that assessed subjective feelings such as mood and alertness alongside cognitive function also tended to include a subjective assessment of satiety which may also be related to mood. Hetherington et al. (2013) suggested that alleviating hunger may improve mood and in turn, cognitive function. However, this relationship appears quite complex. In adults, feelings of ‘energy’, ‘lively’, ‘calm’ and ‘relaxed’ decreased more with higher sensations of hunger, whereas cognitive performance improved (Fischer, Colombani, & Wenk, 2004).

There is consistent evidence that breakfast consumption, relative to breakfast omission, is associated with improved subjective feelings of mood and alertness in children and adolescents. Defeyter and Russo (2013) reported a positive effect of breakfast consumption, compared to no breakfast on alertness, calmness and contentment factor scores derived from the Bond-Lader Visual Analogue Scales (VAS; Bond & Lader, 1976) following cognitive testing. Subjective VAS ratings of hunger were also significantly lower following breakfast compared with no breakfast. Similarly, alertness and contentment factor scores from the Bond-Lader VAS were positively affected by the consumption of two different RTECs and a glucose drink relative to no breakfast (Wesnes et al., 2003). However, the positive effects on alertness and contentment following the glucose drink reduced to levels of that in the no breakfast condition by 10:00am (+90 minutes post breakfast). Subjective feelings of hunger were significantly lower following the two RTECs relative to no breakfast, but the glucose drink had no effect on these subjective satiety measures. Breakfast consumption relative to fasting had a positive effect on energy factor scores (included adjectives: ‘active’, ‘energetic’, ‘alert’, ‘lively’ and ‘wide-awake’) and tiredness factor scores (included adjectives: ‘sleepy’, ‘tired’, ‘drowsy’, ‘exhausted’ and ‘fatigued’) measured before cognitive testing using a modified Activation-Deactivation Checklist (Cooper et al., 2011). There was, however, no effect on tension (included adjectives: ‘anxious’, ‘nervous’, ‘fearful’, ‘worried’ and ‘tense’) and calmness factor scores (included adjectives: ‘restful’, ‘calm’, ‘at-rest’, ‘laid-back’ and ‘quiet’). Cooper et al. (2011) also reported that subjective VAS ratings of hunger were lower following breakfast relative to no breakfast. Breakfast consumption relative to fasting increased VAS ratings of ‘cheerfulness’ and ‘energy’ in children who were habitual breakfast consumers (Kral et al., 2012).

Widenhorn-Müller et al. (2008) reported positive effects of breakfast consumption relative to breakfast omission on subjective feelings of mood; however, the effects differed according to gender and time of assessment. In males, consumption of breakfast increased positive affect factor scores (included adjectives: ‘happy’, ‘well’ and ‘cheerful’) before and after cognitive testing and information uptake factor scores (included adjectives: ‘fascinated’, ‘interested’, and ‘uninterested’) before cognitive testing. In females, breakfast consumption increased alertness factor scores (included adjectives: ‘tired’, ‘sleepy’ and ‘awake’) before and after cognitive testing compared with no breakfast. In both males and females, negative affect factor scores (included adjectives: ‘depressed’, ‘unhappy’, and ‘queasy’) and arousal factor scores (included adjectives: ‘calm’, ‘nervous’ and ‘agitated’) were not affected by breakfast consumption. Two studies by Mahoney et al. (2005) also demonstrated positive effects of breakfast (oatmeal and RTEC) vs. no breakfast on feelings of subjective state, but effects differed according to age and time of assessment. School children aged 9-11 years felt more motivated after the cognitive testing (+120 minutes), but not before (+60 minutes post breakfast) following oatmeal or RTEC consumption compared with no breakfast. There were no effects of breakfast condition on feeling ‘tired’, ‘happy’, ‘relaxed’, ‘alert’ or ‘stressed’. In addition, ratings of hunger were lower before and after cognitive testing following consumption of oatmeal and RTEC relative to no breakfast. Children aged 6-8 years felt more alert before and after cognitive testing following RTEC consumption compared with no breakfast, but only felt more alert before the cognitive testing following oatmeal compared with no breakfast. There were no effects of the breakfast condition on feeling ‘tired’, ‘happy’, ‘relaxed’, ‘motivated’ or ‘stressed’. The observation that effects of breakfast on subjective feelings of mood, alertness and motivation can differ before and after cognitive testing may be because carrying out demanding cognitive tests can cause fatigue or may induce a negative mood. Similarly, before testing children may be more nervous, anxious or tense and after more relaxed and calm. Therefore, when looking at the effects of breakfast on feelings of subjective state it is also important to take into consideration the association between cognitive testing and feelings of subjective state.

The positive changes in subjective feelings of mood, alertness and motivation following breakfast may in turn facilitate improve cognitive performance, by increasing children’s ability to concentrate and/or motivation to try hard on cognitive tasks. There is evidence that mood state modulates cognitive function, but the nature of the relationship is not straightforward. Mood is also known to influence memory (Lewis & Critchley, 2003). Mood congruence refers to the facilitation of recall of emotional information during moods that match the emotional content of the to-be-remembered information (Lewis & Critchley, 2003). Mood dependence refers to the facilitation of memory when mood at the time retrieval is matched to mood at encoding, but the to-be-remembered material is normally emotional neutral (Lewis & Critchley, 2003). In adults, VAS ratings of wakefulness positively correlate with performance on cognitive tasks (Jakala, Riekkinen, Sirvio, Koivisto, & Riekkinen, 1999). VAS ratings of alertness also correlate with cognitive performance rhythms across the morning (Monk et al., 1997). Furthermore, changes in VAS ratings of feeling “muddled” after low, medium and high-fat lunches mapped on to changes in reaction time at +30, +90 + 150 minutes post intervention, such that reaction times were slower as feelings of confusion increased (Lloyd et al., 1994).

Studies in adolescents have also shown that mood and cognitive performance are related, but the nature of the relationship differs before and after cognitive testing. Before cognitive testing, ratings of ‘happy’, ‘friendly’, ‘relaxed’, ‘calm’, ‘angry’, ‘sad’ and ‘dissatisfied’ are negatively associated with cognitive performance (Micha, 2008; Micha et al., 2010). Feeling more nervous before the cognitive testing is positively associated with cognitive performance (Micha, 2008). After cognitive testing, feelings such as ‘friendly’,’ calm’, ‘happy’, ‘contented’ are negatively associated with cognitive performance. Feelings such as ‘drowsy’, ‘sluggish’, ‘tired’ are positively associated with performance (Micha, 2008; Micha et al., 2010). The unexpected finding that feeling more friendly and happy is associated with poorer performance may be because these adolescents feel more relaxed and friendly towards the researchers and are therefore not motivated or aroused by the testing situation. Similarly, adolescents who felt more nervous before the cognitive testing may have performed better because they were more aroused by the testing situation which in turn enhanced their attention and response. Negative feelings such as ‘sluggish’, ‘drowsy’ after the cognitive testing may have been associated with superior performance because these participants tried harder or were more engaged with the cognitive tasks and so were feeling more fatigued after trying to perform well. However, studies in children and adolescents have shown that acute improvements in subjective feelings of mood, motivation and alertness are not always accompanied by improvements in cognitive performance (Kral et al., 2012; Defeyter & Russo, 2013) which suggests other mechanisms of action may facilitate cognitive performance.

2.6 Conclusion

From the studies reviewed, the data suggest that consuming breakfast has a short-term beneficial effect on cognitive function measured within 4 hours post-ingestion in children and adolescents. This effect was most consistent for attention, working memory and immediate visual-spatial memory. However, overall, the effects observed were not consistent and were coupled with null findings from many studies. The effects of breakfast composition and the long term effects of consuming breakfast are unclear due to insufficient studies in this area and problematic experimental designs. The potential for breakfast to impact upon cognitive performance appears to be influenced by the nutritional status of the child, with undernourished children demonstrating increased sensitivity to and/or gaining most benefits from breakfast manipulations. Fifty-four studies is a reasonable of body of evidence, but findings are equivocal. There is scope to assess the effects of breakfast on cognitive performance and address certain methodological considerations. Children (aged 6-10 years) are overrepresented in both acute and chronic studies. Further evidence is particularly required in adolescent samples in whom there are far fewer studies. Evidence is also needed in more ecologically valid research conditions, using cognitive tasks sensitive to nutritional manipulations and studies require larger samples with sufficient power to detect a statistically significant effect.

This SRR also highlighted the potential for breakfast to improve several aspects of subjective feelings of mood, mental alertness and motivation in the short-term and the potential for subjective feelings and cognitive testing to reciprocally influence each other. There is also potential for perceived satiety to influence subjective feelings and cognitive function. Because of the various interactions between breakfast consumption, cognitive performance and associated subjective feelings of mood, it would be insightful for further work in this thesis to assess the effect of breakfast on subjective feelings of mood, motivation and mental alertness alongside cognitive performance, with age-appropriate measures of feelings of subjective state taken both before and after cognitive testing and at baseline. If clear effects of breakfast on cognitive performance are observed, it would be useful to establish if beneficial effects on subjective feelings of mood, motivation, alertness and satiety occur at similar time points which could suggest a potential, indirect, mechanism of action of the effect of breakfast on cognitive performance. Nevertheless, the effects of breakfast on subjective feelings are important endpoints irrespective of any benefit to cognitive performance. Far fewer studies measure subjective feelings alongside cognitive performance which highlights the scope to assess the effects of breakfast on both of these factors in future studies.

3 Study 1: The acute effect of breakfast compared with no breakfast on cognitive performance in 11-13 year old adolescents

Statement of Contribution

The study reported in this chapter was carried out by a team which included Dr. Alexa Hoyland and Rebecca Pyatt. Dr. Alexa Hoyland was largely responsible for the conception and design of the study. However, all researchers contributed to the conception and design of the study, design of questionnaires, selection of measures, logistics of the field work, recruitment of participants, collection and management of data and management and training of undergraduate project students who assisted in the classroom testing. The candidate is a certified CANTAB rater and led the majority of the cognitive testing sessions, directing and managing the undergraduate assistants. The candidate was solely responsible for the statistical analysis and interpretation of the data presented in this chapter. The candidate was solely responsible for writing the chapter and the production of all tables and figures. Supervisors provided editing and proof-reading assistance with the chapter.

3.1 Introduction

In Chapter 2, studies examining the effects of breakfast on children's and adolescents' cognitive performance were reviewed. Support for a transient improvement in cognitive performance following breakfast consumption, relative to fasting, was demonstrated in several studies. However, the relationships observed were neither consistent nor clear cut. Methodological differences between studies may account for some of the inconsistencies observed. More research is needed to provide a clearer understanding of the effects of breakfast on cognitive performance in children and adolescents.

A key outcome of the SRR in Chapter 2 was the recommendation for further work to consider the effects of breakfast consumption on cognitive performance in adolescents. Only 13 published studies have included adolescents aged >11 years (i.e. of secondary school age). Therefore, the study reported in this chapter examined the effect of breakfast in a sample of young adolescents attending a UK secondary school. The study specifically targeted adolescents aged 11-13 years for the reasons outlined in Chapter 1, section 1.1.1.

Some of the studies reviewed in Chapter 2 were criticised for their chosen testing environment. Most previous acute studies were laboratory based. Few studies have conducted testing in the school environment, alongside the normal school day. Although field based studies can be problematic in terms of control and compliance to procedures, they offer greater ecological validity. In laboratory based studies, participants' behaviour may change due to the novel testing environment and because they are removed from their normal routine. This highlighted the need for more ecologically valid evidence from school-based studies.

Similarly, the SRR highlighted the need for more ecologically valid breakfast manipulations. Previous studies employing breakfast vs. no breakfast comparisons have used either fixed or ad libitum breakfast interventions, with the majority using the former. Only two previous studies in adolescents have employed an ad libitum breakfast manipulation (Cooper et al., 2011; Dickie & Bender, 1982). Whilst a fixed breakfast intervention reduces the variability in intake within the breakfast condition, it is unlikely to accurately reflect what the participants might usually consume outside of the study. This approach also assumes that 'one-size-fits-all' in terms of portion size. However, in a heterogeneous sample of adolescents, there is likely to be large variation in body weight, growth trajectories, levels of physical activity and therefore, energy requirements. Hence, from the SRR, it was concluded that an ad libitum breakfast manipulation is more appropriate to resemble habitual intake and to ensure suitability of portion size.

Another key consideration highlighted from the SRR was the need for more studies to assess subjective feelings of mood, satiety, mental alertness and motivation alongside cognitive performance. Concomitant subjective feeling measures are recommended in studies assessing the effect of dietary manipulations on cognitive function because of the reciprocal relationship between mood and cognitive function (Dye & Blundell, 2002; Hetherington et al., 2013; Isaacs & Oates, 2008; Schmitt et al., 2005). Breakfast-induced changes in feelings of subjective state are also important endpoints independently. Despite this, it is extremely rare for studies to include assessments of mood or subjective state before and after cognitive testing. In addition, it is uncertain whether measures of subjective feelings designed for use in adults are well understood by children and adolescents (Cooper et al., 2011).

Another outcome of the SRR (Chapter 2) related to the measurement of cognitive performance. The cognitive tests employed in previous research were not always selected on the basis of their capacity to differentiate subtle differences in cognitive performance following nutritional manipulations. However, there were several indications that certain tasks assessing the same cognitive domain were more sensitive to the effects of breakfast than others. Many cognitive tests have the capacity to discriminate between groups or populations (e.g. for diagnostic purposes) but this does not mean that these tests are suitable for repeated administration to detect differences that occur between treatments groups over time (Wesnes, 2010). Hence, the literature was examined, in order to identify tests able to detect differences in performance following nutrient intervention.

3.2 Study aims

The aims of the study reported in this chapter were as follows:

I. To examine the acute effect of breakfast (RTEC and milk) vs. no breakfast on cognitive performance in 11-13 year old adolescents.

II. To examine the acute effect of breakfast (RTEC and milk) vs. no breakfast on subjective state in 11-13 year old adolescents.

3.3 Hypotheses

There were three main hypotheses:

I. Consumption of breakfast will have a positive acute effect on cognitive performance compared with breakfast omission in 11-13 year olds.

II. Consumption of breakfast, relative to fasting, will lead to greater perceived satiety and improved feelings of mood, motivation and mental alertness.

III. Cognitive and subjective effects of the breakfast manipulation will be more apparent in the late-morning compared to mid-morning.

3.4 Methodology

3.4.1 Participants

The study sample consisted of males and females aged 11-13 years who were recruited to take part in the study from a UK secondary school. This secondary school is large (approximately 1350 pupils), multicultural and its pupils are predominantly lower SES (68% eligible for FSMs). Ages 11-13 years correspond to compulsory secondary school Years 7 and 8 in the British school system, where Year 7 is the first year of secondary education. A total of 369 participants (males: 191 [51.8%]; females: 178 [48.2%]) aged 12.08 ± 0.58 years were eligible to take part in this study. Of the 369 participants invited to take part, 111 (30.1%) participants withdrew, did not complete the study or were unable to take part for various reasons (see Appendix 9.14). Of the 258 remaining participants, 32 (12.40%) were excluded from the analysis due to lack of compliance on the test day (did not eat >15g of RTEC or missed one test session). This gave a final sample size of 226 participants, described in section 3.5.1. Of the 226 participants included in the sample, 5 returned incomplete data sets with respect to the outcome measures and were excluded from some, but not all, of the analyses.

3.4.2 Inclusion and exclusion criteria

Participants were recruited using the following inclusion and exclusion criteria.

3.4.2.1 Inclusion criteria

- Male or female, aged 11-13 years
- Willingness to consume RTEC with semi-skimmed cow's milk during the study. This was determined by a score of >5 on a taste test Likert scale for at least one of four RTECs (see section 3.4.4.1)
- Ability to follow verbal and written instructions in English
- Normal vision, with appropriate corrective lenses if required

3.4.2.2 Exclusion criteria

- Inability to understand the objective of the cognitive tests or carry out the tests
- Any food allergies or intolerances (e.g. coeliac, lactose intolerance)
- Acute illness, or feeling unwell, within the week prior to testing
- Hearing impairment that precluded the normal use of headphones
- Consumption of less than 15g of RTEC on the test day

3.4.3 Design

This study employed a randomised, parallel groups design. Both screening and the test day were conducted at school on normal school days (Monday-Thursday only).

3.4.4 Intervention

3.4.4.1 Test meal manipulation

There were two conditions in this parallel groups study:

A Breakfast: Ad libitum RTEC, from a choice of Kellogg's© Mini Max, Kellogg's© Start, Kellogg's© Cornflakes or Kellogg's© Rice Krispies, with semi-skimmed cow's milk. Ad libitum water intake

B No breakfast: Ad libitum water intake

Macronutrient composition and energy provided by the four test breakfast options are given per 100g and for the maximum amount administered on test days in Table 3.1 and Table 3.2 respectively. The choice of RTECs offered in the breakfast condition was chosen on the basis of pilot work. This pilot work intended to identify a range of RTECs readily consumed, palatable and acceptable to 11-13 year olds by conducting RTEC taste testing sessions at the school. It was important to choose RTECs which were palatable to the sample under study, as palatability may affect mood (Macht & Mueller, 2007). Choosing RTECs readily consumed by 11-13 year olds also aimed to preserve the ecological validity of the intervention.

Table 3.1: Nutritional composition (per 100g) of the test breakfasts.

Energy, macronutrient	Cornflakes[b]	Start[b]	Rice Krispies[b]	Mini Max[b]	Milk[c]
GSA (g/ml)[a]	30	30	30	40	125
Energy (Kcal)	378	390	383	370	48
Total Carbohydrate (g)	84	79	87	73	4.6
Sugar (g)	8	24	10	18	4.6
Protein (g)	7	8	6	11	3.5
Total Fat (g)	0.9	3.5	1	2	1.8
Saturated fat (g)	0.2	2	0.2	0.3	1.1
Non-starch polysaccharides	3	5	1	8	<0.05
Sodium (g)	0.5	0.4	0.45	0.01	0.14

[a] Guideline Serving Amount (GSA) given for information only.
[b] Kellogg's©. Macronutrient nutritional information from www.kelloggs.co.uk.
[c] Sainsbury's©. Macronutrient information from www.sainsburys.co.uk.

Table 3.2: Nutritional composition per maximum amount available of the test breakfasts.

	Cornflakes[a]	Start[a]	Rice Krispies[a]	Mini Max[a]	Milk[b]
Quantity available (g/ml)	70	70	70	70	300
Energy (Kcal)	264	273	268	259	33
Total Carbohydrate (g)	58.80	55.30	60.90	51.10	3.22
Sugar (g)	5.60	16.80	7.00	12.60	3.22
Protein (g)	4.90	5.60	4.20	7.70	2.45
Total Fat (g)	0.63	2.45	0.70	1.40	1.26
Saturated fat (g)	0.14	1.40	0.14	0.21	0.77
Non-starch polysaccharides	2.10	3.50	0.70	5.60	Trace
Sodium (g)	0.35	0.28	0.32	0.01	0.10

[a] Kellogg's©. Macronutrient nutritional information from www.kelloggs.co.uk.
[b] Sainsbury's©. Macronutrient information from www.sainsburys.co.uk;

At screening, participants were asked to try a small amount (5-10g) of each RTEC (with semi-skimmed milk) and rate each for taste on a 10-point Likert scale (see Appendix 9.15). Participants then chose one RTEC to consume as a test breakfast from those which scored >5 points on the Likert scale. This was to ensure the breakfast manipulation was palatable and to increase compliance. Where a participant refused semi-skimmed cow's milk at screening, the participant was excluded from the study (as per inclusion/exclusion criteria; see section 3.4.2).

On the test day, participants arrived at school in an assumed fasted state having been asked not to consume any food or drink after 2100 hours on the previous evening (with the exception of ad libitum water intake). Breakfast was administered in the school dining area. Breakfast preparation and instructions to participants were standardised. The RTECs were presented in small, individual, unbranded white boxes in 70g maximal amounts. The boxes were opaque to avoid cross-comparison between participants. Semi-skimmed milk was served in small, individual glass jugs in 300ml maximal amounts. Participants were permitted to self-serve their chosen RTEC and milk in an amount habitual for them and were instructed to eat until they were comfortably full. The addition of table sugar to the test meal was not permitted. Participants were required to eat/drink all of the breakfast/water within 15 minutes. Participants in both conditions were permitted ad libitum water intake during the 15 minute breakfast session. Following the breakfast session, the amount of RTEC and milk leftover was weighed and recorded to determine the amount consumed. Throughout the remainder of the morning, participants were fasted but permitted ad libitum water intake until the school's scheduled lunch period. The school has a policy that pupils are not permitted to eat or drink (except water) during lessons which aided compliance with the fasting regime.

Providing a maximal 70g portion allowed participants to consume a breakfast suitable for them in terms of size, and that broadly reflected their habitual intake. It was also deemed necessary to employ an ad libitum breakfast meal as previous research has suggested that deviation from habitual meal size may have adverse effects on mood and cognitive function (Lloyd et al., 1994; Lloyd, Rogers, Hedderley, & Walker, 1996). Hence, benefits to subjective mood state and cognitive performance may be most apparent with test meals that resemble habitual meals.

3.4.4.2 End of test day snacks

At the end of each test day, participants in both conditions were offered a snack upon leaving from a choice of several snack bars, boxes of raisins, yoghurts and cartons of fruit juice (see Appendix 9.16 for nutritional information). At the end of test day, participants were immediately able to consume lunch in the school canteen.

3.4.5 Measures

3.4.5.1 Socio-demographic measures

The following demographic measures were taken from school records:

- Age
- Gender
- Ethnicity
- English as an additional language (EAL) status
- CAT scores
- FSM status (as proxy indicator for SES)
- Colour vision assessment (Ishihara plate test for colour vision; Ishihara, 1951)

CAT scores were used as an indication of the cognitive abilities of the sample. The test, scoring and its use is described in detail in Chapter 5; section 5.4.4.4. FSM status was used as a proxy for SES. In England, pupils who are of compulsory school age in full time education are recorded as claiming FSMs if their parents/guardians receive certain support payments and have applied to their local authority to claim FSMs. Broadly, to be eligible for FSMs, pupils must be from families without a member working >24 hours per week and/or from low or no income families with limited capital assets. FSM status is an acceptable proxy of SES and a valid indicator of low income families and is associated with parental education level (Gorard, 2011; Hobbs & Vignoles, 2010). Participants who were claiming FSMs were classified as low SES and participants who were not claiming FSMs were classified as middle-high SES. Approximately 68% of the school's pupils claim FSMs, a level considerably higher than the proportion of pupils claiming nationally and in the Leeds Local Education Authority (LEA) in 2013 (16.0% and 19.4% respectively; Department for Education, 2013c). The use of CAT and SES measures in the present study was to exclude overall differences between breakfast conditions as an explanation for differences in cognitive performance that were intended to be attributed to the breakfast manipulation.

Colour vision was assessed at screening as one of the cognitive tests (PAL) required participants to differentiate between colours. At the first screening session, potential participants were tested for colour vision deficiencies using the Ishihara Tests for Colour-Blindness 10th ed. (Ishihara, 1951). No participants were identified as having colour vision deficiencies.

3.4.5.2 BMI

The height and weight of each participant was measured and recorded by trained researchers in order to determine BMI standard deviation scores (BMI SDS) and weight classification. BMI in children and adolescents changes with age and patterns of growth differ between girls and boys. Consequently, the standard BMI calculation and classification system for adults (>18 years) is inappropriate for use in children and adolescents. Rather than employing fixed BMI values to classify individuals, BMI SDS were classified using cut-offs to define overweight and obese adolescents (Cole, Freeman, & Preece, 1995) which is recommend by the National Institute of Clinical Excellence (NICE; NICE, 2013). These cut-offs were based on the British 1990 growth reference data representative of England, Scotland and Wales (Cole et al., 1995).

BMI SDS were calculated using the LMSgrowth Microsoft Excel add-in which expresses BMI as a SDS based on the British 1990 growth reference data (Cole, 1990). BMI SDS indicate how many units of the SD a child's BMI is above or below the national average BMI value for their age group and sex. The Department of Health's epidemiological cut-offs were used to define overweight and obesity as the 85th and 95th centiles (z scores 1.04 and 1.64 respectively) on the UK 1990 BMI reference curves (Cole et al., 1995). The Department of Health clinical cut offs (91st and 98th centiles, z scores 1.33 and 2.00 respectively) are recommended for use in clinical settings with individual children/adolescents (NICE, 2013). This study applied the more conservative epidemiological thresholds as these are more routinely used for population monitoring (NICE, 2013). However, the Scientific Advisory Committee on Nutrition (SACN) state that epidemiological cut-offs are arbitrary and result in a higher prevalence of overweight and obese participants compared with clinical cut-offs (SACN, 2012). To classify underweight participants, a cut-off at -2 SD scores was applied (WHO, 1995).

3.4.5.3 Habitual breakfast intake

Participants completed a self-report written questionnaire at screening (see Appendix 9.17). The questionnaire contained three items relating to the participant's habitual breakfast consumption frequency and food type. It was deemed important to establish if any differences in habitual breakfast behaviour existed across study breakfast conditions as this would be likely to influence the effects of breakfast consumption, and breakfast omission, on cognitive performance and subjective state.

3.4.5.4 Cognitive testing battery

The Cambridge Neuropsychological Test Automated Battery (CANTAB; Cambridge Cognition Ltd) was used to assess cognitive performance. The CANTAB battery of cognitive tests are validated and standardised with a normative database from healthy populations aged 4-90 years. The battery was administered on individual touch-screen portable computers. Testing was conducted in groups of 15-20 participants, in a quiet classroom which was consistent across test days. The environment was controlled as much as possible to limit effects of external distractions, noise, lighting and temperature. Testing was conducted by a certified CANTAB rater (see Appendix 9.18 for rater certificate). Standardised administration scripts were used to ensure consistency in administration. These scripts were developed in collaboration with Cambridge Cognition Ltd.

Participants were given the opportunity to practise a version of the cognitive test battery at screening. This ensured that the participants understood the instructions and responding requirements, were capable of carrying out the tests, and reduced possible test anxiety. This training session also aimed to minimise practice effects on the test day by allowing participants to reach a relatively stable level of performance.

Three cognitive testing batteries were administered on the test day. Each cognitive test battery lasted approximately 20-25 minutes. The first battery was administered immediately before the intervention, at 0840 hours (t = -25 minutes pre-intervention), and provided a measure of baseline performance. The second battery was administered mid-morning, during the school's scheduled break-time, at 1015 hours (t = +70 minutes post- intervention). The timing of the 2nd battery facilitated compliance to the fasting regime, since participants did not have the opportunity to consume any food and/or drink during break time. The third battery was conducted in the late-morning, immediately prior to the school's scheduled lunch period, and began at 1240 hours (t = +215 minutes post- intervention).

3.4.5.5 Task description

The cognitive test battery is summarised in Table 3.3. The battery included three tests of reaction time, sustained attention, and immediate visual-spatial memory. The battery was designed to be appropriate, whilst suitably demanding, for the study's sample of 11-13 year olds. All tests within the CANTAB battery have been successfully used to measure cognitive functions in individuals from ages 4-90 years (Luciana, 2003). Pilot work was conducted prior to the study in a sample of primary school children aged 11 years, the youngest age in the intended sample, to inform the choice of cognitive tasks included in the study's test battery. Tasks which were interesting, engaging and motivating were chosen where possible. The pilot work indicated that the 11 year olds were able to perform the cognitive tests chosen and had a good understanding of the requirements and responding procedures. The primary school children completed the battery within the time permitted. Whilst a formal statistical analysis on the pilot test was not conducted, the primary school children reported that they found the tasks challenging, but were able to carry out the tasks, without floor or ceiling effects.

This battery was also selected to detect subtle differences in cognitive function. Consumption of RTEC or a carbohydrate intensive breakfast has been shown to positively affect reaction time, sustained attention and visual-spatial memory, relative to a fasted state (Maffeis et al., 2012; Mahoney et al., 2005; Wesnes et al., 2003). The battery included those cognitive domains and specific cognitive tasks that have previously been found to be sensitive to nutritional manipulations.

Table 3.3. Cognitive test battery

Task	Cognitive domain	Order	Length (min)	Cumulative length (min)
Simple and 5-choice reaction time	Reaction time	1	4-5	5
Rapid Visual Information Processing	Visual sustained attention	2	9*	14
Paired Associates Learning	Immediate visual-spatial memory	3	7*	21

*Approximate timings only. Test length dependent on the response speed and ability of the participant.

3.4.5.5.1 Domain: Reaction time

The SRT and 5-Choice Reaction Time (5-CRT) tasks were used to assess reaction time. Previous studies which have included measures of reaction time using simple and choice reaction time paradigms have detected acute changes induced by a nutritional manipulation in both children and adolescents (Ingwersen et al., 2007; Taib, Shariff, Wesnes, Saad, & Sariman, 2012; Wesnes et al., 2003; Wesnes et al., 2012). CANTAB SRT and 5-CRT tasks have detected small changes in performance in response to a nutraceutical intervention in adults (Attwood, Higgs, & Terry, 2007).

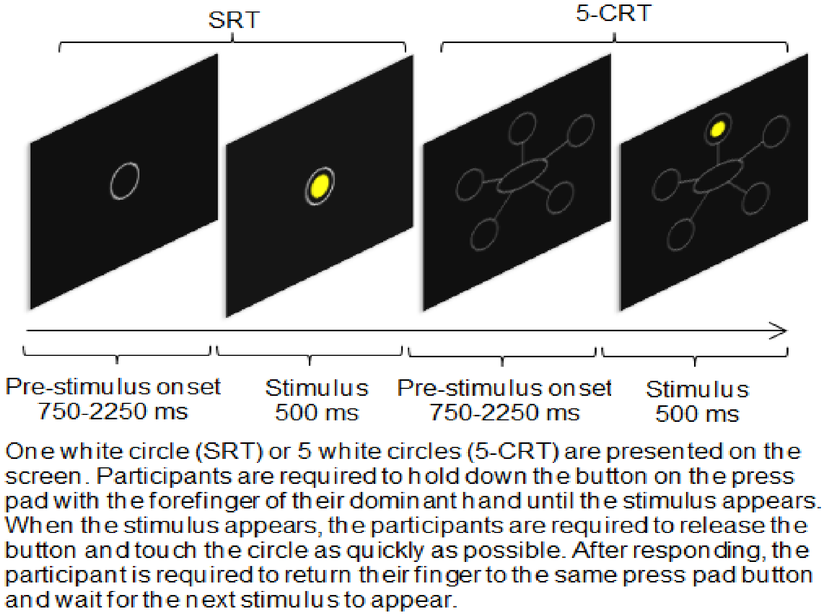
3.4.5.5.1.1 Simple Reaction Time task

The SRT task requires the participant to respond to a stimulus (yellow dot within a white circle) presented in the centre of the computer screen by touching the screen as quickly as possible (see Figure 3.1). The task consists of 5 practice trials and 14 assessed trials which collectively last approximately 2 minutes, dependent on participant response speed. During the practice trials, feedback is provided to the participant to indicate accuracy and speed of their performance. If a participant makes two or more errors during the practice trials, a second block of practice trials is automatically administered. If they make fewer than two errors the test continues onto the assessed trials. Outcome variables were reaction time (decision time; ms), movement time (ms) and number of errors (see Appendix 9.19).

3.4.5.5.1.2 5-Choice Reaction Time task

The 5-CRT task employs the same paradigm as the SRT task, except the stimulus appears in one of five locations on the computer screen requiring the participant to choose the correct location (see Figure 3.1). Outcome variables were reaction time (decision time; ms), movement time (ms) and number of errors (see Appendix 9.19).

Figure 3.1: Outline of SRT and 5-CRT tasks



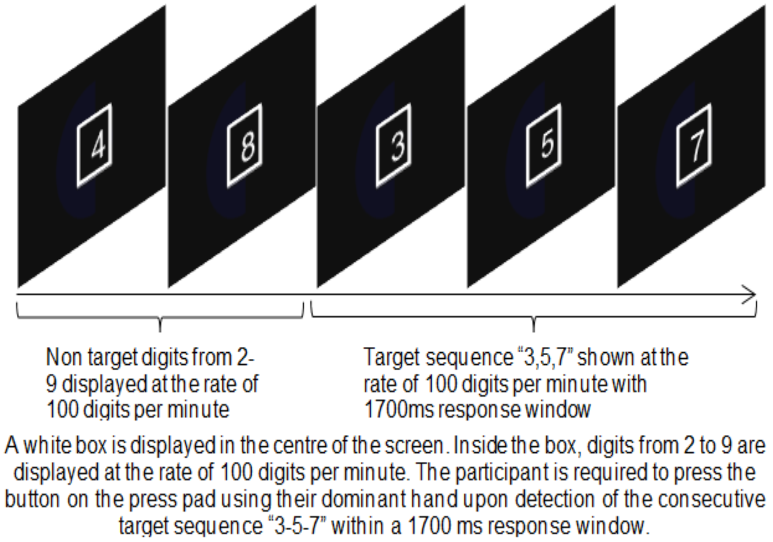
3.4.5.5.2 Domain: Visual sustained attention

3.4.5.5.2.1 Rapid Visual Information Processing task

The RVIP was used to measure visual sustained attention (see Figure 3.2). Participants are required to detect a 3-digit target sequence within a continuous, rapidly presented digit series on the computer screen. Participants respond by pressing the press pad upon detection of the consecutive target sequence “3-5-7”. The task consists of a 2 minute practice phase followed by a 7 minute assessed phase. The first minute of the assessed stage is a ‘run-in’ period; therefore responses from the last six minutes are included as outcome variables. These six minutes (termed blocks 1-6) contain nine target sequences each (54 in total). Outcome variables for this task were number correct by block, total number correct, number of false alarms, number of correct rejections and reaction time (ms) (see Appendix 9.20).

The RVIP task has shown sensitivity to nutritional manipulations, including glucose and cocoa flavonoids interventions (Reay, Kennedy, & Scholey, 2006; Scholey et al., 2010). Derivatives of the task (e.g. response is required to a 2-letter target sequence among a letter series) have detected acute changes induced by a breakfast manipulation in school children (Busch et al., 2002). The CANTAB RVIP task has detected changes in sustained attention induced by low-dose caffeine manipulations (Durlach, 1998; Elsabagh, Hartley, Ali, Williamson, & File, 2005).

Figure 3.2: Outline of RVIP task



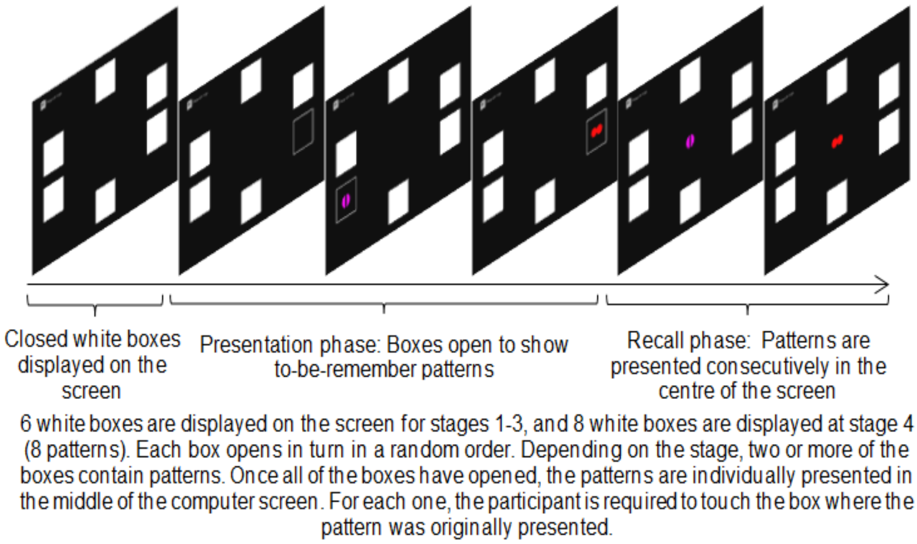
3.4.5.5.3 Domain: Immediate visual-spatial memory

3.4.5.5.3.1 Paired Associates Learning

The PAL was employed to measure immediate visual-spatial memory (see Figure 3.3). The duration of the task is 7-9 minutes, depending on response times and stage reached. The task consists of 1 practice stage followed by 4 assessed stages. At each stage, white boxes are displayed on the screen and open in a random order. Depending on the stage, two or more of these boxes contain patterns. After all boxes have opened, each previously presented pattern is shown in the centre of the screen and the participant is required to indicate the previously shown location of the pattern by touching the relevant white box on the screen. As the task proceeds, these assessed stages increase in difficulty by increasing the number of patterns presented. The number of patterns presented at stages 1, 2, 3 and 4 are 2, 3, 6 and 8 respectively. At each stage, the participant is given a maximum of six attempts (termed trials) to recall all of the correct pattern locations. If a participant is unable to recall all of the correct pattern locations within six attempts, the test terminates. Hence, a participant has to succeed on a level in order to advance to the next level. Parallel forms were presented at each test session. Outcome variables for this task were total number of errors, total number of trials and first trial memory score (see Appendix 9.21)

Tests of visual-spatial memory which involve immediate object location recall have shown sensitivity to detect acute changes induced by breakfast manipulations in children and adolescents (Ingwersen et al., 2007; Mahoney et al., 2005; Wesnes et al., 2003). The CANTAB PAL task has shown sensitivity to food components, including docosahexaenoic acid in adults (Yurko-Mauro et al., 2010).

Figure 3.3: Outline of PAL task. Stage 1 (2 pattern recall) shown.



3.4.5.6 Subjective evaluation of satiety, mood, mental alertness, motivation and cognitive test performance

Concomitant ratings of subjective mood, alertness and motivation were taken throughout the test morning using 7 unipolar VAS. The unipolar VAS is a horizontal line, 100mm in length, anchored by the extreme intensities of a single subjective feeling (e.g. '*not at all*' to '*very*'). The participant marks on the line at the point that they feel represents their perception of their current state. VAS have been shown to be reliable measures of subjective state in children aged >7 years (Shields, Palermo, Powers, Grewe, & Smith, 2003). The descriptors were chosen and adapted from those used in previous studies (Chapter 2; section 2.5.3.6) to reflect dimensions of motivation, alertness and mood. The mood descriptors were piloted in a small sample of 11 year olds to ensure suitability for the study population. Pilot testing also revealed that the 11 year olds tended to respond at the extremes of the scales or the midpoint without utilising the full scale range. To reduce this responding tendency, participants were given the opportunity to practise the VAS during screening and given clear instructions about how to use the scale. One further VAS, with the same format, was used to assess hunger. Following cognitive testing, 4 VAS were included to assess perceived test battery difficulty, perceived performance, and concentration and frustration during the test battery using scales adapted from the NASA Task Load Index (Hart & Staveland, 1988). This provided a subjective assessment of cognitive performance and workload.

VAS were presented electronically using the CANTAB equipment. Participants responded to each VAS using the touch screen by moving the cursor along a 100mm line with extreme anchors at each end. The initial location of the cursor was at the 50mm mark. There were 100 points on the scale, yielding possible scores of 0-100. Participants were asked to rate their subjective state immediately before and after breakfast and each cognitive test battery. At each measurement point, participants completed a total of 8 or 12 VAS items (see Appendix 9.22 and 9.23). The 8-item VAS (pre-cognitive testing and following breakfast) assessed satiety, mood, motivation and mental alertness and the 12-item VAS (post cognitive testing only) contained an additional four items relating to perceived test battery difficulty, perceived performance, and concentration and frustration during the test battery. The 8-item VAS took approximately 3 minutes to complete and the 12-item VAS took approximately 4 minutes to complete.

3.4.6 Procedure

3.4.6.1 Screening

Participants attended two screening sessions in the week prior to the scheduled test day. At the first screening session (Day 0), participants completed a self-report written questionnaire (see Appendix 9.17). The questionnaire contained items relating to the participant's habitual breakfast behaviour, medical conditions, food allergies and intolerances. Participants' height and weight was also measured. Participants were also tested for colour vision. Lastly, participants were given the opportunity to try a small amount of each RTEC (with semi-skimmed milk) and choose the RTEC they wished to consume as a test breakfast. At the second screening session (Day 5), each pupil completed a practise version of the cognitive test battery, and the 8 and 12-item VAS. On the day prior to the scheduled test day (Day 6), memos were distributed to remind participants not to eat or drink anything after 2100 hours (with the exception of ad libitum water intake). In addition, text messages were sent to parents/guardians via the school's secure text system to remind them that their child should not eat anything after 2100 hours that evening. The test day was carried out on Day 7, exactly one week after the first screening session.

3.4.6.2 Randomisation procedure

Participants were randomly allocated into breakfast and no breakfast conditions. The randomisation procedure was carried out by an independent statistician (Quadt Consultancy BV). Randomisation lists were created within each school class and by gender. Participants and researchers were blind to their assigned condition until the intervention on the test day.

3.4.6.3 Test day

The test day schedule is given in Table 3.4. On the test day, participants arrived at school at 0830 hours in an assumed fasted state. The researchers collected the participants from their first lesson and escorted them to the testing room for the baseline test session. Participants completed the 8-item VAS, cognitive test battery, followed by the 12-item VAS. At 0905 hours, participants were served breakfast or no breakfast in the school dining area with 15 minutes for consumption. Following the intervention, participants were escorted back to the testing room where they completed a post-breakfast 8-item VAS.

Participants attended their second lesson as usual until 1015 hours when they were collected from class for test session one. Participants attended their third and fourth lesson as normal but were collected at 1240 hours from their fourth lesson for test session two. The testing procedure followed the same format in test sessions one and two as the baseline test session.

Table 3.4: Schedule of events during the test day

Time	T=	Activity	Concomitant school activity
0830	-35	Arrival at school	Arrival at school
0835	-30	Registration and arrival at testing room	Lesson 1
0840	-25	Baseline measures • VAS 8-item (T1) • Baseline cognitive test battery • VAS 12-item (T2)	Lesson 1
0905	0	Breakfast (or no breakfast) served and consumed	Lesson 1
0920	+15	Post-breakfast measures • VAS 8-item (T3)	Lesson 1
1015	+70	Test session 1 measures • VAS 8-item (T4) • Test session 1 cognitive test battery • VAS 12-item (T5)	Lesson 2 (ends at 10:30) Break-time (10:30 - 10:45)
1240	+215	Test session 2 measures • VAS 8-item (T6) • Test session 2 cognitive test battery • VAS 12-item (T7)	Lesson 4 (ends at 12:45) School lunch period
1310	+245	End of test day • End of test day snacks	School lunch period

3.4.7 Ethical considerations

3.4.7.1 Approval

Prior to commencement of the study, ethical approval was obtained from the Institute of Psychological Sciences (IPS) Ethics Research Committee at the University of Leeds, UK (Reference:10-0105, Date: 27/12/2010, Appendix 9.24). All researchers involved in the study were in possession of enhanced Criminal Records Bureau clearance. All participants were fully supervised during their testing sessions. Parents and teachers were not present during data collection. All data gathered were strictly confidential and anonymised.

3.4.7.2 Recruitment and assent

This study adopted a process of assent to determine whether potential participants and their parents/guardians were willing to take part in the study. This was in line with normal protocol at the school for extraordinary activities such as these. Prior to data collection, the pupils received a school assembly given by the researchers to introduce the study. Immediately following the assembly, a letter was sent home to each parent/guardian of school pupils in Years 7 and 8, containing a cover letter and information sheet for the parent/guardian (see Appendix 9.25) and an information sheet for the pupils (see Appendix 9.26). These letters provided the parents and pupils with written information about the purpose of the study and its requirements for participation. The pupil version was specifically designed, in terms of readability and content, to aid understanding. For the pupils, this information was reiterated at screening and they were given the opportunity to ask questions.

Parents were informed in the parent information letter that they should contact the researchers, via email or telephone, with any questions or queries regarding the study. In addition, parents/guardians were informed that if they were happy for their child to take part in the study they did not need to respond to the letter or notify the researchers, and consent (by a process of assent) would be assumed. Alternatively, if parents/guardians were not happy for their child to participate in the study, they were told they had three ways in which they could inform the researchers: (a) via email, (b) via telephone or text (with voicemail and call-back service), or (c) by returning a slip to the school with their child, which was enclosed with the letter.

All teaching staff affected by the study were contacted via email and given detailed explanations of what the study entailed and how their classes would be affected, and were given the opportunity to exclude their class from the study if they wished. It was reiterated to teachers that pupils were not permitted to consume food or drink (except water) whilst taking part in the study.

3.4.7.3 Study withdrawal and confidentiality

Participants and their parents/guardians were told that participants could withdraw at any point before or during the study without giving a reason. All information gathered remained strictly confidential and was anonymised prior to analysis and reporting. If a participant withdrew part way through, any data collected were excluded from the analysis.

3.4.7.4 Adverse events

Adverse events (AEs) are described as any undesirable experience occurring to a participant during a study, whether or not considered related to the test breakfast or study procedures. Before the study began, research staff were instructed to document reported or observed AEs at the time they were reported or observed using a standard form (see Appendix 9.27). Any AEs were to be reported to the IPS Ethics Committee, according to ethical requirements, and followed up until they were resolved. There were no AEs recorded in this study.

3.4.8 Power analysis

To estimate the number of participants required to detect a statistically significant difference between two groups, power was calculated based on the effect size observed in Ingwersen et al. (2007) for the outcome measure “Secondary Memory”. The calculation was conducted by an independent statistician (Quadt Consultancy BV) using G*Power 3.1 and indicated that a sample of 90 participants per group (n=180) would be sufficient to detect an effect size of the same magnitude as that observed by Ingwersen et al. (2007; effect size = 0.42), with an alpha of 0.05 and 80% power. The equivalent calculation with an alpha of 0.05 and 90% power was 121 participants per group (n=242).

3.4.9 Statistical analysis

Statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS) version 21 (SPSS, Inc. Chicago, USA) and the significance level (α-level) was set as $p<0.05$. All data were plotted as means (± standard error [SE]) unless otherwise stated. Baseline characteristics were compared using independent groups t-tests for continuous variables and Pearson’s chi-squared (χ^2) tests for categorical variables.

3.4.9.1 Analysis of the effect of breakfast on cognitive performance

There are two commonly used approaches to the analysis of data from pre-post test experimental designs: analysis of change from baseline (post-pre) scores using ANOVA models or analysis of raw scores with baseline as a covariate using ANCOVA models (Senn, 2006; Vickers & Altman, 2001). However, the ANCOVA approach is preferred due to the increased power offered by this technique (Egbewale, Lewis, & Sim, 2014; Loh, 2009; Van Breukelen, 2006; Vickers, 2001; Vickers & Altman, 2001).

ANCOVA increases statistical power by accounting for that portion of the variance in post-intervention cognitive performance that can be explained by differences in cognitive performance at baseline. Hence, the residual error variation in cognitive performance is reduced, increasing precision in the estimation of the effects of study condition and thus statistical power. Further, this technique ensures that potential post-test differences in cognitive performance between conditions truly result from the study condition and are not an effect of random baseline differences between study conditions. In this respect, change scores may not be reliable because they are affected by any baseline imbalances between study conditions and may be susceptible to regression towards the mean (Vickers & Altman, 2001). There were few significant differences in cognitive performance at baseline in the current study suggesting that randomisation was successful (see Appendix 9.28). However, the presence of trends for differences at baseline on some cognitive outcome measures underlines the importance of including baseline as a covariate in the analysis to prevent incorrectly attributing effects to the intervention when these are actually a function of differences at baseline. Moreover, even in randomised trials where there are no imbalances at baseline, the ANCOVA technique is still superior and recommended due to the increased statistical power (Van Breukelen, 2006).

There are fewer assumptions to be confirmed using the ANOVA change score approach. However, ANCOVA is superior even when the assumptions are violated due to the increased power conferred (Senn, 1994, 2006). Furthermore, Senn (1994; 2006) argues that if the assumption of homogeneity of regression is violated this should not deter the use of ANCOVA because a significant covariate by condition interaction will exist whether or not the ANCOVA approach is used. Hence, the effect of condition will vary with baseline cognitive performance regardless of whether the covariate is included in the analysis and therefore may be meaningful. This is supported by previous findings which suggest that the effects of nutritional manipulations on cognitive performance can vary as a function of baseline cognitive performance (Dye et al., 2010).

For the reasons discussed above, cognitive performance outcome variables were analysed using mixed ANCOVA models with condition (2 levels; breakfast and no breakfast) as the between subject factor and session (2 levels; test session one and test session two) as the repeated measures factor and baseline test performance as the covariate. Main effects and interactions were explored using post-hoc pairwise comparisons with the Bonferroni correction. For brevity, F values and corresponding significance values for main effects and interactions in the ANCOVA model for each cognitive outcome variable are shown in Appendices 9.29-9.32.

The relevant assumptions were checked for each ANCOVA model as prescribed by Tabachnick and Fidell (2007). Data for which residuals illustrated a skewed distribution were normalised by transformation of the data and/or the removal of outliers. Where data were transformed in order to normalise the distribution of residuals, the raw data scores are plotted for clarity. Cases were considered outliers when standardised residuals exceeded ±3.3 and were removed from the analysis. Levene's test was used to examine the homogeneity of variance of the between-subjects factor (i.e. condition). Homogeneity of regression slopes was tested by including baseline*condition and baseline*session interactions in the ANCOVA models (Tabachnick & Fidell, 2007). Where a significant baseline*condition and baseline*session occurred, indicative of heterogeneity of regression slopes, these interactions were explored using linear regression plots of baseline performance (x axis) against subsequent performance in test session one and two (y axis) according to the breakfast condition or session (represented by a separate regression lines).

In ANCOVA models, the main effects test the difference in means between conditions and sessions when baseline is held constant at zero. Therefore, these effects are only informative when there is no interaction with baseline cognitive performance (i.e. when homogeneity of regression slopes is present). Where a baseline*condition or baseline*session interaction is present, the main effect is not informative and the post-hoc comparisons must be consulted. Post-hoc comparisons test the difference in least square means (LSMs) between conditions and sessions when baseline is held constant at the grand mean (overall sample mean). LSMs are adjusted for the grand mean and therefore best represent the whole sample. In the case of heterogeneity of regression slopes, post-hoc comparisons provide the most appropriate test of the effect in question for the whole sample (Quadt Consultancy BV, personal communication). Where there is no interaction with baseline, the post-hoc comparisons will be approximately equivalent to the ANCOVA results.

3.4.9.2 Analysis of the effect of breakfast on subjective state and cognitive test evaluation

VAS measures of perceived satiety, mood, motivation and alertness were analysed using similar models to the cognitive test data. Baseline measures of subjective state were taken immediately prior to the baseline cognitive test battery (Time 1 [T1]). Measures during the period from post-breakfast to pre-lunch (T3-T7) were included in the analysis of each subjective state outcome (see Table 3.4; section 3.4.6.3). Therefore, the ANCOVA models included breakfast condition (2 levels; breakfast and no breakfast) as the between subject factor and time (5 levels; T3-T7) as the repeated measures factor and baseline ratings of each subjective state as the covariate. For VAS measures of cognitive test performance evaluation, baseline ratings were taken at T2, which was immediately after the baseline cognitive test battery (see Table 3.4; section 3.4.6.3). Measures during the period from post-breakfast to pre-lunch (T5, T7) were included in the analysis. Therefore, the ANCOVA models included breakfast condition (2 levels; breakfast and no breakfast) and time (2 levels; T5, T7) as the repeated measures factor and baseline ratings of each subjective state as the covariate. Main effects and interactions were explored using post-hoc pairwise comparisons using the Bonferroni correction.

The relevant assumptions were checked for each ANCOVA model as described in section 3.4.9.1. The assumption of sphericity was checked using Mauchley's test of sphericity and where significant, Greenhouse Geisser's (GG) correction was applied (indicated by "GG adjusted"). There were no significant differences in VAS ratings at baseline between conditions (see Appendix 9.28). For brevity, F values and corresponding significance values for main effects and interactions in the ANCOVA model for each subjective state and cognitive performance evaluation outcome variable are shown in Appendices 9.33 and 9.34.

3.5 Results

3.5.1 Participant demographic characteristics

Participant demographic characteristics are shown in Table 3.5. The sample consisted of 226 participants (53.1% male, 46.9% female) aged 11-13 years (mean age ± SD: 12.02 ± 0.58) in school Year 7 (55.3 %) and 8 (44.7%). The sample was ethnically diverse. Approximately two thirds (68.6%) of the sample were White British, 19.5% were Asian/British Asian, 5.3% were Black British/African/Caribbean with the remaining 6.6% participants from mixed or other ethnic backgrounds. A relatively large proportion of the sample had EAL (27.0%). Over a third (38.9%) of participants were classified as low SES. The BMI SDS varied widely with a mean BMI SDS of 0.79 ± 1.24. Most participants were classified as normal weight (142 [60.7%]), but a relatively large proportion of participants were obese (68 [29.1%]). Only two (0.9%) participants were classified as underweight and the remaining 14 (6.2%) participants were overweight. The overall mean CAT standard age score (SAS) was 90.53 ± 10.90 which is below the national mean of 100 ± 15 (see Chapter 5; section 5.4.4.4.2). Table 3.5 shows a statistical comparison of demographic characteristics of the participants according to the breakfast condition to which they were randomly assigned. Independent groups t-tests and Pearson's chi-squared tests demonstrated no significant differences between characteristics of participants assigned to each study condition (all $p>0.05$).

Table 3.5: Participant characteristics and statistical comparison of demographic characteristics by study condition

Demographic characteristics	Total		No breakfast		Breakfast		Statistic
	n	%	n	%[a]	n	%[a]	χ^2, df, p-value[b]
Gender							
Male	120	53.1	61	52.6	59	53.6	χ^2=0.03,df=1, p=0.867
Female	106	46.9	55	47.4	51	46.4	
Ethnicity							
White British	155	68.6	77	66.4	78	70.9	χ^2=2.99,df=4, p=0.560
Asian/ British Asian	44	19.5	26	22.4	18	16.4	
Black British/African/Caribbean	12	5.3	5	4.3	7	6.4	
Mixed	7	3.1	3	2.6	4	3.6	
Other	8	3.5	5	4.3	3	2.7	
School year group							
Year 7	125	55.3	59	50.9	66	60.0	χ^2=1.24,df=1, p=0.266
Year 8	101	44.7	57	49.1	44	40.0	
SES							
Middle/high SES	138	61.1	77	66.4	61	55.5	χ^2=2.83,df=1, p=0.122
Low SES	88	38.9	39	33.6	49	44.5	
EAL							
No	165	73.0	83	71.6	82	74.5	χ^2=0.13,df=1, p=0.910
Yes	61	27.0	33	28.4	28	25.5	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**T-value, df, p-value[c]**
Age (years)	12.02	0.58	12.04	0.58	12.01	0.59	t(224) 3.25, p=0.745
Height (cm)	152.80	8.41	151.74	7.91	153.88	8.80	t(224) -1.96, p=0.075
Weight (kg)	48.75	13.70	47.46	13.26	50.13	14.14	t(224) -1.49, p=0.137
BMI SDS	0.79	1.24	0.70	1.23	0.88	1.24	t(224) -1.09, p=0.275
CAT SAS score	90.53	10.90	90.53	10.77	90.52	11.09	t(218) 0.10, p=0.992

[a] Percentage within condition. [b] Pearson's chi-squared value for differences in categorical demographic variables between study conditions
[c] *p*-value (two tailed) for independent samples t-test.

3.5.2 Habitual breakfast consumption

Participants' self-defined breakfast habits and frequency of breakfast intake per week are shown in Table 3.6. Most participants indicated that they normally (39.4%) or sometimes consumed breakfast (48.7%). A small proportion of participants indicated that they did not normally consume breakfast (11.9%). Participants' frequency of breakfast intake per week indicated that approximately a third of participants never (0 days/week) or rarely (1-2 days/week) consumed breakfast. Only 26.5% of participants reported that they consumed breakfast every day. Pearson's chi-squared tests demonstrated no significant differences between habitual breakfast consumption of participants assigned to each study condition (all $p>0.05$; Table 3.6).

Table 3.6: Self-defined habitual breakfast consumption, frequency of breakfast intake per week (n;%) and statistical comparison by study condition

Breakfast consumption	Total		No breakfast		Breakfast		Statistic
	n	%	n	%[a]	n	%[a]	χ^2, df, p-value
Self-defined breakfast habit							
Yes	89	39.4	51	44.0	38	34.5	χ^2=2.48,df=2, p=0.290
No	27	11.9	11	9.5	16	14.5	
Sometimes	110	48.7	54	46.6	56	50.9	
Frequency of breakfast/week							
0	16	7.1	8	6.9	8	7.3	χ^2=5.65,df=4, p=0.206
1-2	60	26.5	23	19.8	37	33.6	
3-4	53	23.5	31	26.7	22	20.0	
5-6	37	16.4	21	18.1	16	14.5	
7	60	26.5	33	28.4	27	24.5	

[a] Percentage within condition

3.5.2.1 Food choices at breakfast

Foods and drinks usually consumed for school-day and weekend breakfast meals are shown in Table 3.7 (N.B. some participants consumed more than one item at each meal). RTECs were the most frequently consumed food for breakfast on school days (42.9%) and bread was the most commonly consumed food for breakfast during weekends (35.0%). Eggs were frequently consumed on weekends (19.5%), but not on school days (1.3%). Meat was also more frequently eaten on weekends (9.3%) than on school days (0.9%). Very few participants reported ever consuming fruit for breakfast on both school-days and weekends (4% and 0.9% respectively). Tea and coffee were the most frequently consumed beverages at breakfast on school days and weekends (9.3% and 8.8% respectively). Encouragingly, very few participants reported consuming snack food and confectionary for breakfast on school days and weekends (≤3.1%).

Table 3.7: Number[a] and percentage of sample consuming eighteen food and drink groups for school-day and weekend breakfast meals

Food group	School-day		Weekend	
	n	%	n	%
Cereals and cereal products				
Bread (all types)	70	31.0	79	35.0
RTECs (including muesli)	97	42.9	54	23.9
Oats, porridge	0	0.0	1	0.4
Other cereals (pasta, rice, pizza)	2	0.9	0	0.0
Cake, pastries, sweet buns	6	2.7	2	0.9
Biscuits, breakfast biscuits or bars	5	2.2	7	3.1
Meat, eggs				
Meat and meat products	2	0.9	21	9.3
Egg (in various forms)	3	1.3	44	19.5
Fruit and vegetables				
Fruit (including smoothies)	9	4.0	2	0.9
Milk and milk products				
Milk (to drink)	10	4.4	2	0.9
Cheese	0	0.0	2	0.9
Snack food and confectionary				
Savoury snack (crisps)	4	1.8	1	0.4
Chocolates or sugar confectionary	7	3.1	7	3.1
Sweet spreads	2	0.9	0	0.0
Beverages				
Tea and coffee	21	9.3	20	8.8
Fruit juices	18	8.0	11	4.9
Soft drinks	17	7.5	9	4.0
Water	17	7.5	6	2.7

[a] One participant can have more than one entry

3.5.3 Breakfast intervention

3.5.3.1 Self-serve RTEC intake

The most popular RTECs chosen for consumption in the breakfast manipulation were Start and Mini Max**.** Table 3.8 shows RTEC and milk intake according to RTEC type. The amounts consumed varied considerably between participants and RTEC type. The RTECs are representative of four different RTEC styles which differ in appearance, volume and energy density. This is reflected in the variability of intake between the four types of RTECs. RTEC portion sizes (RTEC only) were largest for Mini Max (58.27 ± 16.36g), followed by Start (47.78 ± 17.08g), followed by Rice Krispies (46.31 ± 14.43g), and were smallest for Cornflakes (34.46 ± 17.32g). Across all four RTEC types, total mean RTEC intake was 49.46g ± 17.60g. Total mean intake of milk was 133.51g ± 79.44g.

The large variation in RTEC and milk intake suggests that the use of an ad libitum breakfast manipulation was most appropriate to provide a portion size suitable for each participant. It also suggests that it would have been difficult to select an appropriate portion size for testing for the sample. It also suggests that the GSAs are not suitable as intake across all four RTECs were higher (see section 3.4.4.1; Table 3.1 for GSAs). This variation in intake may be due to different portion sizes required by adolescents of this age range as a result of different growth trajectories, body weights (see section 3.5.1; Table 3.5 for BMI SDS), physical activity levels and consequently energy needs.

Across both conditions, 25 participants consumed water which was provided by the researchers (no breakfast condition: n=15; breakfast condition: n=10). Overall mean intake of water was low (86.60 ± 59.56 ml), but higher in the breakfast condition compared with the no breakfast condition (137.27 ± 26.40, 49.53 ± 48.45 ml respectively)

Table 3.8: RTEC and milk consumption in the study intervention

		Mini Max	**Start**	**Corn-flakes**	**Rice Krispies**	**Total**
		n=30	**n=61**	**n=8**	**n=11**	**n=110**
RTEC intake(g)	**Mean**	58.27	47.78	34.46	46.31	49.46
	SD	16.36	17.08	17.32	14.43	17.60
Milk intake(g)	**Mean**	153.6	112.97	154.13	177.42	133.51
	SD	83.31	68.6	80.28	96.93	79.44
Total intake(g)	**Mean**	211.87	160.75	188.58	223.73	182.98
	SD	91.96	74.71	88.19	103.83	86.64

N.B. All Kellogg's©; Participants provided 70g of RTEC; 309g/300ml of semi-skimmed milk

3.5.3.2 Energy and macronutrient intake at breakfast

Table 3.9 shows mean intake of energy and macronutrients for the breakfast condition according to RTEC type. The overall mean intake of energy was 253 ± 86 Kcals. Overall macronutrient intake was: 44.81 ± 14.95 total carbohydrate (g), 8.97 ± 3.87 protein (g), 3.72 ± 1.57 total fat (g) and 2.69 ± 1.64 non-starch polysaccharides (g). Those who chose Mini Max consumed most energy (289 ± 86 Kcals), because of the higher energy density and higher intake (g) of this type of RTEC. There was little difference in mean protein and fat intake (both absolute and as % of food energy) between RTEC types. However, participants who consumed Mini Max or Start consumed more sugar (both absolute intake and as % of food energy) than Cornflakes or Rice Krispies (Mini Max: 17.55 ± 5.80g; Start: 16.66 ± 5.76g; Cornflakes: 9.85 ± 4.40g; Rice Krispies: 12.79 ± 5.23g). This may have driven the popularity of Mini Max and Start. Those who consumed Mini Max consumed more non-starch polysaccharides (4.66 ± 1.31g) than all other RTEC types.

Table 3.9: Mean (SD) energy and macronutrient consumption (g) and proportion (%) of energy from macronutrients for RTEC + milk consumed in the study intervention.

Energy, macronutrient	Mini Max		Start		Cornflakes		Rice Krispies		Average	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Energy (Kcal)	289.32	86.48	240.56	81.35	204.22	87.45	262.54	85.92	253.27	86.16
Total Carbohydrate (g)	49.60	14.11	42.94	14.61	36.03	16.29	48.45	14.99	44.81	14.95
% of food energy	64.67	3.14	67.03	4.60	66.28	5.84	69.82	5.78	66.64	4.68
Sugar (g)	17.55	5.80	16.66	5.76	9.85	4.40	12.79	5.23	16.01	5.98
% of food energy	22.58	1.46	25.95	1.48	18.01	3.45	17.95	3.07	23.64	3.53
Protein (g)	11.79	4.07	7.78	3.04	7.81	3.45	8.99	3.84	8.97	3.82
% of food energy	16.12	1.43	12.88	2.41	15.24	2.68	13.41	2.69	13.97	2.64
Total Fat (g)	3.93	1.67	3.71	1.50	3.08	1.51	3.66	1.81	3.72	1.57
% of food energy	11.94	2.38	13.81	2.95	13.51	3.90	12.14	3.68	13.12	3.05
Saturated fat (g)	1.71	0.86	2.09	0.84	1.61	0.82	1.87	0.98	1.93	0.87
% of food energy	5.14	1.49	7.77	1.62	7.05	2.25	6.17	2.14	6.85	2.03
Non-starch polysaccharides (g)	4.66	1.31	2.39	0.85	1.03	0.52	0.46	0.14	2.69	1.64

3.5.4 Cognitive performance

The effects of breakfast condition on cognitive performance are presented below. The ANCOVA models for each cognitive outcome variable are shown in Appendices 9.29-9.32. For all cognitive outcome variables, baseline performance was a highly significant predictor (all $p<0.001$) of post-intervention performance at test session one and two (see Appendices 9.29-9.32) confirming the suitability of this covariate in the analyses (Tabachnick & Fidell, 2007). There was missing data for one participant for SRT and 5-CRT who was excluded from the analyses of these outcomes.

3.5.4.1 Simple Reaction Time task

3.5.4.1.1 Reaction time

Reaction time in the SRT task is the mean duration (ms) between the onset of the stimulus and the time at which the participant released the button in correct, assessed trials and reflects the time taken to make the decision to move (i.e. decision time). The distribution showed a positive skew. The data were log transformed and 9 outliers with very slow response times were removed to improve normality of distribution. Figure 3.4 shows untransformed LSM reaction time ±SE (ms) for the SRT task at test session one and two following breakfast or no breakfast. The sample's overall mean baseline reaction time (adjustment value) is depicted by the green line.

The ANCOVA analysis revealed no main effect of condition, $F(1,212) = 2.03$, *ns*, or session, $F(1,212) = 0.03$, *ns*, but a significant condition*session interaction was present, $F(1,212) = 4.30$, $p<0.05$, suggesting that the effect of condition on reaction time was different between test sessions when baseline scores were held constant. However, the significant condition*session interaction was nullified by the presence of a significant baseline*session*condition interaction, $F(1,212) = 4.21$, $p<0.05$, suggesting that the assumption of homogeneity of regression slopes was violated. The significant baseline*session*condition interaction suggests that the effect of condition on reaction time varied between test sessions as a function of reaction time at baseline.

These interactions can be interpreted by inspection of linear regression plots of baseline reaction times against subsequent reaction times at test session one (Figure 3.5a) and two (Figure 3.5b) according to breakfast condition (represented by separate regression lines). At test session one (Figure 3.5a), reaction times for participants in the breakfast condition tended to be slower compared to no breakfast. The parallel regression lines indicate that the effect of condition on reaction time at test session one was similar across baseline reaction time. However, at test session two (Figure 3.5b), the different gradients and divergence of the regression lines reflects the significant 3-way baseline*session*condition interaction. Similar to test session one, Figure 3.5b suggests that at test session two reaction times for participants in the breakfast condition tended to be slower compared to no breakfast, however this pattern of effects was only apparent when baseline performance was poorer (i.e. slower baseline reaction times).The difference between conditions was greater when baseline performance was poorer (i.e. slower baseline reaction times), indicated by the greater separation between regression lines. The reverse pattern of effects of condition was apparent when baseline performance was better (i.e. faster baseline reaction times), such that participants had faster reaction times at test session two in the breakfast condition relative to no breakfast. This is indicated by the divergence of the regression lines at faster baseline reaction times. This indicates that an advantage of breakfast for reaction time was evident only for participants with faster reaction times at baseline.

The post-hoc pairwise comparisons using the Bonferroni correction compared reaction times between sessions and conditions when baseline was held constant at the overall sample mean. These comparisons were used in the event of heterogeneity of regression slopes (see section 3.4.9.1). The pairwise comparisons at mean baseline revealed no significant difference between conditions at test session one and two. However, there was a highly significant difference between sessions at mean baseline ($p<0.001$). This latter relationship is reflected in Figure 3.4 which indicates that mean reaction time was significantly slower at test session two than test session one, when baseline was equal to the overall mean of the sample. This demonstrates a decline in performance across the morning.

Figure 3.4: SRT mean ± SE reaction time (ms). Plotted are untransformed LSMs.

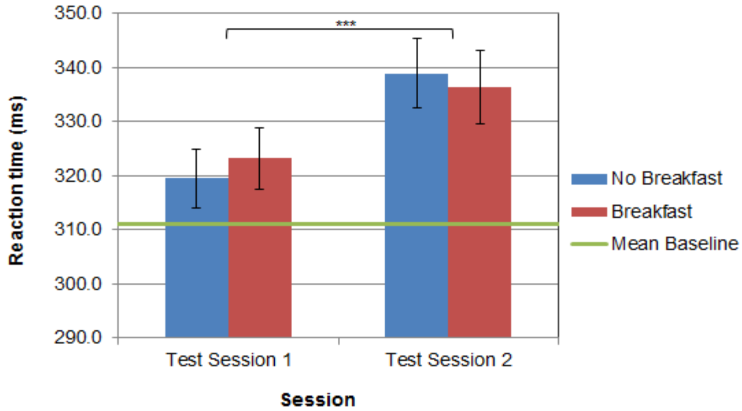
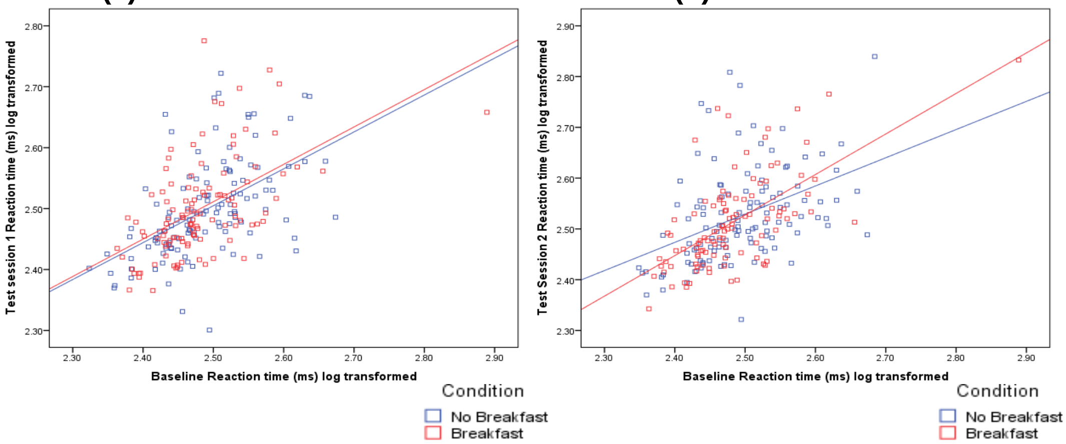


Figure 3.5: Regression plot of baseline on post-intervention reaction times at test session (a) one and (b) two on the SRT task according to condition.

(a) Test session one **(b) Test session two**



3.5.4.1.2 Movement time

Movement time in the SRT task is the mean time taken (ms) to touch the stimulus after the button has been released in correct, assessed trials and is therefore the time taken to press the target stimulus after the decision to move has been taken. The distribution showed a positive skew and was normalised by the removal of 6 outliers with very slow response times. The adjusted LSMs ± SE shown in Figure 3.6 suggest that movement time was faster following breakfast compared to no breakfast at both test sessions, but more discernibly so at test session two. The ANCOVA analysis revealed a trend for a main effect of session, $F(1,215) = 3.48$, $p=0.063$, and a significant condition*session interaction, $F(1,215) = 4.00$, $p<0.05$. The main effect of condition was non-significant, $F(1,215) = 0.50$, *ns*. The condition*session interaction was nullified by a trend towards a baseline*session*condition interaction, $F(1,215) = 3.43$, $p=0.064$, indicating that the assumption of homogeneity of regression slopes was violated. This indicated that the effect of breakfast condition and test session differed according to performance at baseline.

Inspection of the linear regression plot of baseline movement times against movement times at test session one (Figure 3.7a) suggests that participants in the breakfast condition tended to be faster relative to no breakfast. This pattern of effects was more apparent when baseline performance was poorer (i.e. slower baseline movement times), depicted by the greater separation between the regression lines at slower baseline movement times. However, the divergence of the regression lines at faster baseline movement times indicates that the reverse pattern of effects of condition was apparent when baseline movement time was faster, such that at test session one participants were slower in the breakfast condition relative to no breakfast (Figure 3.7a). At test session two (Figure 3.7b), movement times were faster in the breakfast condition compared to the no breakfast condition, which was consistent across baseline performance (depicted by parallel regression lines).

The post-hoc comparisons at mean baseline using the Bonferroni correction indicated that the difference between sessions was not significant. The difference between conditions was significant at test session two only (*p*<0.05). Movement times were significantly faster in the breakfast condition relative to the no breakfast condition at test session two. This pattern of results is reflected in Figure 3.6 and Figure 3.7b.

Figure 3.6: SRT mean ± SE movement time (ms). Plotted are LSMs.

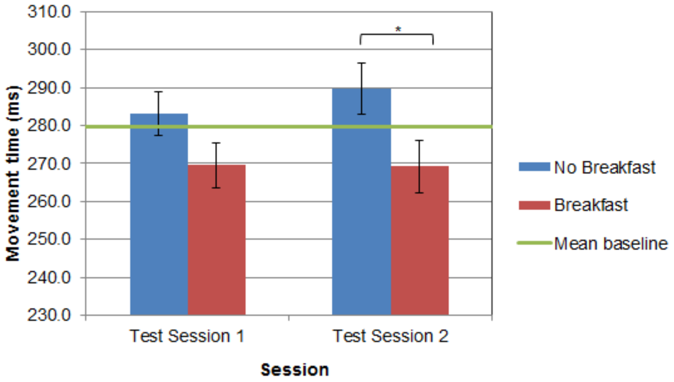
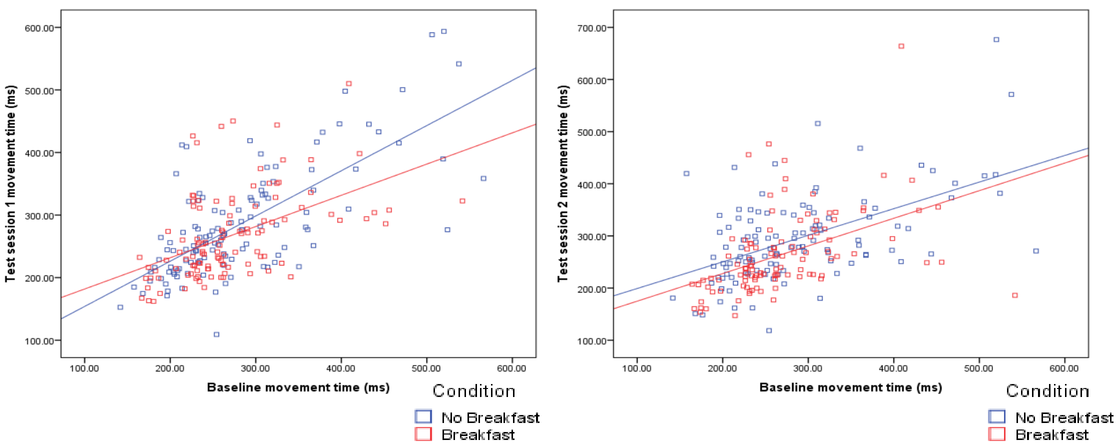


Figure 3.7: Regression plot of baseline on post-intervention movement times at test session (a) one and (b) two on the SRT task according to condition.

(a)Test session one **(b) Test session two**

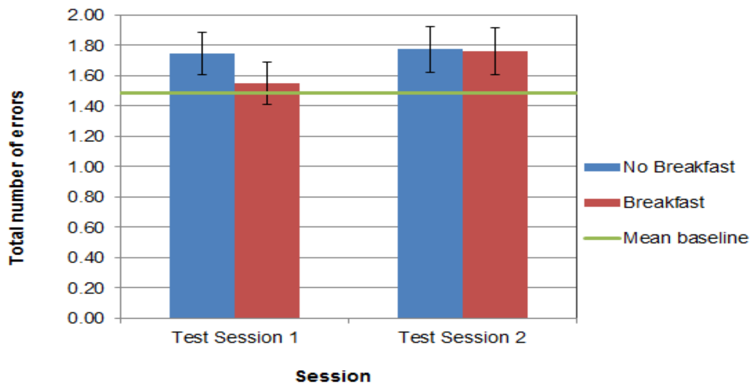


3.5.4.1.3 Accuracy

3.5.4.1.3.1 Total errors

There were three possible errors in the SRT task: errors of inaccuracy, prematurity or no response. The sum of the three possible error types yields a total error score, indicative of task accuracy. Inspection of Figure 3.8 indicates that across both test sessions, the total number of errors made by participants was low suggesting that task accuracy was high. The assumption of homogeneity of regression slopes was satisfied, demonstrated by non-significant baseline*condition, $F(1,221) = 1.62$, *ns*, and baseline*session, *F*(1,221) = 0.01, *ns*, interactions. The ANCOVA model demonstrated no significant main effect of condition, *F*(1,221) = 0.25, *ns*, or session, *F*(1,221) = 0.39, *ns*, and no significant condition*session interaction, *F*(1,221) = 0.37, *ns*. There was, therefore, no difference in the number of errors committed between conditions or sessions on the SRT task, reflected in Figure 3.8.

Figure 3.8: SRT mean ± SE total number of errors. Plotted are LSMs.



3.5.4.2 5-Choice Reaction Time task

3.5.4.2.1 Reaction time

Reaction time (decision time) in the 5-CRT task is as per the SRT task. The distribution showed a positive skew. The data were log transformed and seven outliers with very slow response times were removed in order to improve normality of distribution. Figure 3.9 shows untransformed LSM reaction time ± SE for the 5-CRT task following breakfast or no breakfast at test session one and two. The ANCOVA model revealed no significant main effect of session, *F*(1,214) = 2.47, *ns*, or condition, *F*(1,214) = 0.19, *ns*. The ANCOVA model demonstrated a significant condition*session interaction, *F*(1,214) = 6.89, $p<0.01$, however, a significant baseline*session*condition interaction was also present, *F*(1,214) = 7.21, $p<0.01$, suggesting that the model did not meet the assumption of homogeneity of regression slopes.

Figure 3.10 shows linear regression plots of baseline reaction times against post-intervention reaction times at test session one (a) and two (b) by condition. It is evident from Figure 3.10 that the significant 3-way interaction arises from a difference in the relationship between baseline and post-intervention reaction times for the two breakfast conditions, which differ at test session one and two. At test session one (Figure 3.10a), reaction times were faster following breakfast relative to no breakfast when baseline reaction times were slower. At faster baseline reaction times, the reverse relationship was observed, such that reaction times at test session one were slower following breakfast relative to no breakfast (Figure 3.10a). At test session two, the plot (Figure 3.10b) shows that breakfast consumption tended to result in slower reaction times at test session two relative to breakfast omission. There was greater separation between conditions at slower baseline reaction times, indicating that when baseline reaction times were slower, breakfast consumption inhibited reaction time at test session two to a greater extent than when baseline reaction time was faster (Figure 3.10b). The reverse relationship was observed when baseline reaction time was faster, with participants having faster post-intervention reaction time at test session two in the breakfast condition relative to the no breakfast condition (Figure 3.10b).

The post-hoc comparison of the LSMs between conditions at test session two was significant, where reaction times were significantly slower in the breakfast condition than no breakfast (p<0.01). This relationship is reflected in Figure 3.9. Taken together with the regression plot at test session two (Figure 3.10b), the results suggests that the negative effect of breakfast on reaction time at test session two was largely driven by participants who performed worse (i.e. slower) at baseline.

Figure 3.9: 5-CRT mean ± SE reaction time (ms). Plotted are untransformed LSMs.

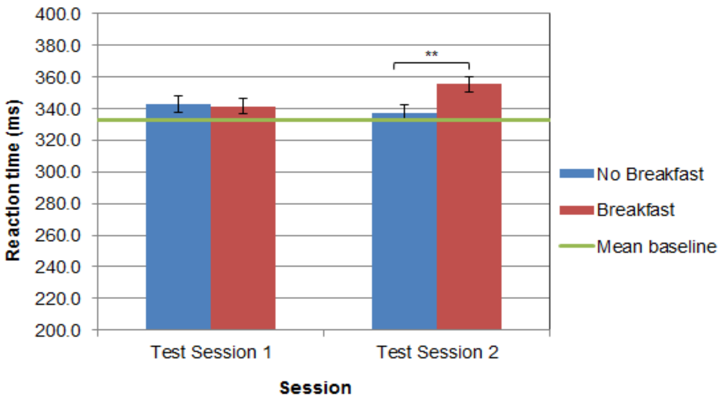
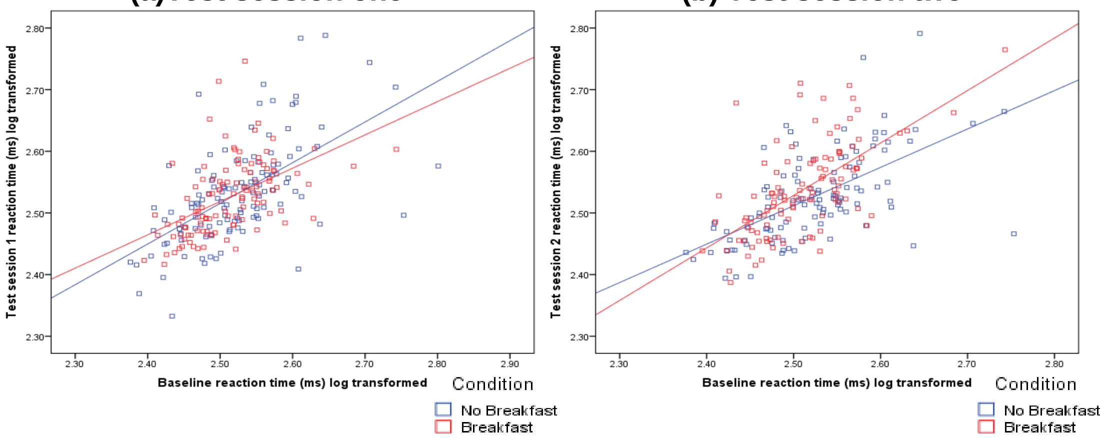


Figure 3.10: Regression plot of baseline on post-intervention reaction times at test session (a) one and (b) two on the 5-CRT task according to condition.

(a)Test session one **(b) Test session two**



3.5.4.2.2 Movement time

The distribution of movement time data on the 5-CRT task showed a positive skew and was normalised by the removal of 10 outliers with very slow reaction times. Figure 3.11

shows LSM movement time ± SE for the 5-CRT task following breakfast or no breakfast at test session one and two. The ANCOVA model revealed a significant main effect of session, $F(1,211) = 7.41$, $p<0.01$, and condition, $F(1,211) = 5.32$, $p<0.05$, however main effects were nullified by the presence of a baseline*session interaction, $F(1,211) = 6.68$, $p<0.01$. This significant interaction indicates that baseline movement time had a different relationship with post-intervention movement time at test session one compared with test session two, which is evident in the linear regression plot in Figure 3.12. There was a greater separation of the regression lines at slower baseline movement times, such that when baseline performance was slower, movement time was faster in session two compared to session one. The reverse effect of session was evident at faster baseline movement times, such that when baseline performance was faster, movement time was faster in session one than session two. However, post-hoc comparisons of the LSMs indicated that the difference between sessions was not significant. There was, however, a significant difference between conditions at test session one and test session two when baseline was held constant at the grand mean ($p<0.05$). This latter relationship is reflected in Figure 3.11 which illustrates that movement time was significantly faster following breakfast relative to no breakfast at both test sessions.

Figure 3.11: 5-CRT mean ± SE movement time (ms). Plotted are LSMs.

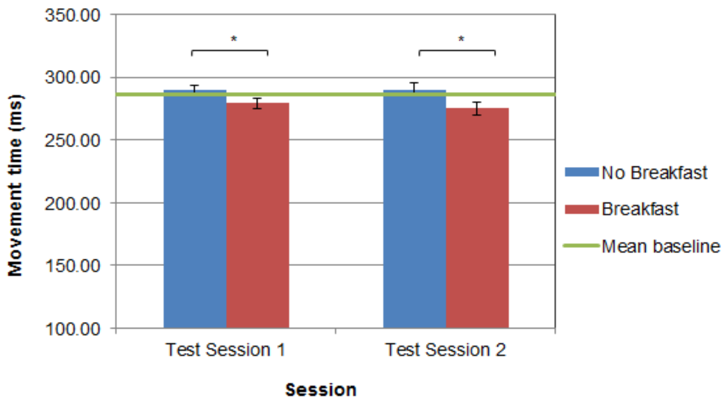
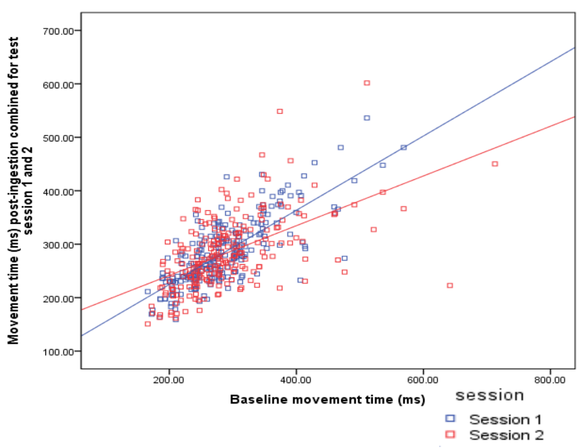


Figure 3.12: Regression plot of baseline on post-intervention movement times (ms) combined for test session one and two on the 5-CRT task by session.



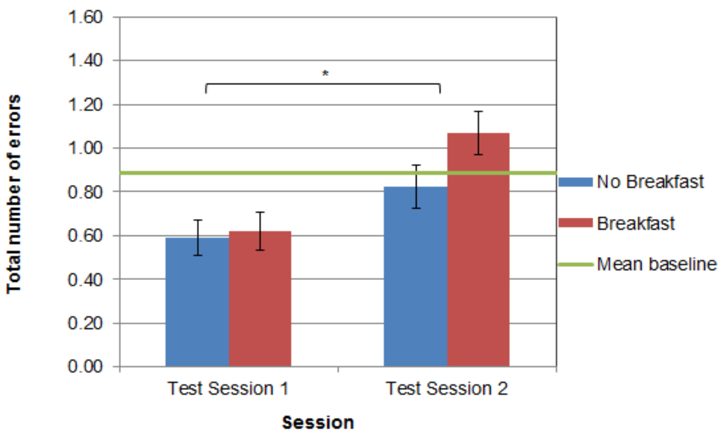
3.5.4.2.3 Accuracy

3.5.4.2.3.1 Total errors

There were three possible errors in the 5-CRT task: errors of inaccuracy, prematurity or no response, as per the SRT task. The sum of the three possible error types on the 5-CRT yields a total error score, indicative of task accuracy. Three data points were identified as outliers and were removed from the analysis. Inspection of Figure 3.13 indicates that across all sessions, the total number of errors made by participants was very low suggesting that task accuracy was high. Unexpectedly, fewer errors were made on the 5-CRT task compared with the SRT task (see Figure 3.7).

The assumption of homogeneity of regression slopes was satisfied, demonstrated by a non-significant baseline*condition, $F(1,218) = 0.97$, *ns*, and baseline*session, $F(1,218) = 0.01$, *ns*, interaction. The ANCOVA model demonstrated no significant main effect of condition, $F(1,218) = 2.09$, *ns*, or a significant condition*session interaction, $F(1,218) = 1.45$, *ns*. However, there was a significant main effect of session, $F(1,218) = 9.39$, $p<0.05$, such that the number of errors was significantly higher in test session two compared to test session one when baseline is equal to zero. This decline in task accuracy on from mid- to late-morning the 5-CRT task is reflected in Figure 3.13.

Figure 3.13: 5-CRT mean ± SE total number of errors. Plotted are LSMs.



3.5.4.3 Rapid Visual Information Processing task

3.5.4.3.1 Accuracy

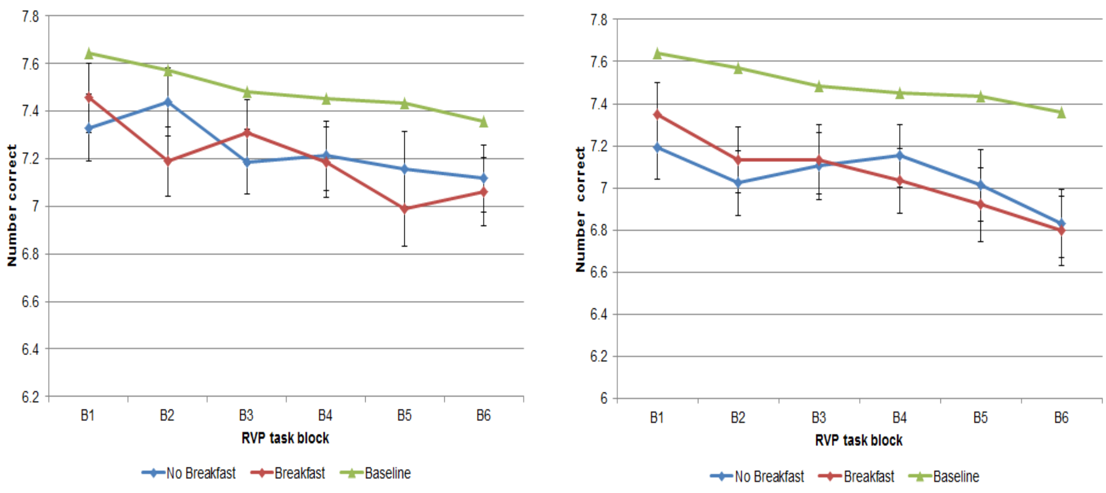
3.5.4.3.1.1 Number correct

The number correct outcome variable represents the total number of target sequences that were responded to within the allowed time (1700ms) during each assessed block (1 minute time bin), with 9 possible target sequences in each block. The number of correct targets were analysed separately by block, where each of the six blocks represents a one minute time bin with the same number of target sequences. These analyses give an indication of performance in relation to time on task. Total number correct across the six assessed blocks was also analysed. This latter analysis provides an indication of overall task performance.

Figure 3.14 provides a time-on-task plot of the number of correct targets achieved in each block across the task for test session one (a) and two (b). There was a steady decrease in the number of correct targets achieved across the task during both test sessions, indicating a decrease in performance with time. The difference between conditions varied at each time point and there was no clear advantage for one condition over another.

Figure 3.14: RVIP task mean number of correct targets ± SE. Plotted are LSMs.

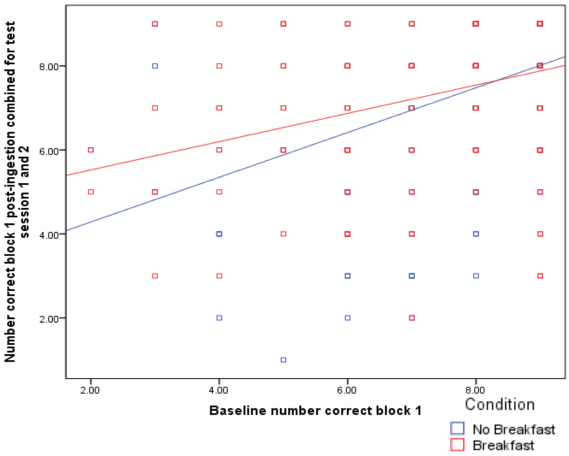
(a) Test session one **(b) Test session two**



(i) *Block 1*

The ANCOVA analysis showed no significant main effect of session, *F*(1,222) = 1.69, *ns*, and no significant condition*session interaction, *F*(1,222) = 0.46, *ns*. The ANCOVA analysis revealed a trend for a main effect of condition, *F*(1,222) = 3.34, *p*=0.065, however, a trend for a baseline*condition interaction was also found, *F*(1,222) = 2.91, *p*=0.089. This is evident in the linear regression plot (Figure 3.15) of baseline number correct in block 1 against post-intervention number correct in block 1 for test sessions one and two. The figure suggests that participants in the breakfast condition tended to perform better than those in the no breakfast condition, but the greater separation of the regression lines at lower baseline performance suggests that this was largely driven by participants with poorer baseline performance. The post-hoc comparison indicated that there no significant difference between conditions at mean baseline. There was therefore no difference between the number of correctly identified targets between conditions at block 1 (reflected in Figure 3.14).

Figure 3.15: Regression plot of baseline on post-intervention number correct in block 1 combined for test sessions one and two on the RVIP task by condition.



(ii) *Blocks 2, 3, 5 and 6*

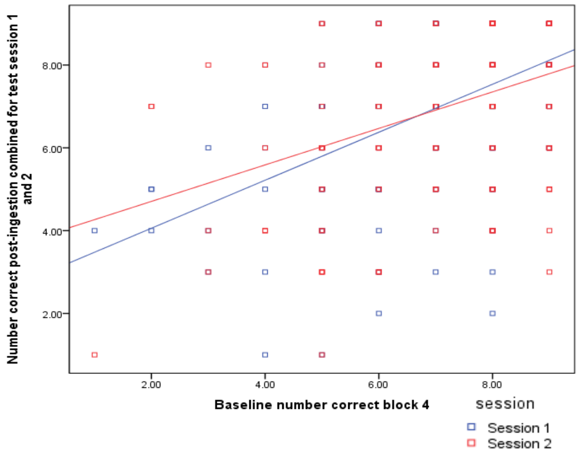
The same pattern of results was observed for Block 2, 3, 5, and 6. For brevity these results are reported together. Two data values identified as outliers in block 2 were removed. Three data values identified as outliers in block 3 were removed. There were no significant baseline*condition, smallest $F(1,222) = 0.30$, *ns*, or baseline*session interactions, smallest $F(1,222) = 0.32$, *ns*, for number correct at block 2, 3, 5, and 6, and therefore the assumption of homogeneity of regression slopes was met. The ANCOVA models indicated no significant main effect of condition, smallest $F(1,222) = 0.06$, *ns*, or session, smallest $F(1,222) = 0.01$, *ns*, and no significant condition*session interaction, smallest $F(1,222) = 0.01$, *ns*. There was therefore no difference between the number of correctly identified targets between conditions at block 2, 3, 5, and 6 (reflected in Figure 3.14).

(iii) *Block 4*

The ANCOVA model revealed no significant main effect of condition, $F(1,222) = 0.17$, *ns*, and no significant condition*session interaction, $F(1,222) = 0.15$, *ns*. There was a trend for a main effect of session, $F(1,222) = 3.22$, $p=0.074$. However, there was a significant baseline*session interaction, $F(1,222) = 4.11$, $p<0.05$, indicating the effect of session on the number of correct targets achieved in block 4 differed as a function of baseline performance.

This interaction is clear in Figure 3.16 depicted by the different gradients and divergence of the regression lines. When baseline performance was poor (lower baseline values), performance mid-morning (test session one) was worse than late-morning (test session two). There was greater separation between sessions at lower baseline performance. However, when baseline performance was good (higher baseline values), performance was better mid-morning (test session one) compared with late-morning (test session two). Post-hoc comparisons of the LSMs adjusted for overall mean baseline indicated that the difference between sessions and conditions was not significant (reflected in Figure 3.14). There was therefore no difference between the number of correctly identified targets between conditions at block 4.

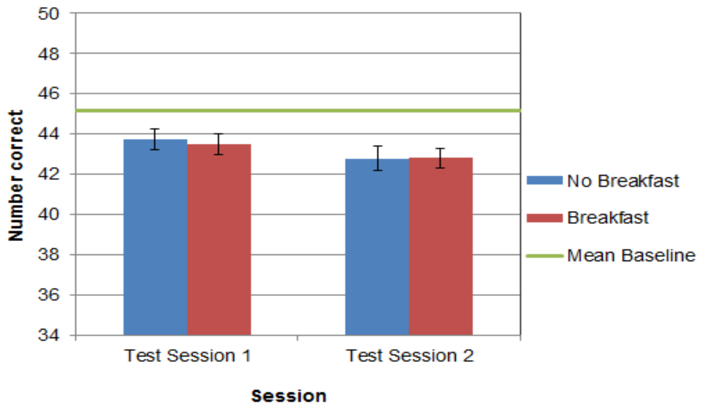
Figure 3.16: Regression plot of baseline on post-intervention number of correct targets in block 4 combined for test sessions one and two according to session.



(iv) Total number correct across task blocks

The distribution of the total number correct data showed a negative skew, which was normalised by the removal of four outliers. There were no significant baseline*condition, *F*(1,218) = 0.65, *ns*, or baseline*session, *F*(1,218) = 1.80, *ns*, interactions for total number correct indicating homogeneity of regression slopes. The ANCOVA model demonstrated no significant differences between the number of correctly identified targets across all blocks between conditions, *F*(1,218) = 0.02, *ns*. There was also no difference in the number of correctly identified targets between sessions, *F*(1,218) = 0.92, *ns*, and no significant condition*session interaction, *F*(1,218) = 0.10, *ns*. This indicated that overall RVIP task accuracy across all blocks was not improved by the consumption of breakfast relative to no breakfast at both test sessions and that performance across the morning stayed largely constant, as illustrated in Figure 3.17.

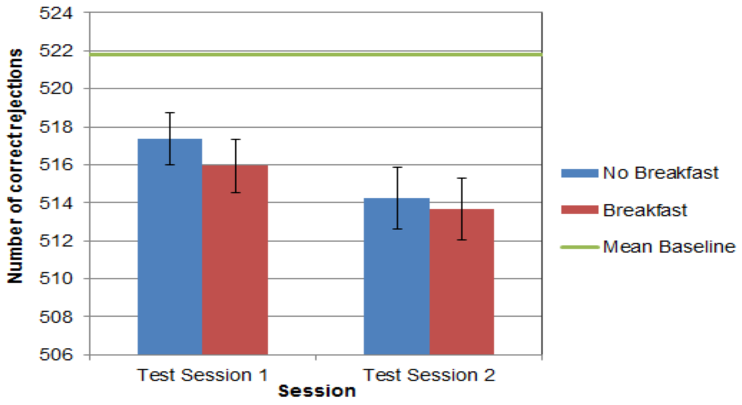
Figure 3.17: RVIP task mean number of correct targets ± SE. Plotted are LSMs.



3.5.4.3.1.2 Number of correct rejections

The total number of correct rejections outcome variable refers to the number of stimuli that were non-target sequences and were (correctly) not responded to. There were 91 non-target stimuli per block. The data showed a negative skew and were normalised by the removal of eight outliers. Homogeneity of regression slopes was confirmed, demonstrated by the non-significant baseline*condition, $F(1,214) = 0.43$, *ns*, and baseline*session, $F(1,214) = 1.53$, *ns*, interactions. The ANCOVA model indicated no significant main effect of condition, $F(1,214) = 0.28$, *ns*, and no significant condition*session interaction, $F(1,214) = 0.16$, *ns*. Figure 3.18 suggests that performance declined across the morning. The number of correct rejections was highest at baseline, and lowest late-morning (test session two) compared with mid-morning (test session one; Figure 3.18). However, there was no significant difference in the number of correctly rejected stimuli between sessions, $F(1,214) = 1.03$, *ns*.

Figure 3.18: RVIP task mean number of correct rejections ± SE. Plotted are LSMs.



3.5.4.3.1.3 Number of false alarms

The total number of false alarms was the number of times a participant responded to non-target stimuli. This included pressing the response button outside of the response window, or more than once during the response window. The data displayed a positive skew and were normalised by the removal of eight outliers which showed extremely highly false alarms. These outliers were potential indications of guessing behaviour. The ANCOVA revealed a trend for a main effect of condition, $F(1,214) = 3.62$, $p=0.058$, and a trend for a main effect of session, $F(1,214) = 3.15$, $p=0.078$, but no significant condition*session interaction, $F(1,214) = 1.00$, *ns*. However, the observed trends were nullified by the presence of a significant baseline*condition interaction, $F(1,214) = 6.50$, $p<0.01$, and a trend for a baseline*session interaction, $F(1,214) = 3.15$, $p=0.078$.

The significant baseline*condition interaction is illustrated in the linear regression plot (Figure 3.19) of baseline number of false alarms against post-intervention number of false alarms combined for test session one and two by condition. The plot suggests that the number of false alarms was lower in the breakfast condition relative to no breakfast, with the largest separation between conditions when the number of false alarms was higher at baseline. This indicates that the advantage of breakfast was more apparent for participants with poorer baseline performance (i.e. higher baseline values). Post-hoc comparisons indicated that the difference between conditions was not significant when adjusted for overall mean baseline, however the difference between test sessions was significant ($p<0.05$), such that the number of false alarms was significantly higher late-morning at test session two than mid-morning at test session one. This latter relationship is reflected in Figure 3.20.

Figure 3.19: Regression plot of baseline on post-intervention number of false alarms combined for test session one and two on the RVIP task by condition.

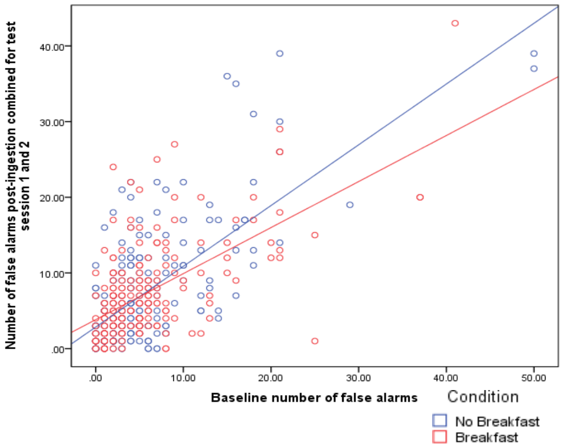
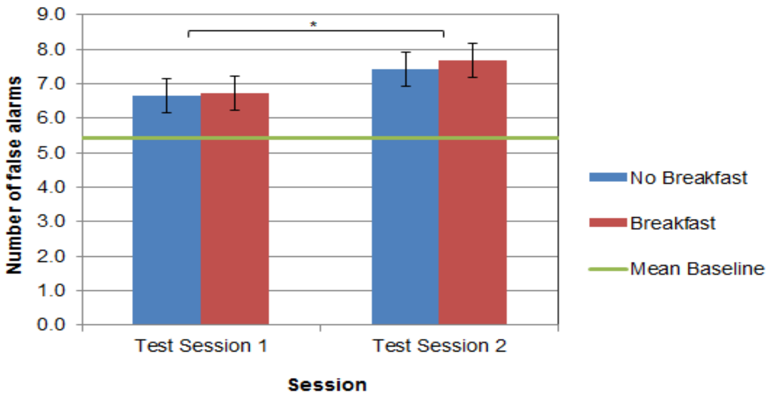


Figure 3.20: RVIP task mean number of false alarms ± SE. Plotted are LSMs.



3.5.4.3.2 Reaction time

The reaction time outcome variable for the RVIP task is defined as the mean response latency (ms) between stimulus presentations and when the participant responded during assessment blocks where the participant responded correctly. The reaction time data for the RVIP task displayed a positive skew and were normalised by the removal of 6 outliers showing extremely slow reaction times. The ANCOVA model revealed no significant main effect of condition, $F(1,216) = 0.01$, *ns*, or session, $F(1,216) = 2.84$, *ns*, and no significant condition*session interaction, $F(1,216) = 0.03$, *ns*. However, there was a trend for a baseline*session interaction $F(1,216) = 3.12$, $p=0.079$. This interaction is clear in the linear regression plot of baseline reaction time and post-intervention reaction time by session (Figure 3.21). The divergence of the regression lines indicates that when reaction time was slower at baseline, performance was better late-morning (test session two) compared with mid-morning (test session one) with the reverse pattern at faster baseline reaction times. The difference between the sessions was larger when baseline performance was lower, indicated by slower reaction times. However, there were no significant differences in reaction time between sessions or conditions when post-hoc comparisons were inspected adjusting for mean baseline. This suggests that reaction time on the RVIP task was not improved by the consumption of breakfast relative to no breakfast across both test sessions and did not change across the morning, reflected in Figure 3.22.

Figure 3.21: Regression plot of baseline on post-intervention reaction time combined for test session one and two on the RVIP task according to session.

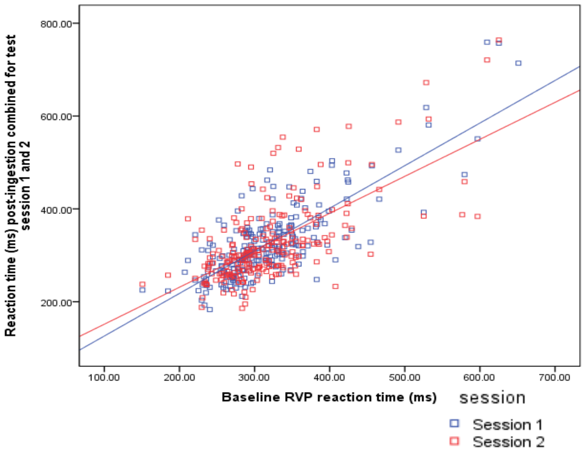
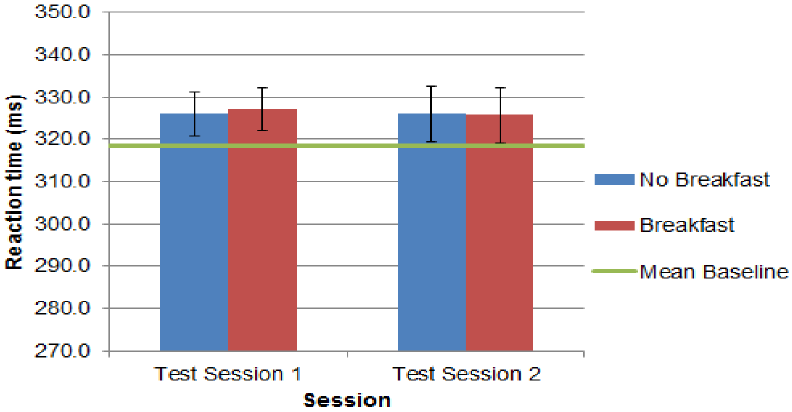


Figure 3.22: RVIP task mean reaction time (ms) ± SE. Plotted are LSMs.

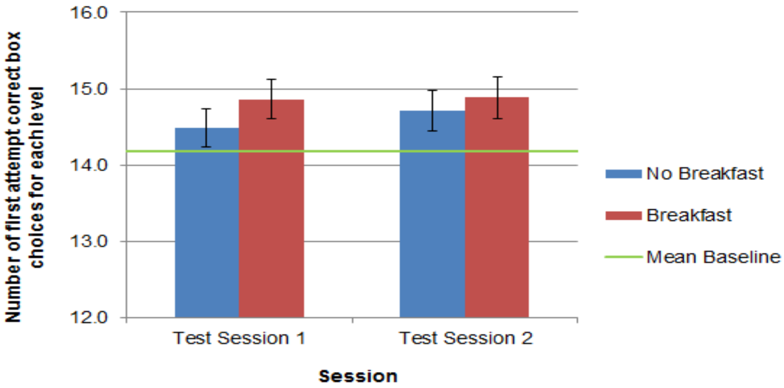


3.5.4.4 Paired Associates Learning task

3.5.4.4.1 First trial memory score

The first trial memory score refers to the number of correct pattern choices that were made on the first attempt at each difficulty level of the task, summed across levels. This measure indicates immediate ability to store visual-spatial information. Scores range from 0 to 19. The ANCOVA revealed no significant baseline*condition, $F(1,222) = 1.07$, *ns*, or baseline*session, $F(1,222) = 0.47$, *ns*, interaction and therefore the assumption of homogeneity of regression slopes was met. Figure 3.23 suggests that performance improved across the morning relative to baseline. Performance also appeared slightly superior following breakfast compared with no breakfast (Figure 3.23). However, the ANCOVA indicated no significant main effects of condition, $F(1,222)= 0.81$, *ns*, or session, $F(1,222) = 0.36$, *ns*, and no significant condition*session interaction, $F(1,222) = 0.23$, *ns*, for the first trial number correct pattern choices for each level. Therefore, there was no difference in the first trial memory score between conditions or sessions.

Figure 3.23: PAL task mean first trial number correct summed across each level ± SE. Plotted are LSMs.



3.5.4.4.2 Total number of trial attempts (adjusted)

A participant's ability to learn the correct locations of patterns can be interpreted from the number of trials undertaken during the test. A larger number of trials indicates slower learning since the participant has made more attempts to complete that level. Participants were permitted a maximum of 6 trials in which to complete each level. Possible scores, for attempts taken at each level, therefore range from 1-6. Across the four levels, therefore, there are a maximum of 24 trials and possible total scores range from 4-24 (with 4 being best performance). The total trials (adjusted) variable refers to the number of trials attempted throughout the entire task. Some participants did not reach level 4 (8 patterns) because they did not complete level 3 (6 patterns). Hence, the total trials score is adjusted for assessment problems that they did not reach (an estimate of the number of trials they would have made on any levels they did not reach). Figure 3.24 suggests that learning improved across the morning relative to baseline, indicated by a lower number of trials at test session one and two compared with baseline. Figure 3.24 also suggests that learning was slower following breakfast relative to no breakfast in the late-morning (test session two).

The data displayed a positive skew which were normalised by the removal of six outliers. The ANCOVA revealed a significant main effect of condition, $F(1,216) = 6.90$, $p<0.01$. There was no significant main effect of session, $F(1,216) = 2.53$, *ns*, or a significant condition*session interaction, $F(1,216) = 0.49$, *ns*. The main effect of condition was nullified by the presence of a significant baseline*condition interaction, $F(1,216) = 5.84$, $p<0.05$, indicating heterogeneity of regression slopes. The significant baseline*condition interaction is illustrated in the linear regression plot (Figure 3.25) of baseline total trials against post-intervention total trials combined for test sessions one and two according to condition. The plot suggests that more attempts were made (indicative of slower learning) in the no breakfast condition relative to breakfast, however this pattern of effects was only apparent when baseline performance was poorer (i.e. higher baseline values). The difference between conditions was greater when baseline performance was poorer (i.e. higher baseline values), indicated by the greater separation between regression lines. At lower baseline values (indicative of better learning) the reverse pattern of effects of condition was apparent, such that participants made more attempts post-intervention in the breakfast condition relative to no breakfast. This is depicted by the divergence of the regression lines at lower baseline values. This indicates that the advantage of breakfast is evident only for participants with poorer baseline performance (i.e. higher baseline values). However, the post-hoc comparison indicated that the difference between conditions was not significant when adjusted for overall mean baseline.

Figure 3.24: PAL task mean total number of trials adjusted for levels reached ± SE. Plotted are LSMs.

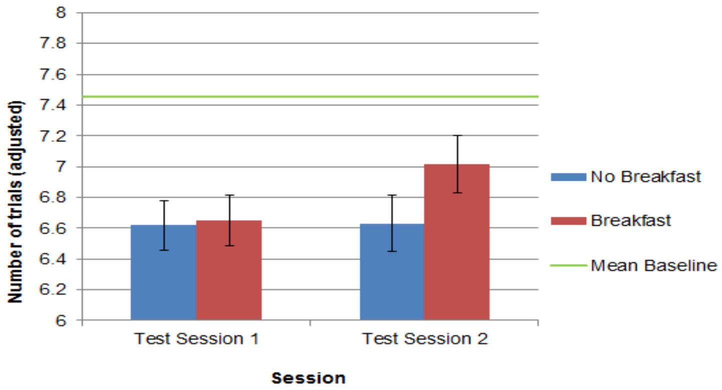
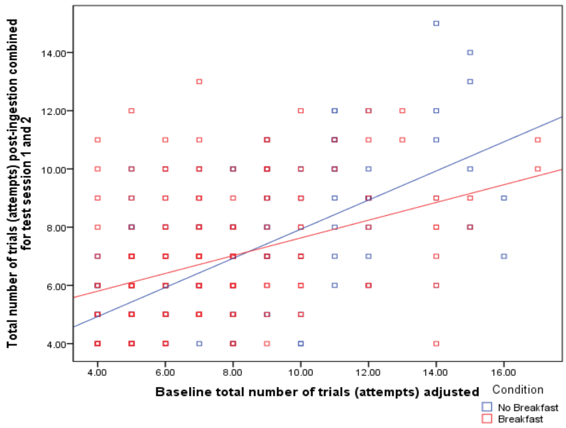


Figure 3.25: Regression plot of baseline on post-intervention total number of trials (adjusted) combined for test sessions one and two on the PAL task by condition.



3.5.4.4.3 Total number of errors (adjusted)

PAL task errors are the number of incorrect box choices made by a participant for a pattern at each level of the task. The total errors (adjusted) variable refers to the number of errors made throughout the entire task with an adjustment for any levels that were not reached, as per total trials adjusted variable (section 3.5.4.4.2). The data showed a positive skew and were normalised by the removal of four outliers. The ANCOVA revealed no main effect of condition, $F(1,218) = 2.34$, *ns*, or session, $F(1,218) = 0.83$, *ns*, and no significant condition*session interaction, $F(1,218) = 0.61$, *ns*. However, the analysis revealed a significant baseline*condition interaction, $F(1,218) = 6.00$, $p<0.05$, and a trend for a baseline*session interaction, $F(1,218) = 3.31$, $p=0.070$, indicating heterogeneity of regression slopes. The significant baseline*condition interaction is illustrated in Figure 3.26, suggesting that an advantage of breakfast relative to no breakfast is more evident for participants who performed worse at baseline (i.e. higher number of errors). However, the post-hoc comparisons at mean baseline showed no significant difference between conditions or sessions. This relationship can be observed in Figure 3.27.

Figure 3.26: Regression plot of baseline on post-intervention PAL task total number of errors (adjusted) combined for test sessions one and two by condition.

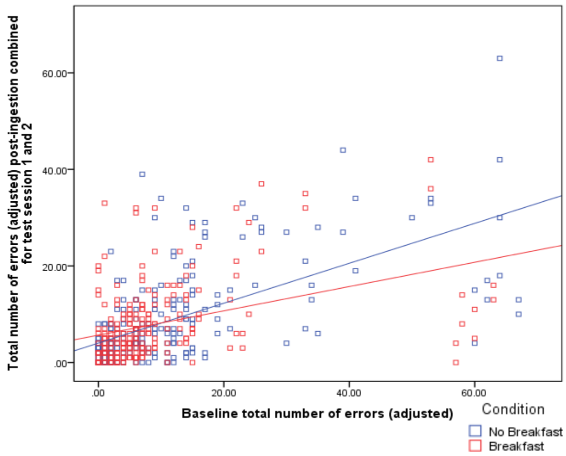
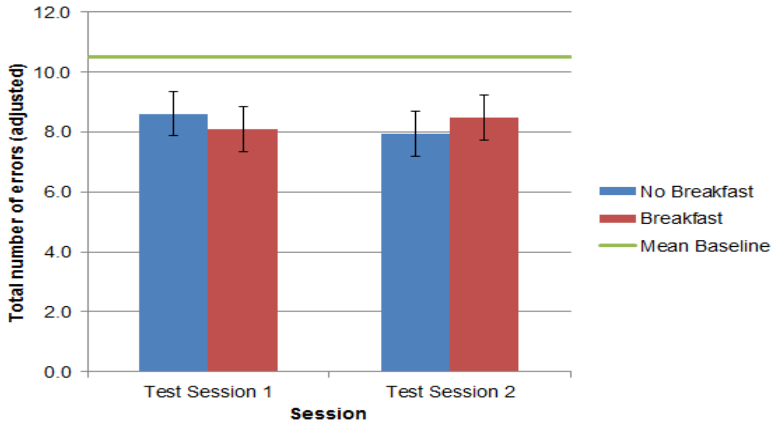


Figure 3.27: PAL task mean total number of errors adjusted for levels reached ± SE. Plotted are LSMs.



3.5.5 Subjective evaluation of appetite, mood, motivation, mental alertness and cognitive test performance

The results of the VAS measures are reported below. The ANCOVA model for each VAS outcome variable is shown in Appendices 9.33 and 9.34. For all VAS outcome variables, baseline ratings were a highly significant predictor (all $p<0.001$) of post-intervention ratings at all time-points across the morning (see Appendices 9.33 and 9.34). For brevity, where a baseline*condition, baseline*time or baseline*time*condition interaction was significant, the interactions were plotted using linear regression plots and are shown in Appendices 9.35-9.42. There were missing data for four participants for the VAS subjective state outcomes who were therefore excluded from the analyses of these outcomes. There missing data for three participants for the cognitive test evaluation VAS who were therefore excluded from the analyses of these outcomes.

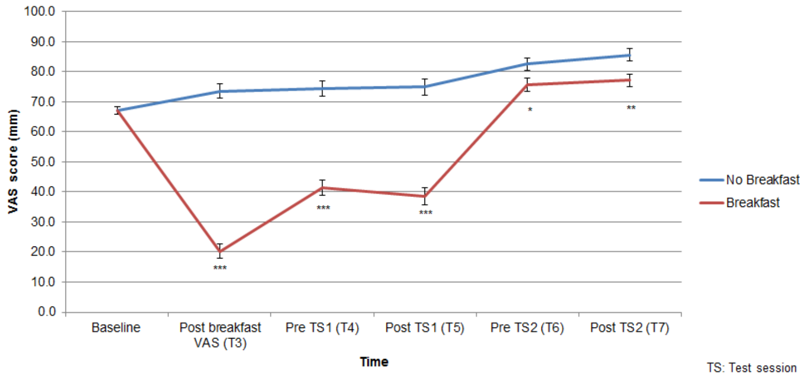
3.5.5.1 Subjective satiety

Figure 3.28 shows VAS ratings of hunger across the morning at baseline (T1) and T3-T7 (see Table 3.4; section 3.4.6.3), which illustrates enhanced satiety in the breakfast condition relative to no breakfast at all post-intervention time points. The difference between conditions was largest immediately following the intervention (T3) and at T4-T5 (Figure 3.28). Figure 3.28 also demonstrates that in both conditions, satiety decreased across the morning and was lowest immediately pre-lunch, as expected. Correspondingly, the ANCOVA model revealed a significant main effect of time, $F(3.22,702.88) = 30.37$, GG adjusted $p<0.001$, and condition, $F(1,218) = 18.92$, $p<0.001$, and a trend for a condition*time interaction, $F(3.22,702.88) = 2.32$, GG adjusted $p=0.069$. However, a significant baseline*time*condition interaction was present, $F(3.22,702.88) = 4.03$, GG adjusted $p<0.01$, suggesting that the model did not meet the assumption of homogeneity of regression slopes.

The significant 3-way baseline*time*condition interaction indicates that ratings of hunger at baseline influenced ratings at each time point in a different manner for breakfast and no breakfast conditions. Appendix 9.35 shows linear regression plots of hunger ratings at baseline against subsequent hunger ratings at T3-T7 (Figure 9.1a-e respectively) according to condition (represented by separate regression lines). At T3-T4 (Figure 9.1a, b) hunger ratings were much lower in the breakfast condition relative to no breakfast and there was greater separation in hunger ratings between conditions when ratings of hunger at baseline were higher. This suggests that for participants who were hungrier at baseline, breakfast enhanced subsequent satiety to a greater extent during the +15 to +70 minutes post-intervention period (T3-T4) relative to no breakfast, compared to participants who were less hungry at baseline. However, this relationship between baseline ratings and condition was different at T6 and T7, giving rise to the significant 3-way interaction with time (Figure 9.1d, e). At T6-T7 hunger ratings were again lower in the breakfast condition relative to no breakfast but the difference between conditions was more apparent when baseline ratings of hunger were lower. At T5, hunger ratings were again much lower in the breakfast condition relative to no breakfast, but this was consistent across baseline ratings of hunger (depicted by parallel regression lines; Figure 9.1). Hence, participants responded differently to the intervention at different time points depending on their level of hunger at baseline.

Post-hoc comparisons at mean baseline using the Bonferroni correction between conditions and time points were inspected. Hunger ratings were significantly higher in the no breakfast condition at T3, T4, T5, T6 and T7 (largest p=0.028). Therefore, the consumption of breakfast enhanced satiety relative to no breakfast immediately following the intervention and for the remainder of the morning including both test sessions. Taken together with the baseline*time*condition interaction, the results indicate that breakfast, relative to no breakfast, significantly enhanced subsequent satiety at T3-T4 to a greater extent in participants who were hungrier at baseline. However, at T6-T7, the significant difference in hunger ratings between conditions was more apparent in participants who were less hungry at baseline.

Figure 3.28: Mean VAS ratings of hunger ± SE. Plotted are LSMs.

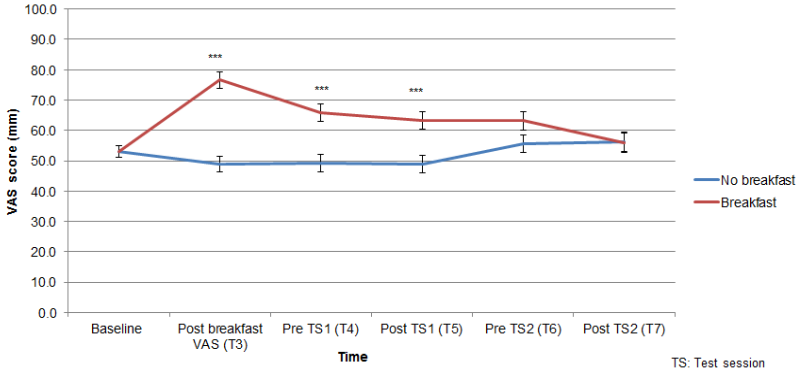


3.5.5.2 Subjective mood, alertness and motivation

3.5.5.2.1 Subjective cheerfulness

The ANCOVA revealed no significant baseline*condition, $F(1,218) = 0.01$, *ns*, or baseline*time, $F(3.56,777.92) = 0.87$, *ns*, interaction and therefore the assumption of homogeneity of regression slopes was met. Figure 3.29 suggests that participants in the breakfast condition were more cheerful immediately following breakfast and in the mid-morning relative to the no breakfast condition. Figure 3.29 also suggests that there was little difference in ratings of cheerfulness between conditions later in the morning and also suggests that in the no breakfast condition, cheerfulness tended to remain stable across the morning. This pattern of results was reflected in the ANCOVA model which revealed a significant main effect of condition, $F(1,218) = 4.59$, $p<0.05$, and a significant condition*time interaction, *F*(3.56,777.92) = 4.32, GG adjusted *p*<0.01. The main effect of time was not significant, *F*(3.56,777.92) = 0.59, *ns*. Post-hoc comparisons at mean baseline using the Bonferroni correction indicated that cheerfulness ratings were significantly higher in the breakfast condition at T3, T4, T5 (largest *p*<0.001) with a trend present at T6 (*p*=0.073). Therefore, breakfast enhanced mood immediately following breakfast until the start of test session two.

Figure 3.29: Mean VAS ratings of cheerfulness ± SE. Plotted LSMs.



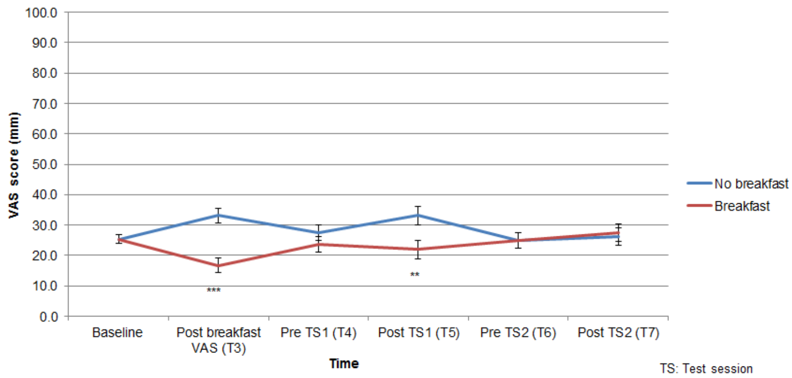
3.5.5.2.2 Subjective ratings of bad temper

Ratings of bad temperedness tended to be stable across the morning and there was little difference in ratings between conditions (Figure 3.30). Ratings of bad temperedness were low in both conditions, with ratings lowest in the breakfast condition at T3 and T5 (Figure 3.30). This is reflected in a non-significant main effect of time, *F*(4,872) = 1.03, *ns*, and condition, *F*(1,218) = 2.71, *ns*, and a non-significant condition*time interaction, *F*(4,872) = 1.12, *ns*, from the ANCOVA model. However, the baseline*time*condition interaction was significant, *F*(4,872 = 4.60, *p*<0.01. This suggests that participants responded differently to the intervention at different time points depending on their level of bad temperedness at baseline.

Appendix 9.36 shows linear regression plots of ratings of bad temperedness at baseline against subsequent bad temperedness ratings at T3-T7 (Figure 9.2a-e respectively). At T3-T5, breakfast functioned to decrease ratings of bad temperedness post-intervention relative to no breakfast (Figure 9.2a-c). However, the difference in ratings between conditions varied at T3-T5, contributing to the 3-way interaction with time. There was greatest separation in ratings of bad temperedness between conditions at T3 (immediately post breakfast) particularly when baseline ratings of bad temperedness were high. In contrast, the parallel regression lines at T4 and T5 indicate that the effect of condition on bad temperedness ratings was similar across different ratings of baseline bad temperedness. The effect of condition on bad temperedness ratings reversed at T6 and T7, such that breakfast functioned to increase ratings of bad temperedness post-intervention when baseline ratings of bad temperedness were high, contributing to the 3-way interaction with time (Figure 9.2d-e).

Post-hoc comparisons at mean baseline using the Bonferroni correction were inspected. Post-hoc analyses indicated that during the morning those who skipped breakfast felt significantly more bad tempered immediately post-breakfast (T3, $p<0.001$) and immediately following test session one (T5, $p<0.01$) than those who had eaten breakfast (Figure 3.30). Taken together with the significant baseline*time*condition interaction, this illustrates that at T3, the significant difference between conditions was largely driven by participants who had worse bad temperedness ratings at baseline.

Figure 3.30: Mean VAS ratings of bad temperedness ± SE. Plotted are LSMs.



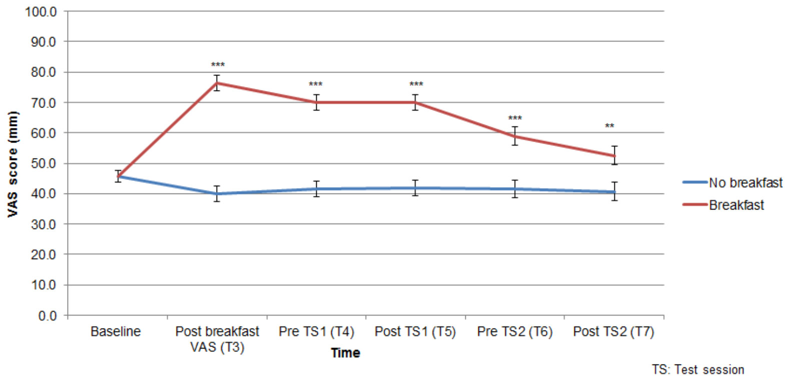
3.5.5.2.3 Subjective energy levels

Figure 3.31 indicates that in the breakfast condition, there was a steady decrease in ratings of subjective energy levels across time, but energy ratings remained higher at all post-intervention time points relative to no breakfast. The difference in energy ratings between conditions was largest immediately following breakfast (T3), due to a marked increase in the energy ratings of participants who had consumed breakfast. In the no breakfast condition, perceived energy levels were relatively low (below 50mm mid-point) and remained stable across the morning. This was reflected in the ANCOVA model, in which significant main effects of time, $F(3.14,685.01) = 3.76$, GG adjusted $p<0.01$, condition, $F(1,218) = 36.61$, $p<0.001$, and a significant condition*time interaction, $F(3.14,685.01) = 12.18$, GG adjusted $p<0.001$, were revealed. However, these significant effects were nullified by the presence of a significant baseline*time*condition interaction, $F(3.14,685.01) = 4.31$, GG adjusted $p<0.01$, and significant baseline*condition interaction, $F(1,218) = 4.44$, $p<0.05$, indicating heterogeneity of regression slopes.

The significant baseline*time*condition interaction is shown in Appendix 9.37, Figure 9.3a-e. Figure 9.3a-e suggest that ratings of energy at baseline influenced ratings of energy at each post-intervention time point in a different manner for breakfast and no breakfast conditions. At each time point, ratings of energy were higher in the breakfast condition relative to no breakfast, however the difference in ratings between conditions was largest at T3-T5 when baseline ratings of energy were low, shown by the greater separation of regression lines at lower baseline energy levels (Figure 9.3a-c). In contrast, later in the morning at T6 and T7 (Figure 9.3d-e), the difference in ratings of energy between conditions was smaller and constant across baseline energy levels.

Post-hoc comparisons at mean baseline using the Bonferroni correction indicated that energy ratings were significantly higher in the breakfast condition at T3, T4, T5, T6 and T7 (largest $p<0.01$). This suggests that participants in the breakfast condition felt significantly more energetic immediately following the intervention and for the remainder of the morning, across both test sessions. Further, taken together with the significant baseline*time*condition interaction, the results suggest that the significant effects of condition at T3-T5 are largely driven by participants who had lower perceived levels of energy at baseline. This pattern of results is illustrated in Figure 3.31 and Figure 9.3a-e in Appendix 9.37.

Figure 3.31: Mean VAS ratings of energy ± SE. Plotted are LSMs.

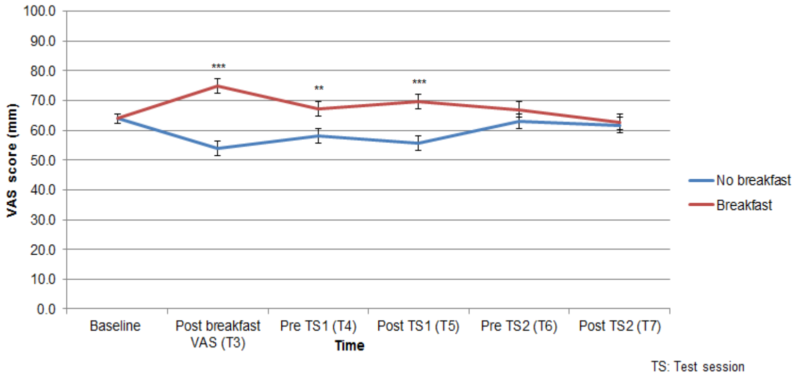


3.5.5.2.4 Keenness to try hard

For ratings of keenness to try hard, the ANCOVA model demonstrated a highly significant main effect of condition, $F(1,218) = 13.54$, $p<0.001$, and condition*time interaction, $F(3.28,715.34) = 5.17$, GG adjusted $p<0.001$. The main effect of time was non-significant, $F(3.28,715.34) = 0.60$, *ns*. However, the ANCOVA indicated a significant baseline*condition interaction, $F(1,218) = 6.36$, $p<0.05$, suggesting that the effects of condition on ratings of keenness to try hard differed according to baseline ratings (see Appendix 9.38; Figure 9.4). The linear regression plot (Figure 9.4) of baseline ratings against post-intervention ratings at T3-T7 combined in Appendix 9.38 illustrates this significant interaction. The plot suggests that breakfast functioned to increase ratings of keenness to try hard at T3-T7 relative to no breakfast to a greater extent in participants who had less motivation at baseline. This is depicted by the greater separation of regression lines at lower baseline ratings of ‘keen to try hard’.

Post-hoc comparisons at mean baseline using the Bonferroni correction indicated that ratings of keenness to try hard were significantly higher in the breakfast condition, relative to no breakfast, at T3, T4 and T5 (largest *p*<0.01). This suggests that breakfast increased motivation immediately following breakfast and during mid-morning, however it did not benefit motivation in the late-morning (reflected in Figure 3.32). Taken together with the significant baseline*condition interaction, the results suggest that the advantage of breakfast for motivation was largely driven by ratings of participants who had low motivation at baseline.

Figure 3.32: Mean VAS ratings of keenness to try hard ± SE. Plotted LSMs.

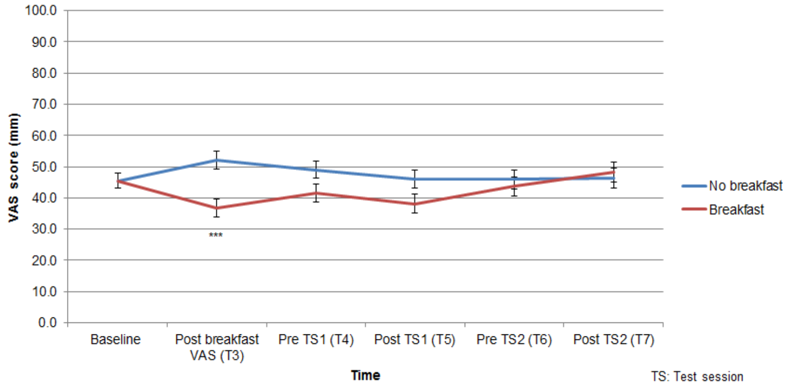


3.5.5.2.5 Subjective ease of distraction

For ratings of ease of distractibility, the ANCOVA revealed a non-significant main effect of time, $F(3.79,825.51) = 0.82$, *ns*, condition, $F(1,218) = 2.19$, *ns*, and non-significant condition*time interaction, $F(3.79,825.51) = 1.25$, *ns.* However, the ANCOVA showed a highly significant baseline*condition interaction, $F(1,218) = 9.32$, $p<0.001$, and significant baseline*time*condition interaction, $F(3.79,825.51) = 3.02$, GG adjusted $p<0.05$. This suggests that the relationship between baseline ratings of distractibility influenced ratings at each post-intervention time point in a different manner for breakfast and no breakfast conditions (see Appendix 9.39; Figure 9.5a-e). Where ratings of distractibility were high at baseline, the consumption of breakfast reduced the intensity of subsequent distractibility across the morning at T3-T6, relative to no breakfast (Figure 9.5a-d). However, at lower baseline levels, the reverse relationship was apparent, such that breakfast consumption increased subsequent distractibility at T3-T6 relative to no breakfast. This is portrayed by the divergence of the regression lines at lower ratings of ease of distractibility at T3-T6 (Figure 9.5a-d). At T3-T6, this relationship was similar. However, at T7, there was little difference in ratings of distractibility between conditions which was constant across baseline perceptions of distractibility, creating the 3-way interaction (Figure 9.5e).

Post-hoc comparisons at mean baseline using the Bonferroni correction indicated that in the breakfast condition, perceptions of ease of distraction were significantly lower immediately post breakfast (T3, $p<0.001$) relative to no breakfast. There were trends present for the same effect at the beginning of test session one (T4, $p=0.070$) and immediately following test session one (T5, $p=0.064$). Therefore, the participants in the breakfast condition felt they would be less easily distracted immediately following the intervention (Figure 3.33), an effect which was more demonstrable for participants who felt they would be more easily distracted at baseline (Figure 9.5a; Appendix 9.39).

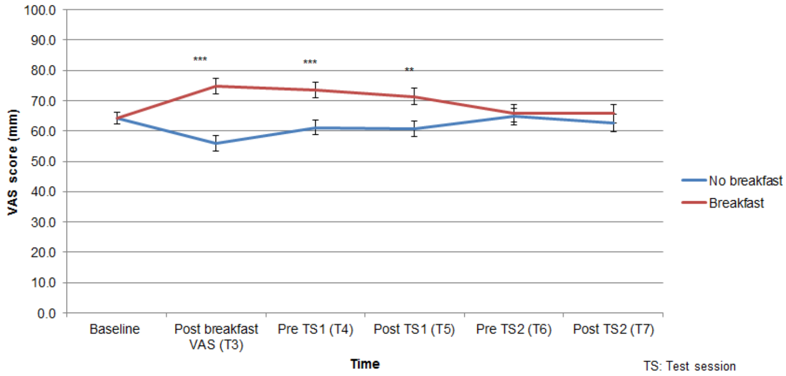
Figure 3.33: Mean VAS ratings of ease of distractibility ± SE. Plotted are LSMs.



3.5.5.2.6 Perceived ease of focussing

For ratings of perceived ease of focussing, the ANCOVA model demonstrated a highly significant main effect of condition, $F(1,218) = 15.65$, $p<0.001$, and significant condition*time interaction, $F(3.69,803.54) = 3.33$, GG adjusted $p<0.05$. The main effect of time was non-significant, $F(3.69,803.54) = 0.44$, *ns*. The significant main effect of condition and interaction with time were nullified by the presence of a significant baseline*condition interaction, $F(1,218) = 8.21$, $p<0.01$, suggesting that the effect of condition differed according to baseline perceptions of ease of focussing. This interaction is evident in the linear regression plot of baseline ratings against post-intervention ratings at T3-T7 combined (see Appendix 9.40; Figure 9.6). It is apparent that breakfast consumption functioned to increase ratings of ease of focussing across the morning, relative to no breakfast, to a greater extent in participants who were less able to focus at baseline. Post-hoc comparisons at mean baseline using the Bonferroni correction indicated that ratings of ease of focussing were significantly greater in the breakfast condition at T3, T4 and T5 (largest $p<0.01$). Taken together with the baseline*condition interaction, the results suggest that participants who consumed breakfast reported finding it easier to focus than those who skipped breakfast (reflected in Figure 3.34), an effect which was stronger for participants who reported finding it less easy to focus at baseline (reflected in Figure 9.6; Appendix 9.40).

Figure 3.34: Mean VAS ratings of ease of focussing ± SE. Plotted are LSMs.



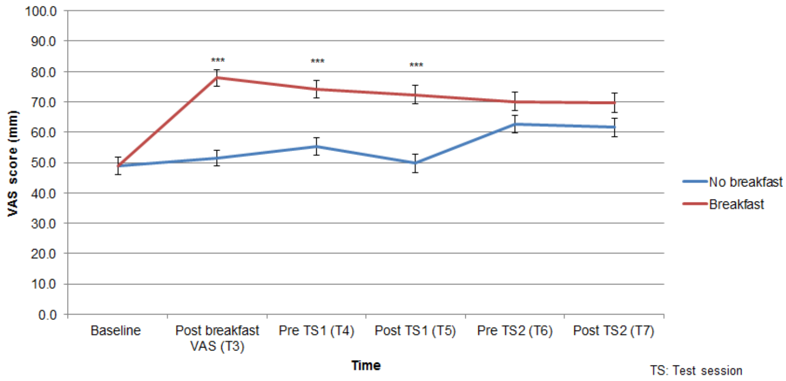
3.5.5.2.7 Feeling awake

Figure 3.35 suggests that ratings of feeling awake were higher in the breakfast condition, to a greater or lesser degree at each post-intervention time point, relative to no breakfast. This pattern of results was reflected in the ANCOVA model. The main effect of condition, $F(1,218) = 14.90$, $p<0.001$, and condition*time interaction, $F(3.49,760.12) = 8.36$, GG adjusted $p<0.001$, were highly significant. The main effect of time was non-significant, $F(3.49,760.12) = 1.11$, *ns*. The significant main effect of condition and interaction with time were nullified by the presence of a significant 3-way baseline*time*condition interaction, $F(3.49,760.12) = 2.70$, GG adjusted $p<0.05$. The significant baseline*time*condition interaction suggests that the effects of condition and time on ratings of feeling awake post-intervention differed depending on baseline ratings of feeling awake. Figure 9.7a-e in Appendix 9.41 illustrates this 3-way interaction. At all post-intervention time points, participants in the breakfast condition reported feeling more awake than participants in the no breakfast condition (see Appendix 9.41; Figure 9.7a-e). This relationship was consistent across different baseline ratings of feeling awake at T5-T7, depicted by the relatively parallel regression lines (Figure 9.7c-e). However, immediately following the intervention and at the beginning of test session one (T3-T4), there was greater separation in ratings of feeling awake between conditions when ratings of feeling awake were lower at baseline (Figure 9.7a-b). Therefore, breakfast functioned to increase subsequent ratings of feeling awake at T3 and T4, relative to no breakfast, to a greater extent in participants who reported feeling less awake at baseline.

Post-hoc analyses at mean baseline using the Bonferroni correction indicated that ratings of feeling awake were higher in the breakfast condition at T3,T4 and T5 (largest $p<0.001$) relative to no breakfast. There were trends for higher ratings of feeling awake in the breakfast condition compared with no breakfast at T6 and T7 ($p=0.077$, $p=0.073$ respectively). Therefore, participants reported feeling more awake in the breakfast condition compared with no breakfast immediately after breakfast up until late-morning

(Figure 3.35). This significant effect of condition at T3 and T4 was largely driven by participants who reported feeling less awake at baseline (Figure 9.7a-b; Appendix 9.41).

Figure 3.35: Mean VAS ratings of feeling awake ± SE. Plotted are LSMs.

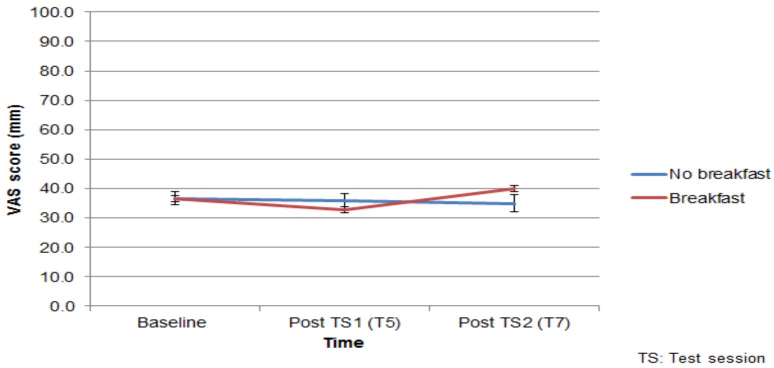


3.5.5.3 Cognitive test evaluation ratings

3.5.5.3.1 Perceived test battery difficulty

The assumption of homogeneity of regression slopes was satisfied, indicated by non-significant baseline*time, $F(1,219) = 0.40$, *ns*, and baseline*condition, $F(1,219) = 1.86$, *ns*, interactions. The ANCOVA showed no significant main effects of condition, $F(1,219) = 1.68$, *ns*, or time, $F(1,219) = 2.24$, *ns*, and no significant condition*time interaction, $F(1,219) = 0.37$, *ns*. Participants reported that they found the test battery equally difficult across the morning with little difference between the conditions (Figure 3.36).

Figure 3.36: Mean VAS ratings of test battery difficulty ± SE. Plotted are LSMs.

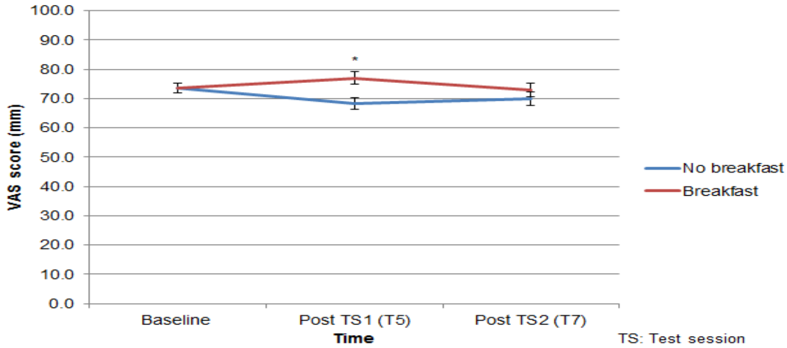


3.5.5.3.2 Perceived concentration during the test battery

For ratings of the degree of concentration during the test battery, the ANCOVA revealed a significant main effect of condition, $F(1,219) = 4.74$, $p<0.05$, and a trend for a condition*time interaction, $F(1,219) = 3.31$, $p=0.070$. There was no significant effect of time, $F(1,219) = 2.83$, *ns*. There was a significant baseline*time interaction $F(1,219) = 3.94$, $p<0.05$, indicating that ratings of concentration at each post-intervention time point differed according to ratings of concentration at baseline (see Appendix 9.42; Figure 9.8). Figure 9.8 suggests that participants reported that they concentrated more late-morning (post-test session two) relative to mid-morning (post-test session one) when perceived concentration ratings were low baseline (Appendix 9.42; Figure 9.8). This relationship was reversed when perceived concentration ratings were high at baseline, such that perceived concentration was lower later in the morning (post-test session two) relative to mid-morning (post-test session one).

Post-hoc comparisons at mean baseline using the Bonferroni correction indicated that there were no significant differences in ratings of the degree of concentration between sessions, but there was a significant difference in ratings between conditions at test session one ($p<0.05$). This effect of condition is observable in Figure 3.37. Figure 3.37 also shows that irrespective of condition, there was little difference in perceived concentration level between the sessions and, overall, participants reported that they had concentrated hard during the test batteries.

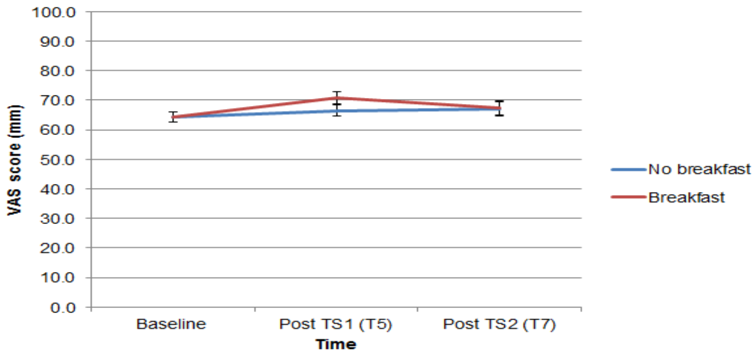
Figure 3.37: Mean VAS ratings of concentration level ± SE. Plotted are LSMs.



3.5.5.3.3 Perceived performance

For perceived performance on the cognitive test battery, the ANCOVA model revealed no significant baseline*condition, $F(1,219) = 0.01$, *ns*, or baseline*session, $F(1,219) = 2.52$, *ns*, interaction, indicating homogeneity of regression slopes. As shown in Figure 3.38, participants rated their performance on the cognitive test battery as fairly high and there was little difference in perceived levels of performance between test sessions or conditions. This was confirmed by the ANCOVA which revealed no significant main effect of time, $F(1,219) = 1.82$, *ns*, or condition, $F(1,219) = 0.88$, *ns*, and no significant condition*time interaction, $F(1,219) = 1.28$, *ns*.

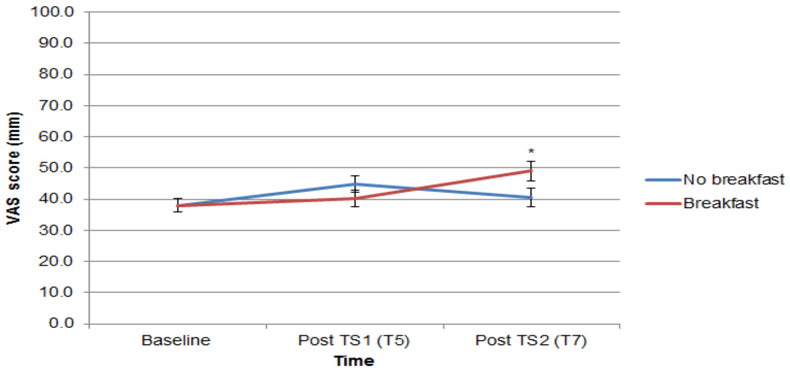
Figure 3.38: Mean VAS ratings of test battery performance ± SE. Plotted are LSMs.



3.5.5.3.4 Frustration

Figure 3.39 shows ratings of perceived frustration during the test battery, indicating that participants experienced some frustration during the test batteries. The ANCOVA model revealed no significant baseline*condition, $F(1,219) = 0.12$, *ns*, or baseline*session, $F(1,219) = 0.03$, *ns*, interaction, indicating homogeneity of regression slopes. The ANCOVA model demonstrated that the main effects of condition, $F(1,219) = 0.37$, *ns*, and time, $F(1,219) = 0.29$, *ns*, were not significant. However, the interaction between condition*time was significant, $F(1,219) = 8.99$, $p<0.01$. Post-hoc comparisons at mean baseline using the Bonferroni correction indicated that ratings of frustration were significantly higher later in the morning after test session two in the breakfast condition, relative to no breakfast ($p<0.05$; see Figure 3.39). There was no difference in ratings of frustration between conditions mid-morning after test session one (Figure 3.39).

Figure 3.39 Mean VAS ratings of frustration ± SE. Plotted are LSMs.



3.6 Interim summary of findings

Findings from this study are summarised as follows:

3.6.1 Effects of condition on cognitive performance

A summary of the effect of breakfast vs. no breakfast on all cognitive performance outcomes is shown in Table 3.10.

- The effects of breakfast were subtle and in most instances failed to reach statistical significance, despite the large sample size.
- Where significant positive effects of breakfast on cognitive performance occurred, 2/3 significant effects occurred later in the morning at test session two.
- Measures showed fractionation in the performance facilitation effects induced by the consumption of breakfast, such that facilitation from breakfast was specific to certain tasks and parameters within these tasks.
- For all cognitive outcome variables, baseline performance predicted post-intervention performance at test session one and two.

- There were several indications that the effects of breakfast condition and cognitive test timing differed according to cognitive performance at baseline. These interactions are summarised in Appendix 9.43; Table 9.7.

3.6.1.1 Reaction time (SRT and 5-CRT tasks)

- The most consistent support was for an advantage of breakfast relative to no breakfast, such that reaction time was faster following breakfast.
- There was fractionation of the enhancement effects of breakfast observed on the SRT and 5-CRT tasks. The significant differences between conditions were observed only for movement time, indicating that psychomotor speed was significantly faster following breakfast compared with no breakfast at mid-and late-morning.
- Advantages for breakfast relative to no breakfast were not consistent. Decision time later in the morning was significantly slower following breakfast than no breakfast on the 5-CRT task. However, the magnitude of this effect was greater for those who exhibited poorer performance at baseline.
- There was no significant effect of condition on task accuracy, reflected in the number of errors, on both the SRT and 5-CRT tasks.
- There was a general decline in performance on the reaction time tasks across the morning for most outcomes. Further, reaction time on the SRT task and accuracy on the 5-CRT was significantly worse late-morning than mid-morning, irrespective of breakfast consumption.

3.6.1.2 Visual sustained attention (RVIP task)

- There was no effect of condition on visual sustained attention. Measures of accuracy and reaction time on the RVIP task were not facilitated by breakfast consumption relative to breakfast omission.
- Visual sustained attention declined across the morning in both conditions, reflected by a decline in task accuracy. The difference between mid- and late-morning test sessions did not reach statistical significance for the number of correct targets and number of correct rejections. However, significantly more false alarms were made late-morning than mid-morning irrespective of breakfast consumption.

3.6.1.3 Immediate visual-spatial memory (PAL task)

- There was no effect of condition on any indices of immediate visual-spatial memory.
- Visual-spatial memory tended to improve across the morning. This may be indicative of practice effects on this task; however, differences between test sessions did not reach statistical significance.

Table 3.10: Summary of the effects of breakfast condition on cognitive performance according to task and time session

Outcome group	Variable	Effect of condition	
		Mid-morning	Late-morning
		TS1	TS2
Simple Reaction Time task			
Reaction time	Reaction time (ms)	O	O
Movement time	Movement time (ms)	O	+
Errors	Total number of errors	O	O
5-Choice Reaction Time task			
Reaction time	Reaction time (ms)	O	–[a]
Movement time	Movement time (ms)	+	+
Errors	Total number of errors	O	O
Rapid Visual Information Processing task			
Accuracy	Number correct block 1	O	O
	Number correct block 2	O	O
	Number correct block 3	O	O
	Number correct block 4	O	O
	Number correct block 5	O	O
	Number correct block 6	O	O
	Number correct all blocks	O	O
	Number of correct rejections	O	O
	Number of false alarms	O	O
Reaction time	Reaction time (ms)	O	O
Paired Associates Learning task			
Immediate recall	First trial memory score	O	O
Learning	Number of trial attempts	O	O
Errors	Number of errors	O	O

[a] Negative effect of breakfast greater for participants with poorer baseline performance
Key: + indicates significant positive effect of breakfast. – indicates significant negative effect of breakfast. O indicates no significant effect of breakfast.
Abbreviations: TS: test session

3.6.2 Effects of condition on subjective state

A summary of the effects of breakfast vs. no breakfast on all subjective state VAS measures is shown Table 3.11.

- The pattern of effects of condition on cognitive performance did not map onto the pattern of effects of condition on subjective feelings.
- The results indicate that there was an advantage of breakfast, relative to no breakfast, for each of the eight subjective states assessed.
- For all VAS outcome variables, baseline ratings predicted post-intervention ratings at all time-points across the morning.
- The effects of condition on subjective satiety, mood, motivation and mental alertness were all moderated by baseline satiety, mood, motivation and mental alertness. Only in one instance (cheerfulness) was the effect of condition consistent across baseline ratings.

- The significantly better perceived mood, motivation and mental alertness following breakfast consumption had typically dissipated by the start of test session two (see Table 3.11). However, adolescents who ate breakfast felt significantly less hungry and more energetic relative to those who fasted immediately after the intervention up until the start of the school's scheduled lunch period.

3.6.2.1 Satiety

- The consumption of RTEC and milk as breakfast (0905 hours) had a strong satiating capacity relative to fasting, which lasted until the school's lunch period (1310 hours).
- A complex relationship between baseline hunger levels, condition and time was present. Until 1015 hours, breakfast, relative to no breakfast, significantly enhanced satiety to a greater extent in adolescents who were hungrier at baseline. However, between 1240-1310 hours, breakfast, relative to no breakfast, significantly enhanced satiety to a greater extent in adolescents who were less hungry at baseline. At 1045, breakfast, relative to no breakfast, significantly enhanced satiety consistently across baseline hunger ratings.

3.6.2.2 Mood, alertness, motivation

- The consumption of breakfast relative to fasting significantly improved mood, reflected by increased cheerfulness, until the start of test session two (late-morning).
- Breakfast functioned to reduce ratings of bad temperedness immediately following the intervention and following test session one only. The significant differences between conditions immediately following the intervention were largely driven by adolescents who had worse bad temperedness ratings at baseline. Hence, breakfast functioned to reduce the intensity of feelings of bad temperedness to a greater extent in adolescents who reported worse bad temperedness ratings at baseline.
- The consumption of breakfast relative to fasting significantly improved motivation, reflected by an increase in ratings of keenness to try hard up until the start of test session two. However, the advantage of breakfast for motivation levels was largely driven by adolescents who reported low motivation at baseline.
- The consumption of breakfast relative to fasting significantly improved how energetic adolescents felt. This effect lasted up until the late-morning. However, the advantage of breakfast for energy levels was largely driven by adolescents who reported low levels of energy at baseline.
- The consumption of breakfast relative to fasting significantly improved perceived alertness, reflected by an increase in ease of focussing, feeling awake and a reduction in ease of distractibility. This effect lasted up until the late-morning for ease of focussing and feeling awake. However, the advantage of breakfast for perceived alertness was largely driven by adolescents who reported low alertness at baseline.

Table 3.11: Summary of the effects of breakfast condition on subjective state according to state and time of measurement

Outcome variable	Effect of condition				
	Post-intervention	Mid-morning		Late-morning	
	Post BF VAS	Pre TS1	Post TS1	Pre TS2	Post TS2
Subjective state VAS measures					
Hunger	+[a]	+[a]	+[a]	+[b]	+[b]
Cheerfulness	+	+	+	O	O
Bad temper	+[a]	O	+	O	O
Energy	+[b]	+[b]	+[b]	+	+
Keenness to try hard	+[b]	+[b]	+[b]	O	O
Distractibility	+[a]	O	O	O	O
Ease of focus	+[b]	+[b]	+[b]	O	O
Awake	+[b]	+[b]	+	O	O

a Positive effect of breakfast greater for participants with higher baseline VAS scores
b Positive effect of breakfast greater for participants with lower baseline VAS scores
Key: + indicates significant positive effect of breakfast. – indicates significant negative effect of breakfast. O indicates no significant effect of breakfast.
Abbreviations: BF: Breakfast; TS: test session

3.6.3 Cognitive test evaluation

A summary of the effects of breakfast vs. no breakfast on all cognitive test evaluation VAS measures is shown in Table 3.12

- The study condition had no effect on perceived test battery difficulty and perceived test battery performance.
- Adolescents who ate breakfast felt they concentrated more during the mid-morning test session compared to those who had fasted. However, this difference had dissipated by the late-morning test session.
- Unexpectedly, the consumption of breakfast significantly increased perceived frustration during the late-morning test battery relative to fasting. The same adverse effect of breakfast was not demonstrated during the mid-morning test battery.

Table 3.12: Summary of the effects of breakfast condition on cognitive test evaluations according to outcome and time of measurement

Outcome group	Variable	Effect of condition	
		Mid-morning	Late-morning
		Post TS1	Post TS2
Cognitive test evaluation VAS measures			
Difficulty	Test battery difficulty	O	O
Concentration	Level of concentration during test battery	+	O
Performance	Perceived test battery performance	O	O
Frustration	Perceived frustration during test battery	O	-

Key: + indicates significant positive effect of breakfast. – indicates significant negative effect of breakfast. O indicates no significant effect of breakfast.
Abbreviations: TS: test session

3.7 Discussion

The study in this chapter examined the hypothesis that the consumption of breakfast, relative to fasting, would have a positive acute effect on cognitive performance in 11-13 year olds. The study also examined the hypothesis that the consumption of breakfast, relative to fasting, would lead to greater perceived satiety, improved mood, motivation and mental alertness. Finally, the study examined the hypothesis that the degree of improvement in cognitive performance and subjective state would be more apparent late morning.

3.7.1 Temporal pattern of cognitive performance across the morning

The pattern of cognitive performance across the morning indicated that irrespective of condition, performance tended to be slightly poorer at test session two (late-morning) compared with test session one (mid-morning), with the best performance at baseline (early morning). This was indicated by several parameters (e.g. SRT reaction time and accuracy, 5-CRT accuracy and RVIP accuracy). This suggests that there was a general decline in cognitive performance across the school morning. Interestingly, this temporal pattern of performance (superior in the mid- compared with late-morning) was not echoed by concomitant VAS ratings of cognitive test battery performance. Ratings of test battery difficulty, performance, and concentration and frustration during the battery stayed relatively consistent across the morning.

There were some indications that the temporal pattern of cognitive performance across the morning was modified by baseline cognitive performance. Where significant baseline*session interactions occurred, performance was actually superior at the late-morning test session (test session two) relative to the mid-morning test session (test session one) but only for adolescents who exhibited poorer baseline performance. The reverse, and more typical, relationship was apparent when adolescents performed better at baseline, such that performance was better at the mid-morning test session (test session one) than at the late-morning test session (test session two). However, for the majority of outcomes, there were no significant baseline*session interactions.

In some of the previous studies examining acute effects of breakfast on cognitive performance, a steady decline in performance across the morning has been observed and breakfast consumption functioned to attenuate this decline (Ingwersen et al., 2007; Wesnes et al., 2003). Hence, performance at baseline was superior compared to post-intervention performance. Therefore, the consumption of breakfast may function to attenuate the magnitude of the decline in performance across the morning observed under fasting conditions, rather than enhancing performance to above baseline levels.

This performance deterioration may reflect cognitive fatigue due to repeated testing sessions alongside normal school lessons. Similarly, it is also possible that the decline in performance may be due to boredom effects, such that motivation for the tasks diminishes during the morning and is lowest at the final test session. In addition, test session two coincided with the period immediately prior to the school lunch period, when hunger levels were high. Increased hunger levels during test session two may have exacerbated the cognitive fatigue induced by repeated testing and may account for the superior performance in the mid-morning compared to late-morning by reducing the adolescents' ability to concentrate. This is supported by studies showing that school children and adults who attempt to restrict their dietary intake also tend to perform worse on cognitive tasks (Brunstrom, Davison, & Mitchell, 2005; Green & Rogers, 1998), although research on the effects of hunger on cognitive performance is lacking.

Whilst performance on the tests of reaction time (SRT, 5-CRT) and visual sustained attention (RVIP) typically declined across the morning, visual-spatial memory performance (PAL) tended to improve across the morning. This may be indicative of a practice effect on this task. However, the difference in PAL task performance between test sessions did not reach statistical significance. The use of parallel versions across test sessions, practice stages at the start of each task and pre-study training aimed to prevent practice effects by allowing time for participants to achieve a relatively stable level of performance (Wesnes & Pincock, 2002).

3.7.2 Effects of breakfast vs. no breakfast on cognitive performance

The present study found very modest support for an improvement in cognitive performance following breakfast consumption relative to fasting. The effects of breakfast on objective measures of cognitive function were subtle and, in most instances, failed to reach statistical significance. Therefore, the results did not fully support the hypothesis that breakfast consumption, relative to fasting, benefits cognitive performance in adolescents aged 11-13 years. Similarly, there were also limited effects of breakfast consumption on perceived test battery difficulty and subjective assessment of cognitive performance.

3.7.2.1 Reaction time performance

Where significant positive effects of breakfast consumption on cognitive performance occurred, facilitation was specific to certain cognitive tasks and parameters within these tasks. Positive effects of breakfast consumption relative to fasting occurred only on tests of reaction time. This suggests that reaction time, specifically, is favourably affected by the consumption of breakfast. However, there was also fractionation of the enhancement effect observed, such that only certain parameters of the reaction time tasks were found to be favourably affected by the consumption of breakfast. The significant positive effects were observed specifically for movement time, suggesting that the benefit of breakfast on reaction time is more apparent for the psychomotor component of reaction time rather than the decision component. Accuracy on the reaction time tasks also appeared not to benefit from the consumption of breakfast, suggesting that effects were specific to the psychomotor component of reaction time. Further, there was evidence of a speed-accuracy trade off. On the 5-CRT task, the number of errors committed was higher following breakfast, relative to no breakfast, but the difference between conditions did not reach significance.

The study's findings that suggest the benefit of breakfast on reaction time performance has not been widely replicated, but are supported by some previous research. There have been 6 published studies to date that have examined the acute effect of breakfast relative to fasting on reaction time, of which 3 studies included adolescents (see Chapter 2; section 2.3.4.1). Two studies have shown similar benefits to SRT and CRT following consumption of breakfast compared with fasting in adolescents (Cooper et al., 2011; Wesnes et al., 2003). However, Cooper et al. (2011) found benefits on task accuracy, rather than response time outcomes, contrary to the current study's findings.

3.7.2.1.1 Temporal pattern of effects of breakfast vs. no breakfast on reaction time performance

Within the small number of significant effects of condition on cognitive performance, 2/3 significant effects occurred in the late morning testing session. This suggests that the significant improvement in movement time following breakfast was more apparent in the late-morning. The decrement in cognitive performance observed in the late-morning may have provided the opportunity to detect significant positive effects of breakfast consumption. This may reflect the effect of a greater decline in performance in the no breakfast group due to the lengthier duration of food deprivation. At mid-morning, performance might be better protected, masking any effects of breakfast. Alternatively, the effects may be more demonstrable in the late morning when the metabolic challenge of eating breakfast has subsided. The results are largely consistent with some previous research which supports the notion that breakfast consumption is most beneficial for performance later in the morning at +180 minutes post breakfast (see Chapter 2; section 2.5.1.2). This suggests that the consumption of breakfast is associated with improved cognitive performance during times of cognitive fatigue. However, it should be noted that late-morning effects of condition were not pervasive across all tasks employed. Null effects of condition were found in the late-morning on the majority of outcomes. Hence, the evidence is not robust enough to fully support the hypothesis that the degree of improvement to cognitive performance is more demonstrable late-morning than mid-morning.

3.7.2.2 Visual-spatial memory performance

Excluding SRT and 5-CRT movement time, the study intervention failed to exert an advantageous effect on all other cognitive outcomes. There was no effect of breakfast consumption on any indices of immediate visual-spatial memory (PAL). The lack of observed effects on the PAL task suggests a lack of effect of breakfast consumption on the cognitive domain of visual-spatial memory. In contrast, the SRR in Chapter 2 indicated that measures of immediate visual-spatial memory were more frequently associated with positive effects of breakfast consumption relative to fasting compared to other cognitive domains. There have been 13 studies published to date that have examined the acute effects of breakfast relative to fasting on immediate visual-spatial memory of which 6 showed a significant facilitation by breakfast (Chapter 2; see section 2.3.2.2.1). However, only 2 of these studies showed a positive effect of breakfast consumption on immediate visual-spatial memory in adolescents. Moreover, null effects of breakfast consumption relative to fasting on visual-spatial memory have been replicated in 6 studies which parallel the results of the current study (Chapter 2; see section 2.3.2.2.1). Therefore, overall it remains unclear how breakfast, relative to fasting, may impact visual-spatial memory performance in adolescents.

3.7.2.3 Visual sustained attention

There was no evidence that breakfast consumption relative to fasting is beneficial for visual sustained attention (RVIP), suggesting that breakfast consumption does not benefit adolescents' attention at school. This finding is largely contrary to previous research. Previous findings, although quite mixed, generally show a positive transient effect of breakfast consumption on tasks assessing sustained attention, usually via continuous performance tasks. This evidence is reviewed in the SRR in Chapter 2, section 2.3.3.1. However, many of these previous studies were conducted in children. In adolescent samples specifically, similar null findings to that of the current study have recently been reported (Defeyter & Russo, 2013; Kral et al., 2012). Hence, it seems that effects on visual-sustained attention are more demonstrable in younger samples and this may explain the lack of observed effects in the current study.

3.7.2.4 Moderation of effects by baseline cognitive performance

There were several indications that the effects of breakfast on cognitive performance differed according to cognitive performance at baseline. Moderation of the effects of condition on cognitive performance by baseline performance was observed across all three cognitive tasks, suggesting that this finding is reliable. Overall, most interactions with baseline cognitive performance (5/7) indicated a greater advantage for breakfast when baseline performance was poorer (with the reverse relationship when baseline performance was better). For example, the advantage observed for movement time at test session one on the SRT task following breakfast was greater for participants who exhibited slower performance at baseline. In only 2/7 interactions, was there a greater advantage for breakfast where baseline performance was better. This suggests that the magnitude of the benefit of breakfast was greater for those who exhibited poorer performance at baseline. This is likely since those individuals who performed worse at baseline had more room to improve their performance on the task. In contrast, higher performing individuals may already be producing maximum or near maximum scores on the task. This represents a ceiling effect, where the opportunity for improvement from breakfast consumption is reduced.

3.7.3 Effects of breakfast vs. no breakfast on subjective state

Whilst the study manipulation failed to exert consistent effects on objective cognitive performance, significant effects on subjective satiety, mood, motivation and mental alertness were observed. These results indicate that there was an advantage for breakfast for each of the eight subjective states assessed. Furthermore, these effects were apparent immediately after consuming breakfast and continued until the mid- or late-morning. The better perceived mood, motivation and mental alertness following breakfast consumption had typically dissipated by the start of test session two in the late-morning (1240 hours; T6-7). However, perceived hunger was lower and energy levels were greater in adolescents who ate breakfast for the entire testing morning following the intervention. This provides strong evidence for subjective benefits of breakfast consumption relative to fasting and supports the hypothesis that the consumption of breakfast results in greater perceived satiety, mood, motivation and mental alertness, relative to breakfast omission. There was little evidence to suggest that the effect of breakfast on the subjective state outcomes differed before or after cognitive testing. For all subjective state outcomes excluding 'bad temperedness', effects were present before and after cognitive testing. Ratings of bad temperedness only showed a benefit of breakfast consumption following cognitive testing session one, not before (see Table 3.11). This effect was driven by an increase in bad temperedness in the no breakfast condition following cognitive testing session one. This suggests that breakfast consumption was able to prevent an increase in bad temperedness caused by a demanding cognitive testing situation. It is possible that this effect would not occur without a demanding testing situation. Breakfast consumption also prevented an increase in bad temperedness observed in the no breakfast condition immediately following the administration of the test meals. This increase in bad temperedness was probably due to the disappointment of not receiving breakfast. Furthermore, breakfast consumption reduced bad temperedness ratings immediately following the administration of breakfast relative to baseline, which may be related to the immediate alleviation of hunger.

These findings are in accordance with previous findings demonstrating advantageous effects on subjective feelings of mood, motivation and alertness following breakfast consumption relative to no breakfast in adolescents (Cooper et al., 2011; Defeyter & Russo, 2013; Widenhorn-Müller et al., 2008). However, comparisons between the current study and previous studies assessing subjective mood and alertness should be made cautiously. In previous studies, different descriptors are used and are not entirely comparable. Further, previous studies have used either VAS or Likert scale questionnaires, which although responses correlate strongly (van Laerhoven, van der Zaag-Loonen, & Derkx, 2004), have different measurement properties. Finally, most previous studies have used bipolar VAS, rather than unipolar VAS. Bipolar scales measure two opposing constructs (e.g., alert-drowsy, happy-sad) and are generally considered more difficult for participants to understand (Wewers & Lowe, 1990). In contrast, the unipolar scales used in the current study measure one construct. Such differences do not lend themselves to an easy comparison of these scales.

Interestingly, there was discordance between the subjective effects of breakfast consumption and the objective cognitive effects of breakfast consumption. Some previous research suggests that cognitive function and mood are correlated (Chapter 2; section 2.5.3.6). Thus, changes in subjective mood and alertness may give rise to changes to cognitive function. However, the breakfast-induced improvement in mood, motivation, alertness and greater satiety in the present study did not appear to enhance cognitive function. For many of the subjective ratings, differences between the conditions had dissipated by the late-morning (prior to test session two) yet this was when differences in objective cognitive performance between conditions were detected. For many of the subjective state VAS measures, the magnitude of the difference between conditions decreased across the morning. Hence, this does not support the hypothesis that subjective state effects of the manipulation might be stronger late-morning than mid-morning. The effects of breakfast on subjective state and cognitive function appear to be distinct. Positive effects on subjective state in the absence of concomitant effects on objective cognitive functions tasks have been reported elsewhere (Kral et al., 2012). From this study, it appears unlikely that benefits to cognitive function are mediated by benefits to mood, alertness, motivation and satiety in a temporally apparent manner. Alternatively, subjective and objective cognitive function effects may be related, but not concomitantly.

3.7.3.1 Moderation of effects by baseline subjective state

Subjective state outcomes showed increased sensitivity to the breakfast intervention in some participants, but not in others. The effects of condition on subjective satiety, mood, motivation and mental alertness were all moderated by baseline satiety, mood, motivation and mental alertness. Only in one instance (cheerfulness) was the effect of condition consistent across baseline ratings. The significant interactions of condition with baseline subjective state tended to demonstrate that in participants experiencing more intense negative levels of these subjective states, the consumption of breakfast attenuated the intensity of these subjective states across the morning to a greater extent than adolescents who reported lower ratings of these subjective states. Where satiety, mood, motivation and mental alertness were high at baseline, the same positive effect of breakfast was not always apparent. This suggests that breakfast was not capable of increasing ratings (or feelings) beyond the almost ceiling level of reporting.

3.8 Conclusion

The results of the present study provide clear evidence that the consumption of breakfast at school is beneficial for subjective state across the morning. However, there was limited evidence to suggest that breakfast consumption benefited objectively measured cognitive task performance. One hour post breakfast consumption appeared to correspond to the peak response of breakfast-induced subjective mood, alertness, satiety and motivation changes, however, cognitive performance did not follow the same time course. Hence, it appears that subjective state effects are temporally distinct from objective cognitive performance effects. There was some evidence that breakfast consumption facilitated faster reaction time (movement time), but most other cognitive parameters showed no effects of breakfast condition. Overall, the results provide limited support that breakfast has a positive acute effect on cognitive performance relative to when breakfast is omitted in 11-13 year olds.

4 A SYSTEMATIC RESEARCH REVIEW OF THE EFFECT OF BREAKFAST ON ACADEMIC PERFORMANCE IN CHILDREN AND ADOLESCENTS

Statement of Contribution

The candidate confirms that she was solely responsible for developing and performing the literature searches and the synthesis of the evidence contained in this chapter. The candidate was solely responsible for writing the chapter and the production of all data extraction tables. Supervisors provided editing and proof-reading assistance with the chapter.

4.1 Introduction

There has been widespread research interest in the possibility that breakfast can influence learning in children and adolescents. A good deal of research has considered the short-term effects of breakfast on cognitive performance outcomes in controlled laboratory-based environments. In Chapter 2, studies examining the effects of breakfast on children's and adolescents' cognitive performance were reviewed. Although this evidence is somewhat mixed, support for an advantageous acute effect of breakfast, relative to breakfast omission, on cognitive performance was demonstrated in several studies. Study 1 (Chapter 3) investigated the acute effect of breakfast vs. no breakfast on cognitive performance in 11-13 year olds. The results did not show clear breakfast-induced benefits for cognitive performance. This may be because the cognitive tests employed lack ecological validity and are designed to reflect "best performance" on a particular testing occasion. Therefore, it could have been easier for participants to exert compensatory effort to maintain a good level of performance under fasting conditions than during usual classroom tasks or examinations. During the school day, school children very rarely complete single computer-based tasks which require discrete cognitive domains (e.g. reaction time) in such a controlled environment with examiner prompts. Hence, it might be more informative to investigate the effect of breakfast on more ecologically valid academic performance outcomes.

Much of the interest in the possible beneficial effects of breakfast stems from the potential for breakfast consumption to improve school children's concentration at school which could benefit learning and academic performance (Bellisle, 2004). Thus the positive short-term effects of breakfast on cognitive performance (SRR, Chapter 2 and Study 1, Chapter 3) might be mirrored by short term effects on academic performance. For example, where breakfast is consumed on one particular morning, a transient improvement in performance on school examinations taken on that morning might be discernible. Objective cognitive tests however, may not be relevant to a "real world" classroom situation since these tests are different from ecologically valid measures of academic performance. Furthermore, since measures of academic performance usually assess content that is taught in schools over time rather than specific cognitive functions, short term effects are unlikely as academic outcomes will be highly dependent on prior learning.

The previously published reviews of the effect of breakfast on school children's learning have not specifically considered measures of academic performance (Hoyland et al., 2009; Pollitt & Mathews, 1998). Both Hoyland et al. (2009) and Pollitt and Mathews (1998) were primarily concerned with the effects of breakfast on cognition measured by cognitive tasks. Similarly, two SRRs commissioned by The Food Standards Agency on school food and attainment also concentrated on breakfast provision and cognitive performance (Ells, Hillier, & Summerbell, 2006; Levy, 2013). Hence, in order to evaluate the effects of breakfast consumption on academic performance in children and adolescents, this chapter and published article (Adolphus et al., 2013) aimed to systematically review the available literature within this field.

4.2 SRR aims

The aim of the SRR reported in this chapter was to systematically evaluate the literature specifically relating to the effects of breakfast on academic performance in children and adolescents. The SRR also aimed to consider the methodological challenges inherent in isolating any independent effects of breakfast. The effects of chronic breakfast interventions (SBPs) are considered along with naturalistic observations of the association between habitual breakfast consumption and academic performance.

4.3 Search strategy and search terms

Databases searched were: Ovid MEDLINE, Pubmed, Web of Science, the Cochrane Library, EMBASE and PsychINFO. The following search terms were used:
('breakfast' OR 'breakfast program*') AND ('school performance' OR 'academic performance' OR 'scholastic performance' OR 'academic achievement' OR 'school achievement' OR 'scholastic achievement' OR 'education* achievement' OR 'education*

performance' OR 'school grades' OR 'test scores' OR 'achievement test') AND (child* OR adolescent*). The reference lists of existing reviews and identified articles were examined individually to supplement the electronic search. Additionally, an inventory of existing references obtained from on-going citation alerts was examined. Appendix 9.44 provides a detailed description of the searches and selection process. Studies are limited to academic outcomes in children and adolescents aged 18 years or less and to articles published in English in peer-reviewed journals.

4.4 Results

The literature search identified 25 articles (pooled sample size: n=112,262). Tabulated results are shown in separate tables according to the outcome measures. Studies assessed academic performance by either school grades (Table 4.1) or achievement tests (Table 4.2). Studies were conducted in various developed and developing countries including Norway (2 studies), Korea (2 studies), India (1 study), Iran (1 study), Spain (3 studies), the Netherlands (1 study), Nigeria (1 study), Uganda (1 study), Peru (2 studies), Jamaica (2 studies), New Zealand (1 study), and Australia (1 study). Studies were most frequently conducted in the USA (7/25 studies).

Fifteen studies employed cross-sectional designs to examine the association between habitual breakfast consumption and academic outcomes. Ten studies examined the impact of chronic interventions (SBPs) on academic outcomes. Generally, SBP studies were evaluations of government funded school breakfast provision. Of the studies that were SBP evaluations, 4/10 used randomised controlled designs, 3/10 compared school children who regularly participated vs. non-participants and 3/10 studies used matched schools or classes as controls. Four SBP studies were conducted in inner city locations in the USA and 5 were conducted in developing countries including Jamaica, Peru and Iran. These studies tended to include samples of younger school children who were of low SES and/or undernourished (e.g. defined as <-1-2 SD normal height or weight for age using the US NCHS reference) or nutritionally at-risk (e.g. intake of energy and/or >2 nutrients <50% of the recommended daily allowance [RDA]).

In the included studies, comparisons were made between SBP and no SBP and differing habitual breakfast consumption frequency and composition. Of the 15 cross-sectional studies that compared differing habitual breakfast consumption, 10/15 defined consumption on a frequency basis during a specified time period (e.g. one week) which was assessed via a questionnaire with one-item pertaining to breakfast consumption in 9/10 studies (e.g. how many days do you normally eat breakfast?). One study relied on parental reports of breakfast consumption. A variety of definitions of 'habitual breakfast consumer' were used in the analyses including 7 days/week (2 studies), 7 days/week of family breakfasts (1 study), 6 days/week (1 study), 5 days/week (2 studies), 5 school days/week (1 study), and 4 days/week (1 study). Two studies did not indicate the frequency of breakfast intake per week used to defined habitual breakfast consumption. Five studies dichotomised habitual breakfast consumption, 3 studies used a 3-group classification, 1 study used a 5-group classification system and 2 studies used a 7-group classification system. Four of the 15 cross-sectional studies that compared differing habitual breakfast consumption defined habitual breakfast consumption by the composition of breakfast. Composition was assessed via food diary (2 studies), 24-hour recall (1 study), and questionnaire with a dietary interview (1 study). Habitual breakfast composition was defined by either the energy provided (1 study), the food groups consumed (2 studies) and both the energy and food groups consumed (1 study). One study did not report how a habitual breakfast consumer was defined. Of the 10 studies that evaluated the impact of SBPs, all were SBP vs. no SBP comparisons; no SBP study compared school breakfast meals that differed in composition.

4.4.1 School grades: Overview

Thirteen studies examined the effects of breakfast on school grades (see Table 4.1). The majority (7/13) produced a composite score from school reported grades across a range of subjects, usually considered “core” subjects (e.g. Mathematics, English, Science). Four studies relied on self-reported school grades (Lien, 2007; Stroebele, McNally, Plog, Siegfried, & Hill, 2013) or self-reported subjective ratings of academic performance (e.g. high/low; Øverby, Lüdemann, & Høigaard, 2013; So, 2013). Studies were conducted in school children aged between 7-18 years. Seven studies were carried out in adolescents (≥11 years) and one study was carried out in children (<11 years). Four studies included both children and adolescents. One study included children of low SES (Murphy et al., 1998) and two studies included undernourished children (Gajre et al., 2008; Kleinman et al., 2002). One study did not report any socio-demographic information for the sample (Majekodunmi & Wale, 2013). All thirteen studies identified demonstrated that habitual breakfast consumption (frequency and quality) and SBPs have a positive effect on children’s and adolescents’ academic performance, with four studies observing clearest effects on mathematics grades (Kleinman et al., 2002; Morales, Vilas, Vega, & Para, 2008; Murphy et al., 1998; Øverby et al., 2013).

4.4.1.1 Chronic intervention studies: The effects of SBPs on school grades

Three intervention studies demonstrated positive effects of SBPs on school grades, particularly mathematics grades in well-nourished, undernourished and low SES school children aged 7-12 years. Effects were demonstrable after an intervention period of 3-6 months. In a RCT, a significant increase in school grades was apparent following an intervention providing 250ml 2.5% fat milk at breakfast, which was apparent in girls only

(Rahmani et al., 2011). Although it was not clear if the sample included undernourished children, the effect coincided with a significant increase in weight of the girls following the intervention. In matched control schools, there were no significant changes in school grades. Two US studies that compared school children based on their participation rate in a free SBP demonstrated similar positive effects. Kleinman et al. (2002) found that following a six month SBP, school children who regularly participated in the SBP improved their nutritional status from at risk (energy and/or >2 nutrients <50% RDA) to adequate compared to those who did not participate, and the improvements in nutritional status were associated with a concomitant significant increase in mathematics grades. However, the authors did not directly analyse the effects of SBP participation on school grades. Murphy et al. (1998) reported that following a four month SBP, school children who increased participation were significantly more likely to increase their mathematics grades compared to those who decreased or maintained participation.

4.4.1.2 Cross-sectional studies

Ten cross-sectional studies demonstrated a positive association between habitual breakfast consumption and school grades in adolescents. One study did not report how breakfast was classified in the analysis (Majekodunmi & Wale, 2013). However, a strong positive correlation between breakfast consumption and academic performance was reported.

4.4.1.2.1 Habitual breakfast consumption: Frequency

Frequency of breakfast consumption was associated with academic performance in seven studies. Breakfast skipping (eating breakfast <5 days/week) was associated with lower average annual school grades in a sample of 605 Dutch adolescents aged 11-18 years who were in higher educational streams (Boschloo et al., 2012). This association was evident in both sexes and independent of age. A larger cohort of nearly 6500 Korean school children of similar age range (10-17 years) demonstrated a similar association across all ages. However, the association was stronger in younger school children (10-11 and 13-14 years) than older school children (16-17 years; Kim et al., 2003). Effects were seen in both genders, except for in 10-11 year olds, where the significant association between regular breakfast intake and academic performance was only apparent in boys.

This association is also evident in undernourished adolescents (Gajre et al., 2008). Gajre et al. (2008) demonstrated that eating breakfast >4 days/week significantly predicted total average grades in a sample of adolescents aged 11-13 years, a third of whom were undernourished. Analysis of individual subject domains indicated that regular breakfast eaters had significantly higher grades for science and English, but not mathematics compared to adolescents who never ate breakfast (Gajre et al., 2008).

Lien (2007) demonstrated, in a large sample of Norwegian adolescents aged 15-16 years, that those who never ate breakfast were twice as likely to have lower self-reported school grades compared with those who consumed breakfast every day (7 days/week). Moreover, the odds of having lower self-reported school grades decreased with successive quintiles of breakfast eating frequency suggestive of a dose-response relationship. This finding was consistent in boys and girls but the association differed according to ethnicity with a significant association apparent only in native Norwegians compared with immigrant groups (Lien, 2007). More recent evidence in Norwegian adolescents of a comparable age range (14-16 years) demonstrated a similar relationship between habitual breakfast consumption and self-rated academic performance (Øverby et al., 2013). Regular breakfast consumption was significantly associated with lower odds of self-reported difficulties in writing/reading and mathematics, but the association was stronger for mathematics. However, in both these Norwegian studies, SES was not controlled for in the analysis. A recent internet based study demonstrated a similar relationship between habitual breakfast consumption and self-rated academic performance in over 75,500 adolescents aged 12–18 years (So, 2013). Regular breakfast eaters (7 days/week) were more likely to rate their academic performance as high compared with breakfast skippers (0 day/week). Consistent with this, a US study by Stroebele et al. (2013) also reported that regular breakfast eating was associated with higher self-reported school grades in 10-11 year olds.

4.4.1.2.2 Habitual breakfast consumption: Composition

Two studies demonstrated a consistent association between breakfast composition derived from energy and food groups provided and school grades in adolescents aged 12-17 years. Morales et al. (2008) found that adolescents who habitually ate breakfast that provided >25% of total estimated energy needs and included ≥4 food groups (dairy, cereals, fruit, fat) were more likely to achieve higher grades than those consuming no breakfast or breakfast lacking the specified food groups. Analysis of individual subject domains indicated that mathematics, chemistry and social science grades were highest in full (>25% of total energy needs and ≥4 food groups) and good (<25% energy and 3 food groups) quality breakfast groups compared with no breakfast. Physical education, biology and languages grades were highest in the no breakfast group compared with full and good quality breakfast groups. Supportive findings from Herrero-Lozano and Fillat-Ballesteros (2006) indicated that higher average grades were obtained in adolescents who habitually consumed a breakfast containing three food groups (dairy, cereals, fruit) compared with those consuming no breakfast or breakfast providing one of the specified food groups. The contribution of a mid-morning snack to breakfast quality was also considered in the analysis which indicated a positive association between a mid-morning snack and school grades specific to adolescents who had consumed no breakfast. This suggests a mid-morning snack is only beneficial for adolescents who have skipped or eaten very little for breakfast since this would correct the resulting energy deficiency.

Table 4.1: Tabulation of studies investigating the effect of breakfast on school grades in children and adolescents

Authors, year	Design	Sample	BF intervention/ assessment of BF	Assessment of academic performance	Reported results
Boschloo et al. (2012)	Cross-sectional survey study.	n=605 mean age ± SD: 14.8 ± 1.6 years (range:11-18) Male: 44% Female: 56%. Advanced educational tracks. Well-nourished. Netherlands.	Questionnaire, 1-item to assess BF frequency on school days. BF classified as: 1. BF eaters: 5 days/week 2. BF skippers: <5 days/week	Average end of year school grades for: 1. Dutch 2. Mathematics 3. English (as a foreign language) Grade range: 1(very bad) to 10 (outstanding) Total average grade used in analysis. Attention problems: Attention problems scale from the Dutch Youth Self Report.	BF skipping significantly associated with lower total average grades and more self-reported attention problems. Attention problems partially mediated the relationship between BF skipping and school performance. Adjusted for: age, sex, educational track, parental education.
Gajre et al. (2008)	Cross-sectional survey study.	n=379 aged 11-13 years. Male: ≈55% Female: ≈45% Underweight: 20.8% Stunted: 38.5% NCHS reference. India.	Questionnaire to assess BF eating frequency and type. BF defined as first eating occasion of the morning before school. BF intake classified as: 1. Regular: >4 days/week 2. Irregular: 2-3 days/ week 3. Never BF composition not reported.	End of year grades for: 1. Mathematics 2. Sciences 3. English Total average grade and subject grades used in analysis.	ANOVA indicated that regular BF group had significantly higher science, English and total average grades compared to no BF group. Regression analysis indicated that regular BF significantly predicted total average grades, English grades and science grades. No association between BF and mathematics grades. Lack of adjustment for confounders: Stepwise regression technique used.
Herrero Lozano and Fillat Ballesteros (2006)	Cross-sectional survey study.	n=141 aged 12-13 years. Male: 49.6% Female: 50.4% Well-nourished. Spain.	24 hr recall for BF only. BF intake classified as: 1. Good quality: 3 food groups of dairy, cereals and fruit 2. Improvable quality: Missing one food group 3. Insufficient quality: Missing two food groups 4. Poor quality: No BF Mid-morning snack x BF interaction considered.	Average end of year grade.	Significantly higher average grades obtained in good quality BF groups compared with poor quality. Average grade increased when good quality snack was eaten in poor and insufficient BF quality groups.

Table 4.1: Continued

Authors, year	Design	Sample	BF intervention/ assessment of BF	Assessment of academic performance	Reported results
Kim et al. (2003)	Cross-sectional survey study.	n=6463 aged 10-17 years. Stratified by age: 10-11: n=1935 13-14: n=2194 16-17: n=2334 Male: 53% Female: 47% Well-nourished. Korea.	FFQ and dietary behaviour questionnaire. BF intake classified as: 1. Regular BF 2. No regular BF	Grade from last school semester from school records for: 1. Korean 2. Mathematics 3. Social Studies 4. Science 5. Physical education 6. Music 7. Art 8. Practical course 9. Ethics 10. English (grade 8 & 11)	Regular BF associated with higher average grade in 10-11 year old boys, higher average grade in 13-14 year old boys and girls and higher average grade 16-17 year old boys and girls. Adjusted for: parental education, physical fitness, physical status.
Kleinman et al. (2002)	SBP evaluation. Independent groups design. Compared participants vs. non participants. 6 month intervention.	3 primary schools. n=97 aged 9-12 years. Stratified by nutrition status measured by 24-hr recall. Nutritionally at-risk (energy and/or >2 nutrients <50% RDA): n=29 Adequate: n=68. USA.	Free SBP. Stratified by SBP participation: 1. Often: ≥80% attendance 2. Sometimes: 20-79% attendance 3. Rarely: <20% attendance BF participation recorded for 1 week at beginning and end of intervention	APM: baseline, +6 month follow up. School grades obtained from school records for n=79 participants for: 1. Mathematics 2. Reading 3. Science 4. Social Studies Grade converted into numeric value: A=4, B=3, C=2, D=1, F=0	School children whose nutritional status improved showed significantly larger increases in SBP participation than school children whose nutritional status stayed the same or worsened. Significant increase in mathematics grades in school children who improved nutritional status from at-risk to adequate post intervention. Did not directly analyse the effect of SBP participation on school grades.
Lien (2007)	Cross-sectional survey study.	n=7305 aged 15-16 years. Male: 49.4% Female:50.6% Well-nourished. Norway.	Questionnaire, 1-item to assess BF frequency. BF intake classified as: 1. Seldom/never 2. 1-2 days/week 3. 3-4 days/week 4. 5-6 days/week 5. Everyday	Self-reported most recent grade for: 1. Mathematics 2. Norwegian 3. English 4. Social Science Grade scale: 1 (lowest) to 6 (highest). Total average grade calculated & dichotomised as: 1. ≤3: Low 2. >3: High	Increased odds of having low school grades (≤3) in adolescents who seldom/never ate BF compared with everyday consumption in boys and girls. Increased odds of having low school grades (≤3) in adolescents who seldom/never ate BF compared with everyday consumption in native Norwegians only. No association in immigrants. Adjusted for: parental education, family structure, immigrant status, smoking, dieting, soft drink intake.

Table 4.1: Continued

Authors, year	Design	Sample	BF intervention/ assessment of BF	Assessment of academic performance	Reported results
Majeko-dunmi and Wale (2013)	Cross-sectional survey study.	n=800. 20 secondary schools. No demographic information reported. Nigeria.	BF assessment scale measuring quality and quantity of BF. No other information reported.	Performance on last class test for: 1. English language	Strong positive correlation between BF consumption and English language grade. Conducted simple correlation only, did not adjust for any confounders.
Morales et al. (2008)	Cross-sectional survey study.	n=467 aged 12-17 years. Male: 42% Female: 58% Well-nourished. Spain.	7-day food diary (Mon-Sun) and FFQ.BF intake classified as: 1. Full BF: >25% of TEE, ≥4 food groups of dairy, cereals, fruit, fat 2. Good quality: 3 food groups of dairy, cereals, fruit 3. Better options: Missing one food group 4. Poor quality: Missing two food groups 5. No BF	Average end of course grades for: 1. Language 2. Mathematics 3. Chemistry 4. Biology 5. Social Sciences 6. Physical education Total average grade calculated.	Full and good quality BF groups associated with higher total, mathematics, chemistry and social science grades compared with no BF. Physical education, biology and language grades were highest in no BF group compared with full and food quality BF groups.
Murphy et al. (1998)	SBP evaluation. Independent groups design. Compared participants vs. non participants. 4 month intervention.	3 primary schools. n=133 mean age ± SD 10.3 ± 1.6 years. Male: 44% Female: 56%. Proportion eligible for FSMs or reduced priced meals: >70%. Well-nourished. USA.	Free SBP. Considered nutritionally balanced including milk, RTEC, bread, muffin, fruit, and juice. Stratified by SBP participation: 1. Often: ≥80% attendance 2. Sometimes: 20-79% attendance 3. Rarely: <20% attendance	APM: baseline, +4 month follow up. School grades obtained from school records for: 1. Mathematics 2. Reading 3. Science 4. Social studies Grade converted into numeric value: A=4, B=3, C=2, D=1, F=0	Higher mathematics grades post intervention in school children who regularly participate in SBP compared to those who rarely or sometimes participate. School children who increased their SBP participation were significantly more likely to increase mathematics grades compared to those who had decreased or unchanged participation. No effects of SBP on other grades.
Øverby et al. (2013)	Cross-sectional survey study.	n=475 mean age ± SD: 14.6 ± 0.57 years. Male: 49.6% Female: 50.4% Sample considered representative for weight and ability. Well-nourished. Norway.	Questionnaire and FFQ of selected healthy/unhealthy food items. 1-item to assess BF frequency. BF intake classified as: 1. BF ≥6 days/week 2. BF <6 days/week	Questionnaire to assess self-reported difficulties for: 1. Reading and writing 2. Mathematics Reponses: "Yes, "No", "Don't know" Responses dichotomised: 1. Having difficulties 2. Not having difficulties ("No" & "Don't know")	Regular BF was significantly associated with decreased odds of self-reported learning difficulties in writing and reading and mathematics. High intakes of unhealthy food items were significantly associated with increased odds of mathematical difficulties only. Adjusted for: gender, weight.

Table 4.1: Continued

Authors, year	Design	Sample	BF intervention/ assessment of BF	Assessment of academic performance	Reported results
Rahmani et al. (2011)	SBP evaluation, Cluster RCT 2 intervention school, 2 control schools. 3 month intervention.	4 single-sex primary schools. n=469 Male: 49% mean age ± SD: 7.9 ± 0.8 years. Female: 51% mean age ± SD: 7.5 ± 0.9 years. Iran.	Two conditions: 1. SBP: 250ml 2.5% fat milk at 0930 hrs 2. Control: No milk	APM: baseline, +3 month follow up. Average grade point.	Girls in intervention group had significantly higher average grade point post intervention compared with pre intervention. No significant differences in grade point at baseline compared with follow-up in control schools. Girls were significantly higher in weight following intervention. No significant difference in weight at baseline compared with follow-up in control schools. No effects in boys. Multiple t-tests conducted on outcomes.
So (2013)	Cross-sectional survey study. Korea Youth Risk Behaviour Web-based survey.	n=75643 mean age ± SD: 15.10 ± 1.75 years. Male: 51% Female: 49% Well-nourished. Korea.	Internet questionnaire, 1-item to assess BF frequency. BF intake classified as frequency/ week (0-7).	Self-reported academic performance rating for previous 12 months: 1. Very high 2. High 3. Average 4. Low 5. Very low Dichotomised as: 1. <Average performance 2. ≥Average performance	BF eaters (7 days/week) had increased likelihood of rating higher school performance compared with BF skippers (0 days/week). Adjusted for: age, BMI, smoking, alcohol, parental education, family SES, PA (vigorous and moderate), muscular strength, mental stress.
Stroebele et al. (2013)	Cross-sectional survey study	n=1095 aged 10-11 years Male: 52% Female:47% Missing data for gender: 1% Well-nourished. USA.	Questionnaire. 1-item to assess BF frequency. BF intake classified as: 1. BF ≥5 days/week 2. BF <5 days/week	Questionnaire to assess self-reported usual grades Grade scale: A (highest) to F (lowest). Response dichotomised: 1. A's-B's 2. Some B's and/or or lower grades	BF skippers (<5 days/week) had decreased odds of having higher school grades compared with regular BF eaters (≥5 days/week). Adjusted for: Sex, FSM status.

Abbreviations: ANOVA: Analysis of variance, AOR: Adjusted odds ratio, APM: Academic performance measures, BF: Breakfast, BMI: Body Mass Index, CI: Confidence intervals, FFQ: Food frequency questionnaire, FSM: Free School Meals, GI: Glycaemic index, GL: Glycaemic load, IG: Independent groups, Kcal: Kilocalorie, NCHS: National Centre for Health Statistics, PA: Physical activity, RCT: Randomised control trial, RDA: Recommended daily allowance, RTEC: Ready to eat cereal, TEE: Total energy Expenditure.

4.4.2 Standardised and unstandardised achievement tests: Overview

Age specific achievement tests are routinely administered by schools in developed countries for monitoring progress and performance of school children. Various domains are examined, usually reading, vocabulary, spelling and numeracy/arithmetic. Standardised achievement tests employed by studies include the Wide Range Achievement test (WRAT), the National Assessment Program – Literacy and Numeracy (NAPLAN), Measure of Academic Progress (MAP) and Assessment Tool for Teaching and Learning (asTTle). These tests assess skills that are essential for success at school, such as reading, numeracy, writing and spelling, and their content is based on or similar to the taught curriculum. Nine studies used standardised achievement tests to measure academic performance (see Table 4.2). Two further studies, which were conducted in developing countries, used unstandardised achievement tests developed for the purpose of the research to account for variability in the curriculum and school environment (Acham, Kikafunda, Malde, Oldewage-Theron, & Egal, 2012; Cueto & Chinen, 2008). One study used both standardised and unstandardised tests (Jacoby et al., 1996).

Studies were conducted in school children aged between 5-15 years with most studies (10/12) including both children and adolescents. Two studies were carried out in adolescents (≥11 years) and no study included only children. Seven studies were carried out in well-nourished school children of both sexes. Five studies were conducted in samples of well- and undernourished school children. Where SES was specified, most studies (7/12) were conducted in low SES school children. Evidence indicated a positive effect of SBPs on test scores, with clearest effects on arithmetic scores in both well-nourished and undernourished samples. Evidence also indicated a positive association between habitual breakfast intake frequency and quality, and test scores.

4.4.2.1 Chronic intervention studies: The effects of SBPs on school grades

Six of the seven intervention studies demonstrated positive effects of SBPs on achievement tests in school children aged 6-14 years, with clearest effects on arithmetic scores in undernourished school children. Four of the seven studies demonstrated a benefit of breakfast on arithmetic scores (Cueto & Chinen, 2008; Powell, Walker, Chang, & Grantham-McGregor, 1998; Simeon, 1998; Wahlstrom & Begalle, 1999). Four of the studies were carried out in samples which included undernourished school children (Cueto & Chinen, 2008; Jacoby et al., 1996; Powell et al., 1998; Simeon, 1998) and two studies included low SES samples (Meyers, Sampson, Weitzman, Rogers, & Kayne, 1989; Ni Mhurchu et al., 2013). Effects were demonstrable after an intervention period of at least one month and up to three years.

Two studies found positive effects on arithmetic test scores from the WRAT following a relatively large school breakfast meal (>500Kcal) compared with a low and no energy control in Jamaican undernourished and well-nourished school children (Powell et al., 1998; Simeon, 1998). Powell et al. (1998) performed a 1-year RCT, where undernourished and nourished school children were randomised within classes to receive a school breakfast or low energy control. The positive effect of breakfast on arithmetic scores was mainly demonstrated in younger school children but there were no differential effects by nutritional group (Powell et al., 1998). Simeon (1998) conducted a matched class comparison study of a 10-week SBP vs. no SBP in one primary school. Classes were matched based on year group only. Therefore, it is probable that the classes varied in other characteristics or exposures such as different teachers, which could have influenced the observed improvement in arithmetic performance following the SBP.

Cueto and Chinen (2008) examined the effects of a 3-year mid-morning SBP providing 600 Kcal and 60% of the daily requirements for several vitamins and minerals and 100% of the daily requirement for iron in a large sample of Peruvian school children, two thirds of whom were undernourished (≤ -2 SD height-for-age of the NCHS reference). In this matched school comparison study, the investigators compared school children who had consumed breakfast at home before school (control group) to school children who had consumed breakfast at home in addition to the mid-morning school breakfast (intervention group). No details were collected on the breakfast meals consumed at home but it is likely that these meals varied considerably. Mixed findings were reported. Higher arithmetic and reading scores were demonstrated following the SBP in intervention schools compared to control schools, effects which were specific to multiple-grade schools. Conversely, in full-grade schools, arithmetic and reading scores were lower following the SBP in intervention schools compared to control schools. Another negative consequence was that in the intervention schools, the time spent in the classroom significantly decreased following the SBP.

Similar results were reported by Jacoby et al. (1996) in a RCT comparing the same high energy, nutrient dense SBP vs. no SBP in a different sample of undernourished and nourished Peruvian school children. Rural primary schools were randomised to receive either the SBP or no SBP for one month. School children in the intervention schools who were higher weight-for-height increased vocabulary scores post intervention. The authors suggested that the effect observed in these school children was because they were also stunted and therefore had comparatively higher weight but were actually undernourished. Stunting coupled with normal or above average weight-for-height is a characteristic of poor Peruvian school children who are undernourished, or were undernourished in the early years of life (Jacoby et al., 1996). No effects were observed in normal weight-for-height school children who were therefore likely to be well nourished.

In American school children aged 8-12 years from low SES backgrounds, Meyers et al. (1989) reported greater increases in language and total test scores in SBP attendees compared with non-attendees. Wahlstrom and Begalle (1999) also demonstrated an increase in scores for reading and mathematics from pre to post intervention in American 6-14 year olds. However, both studies were not well-controlled and Wahlstrom and Begalle (1999) did not report the statistical analysis performed. A recent large RCT in pupils from low SES schools in New Zealand failed to show any benefit of a one year SBP on school achievement tests for literacy and numeracy and self-reported reading ability (Ni Mhurchu et al., 2013).

4.4.2.2 Cross-sectional studies

Four cross-sectional studies demonstrated a consistent positive association between habitual breakfast consumption and achievement test scores in school children, including undernourished school children.

4.4.2.2.1 Habitual breakfast consumption: Frequency

Frequency of breakfast consumption was associated with achievement scores in two studies. Acham et al. (2012) demonstrated in well-nourished and undernourished 9-15 year olds, predominantly considered low ability, that those who usually consumed breakfast and a mid-day meal were almost twice as likely to score highly on achievement tests compared to those who had only one meal. This association was specific to boys, and consuming breakfast alone was not associated with academic performance (Acham et al., 2012). Higher mean mathematics MAP scores were associated with habitually eating breakfast (≥5 days/week) compared with less frequent consumption (<5 days/week) in American 11-13 year olds (Edwards, Mauch, & Winkelman, 2011). No association was found between breakfast frequency and reading MAP scores.

4.4.2.2.2 Habitual breakfast consumption: Composition

Two studies demonstrated an association between breakfast composition (energy, food group and micronutrient content) and achievement scores in school children aged 8-13 years. Habitually consuming a breakfast providing <20% of total energy needs was associated with poorer total Scholastic Aptitude Test (SAT) performance, in 9-11 year olds (Lopez-Sobaler, Ortega, Quintas, Navia, & Requejo, 2003). However, SES was not controlled. O'Dea and Mugridge (2012) demonstrated a significant positive association between habitual breakfast intake quality according to food groups (carbohydrate, protein, vitamin C and calcium food sources) and NAPLAN literacy scores in school children aged 8-13 years. No significant association was found between breakfast quality and numeracy scores.

4.4.2.3 Prospective cohort studies

One prospective cohort study in a large cohort of 21,400 school children aged 5-15 years revealed a non-significant association between breakfast eating frequency and scores on standardised achievement tests for reading, mathematics and science following adjustment for an extensive set of confounders (Miller, Waldfogel, & Han, 2012). This was specific to breakfast that was eaten with the family rather than total breakfast intake.

Table 4.2: Tabulation of studies investigating the effect of breakfast on standardised achievement tests in children and adolescents

Authors, year	Design	Sample	BF intervention/ Assessment of BF	Assessment of academic performance	Reported results
Acham et al. (2012)	Cross-sectional survey study.	n=645 aged 9-15 years. Male: 46% Female: 54% Underweight:13% Stunted: 9% Uganda.	Questionnaire, 1-item to assess BF frequency. BF intake classified as: 1. Regular BF 2. Regular mid-day meal 3. Regular BF and/or mid-day meal 4. No BF or mid-day meal	Unstandardised tests: Developed to account for variability in school curriculum. 1. English 2. Mathematics 3. Life Skills 4. Oral comprehension Maximum score of 400. Cut-off of <120 used to define poor performance. 68.4% scored <120.	Boys who had consumed BF and mid-day meal were significantly more likely to score ≥120 than those who only had one meal. No association between BF alone and test scores. Adjusted for household size, mother's education, land quantity owned, school attendance, gender head of household, feeding habits, age, household wealth.
Cueto and Chinen (2008)	SBP evaluation. Independent groups design. Compared matched schools with SBP (11 schools) vs. No SBP (9 schools). Multiple and full grade schools. 3 year intervention	Primary schools. n=590 SBP: n=300, mean age ± SD: 11.87 ± 1.77. Male: 51.7% Female: 48.3% Control: n=290 mean age ± SD: 11.87 ± 1.90. Male: 49.7% Female: 50.3% Comparable nutrition status: 66-69% school children ≤-2 SD height-for-age NCHS. Peru.	Two conditions: 1. Free mid-morning SBP: BF during school break time at 1000-1100 hrs. Milk-like beverage and 6 biscuits (600 Kcal, 19.5g PRO, 20g fat, 60% RDA for micronutrients, 100% RDA for iron). 2. Control: No BF/BF at home Compliance: 82% consumed all of BF. Consumed BF mid-morning following BF at home.	APM: +3-year follow up. Unstandardised tests developed to account for variability in curriculum: 1. Arithmetic 2. Reading comprehension	Higher arithmetic and reading scores in multiple-grade intervention schools compared to control schools at post intervention. Lower arithmetic and reading scores in full grade intervention schools compared to control schools at post intervention.
Edwards et al. (2011)	Cross-sectional survey study.	n=800 aged 11-13 years. n=694 with complete data on gender Male: 48% Female: 52% 13.5% eligible for FSMs Well-nourished. USA.	Adapted questions from Youth Risk Behaviour Surveillance survey. BF intake classified as: 1. BF ≥5 days/week 2. BF <5 days/week	MAP tests. Standardised computer tests for: 1. Mathematics 2. Reading	ANOVA indicated that higher mean mathematics MAP scores in those eating BF ≥5 days/week compared with <5 days/week. Regression analysis indicated BF intake significantly predicted mean MAP mathematics scores. No association between BF and MAP reading scores: Lack of adjustment for confounders: Stepwise regression.

Table 4.2: Continued

Authors, year	Design	Sample	BF intervention/ Assessment of BF	Assessment of academic performance	Reported results
Jacoby et al. (1996) also in Pollitt et al. (1996)	SBP evaluation. Cluster RCT. Independent groups design. 5 intervention schools, 5 control schools, 1 month intervention.	10 Primary schools. n=352. Intervention: n=201, mean age ± SD: 136.2 ± 18 months. Male: 46% Female: 54% Control: n=151, mean age ± SD: 138.9 ± 20 months. Male: 53% Female: 47% Normal, underweight and stunted school children. Peru.	Two conditions, SBP. 1. Intervention: SBP: Milk-like beverage and 6 biscuits (600Kcal, 19.5g PRO, 60% RDA various micronutrients and 100% RDA iron). 2. Control: No SBP, wait list control	APM: baseline, +1 month follow up. Standardised school achievement tests for: 1. Reading comprehension 2. Vocabulary Unstandardised test developed for purpose of study for: 3. Mathematics	No main effects of SBP on all achievement tests. Significant weight x treatment interaction (controlling for height). School children in intervention schools of higher weight increased vocabulary scores post intervention. No effects observed in normal weight school children.
Lopez-Sobaler et al. (2003)	Cross-sectional survey study.	n=180 mean age ± SD: 11.5 ± 1.08 years (range: 9-13). Male: 57% Female: 43%. Well-nourished. Spain.	Weighed 7 day food diary. Definition of BF: Cut-off of ≥20% of daily energy requirement. BF intake classified as: 1. AB: ≥20% of daily energy requirement 2. IB: <20% of daily energy requirement	Spanish SAT-1 tests. Three batteries: 1. Verbal 2. Logical reasoning 3. Calculation	Higher logical reasoning SAT-1 scores obtained by AB group compared with IB group. Higher total SAT-1 scores obtained by AB group compared with IB group. Better quality BF significantly predicated better logical reasoning and total scores.
Meyers et al. (1989)	SBP evaluation. Independent groups design. Compared participants vs. non participants. 3 month intervention.	16 Primary schools. n=1023 aged 8-12 years Male: 51% Female: 49% Low income. Well-nourished. USA.	Two conditions: SBP. Stratified by participation 1. Non attendees: <60% attendance 2. Attendees: ≥60% attendance BF participation recorded for 1 week.	APM: baseline, +3 month follow up. The Comprehensive Test of Basic Skills. 1. Language 2. Reading 3. Mathematics	Lower total scores at baseline in non-attendees. Greater increase in total and language scores in attendees compared with non-attendees. SBP attendance positively associated with total scores at follow up.

Table 4.2: Continued

Authors, year	Design	Sample	BF intervention/ Assessment of BF	Assessment of academic performance	Reported results
Miller et al. (2012)	Prospective cohort study. Part of ECLS-K national study. Data collected in five waves: 1999 (preschool), 2000 (grade 1), 2002 (grade 3), 2004 (grade 5), 2007 (grade 8)	Preschool- primary school children. n=21400 at baseline, n=9700 at final follow up, aged 5-15 years (mean age 6.09 years) Male: 51% Female: 49% Well-nourished. USA.	Parental questionnaire, 1 item to assess family BF frequency. BF classified as frequency/ week (0-7)	Standardised achievement tests 1. Reading 2. Mathematics 3. Science (grades 3, 5, 6)	No significant association between frequency of family BF and test scores. Extensive controls. Adjusted for: Gender, ethnicity, family SES, parental education, family income, parental job prestige, family structure, area of residence, language, maternal employment during preschool, birth weight, teaching quality, school quality, region of residence, parental working hours, single parent family.
Ni Mhurchu et al. (2013)	SBP evaluation. Cluster RCT, stepped wedge (sequential roll-out of intervention over 1 year period). Independent groups design. 1 year intervention.	14 Primary schools. n=424 baseline n=375 follow up mean age ± SD: 9.4 ± 2.0 years (range 5-13 years). Male: 47% Female: 53%. Low SES schools. Well-nourished. New Zealand.	Two conditions: 1. Free SBP: Non-standardised. School selected food: Low-sugar RTEC, low-fat milk, bread, spreads (honey, jam, margarine), chocolate milk powder and sugar. 2. Control: No SBP	APM: baseline, +1 year follow up. Standardised school achievement tests: 1. Literacy 2. Numeracy Self-report assessment of reading ability using questionnaire. Scores ranged from 1 (not very well) to 5 (very well).	ITT: No significant effects on achievement tests and self-report reading ability. Proportion of school children eating BF everyday did not change. Decrease in proportion of school children eating BF at home, increase in proportion of school children eating BF at school.

Table 4.2: Continued

Authors, year	Design	Sample	BF intervention/ Assessment of BF	Assessment of academic performance	Reported results
O'Dea and Mugridge (2012)	Cross-sectional survey study.	n=824 grades 3-7 (aged 8-13 years). Male: 49% Female: 51% n=755 mothers completed telephone interview to report education level. Well-nourished. Australia.	Questionnaire & interview. BF defined as solid/liquid eaten before 1000hrs test day. BF intake classified as: 0. No food/drink 1. Non-nutrient liquid 2. Confectionary/snack food 3. Grain or fruit/ vegetable 4. Grain + vitamin C food source 5. Protein + vitamin C food source 6. Grain + protein food or grain + calcium food source 7. Grain + protein food + vitamin C food source or protein food + calcium food source + vitamin C food source 8. Grain + protein food + calcium food source 9. Grain + protein food + calcium food source + vitamin C food source 10. Grain + protein food + vitamin C food source + calcium source including low-fat option	Standardised school achievement tests from NAPLAN for: 1. Literacy 2. Numeracy	Higher nutritional quality of BF significantly predicted better literacy scores. Non-significant association between BF and numeracy scores. Few school children skipped BF. Adjusted for: age, gender, SES, maternal education.
Powell et al. (1998)	SBP evaluation. RCT. Independent groups design. Randomised within classes to BF vs. low calorie control. 1 school year intervention.	16 Primary schools. n=814 baseline n=791 follow up aged 7-11 years. Undernourished (< -1 SD weight-for-age, NCHS reference): 405 Nourished: 405 Jamaica.	Two conditions: 1. Intervention: Free SBP. Cheese sandwich/spiced bun and cheese, flavoured milk (576-703 Kcal/ 27.1g protein). Served before school. 2. Control: ¼ orange (18 Kcal/ 0.4g protein)	APM: baseline, +1 school year follow up. The Wide Range Achievement Test: 1. Reading 2. Spelling 3. Arithmetic	Significant positive effect of BF on Arithmetic. Grade x Treatment interaction indicated the positive effect on arithmetic scores was mainly demonstrated in younger children. No effects of BF on spelling and reading. No differential effects by nutritional group.

Table 4.2: Continued

Authors, year	Design	Sample	BF intervention/ Assessment of BF	Assessment of academic performance	Reported results
Simeon (1998) Study 1	SBP evaluation. Independent groups design. Compared matched classes with SBP vs. no SBP. 1 school term intervention (10 weeks).	Middle school. n=115 aged 12-13 years Intervention: n=44 Control: n=71 Rural school, low ability streams, low attendance Undernourished: ≈50% Jamaica.	Three conditions as separate school classes. BF at 0900 hrs. 1. School BF: 100ml milk (130Kcal), cake (250Kcal) or meat filled pasty (599Kcal) 2. Syrup drink (31Kcal) 3. No BF	APM: Start of 1st term (without SBP), baseline (start of 2nd term with SBP) +10 week follow up (end of 2nd term) The Wide Range Achievement Test: 1. Spelling 2. Arithmetic 3. Reading (not used in analysis)	Compared conditions on change in test scores in second term when BF given, controlling for change in first term when no BF given. Syrup drink and no BF groups combined to form one control group as no significant differences found on all outcomes. Controlling for change in scores without intervention, intervention group made significantly more improvement on arithmetic test relative to control group post intervention. No effect on spelling.
Wahlstrom and Begalle (1999)	SBP evaluation. Independent groups design but academic comparisons made within intervention schools only (pre-post). 3 year intervention.	Primary schools. n=2901 school children age 6-14 years. Proportion eligible for FSM or reduced priced meals: 20%-77% Well-nourished. USA.	Two conditions: 1. Intervention: Free SBP Unstandardised. Average daily participation rate: 68.9%-97.5%. 2. Control: No SBP (not used in analysis).	APM: baseline +1 year, +2 year + 3 year follow up. School achievement tests, Incomparable across schools. 1. Mathematics 2. Reading	Within school effects (pre-post intervention) show general increase in scores for reading and mathematics. Cannot be solely attributed to SBP. Statistical analysis not reported.

Abbreviations: AD: Adequate breakfast, ANOVA: Analysis of variance, AOR: Adjusted odds ratio, APM: Academic performance measures, BF: Breakfast, CI: Confidence intervals, ECLS-K: Early Childhood Longitudinal Study – Kindergarten Cohort, FFQ: Food frequency questionnaire, FSM: Free School Meals, IB: Inadequate breakfast, Kcal: Kilocalorie, MAP: Measure of Academic Progress, NAPLAN: The National Assessment Program Literacy and Numeracy, NCHS: National Centre for Health Statistics, RCT: Randomised control trial, RDA: Recommended daily allowance, RTEC: Ready to eat cereal, SAT: Scholastic Aptitude Test, SBP: School breakfast program, SD: Standard deviation, SES: Socio-economic status

4.5 Interim summary of findings

A summary of the findings of the 25 studies reviewed according to measurement of breakfast and academic performance is shown in Table 4.3. The findings are also summarised as follows:

- 23/25 studies demonstrated that breakfast consumption has a positive effect on children's and adolescents' academic performance.
- Studies examined academic performance by either standardised achievement tests (12/25 studies) or schools grades (13/25 studies).
- 15/25 studies employed cross-sectional designs to examine the association between habitual breakfast consumption and academic outcomes. 10/25 studies examined the impact of SBPs on academic outcomes.
- A wide range of subject domains were examined. The most frequently measured subject domains were reading/spelling/English and mathematics/arithmetic.
- The most consistent support was for a positive association between habitual breakfast consumption frequency and school grades in adolescents (11-18 years; 7/7 studies) and for a positive effect of SBPs on achievement test scores in school children (6-13 years; 6/7 studies).
- The evidence generally suggested that the effects were not modulated by socio-demographic characteristics.
- Most support was found for a positive effect of breakfast consumption on mathematics grades or arithmetic test scores (9/11 studies).
- There is insufficient data to determine the optimal breakfast, in terms of size and content, for academic performance in children and adolescents. However, the quality of habitual breakfast consumption (energy and food groups provided) appeared to be associated with academic performance (4/4).

Table 4.3: Summary of findings according to measurement of breakfast and academic performance

Reference	Habitual breakfast		Chronic interventions
	Frequency	Composition	SBPs
School grades			
Kleinman et al. (2002)			+
Murphy et al. (1998)			+
Rahmani et al. (2011)			+
Boschloo et al. (2012)	+		
Gajre et al. (2008)	+		
Herrero Lozano & Fillat Ballesteros (2006)		+	
Kim et al. (2003)	+		
Lien (2007)	+		
Majekodunmi & Wale (2012)	+[a]	+[a]	
Morales et al. (2008)		+	
Øverby et al. (2013)	+		
So (2013)	+		
Stroebele et al. (2013)	+		
Achievement tests			
Cueto & Chinen (2008)			+
Jacoby et al. (1996)			+
Meyers et al. (1989)			+
Ni Mhurchu et al. (2013)			O
Powell et al. (1998)			+
Simeon (1998) Study 1			+
Wahlstrom & Begalle (1999)			+
Acham et al. (2012)	+		
Edwards et al. (2011)	+		
Lopez-Sobaler et al. (2003)		+	
O'Dea & Mugridge (2012)		+	
Miller et al. (2012)	O		

[a] Authors did not report how habitual breakfast consumption was classified in the analysis.
Key: + indicates positive effect of BF/association with BF. O indicates no effect/association. Blank cells indicate no measurement.

4.6 Discussion

4.6.1 Principal findings

This SRR identified twenty-three studies that demonstrated suggestive evidence that habitual breakfast consumption (frequency and quality) is associated with children's and adolescents' academic performance. The provision of breakfast at school as part of chronic SBP interventions tended to have positive effects on academic performance, particularly in school children aged 6-13 years in developing countries. However, there are relatively few SBP studies from which to draw conclusions at present. Advantageous effects were not always universal and were sometimes dependent on the age of the school children, type of school and the SBP model. SBPs that offer breakfast provision during lessons can have a negative impact on the amount of teaching time as no compensatory time is accommodated during the rest of the school day. Consequently, the SBP may have better prepared pupils to learn but they would not have fully benefited from this because less teaching time was available. Overall, the present SRR identified relatively few good quality studies. The evidence was largely associative from cross-sectional studies which varied in controls for confounders. Only four RCTs have been conducted to date. The lack of randomised controlled trials precludes firm causal inferences from the current available evidence and the uncontrolled conditions may have contributed towards some of the findings.

4.6.2 Subject domains most affected by breakfast consumption

The evidence for a positive effect of breakfast was most consistent for arithmetic test scores and mathematic grades. Four studies demonstrated clearest effects on mathematic grades (Kleinman et al., 2002; Morales et al., 2008; Murphy et al., 1998; Øverby et al., 2013) and five studies demonstrated a benefit of breakfast on arithmetic scores as well as other subject areas (Cueto & Chinen, 2008; Edwards et al., 2011; Powell et al., 1998; Simeon, 1998; Wahlstrom & Begalle, 1999). However, some of the evidence was inconsistent (Gajre et al., 2008; O'Dea & Mugridge, 2012). Gajre et al. (2008) found that regular breakfast eaters (>4 days per week) had significantly higher grades for science and English compared to those who never eat breakfast, but there was no difference in mathematics grades. However, total average grade, which included mathematics, were significantly higher in the regular breakfast group compared with the no breakfast group. Similarly, the majority of studies employing composite measures of school grades across subject domains show a positive association.

4.6.3 Breakfast frequency and type and academic performance

In studies assessing habitual breakfast consumption, a range of definitions and classifications of habitual breakfast consumption prevented firm conclusions regarding the frequency and composition of breakfast most clearly associated with academic performance. In general, increased frequency of habitual breakfast consumption was consistently positively associated with academic performance. Some evidence suggested that increased quality of habitual breakfast consumption in terms of providing a greater variety of food groups (3-4) and adequate energy (>20-25% of total estimated energy needs) was positively related to academic performance. It was also suggested that mid-morning snack consumption could ameliorate the negative effects of a poor quality breakfast or no breakfast.

Few firm conclusions can be made from SBP studies regarding the composition of breakfast in relation to academic performance. The breakfast meals provided as part of

SBPs varied largely, and some studies failed to report details of the foods offered, nutrient composition and energy provided. Some studies employed large school breakfast meals (>500 Kcals) which were common in studies conducted in developing countries in undernourished school children (Cueto & Chinen, 2008; Jacoby et al., 1996; Powell et al., 1998; Simeon, 1998). However, the majority of school breakfast meals were ad-libitum and participants were permitted a choice of foods to consume which may have more likely reflected school children's habitual breakfast intake. It is often difficult to offer a fixed breakfast manipulation as this is unusual in SBPs where pupils tend to select the type and amount of food they wish to consume from a menu. These studies are more ecologically valid and relevant to usual behaviour but make it difficult to make comparisons based on the breakfast meal itself.

4.6.4 Interaction effects of socio-demographic characteristics

Unlike the effects of breakfast on cognitive performance, benefits for academic performance were not always greater in, or specific to, undernourished or nutritionally at-risk school children. From the studies reviewed, the positive effects of breakfast were evident in both well-nourished and undernourished children and adolescents suggesting that effects were apparent regardless of nutritional status. The majority of studies (18/25) showed effects in well-nourished school children. It is important to note that this SRR assumed that the school children in these studies were well-nourished since they were described as healthy and BMI was within the normal range. However, in some studies no consideration of the nutritional or weight status of the sample was reported and it is therefore likely that the samples included school children who varied in terms of weight and nutritional status. Four studies showed effects in samples in which a proportion of the school children were undernourished but did not report differing effects by nutritional status (Acham et al., 2012; Gajre et al., 2008; Powell et al., 1998; Rahmani et al., 2011). However, this may be because some studies did not specifically consider this factor or because the degree of undernourishment was mild (e.g. Powell et al., 1998). It is possible that positive effects may be more demonstrable in school children who are more severely undernourished.

A small number of the studies suggested that advantageous effects of breakfast for academic performance may be more apparent in undernourished school children or school children who improve their nutritional status (Cueto & Chinen, 2008; Jacoby et al., 1996; Kleinman et al., 2002). However, this could not always be directly attributed to nutritional status. For example, Cueto and Chinen (2008) reported that the positive effects of a SBP on achievement test scores were specific to multiple-grade schools. The authors speculated that the reason for this interaction was because more school children were undernourished in multiple-grade schools. However, the positive effect of breakfast on achievement test scores may equally have been more apparent in multiple-grade schools because of school structure, teaching quality, SES or ability level of the school children.

It was not clear whether other socio-demographic characteristics could modulate the relationship between breakfast consumption and academic performance. Few studies examined possible interactions of socio-demographic characteristics in the relationship between breakfast consumption and academic performance. Where interaction effects did occur, breakfast appeared to differentially affect academic performance in males and females. However, findings were contradictory with some studies suggesting that effects were specific to females (Rahmani et al., 2011) whilst others suggested effects were specific to males (Acham et al., 2012). In addition, one study indicated that gender differences also varied according to age (Kim et al., 2003). However, the majority of studies did not report gender differences and studies commonly demonstrated equivalent increased odds of having lower school grades when skipping breakfast compared with habitually consuming breakfast in both genders (Boschloo et al., 2012; Lien, 2007; So, 2013). Some evidence also suggested that the effect of breakfast on academic performance varies by ethnicity and age (Lien, 2007; Powell et al., 1998), but generally this was an infrequent finding in the review.

4.6.5 Methodological considerations

4.6.5.1 Confounding variables

Research on breakfast and educational outcomes is particularly difficult given the potential for confounding. The majority of studies that employ academic outcomes are cross-sectional, so adjustment for potential confounders is critical. Adequacy of control for confounders varied within the studies identified. It is likely that children and adolescents who eat breakfast differ from those who do not eat breakfast in ways that also influence educational outcomes. An important potential confound is SES. There is consistent evidence that SES is associated with breakfast eating, with school children from higher SES backgrounds more likely to regularly eat breakfast than school children from lower SES backgrounds (see Chapter 1; section 1.2.2). Similarly, there is well established consistent evidence that SES is a central determinant of academic performance and cognitive ability (Brooks-Gunn & Duncan, 1997; Machin & Vignoles, 2004; McCulloch & Joshi, 2001; McLoyd, 1998). However, some studies failed to adequately adjust for SES in their analysis or used various proxy measures of SES which may be inadequate. If SES is not accounted for in the analysis, it is likely associations observed are because school children select into both high breakfast consumption frequency and higher school grade categories as a result of SES. Further work investigating the effects of breakfast on academic performance should carefully consider the role of confounding, and apply adequate controls in the analysis, particularly for SES.

4.6.5.2 Academic performance measures

Studies employed a wide range of outcomes as academic performance indicators, either by use of average school grades or standardised achievement tests. Some studies relied on self-reported school grades (Lien, 2007; Stroebele et al., 2013) or self-reported subjective ratings of academic performance (Øverby et al., 2013; So, 2013) which are open to socially desirable and inaccurate reporting. Moreover, direct measures of academic performance, although ecologically valid are however, crude measures that may be insensitive to the subtle effects of breakfast. Although many confounders are controlled for in the studies reviewed, it may be inappropriate to use broad measures of scholastic achievement such as end of year grades since many other factors interplay to determine grades. There are multiple, modifiable and unmodifiable, determinants of academic performance that may act over and above the subtle nutritional effects of breakfast.

4.6.5.3 Statistical analysis

In some of the studies, the statistical analysis was inappropriate or not reported. For example, one study conducted multiple t-test comparisons on outcomes, raising the probability of Type 1 error (Rahmani et al., 2011). Some studies used stepwise regression analysis or simple correlations where covariates are not always included. Stepwise multiple regression analysis may not be appropriate as this approach seeks to identify the variable(s) that best predict academic performance to produce the most parsimonious model that explains as much variance as the full model with all predictor variables or covariates included (Tabachnick & Fidell, 2007). With this statistical approach, covariates are included in the final model on purely statistical grounds, resulting in a lack of control for confounders which may be causally linked but do not explain a statistically significant proportion of the variance and therefore are not included.

Another common approach to the analysis was to dichotomise ordinal grade categories or continuous outcomes from test scores by grouping into high vs. low performance categories and applying binary logistic regression models for analysis. This approach is inappropriate because of the inevitable loss of information and power to detect a true relationship. This is particularly important given that effects of breakfast on academic performance are likely to be subtle. Furthermore, the choice of cut-point for dichotomisation was not always driven by a recognised or accepted definition of “low/high performance”. In the absence of an *a-priori* cut-point the most common approach was to take the sample median, which may have biased conclusions dependent on the sample under investigation.

4.6.5.4 Design

4.6.5.4.1 Cross-sectional studies

The majority of studies on habitual breakfast consumption are cross-sectional. The dominance of cross-sectional evidence, although offering a unique opportunity to establish the relationship between habitual breakfast consumption and academic performance, provides no indication of causality or temporality. Only one well controlled prospective cohort study has been published to date (Miller et al., 2012) which did not demonstrate a positive association between habitual breakfast consumption and academic performance. This study focussed on breakfast that was eaten with the family rather than total breakfast intake. However, this may still be reflective of habitual breakfast consumption particularly in younger children who are more likely to have family meals (Fulkerson et al., 2006) and since most regular breakfast eaters have breakfast at home (Hoyland et al., 2012).

4.6.5.4.2 Chronic SBP intervention studies

Evaluations of SBPs are particularly difficult to conduct in a controlled and scientifically robust manner as they can be logistically challenging in applied research settings. It is likely that these studies required considerable cooperation from schools, parents, and even local educational authorities. In addition, it may have been difficult to allocate school children to control groups in relation to school food provision as researchers are then withholding a beneficial intervention. Generally, SBP studies were opportunist evaluations of government funded school breakfast provision already in existence. As a consequence, many were not randomised, used quasi-experimental designs and often investigators did not have sufficient control over the design, procedures and the breakfast provision because the evaluation was planned following implementation. In addition, in some studies, baseline measurements were not available. In SBP studies that compared school children who regularly participated with non-participants, condition was self-selected. This is likely to have imposed bias as school children who participate in a SBP may differ systematically in ways which also affect academic performance from those who do not participate. Other studies used matched schools or classes as controls but this approach was often unsatisfactory as school children were often only matched based on age or school year group.

RCTs are the best approach to attempt to determine with certainty the effects of school breakfast provision on academic performance, but there are only four published to date (Jacoby et al., 1996; Ni Mhurchu et al., 2013; Powell et al., 1998; Rahmani et al., 2011).

These studies were also not without limitations. From the studies reviewed, there was only one trial which ran for longer than 3 months (Ni Mhurchu et al., 2013). The intervention duration is particularly important in relation to academic performance because it is likely that a stable period of operation is needed to impact both breakfast eating behaviour and academic outcomes. In some studies, participation rate or compliance with the intervention was not always reported. One RCT reported that participation in the SBP was low and did not increase the total number of school children eating breakfast (Ni Mhurchu et al., 2013). Clearly, the increase in academic performance reported in studies that do not impact breakfast eating behaviour or have low participation rates are likely to be an artefact of other factors.

SBP intervention studies also present difficulties in attributing the direct effects of the breakfast meal or the regime of providing a free school breakfast in a breakfast club environment to academic outcomes (Defeyter et al., 2010). Additionally, it is difficult to isolate any advantageous effects from the impact of concomitant activity taking place in the schools at the same time. SBPs are often associated with increased attendance (Jacoby et al., 1996; Kleinman et al., 2002; Simeon, 1998) punctuality (Murphy et al., 1998), readiness to learn (Wahlstrom & Begalle, 1999), decreased dropout rates (Cueto & Chinen, 2008) better behaviour in the classroom (Bro, Shank, Williams, & McLaughlin, 1994; Richter et al., 1997) and increased pro-social behaviour (Haesly, Nanney, Coulter, Fong, & Pratt, 2014; Shemilt et al., 2004), all of which are likely to impact academic performance concurrently. The positive effects of SBPs on other outcomes that will also influence academic performance make it difficult to attribute the effects either to the breakfast meal or as an artefact of increased attendance and punctuality. However, there was some evidence that the positive effects on academic performance remain when attendance is controlled for in the analysis (Simeon, 1998). This suggests that the effects of SBPs on academic performance are independent of the improved attendance that these programs usually encourage.

4.6.5.5 Dietary assessment

Studies that examine the effects of habitual breakfast consumption on scholastic outcomes also have limitations in terms of how breakfast is measured and defined. Varying definitions of breakfast and classifications of habitual consumption are used. Often dichotomous classifications using different cut-offs (e.g. ≥ 5days/week, < 5 days/week) to define habitual breakfast consumption are employed precluding comparisons between these categories. This crude indication of habitual consumption is unlikely to reflect true intake of breakfast.

4.6.6 Mechanisms

There are no firm conclusions regarding the mechanisms that may mediate the relationship between breakfast consumption and academic performance. It is likely that there are multiple mechanisms of action which may operate synergistically (Grantham-McGregor, 2005). These mechanisms are likely to be long-term and related to the repeated consumption of breakfast over time which, in turn, has cumulative effects on academic performance. If a child's or an adolescent's nutritional, cognitive or behavioural state improves it is likely that they will begin to learn more during lessons. However, the knock-on effects of this increased learning on academic achievement is likely to take time to become apparent, particularly in schools in developing countries in which teaching conditions may be poorer.

4.6.6.1 Cognitive and behavioural mechanisms

Breakfast consumption is associated with positive effects on cognitive performance, which may also improve the ability to learn during lessons. Holding constant teaching quality and attendance at school, this effect on learning may translate, cumulatively, to improved academic performance in the long term assuming that breakfast is consumed repeatedly. In support of this, evidence included in the present SRR found that breakfast skipping was associated with lower average annual grades and that this relationship was partially mediated by higher self-reported attention problems (Boschloo et al., 2012). Similarly, the positive acute effects of breakfast on classroom behaviour such as time on-task should also, in turn, impact academic performance via the increased time spent engaged in the lesson activities and content (Adolphus et al. (2013). The time spent on-task in the classroom is a critical component of learning information taught in schools, and should, therefore, impact academic performance.

4.6.6.2 Nutritional mechanisms

Some evidence suggests that the observed increase in academic performance may be facilitated by the correction of nutritional deficiencies (Kleinman et al., 2002). RTECs, which are fortified with various micronutrients, were commonly consumed as part of breakfast in the studies reviewed. Similarly, the SBPs that operate in developing countries tended to provide fortified breakfast products, particularly with iron and iodine which have both been implicated in improving cognitive function which may ultimately influence academic performance (Falkingham et al., 2010; Grantham-McGregor & Ani, 2001; Tiwari, Godbole, Chattopadhyay, Mandal, & Mithal, 1996).

4.6.6.3 Attendance, punctuality and drop-out rate.

Where breakfast meals are consumed as part of SBPs, the improvements in academic performance observed may be due to increases in attendance, punctuality, readiness to learn and decreases in drop-out rates often associated with SBPs and breakfast clubs (Cueto & Chinen, 2008; Kleinman et al., 2002; Wahlstrom & Begalle, 1999). Many of the studies which evaluated SBPs reported increased school attendance which is likely to have mediated the relationship between breakfast consumption and academic performance, particularly in developing counties. In developing countries with high levels of poverty, the effect of SBPs on attendance may be more pronounced. Here, parents may be more likely to send school children to school if the school contributes towards feeding them.

4.6.7 Conclusion

Despite the shortage of good quality studies, this SRR presents clear evidence that breakfast consumption is positively associated academic performance in children and adolescents. Regular breakfast consumption and the provision of breakfast at school appears to benefit school children’s academic attainment. However, it is not clear whether the effects of SBPs on academic performance can be directly attributed to the breakfast meal itself or to the increased attendance and punctuality that these programs usually encourage. Nevertheless, even without establishing direct effects on attainment, these findings support a valuable role for SBPs regardless of any direct effect of the food consumed. Most support was found for improvements in mathematics and arithmetic attainment. The effects appear to be pervasive irrespective of socio-demographic characteristics; however, few studies directly examined the interaction of socio-demographic variables in the relationship between breakfast consumption and academic performance. In contrast to the plethora of studies evaluating the effect of breakfast on cognitive outcomes, investigation of the effect of breakfast on tangible academic outcomes is scarce. Although the data are consistent, the low quantity of studies and lack of studies in school children in Britain limits the ability to generalise these findings. Hence, this highlights the need for more research to consider the role of breakfast in improving scholastic performance.

5 Study 2: The association between habitual breakfast consumption and academic performance in 11-13 year old adolescents

Statement of Contribution

The primary outcome measures reported in the study presented in this chapter were baseline measures in Study 1. Study 1 was carried out by a team (see statement of contribution for Study 1, Chapter 3). The candidate confirms that she was solely responsible for the conception and design of the study as presented in this chapter. The candidate was solely responsible for the statistical analysis and interpretation of the data in this chapter. The candidate was solely responsible for writing the chapter and the production of all tables and figures. Supervisors provided editing and proof-reading assistance with the chapter.

5.1 Introduction

In Chapter 4, studies examining the effects of breakfast on children's and adolescents' academic performance were reviewed. Relative to the literature concerning breakfast and cognitive performance (Chapter 2), fewer studies have examined how breakfast may affect academic performance. Therefore, assumptions about the benefits of breakfast for school children's learning are based on evidence demonstrating acute effects of breakfast on school children's cognitive performance from laboratory based studies, which may represent an overgeneralisation. The paucity of research may be due to logistical issues of conducting research in schools and/or gaining access to results of academic performance measures used in schools. Additionally, academic outcomes are influenced by many factors and may not be the most sensitive reflection of the effects of breakfast on learning. Nevertheless, academic performance outcomes are ecologically valid. They have most relevance to pupils, parents, teachers and educational policy makers and as a result may produce most impact. The relatively limited available evidence base highlights the need for further exploration of the role of breakfast consumption in relation to academic performance.

The SRR presented in Chapter 4, identified 23 studies which provided evidence that both habitual breakfast consumption and SBPs are positively associated with academic performance in children and adolescents (Chapter 4; Adolphus et al., 2013). Although there is support for a positive association between habitual breakfast consumption and school grades and achievement test scores, a number of studies failed to adequately adjust for SES in their analyses (Gajre et al., 2008; Herrero Lozano & Fillat Ballesteros, 2006; Lien, 2007; Majekodunmi & Wale, 2013; Morales et al., 2008; Øverby et al., 2013). The SRR highlighted the need for further work to consider the impact of confounders, and apply adequate controls in the analysis, particularly for SES. Of the studies included in the SRR, no study to date has examined a sample of school children from UK schools. Hence no study has included measures of academic performance that are typically used for assessment and monitoring in the British school system. Consequently, the study reported in this chapter extends previous work to include a sample of school pupils from a UK school and to examine the association between breakfast consumption and CAT performance, an assessment method routinely used in UK schools.

The CAT is the most widely used reasoning test in UK secondary schools (Lohman et al., 2001; Strand, 2006). The CAT is typically administered at the start of Year 7, when school children are aged 11-13 years, during the important transition point between primary and secondary education. The CAT plays a substantial and important role in schools as part of their non-statutory assessment regime. The results are used for monitoring pupils, streaming pupils into ability bands, identifying underachieving pupils, and predicting future academic achievement (Lohman et al., 2001). The CAT assesses transferable reasoning abilities required for learning in all key stages of the curriculum. Because these abilities are closely linked to achievement in subjects taught in schools, CAT performance is strongly predictive of academic achievement (Lohman et al., 2001; Strand, 2006). Consequently, CAT results are used to predict outcomes of key stage 3 national curriculum (NC) tests taken at the end of Year 9, and GCSE assessments taken at the end of Year 11 (Lohman et al., 2001). The high correlation of CAT scores with subsequent achievement on NC key stage tests and GCSE examinations nationally (Lohman et al., 2001; Strand, 2006) suggests that CAT scores are an acceptable proxy of academic performance. The data reported in this chapter relate to the CAT third edition published in 2001 (Lohman et al., 2001).

5.2 Study aims

The aims of the study reported in this chapter were as follows:

I. To examine the association between habitual breakfast consumption and CAT performance in adolescents aged 11-13 years.
II. To investigate the effects of socio-demographic characteristics on the relationship between habitual breakfast consumption and CAT performance.

5.3 Hypotheses

It was hypothesized that habitual breakfast skipping would be negatively associated with CAT scores in 11-13 year old adolescents, after adjustment for confounding variables. No specific predictions were hypothesized regarding the interaction effects of socio-demographic characteristics in this relationship due to the contradictory and limited previous evidence (see Chapter 4; section 4.6.4). Hence, the investigation of interaction effects was considered exploratory.

5.4 Methodology

5.4.1 Participants

The study sample consisted of males and females aged 11-13 years from a large secondary school in Leeds who were recruited to take part in Study 1 reported in Chapter 3. The participants had completed a questionnaire on habitual breakfast consumption and the CAT enabling the consideration of the associations between these in the present study. A total of 369 participants (males: 191 [51.8%]; females: 178 [48.2%]) aged 12.08 ± 0.58 were eligible to take part in this study. Of the 369 participants invited to take part, 77 (20.9%) returned incomplete questionnaires or did not complete any of the CAT subtests. These 77 participants were excluded. Hence, the final sample for analysis consisted of 292 participants, described in section 5.5.1. Of the 292 participants included in the sample, 15 returned incomplete data sets with respect to the CAT subtests and were therefore excluded from some, but not all, of the analyses.

5.4.2 Inclusion/exclusion criteria

Participants were recruited using the following inclusion and exclusion criteria.

5.4.2.1 Inclusion criteria

- Male or female, aged 11-13 years
- Completed the CAT in school Years 7 or 8.
- Ability to follow verbal and written instructions in English

- Ability to complete both the breakfast habits questionnaire and CAT

5.4.2.2 Exclusion criteria

- No CAT scores available
- Special education needs, including dyslexia. Any child or adolescent whose skill in reading is adversely affected by dyslexia cannot be validly assessed for reasoning ability with the CAT (Lohman et al., 2001).

5.4.3 Design

The study conformed to an observational cross-sectional survey design. Cross-sectional survey data were collected through a self-administered questionnaire on breakfast habits and from school records (demographic information and the CAT data) which was collected as part of Study 1 (Chapter 3). Data collection was carried out at the school alongside participants' normal school routine. Data collection took place in a controlled school environment within an allocated classroom by trained researchers.

5.4.4 Measures

5.4.4.1 Socio-demographic measures

Demographic information on age, gender, ethnicity, FSM status and EAL status were gathered from school records as part of Study 1 (Chapter 3). For ethnicity, the categories Asian and British Asian (18.8%), mixed ethnicity (5.1%), Black British/African/Caribbean (4.5%) and other ethnic background (3.1%) were collapsed due to infrequent occurrence. This provided a dichotomous ethnicity variable with participants coded as “White British” (68.5%) or “other ethnic background” (31.5%). FSM status was used as a proxy for SES. This measure is described in detail in Chapter 3, section 3.4.5.1.

5.4.4.2 BMI

The height and weight of each participant was measured and recorded by trained researchers in order to determine BMI SDS and weight classification. The methods reported in Chapter 3 were used to calculate BMI SDS (Chapter 3; section 3.4.5.2)

5.4.4.3 Assessment of habitual breakfast intake

5.4.4.3.1 Self-report questionnaire

Participants completed a self-report written questionnaire which formed part of the study reported in Chapter 3 (see Appendix 9.17). The questionnaire contained three items relating to the participants' habitual breakfast consumption.

5.4.4.3.2 Classification of habitual breakfast consumption

Participants' habitual breakfast intake frequency (per week) was used to classify habitual breakfast consumption. Habitual breakfast intake frequency (per week) was assessed by the question: "How many times per week do you normally have breakfast?" with the numerical responses: "0", "1-2", "3-4", "5-6" and "7". Habitual breakfast consumption frequency was categorised as rare (0-2 days per week), occasional (3-4 days per week) or frequent (5-7 days per week).

5.4.4.4 Academic performance: CAT performance

Participants' CAT performance was used as a proxy measure of academic performance. The CAT has six levels of difficulty coded A-F, standardised for school children aged 7 years 6 months to 15 years 9 months. Participants completed level D or E which, according to normative data, are suitable for school children aged 10 years 6 months to 12 years 11 months (school Year 7) and 11 years 6 months to 13 years 11 months (school Year 8) respectively (Lohman et al., 2001). The CAT has three timed, multiple-choice test batteries which measured participants' ability to reason with, and manipulate three types of symbols: symbols representing words, symbols representing quantities and symbols representing spatial, geometric or figural patterns. Each battery has three subtests that assess different aspects of that style of reasoning. These are aggregated to provide a standardised measure of verbal, nonverbal and quantitative reasoning ability. A description of the complete CAT battery including abilities tested, time permitted and scoring is shown in Table 5.1.

Table 5.1: Description of the complete CAT battery

CAT battery	Subtests	Description	Time (mins)	Number of questions	Max raw score
Verbal reasoning battery Abilities tested: • Ability to reason and manipulate symbols representing words	Verbal classification	Given three or four words belonging to one class, select which further word from a list of five belongs to the same class.	8	24	78
	Sentence completion	Select one word from a list of five to complete a sentence that is true and logical.	10	24	
	Verbal analogies	Determine the relationship between a pair of words. Decide which of five options would complete a second pair of words using the same relationship.	10	30	
Nonverbal reasoning battery Abilities tested: • Ability to reason and manipulate symbols representing spatial, geometric or figural patterns	Figure classification	Given three shapes belonging to one class, select which further shape from five choices belongs to the same class.	10	24	66
	Figure analogies	Determine the relationship between one pair of shapes. Decide which of five options would complete a second pair of shapes using the same relationship.	10	24	
	Figure analysis	Shown a figure of the method a square piece of paper was folded and where holes were punched through. Select which figure from five choices will resemble how the paper will look when it is unfolded.	10	18	
Quantitative reasoning battery Abilities tested: • Ability to reason and manipulate symbols representing quantities	Number analogies	Determine the relationship between numbers in two example pairs. Select which of five options would complete a third pair of numbers using the same relationship.	12	20	58
	Number series	Determine the rule(s) for a number series. Select which number from a choice of five which completes the series using the same rule(s).	10	20	
	Equation building	Given 4-5 numbers and mathematical operators. Select one answer choice from five options that can be calculated by combining all the given elements to create a valid equation.	14	18	

5.4.4.4.1 Administration

The CAT was administered by teachers in a formal group examination setting during the first school term in October 2010. Participants worked in silence, but questions were permitted. For all test sessions, no unexpected events or incidents were recorded. The CAT was completed in three timed sessions of approximately 30 minutes for each reasoning battery (see Table 5.1). Standardised oral instructions were given at the beginning of each subtest. Each subtest began with an example question and practise questions to ensure that participants were familiar with the test layout and question format before they began the test. This also reduced test anxiety and procedural learning effects on initial questions within the subtests. Participants recorded their responses on optical mark recognition answer sheets which were scored by an external organisation (GL Assessment, London).

5.4.4.4.2 CAT scoring

Each subtest is standardised to a mean of 100 and SD of 15 based on normative population data from a representative sample of ≈16,000 British school children from 566 schools aged 7.6-15.9 years (Lohman et al., 2001). A raw score was obtained for each CAT subtest. The three subtest scores were aggregated and converted into three normative standard age scores (SAS) for verbal, nonverbal and quantitative reasoning. An overall mean SAS was also calculated as the average of the three standardised scores. SAS were calculated by comparing an adolescent's raw score with the national standardisation sample score adjusted for age (see Appendix 9.45).

The decision to use participants' SAS rather than raw scores as outcomes was based on several factors. Firstly, SAS allow for performance to be compared to the general population to place a pupil's performance on a meaningful scale. Secondly, SAS are adjusted to take account of a pupil's age at the time the test was taken. Whilst the CAT had different levels aimed at specific age ranges and school years, within this, participants' ages varied by up to 12 months. This may have resulted in older participants achieving slightly higher raw scores. Hence, use of SAS accounts for age by comparing raw scores to school children of a similar age (within 2 months). Thirdly, SAS are comparable across CAT levels and therefore, allowed the maximum number of cases to be included in the analysis. Finally, SAS are comparable across batteries to permit comparisons between the three domains assessed.

5.4.4.4.3 Indicated outcomes: Predicted GCSE performance

Indicated outcomes are estimates of expected GCSE performance at age 16 years (Year 11) based on CAT performance at age 11-13 years. Indicated outcomes were calculated by an external organisation (GL Assessment, London). The following indicated GCSE outcomes were provided: uncapped point score, capped point score, proportion of pupils likely to achieve ≥ 5 A*-C GCSE grades with and without English and Mathematics, and predicted grades for English and Mathematics. GCSE uncapped and capped point scores were calculated by transforming participants' predicted grades for each subject into corresponding point scores (e.g. A* = 58, A = 52, B = 46 etc.) using the Department for Education point score system (Department for Education, 2013a, 2013d). Predicted points for each subject are then summed to produce point scores. Capped point score is capped at the participant's best 8 predicted GCSE grades.

Indicated outcomes were not included in the analysis as these outcomes are only estimates of GCSE performance. Descriptive information on indicated GCSE outcomes is presented in the results section of this chapter (section 5.5.3.1) to illustrate the expected level of attainment in GCSE assessments for this sample.

5.4.5 Ethical considerations

Prior to commencement of the study, ethical approval was obtained from the IPS Ethics Research Committee at the University of Leeds, UK (Reference: 10-0105, Date: 27/12/2010, see Appendix 9.24). The ethical considerations including recruitment, assent, study withdrawal, confidentiality and AEs are reported in Chapter 3; section 3.4.7.

5.4.6 Statistical analysis

Statistical analyses were performed using SPSS version 21 (SPSS, Inc. Chicago, USA) and the significance level (α-level) was set as $p<0.05$. All data were plotted as means (± SE) unless otherwise stated. Descriptive analyses of breakfast eating patterns including frequency and food type are presented. Descriptive analyses of CAT performance are presented according to gender and are compared to the national standardisation sample (Lohman et al., 2001). All data were summarised and boxplots were produced to screen for outliers and check for normality of distribution. To assess differences in CAT performance in the current sample compared to the national standardisation sample (Lohman et al., 2001), one-sample t-tests were employed on SAS for verbal, non-verbal, quantitative and overall mean SAS. To assess differences in expected GCSE performance in the current sample compared to performance in 2012 for all schools in England and in the Leeds LEA, one-sample t-tests were employed on uncapped and capped GCSE point scores.

5.4.6.1 Primary analysis of the association between habitual breakfast consumption and CAT performance

A series of multiple hierarchical linear regression analyses were performed to establish the extent to which habitual breakfast consumption explained the variance in CAT scores whilst controlling for socio-demographic variables. Four hierarchical multiple regression analyses were conducted on SAS for each battery (verbal, nonverbal and quantitative) and on overall mean SAS score. The "frequent" habitual breakfast consumption category was the reference category in all analyses. Variables were entered into the regression analyses in three blocks. The first model shows the crude (unstandardised [B] and standardised [β]) coefficients and SEs for habitual breakfast consumption only. In the second model, adjustments were made for SES, ethnicity, sex, EAL status and BMI SDS, resulting in adjusted coefficients (B and β) and SEs. In model 3, interaction terms were added to examine interactions between each socio-demographic variable and habitual breakfast consumption. For clarity, only habitual breakfast consumption categories and interaction terms are presented in this chapter. The full regression models and the resulting coefficients (B and β) for habitual breakfast consumption categories, socio-demographic covariates and interaction terms are shown in Appendices 9.46-9.49. Pearson's Product Moment correlation coefficients, produced as part of the multiple regression analyses, between habitual breakfast consumption and CAT SAS were examined initially. Plots of mean SAS by battery and overall mean SAS according to habitual breakfast consumption are shown in Appendix 9.50.

Categorical socio-demographic covariates were coded as follows: ethnicity: 0 (reference) = white British, 1 = other ethnic background; sex: 0 (reference) = male, 1 = female; SES: 0 (reference) = low, 1 = middle/high; EAL: 0 (reference) = no, 1 = yes. Habitual breakfast consumption was transformed into a binary categorical variable by creating two binary dummy variables for "occasional" and "rare" habitual breakfast consumption, with "frequent" as the reference category (Aiken & West, 1991). All dummy variables were entered into the regression analysis in the same block. Regression coefficients indicate the mean difference in CAT SAS for each categorical variable compared to the reference category and the intercept indicates the mean of the reference category (Aiken & West, 1991). To permit testing of interaction terms, new variables were created consisting of all possible two-way interactions between habitual breakfast consumption variables and sex, SES, ethnicity, EAL status and BMI SDS. To avoid the issue of multicollinearity, all predictor variables were centred around zero before interaction terms were created (Foster, Barkus, & Yavorsky, 2006; Rose, Holmbeck, Coakley, & Franks, 2004; Tabachnick & Fidell, 2007). This variable transformation has no impact on the significance or value of the coefficients.

The analyses attempted to control for factors related to both breakfast consumption and academic performance in school children. A series of potential confounders were included in the analyses which included: sex, ethnicity, SES and EAL. Highly statistically significant sex differences in CAT scores have been reported in large samples (>500,000) of British 11-12 year old school children (Calvin, Fernandes, Smith, Visscher, & Deary, 2010; Strand, Deary, & Smith, 2006). There is consistent evidence that SES is a predictor of academic performance and cognitive ability (Brooks-Gunn & Duncan, 1997; Machin & Vignoles, 2004; McCulloch & Joshi, 2001; McLoyd, 1998). Due to the high proportion of participants with EAL, it was likely that the sample had a wide range of language and reading abilities. It was deemed appropriate to consider EAL as a confounding variable to reduce the additional variance arising from language ability, particularly on verbal subtests, which are more vulnerable to such confounds. Having EAL can disproportionately influence performance on verbal reasoning subtests due to the demands placed on reading and familiarity with language (Strand, 2004). Ethnicity was included as a covariate as evidence indicates large differences in attainment associated with ethnicity at age 11, 14 and 16 years (Connolly, 2006; Demack, Drew, & Grimsley, 2000; Strand, 2011). Preliminary regression analyses also indicated that BMI SDS significantly predicted CAT SAS, and was therefore included in the analyses. To test the assumption that these covariates were indeed covariates in the relationship between habitual breakfast consumption and CAT performance, Pearson's Product Moment correlation coefficients, produced as part of the multiple regression analyses were examined. Excluding sex, all socio-demographic covariates correlated significantly with CAT SAS (see Appendix 9.51). Sex was retained as a covariate in the analyses due to the sex differences reported by Strand et al. (2006) and Calvin et al. (2010). All of these covariates are also related to breakfast consumption (Chapter 1; 1.2.2; and see Appendix 9.51).

The relevant assumptions of hierarchical multiple regression analyses were tested. A sample size of 292 with 14 explanatory variables was deemed sufficient for a reliable regression model based on sample size requirements of N $\geq 50 + 8k$, with k equal to the number of explanatory variables (Tabachnick & Fidell, 2007). An examination of the inter-correlations between predictor variables produced as part of the multiple regression analyses (see Appendix 9.51) indicated that none of the predictor variables were strongly correlated which would be indicative of multicollinearity (all coefficients <0.90 ; Tabachnick & Fidell, 2007). Cases were considered outliers when standardised residuals exceeded ±3.3 and were removed from the analysis. Cook's Distance values indicated that no values were >1 suggesting that no cases were particularly influential

(Cook Distance min: 0.00 max: 0.06). Following each regression analysis, a graphical examination of the residuals indicated no departure from normality confirming the data were suitable for regression analysis. Residual scatterplots of standardised residuals against standardised predicted residuals indicated that the assumptions of homoscedasticity and linearity were met.

5.5 Results

5.5.1 Participant demographic characteristics

Participant demographic characteristics are shown in Table 5.2. The sample consisted of 292 participants (males: 157 [53.8%], females: 135 [46.2%]) aged 11-13 years (mean age ± SD: 12.05 ± 0.58) in school Year 7 (53.1%) and 8 (46.9%). Approximately two thirds of the sample were White British (200 [68.5%]). A relatively large proportion of the sample had EAL (79 [27.1%]). Forty percent of participants were classified as low SES. The BMI SDS varied widely with a mean BMI SDS of 0.80 ± 1.25. Three (1%) participants were classified as underweight. Most participants were classified as normal weight (183 [62.7%]), but a relatively large proportion of participants were either overweight (27 [9.2%]) or obese (79 [27.1%]).

Table 5.2: Participant demographic characteristics

Demographic characteristics	n (%)
Gender	
Male	157 (53.8)
Female	135 (46.2)
Ethnicity	
White British	200 (68.5)
Other ethnic background	92 (31.5)
School year group	
Year 7	155 (53.1)
Year 8	137 (46.9)
SES	
Middle/high SES	173 (59.3)
Low SES	119 (40.8)
EAL	
No	213 (73.0)
Yes	79 (27.1)
	Mean (SD)
Age (years)	12.05 (0.58)
Height (cm)	153.15 (8.64)
Weight (kg)	49.02 (13.42)
BMI (SDS/z-scores)	0.80 (1.25)

5.5.2 Habitual breakfast consumption

5.5.2.1 Self-defined breakfast habit

Participants' self-defined breakfast habits and frequency of breakfast intake per week are shown in are shown in Table 5.3. Most participants indicated that they normally consumed breakfast (40.8%) or sometimes consumed breakfast (46.2%). A small proportion of participants indicated that they did not normally consume breakfast (13.0%). Participants' frequency of breakfast intake per week indicated that 8% of participants never (0 days/week) consumed breakfast and approximately a quarter reported that they normally consumed breakfast 1-2 days per week. Only 27.4% of participants reported consuming breakfast every day (7 days/week).

Table 5.3: Self-defined habitual breakfast consumption, frequency of breakfast intake per week (n;%)

Self-defined breakfast habit	**N**	**%**
Yes	119	40.8
No	38	13.0
Sometimes	135	46.2
Frequency of breakfast/week		
0	22	7.5
1-2	70	24.0
3-4	77	26.4
5-6	43	14.7
7	80	27.4

5.5.2.2 Habitual breakfast consumption

Participants were classified into three habitual breakfast consumption categories based on breakfast intake frequency per week. Participants' habitual breakfast consumption is shown in Table 5.4. Approximately a third (31.5%) of participants rarely consumed breakfast. Twenty-six percent were occasional breakfast consumers. The remaining participants (42.1%) were frequent breakfast consumers, consuming breakfast on most days of the week.

Table 5.4: Proportion of participants (n;%) who frequently, occasionally or rarely consumed breakfast

Habitual breakfast consumption	**Frequency per week**	**N**	**%**
Rare	0-2	92	31.5
Occasional	3-4	77	26.4
Frequent	5-7	123	42.1

5.5.2.3 Food choices at breakfast

Foods and drinks usually consumed for school-day and weekend breakfast meals are shown in Table 5.5 (N.B. some participants consumed more than one item at each meal). RTECs were the most frequently consumed food for breakfast on school days (40.1%) and bread was the most commonly consumed food for breakfast during weekends (32.9%). Only 3.1% of participants reported consuming either fruit or vegetables for breakfast on school days and during weekends. Encouragingly, few participants reported consuming snack food and confectionary for breakfast on school days and weekends (<3% of participants). A substantially higher proportion of participants consumed meat and eggs in various forms for weekend breakfast meals (25.4%) compared with school-day breakfast meals (3.4%).

Table 5.5: Number[a] and percentage of sample consuming sixteen food and drink groups for school-day and weekend breakfast meals

Food group	School-day		Weekend	
Cereals and cereal products	**N**	**%**	**N**	**%**
Bread (all types)	87	29.6	96	32.9
RTECs (including muesli)	118	40.1	70	24.0
Other cereals (pasta, rice, pizza)	4	1.4	2	0.7
Cake, pastries, sweet buns	6	2.0	3	1.0
Biscuits, breakfast biscuits or bars	8	2.7	11	3.8
Meat, eggs				
Meat and meat products	3	1.0	35	12.0
Egg (in various forms)	7	2.4	39	13.4
Fruit and vegetables				
Fruit (including smoothies)	7	2.4	1	0.3
Vegetables (including bean and pulses)	0	0.0	3	1.0
Milk and milk products				
Milk (to drink)	17	5.8	8	2.7
Snack food and confectionary				
Savoury snack (crisps)	5	1.7	3	1.0
Chocolates or sugar confectionary	7	2.4	8	2.7
Beverages				
Tea and coffee	23	7.8	27	9.3
Fruit juices	34	11.6	15	5.1
Soft drinks	28	9.5	14	4.8
Water	15	5.1	8	2.7

[a] One participant can have more than one entry

5.5.3 CAT performance

Figure 5.1 shows mean SAS by battery and overall for males, females and all participants compared to the national mean SAS. The overall mean SAS was 90.41 ± 10.77 which equates to stanine 4 which is the lowest band within average performance (see Appendix 9.45). Mean SAS for all three batteries and mean overall SAS were all significantly lower than the national mean, smallest t (284) = -9.93; all p<0.001. Comparing across domains, verbal reasoning ability was lower than nonverbal and quantitative reasoning ability, which may reflect the relatively high proportion of participants with EAL (27.1%) who may have lower English verbal ability. The mean

SAS for verbal reasoning was 87.40 ± 11.79, which corresponds to stanine 3 indicating below average performance. The current sample is not, therefore, representative of reasoning abilities among the general population and represents a low ability group, particularly for verbal reasoning.

Figure 5.1: Mean SAS by battery and overall for males, females and all participants compared to the national mean SAS.

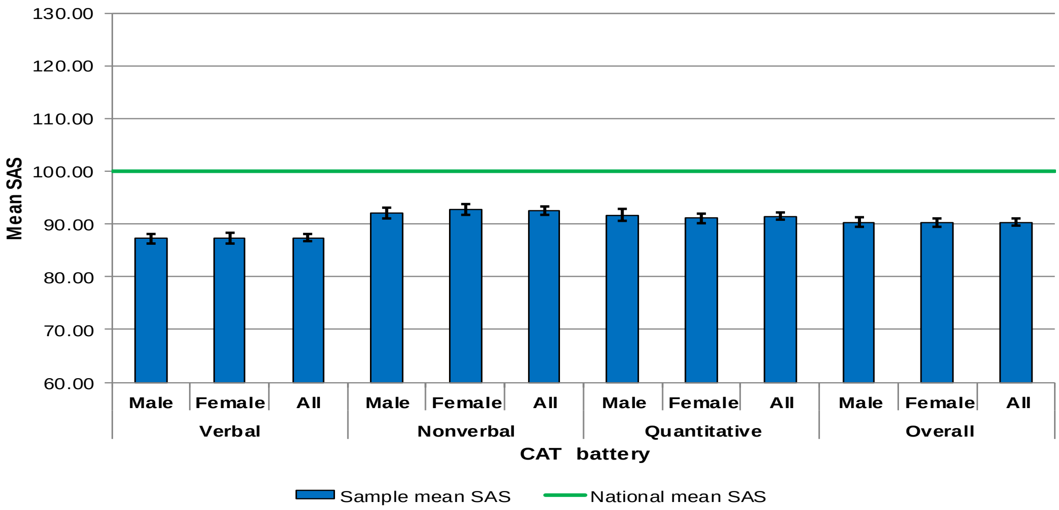
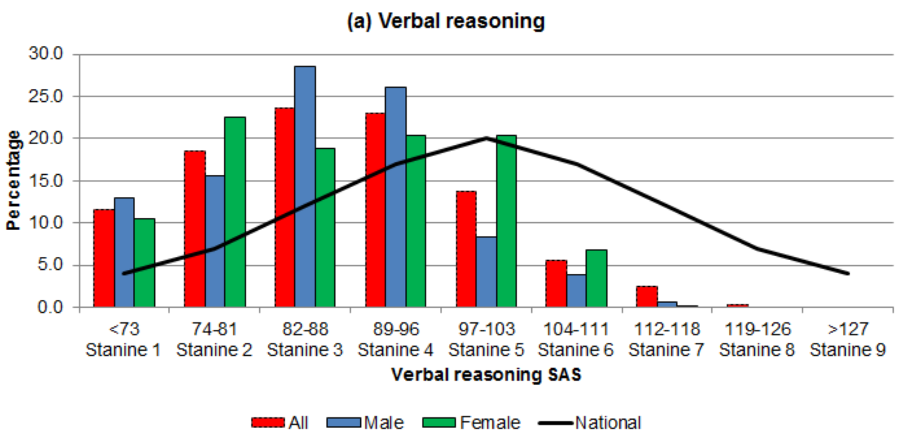
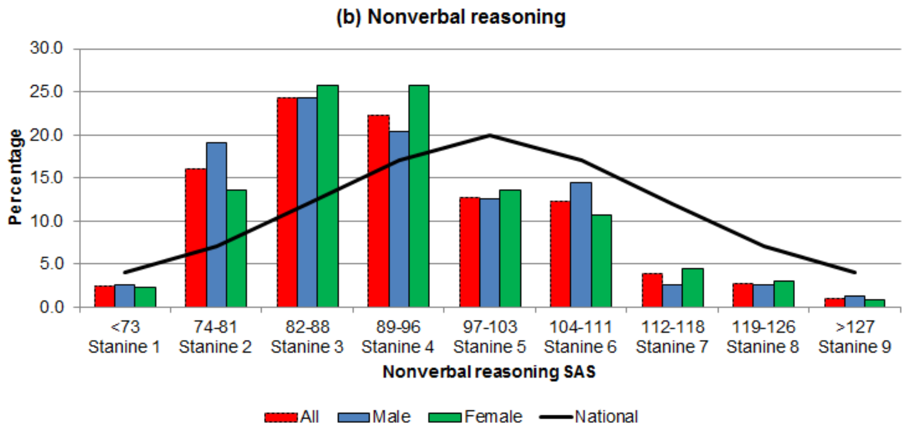
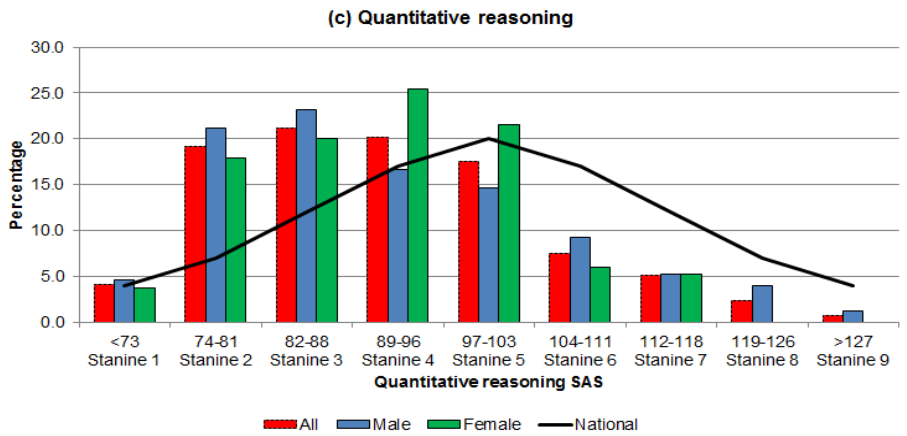


Figure 5.2 illustrates the distribution of scores by stanine band and corresponding SAS range for verbal, nonverbal and quantitative reasoning. This is compared to the expected percentage of school children within each stanine band from the national standardisation sample (see Appendix 9.45). For all batteries, the distribution of scores for all participants in the current sample is positively skewed, indicating that more participants achieved a SAS at the lower end of the distribution than would be expected based on the general population.

Figure 5.2: The percentage of sample within each stanine band and corresponding SAS range for males, females and all participants compared to the distribution of the national standardisation sample for (a) verbal, (b) nonverbal and (c) quantitative reasoning.







5.5.3.1 GCSE indicators

The expected percentage of pupils likely to achieve ≥5 GCSEs at grades A*-C with and without English and Mathematics compared to performance in 2012 for all schools in England and in the Leeds LEA is shown in Table 5.6. Based on CAT performance, only half (51.0%) of participants would be likely to achieve ≥5 GCSEs at grade A*-C. By contrast, in 2012 over 80% of school pupils in the Leeds LEA and in England achieved ≥5 GCSEs at grade A*-C. When this measure was constrained to include at least two GCSEs in English and Mathematics, the expected proportion of participants likely to gain ≥ 5 GCSEs at grade A*-C was 21.2%. This is lower than the proportion of school pupils who achieved ≥5 GCSEs at grade A*-C including English and Mathematics in 2012 in the Leeds LEA and in England (45.7% and 53.2% respectively).

Table 5.6: Expected percentage of participants likely to achieve ≥5 GCSEs at grade A*-C with and without English and Mathematics compared to performance in 2012 for all schools in England (state and independent) and in the Leeds LEA.

Threshold targets	Male	Female	All	National	LEA
≥ 5 A*-C GCSEs	51.0	50.7	51.0	81.9	84.1
≥ 5 A*-C GCSEs including English & Maths	20.6	21.3	21.2	53.2	45.7

Figure 5.3 shows indicated mean uncapped and capped GCSE point score for males, females and all participants compared to performance in 2012 for all schools in England and in the Leeds LEA. Indicated mean uncapped point score was 352.21 ± 86.39 which was significantly lower than the national and LEA averages in 2012, $t(291) = -23.83$, $p<0.001$ and $t(291) = -28.68$, $p<0.001$ respectively. Similarly, indicated mean capped point score was 284.23 ± 54.96 which was significantly lower than the national and LEA averages, $t(291) = -17.88$, $p<0.001$ and $t(291) = -18.13$, $p<0.001$ respectively. Therefore, the current sample is not representative in terms of GCSE attainment among the general population and is likely to represent a low ability group.

Figure 5.3: Indicated mean GCSE point score for (a) uncapped and (b) capped point score for males, females and all participants compared to performance in 2012 in all schools in England and in the Leeds LEA

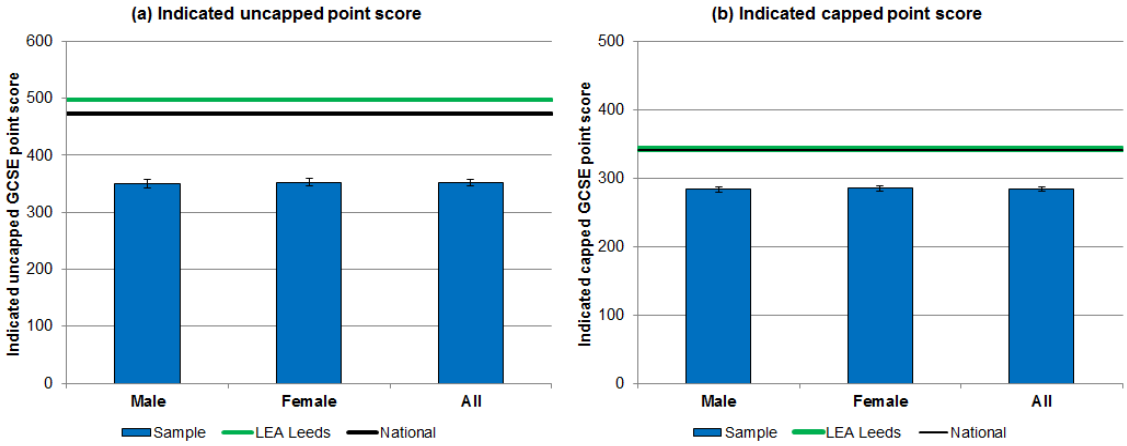
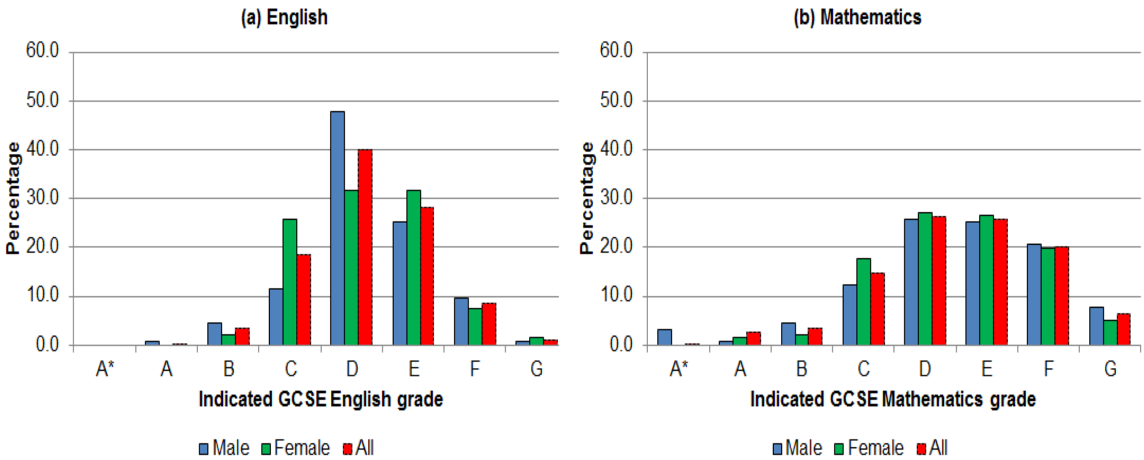


Figure 5.4 illustrates the likely distribution of GCSE grades (highest grade: A* lowest grade: G) in English and Mathematics based on CAT performance. For both subjects, a large proportion of participants were predicted to achieve grades C-F. The proportion of participants likely to gain an A* or A grade was ≤4% for both subjects.

Figure 5.4: Expected distribution of GCSE grades predicted from CAT performance in (a) English and (b) Mathematics



5.5.4 The association between habitual breakfast consumption and CAT scores

5.5.4.1 Correlations between habitual breakfast consumption and CAT SAS

Correlations between habitual breakfast consumption and CAT SAS produced as part of the hierarchical multiple regression analyses are shown in Table 5.7. Habitual breakfast consumption was not significantly associated with performance on any of the CAT subtests or overall performance.

Table 5.7: Correlations between habitual breakfast consumption categories and CAT SAS relative to the reference category of frequent habitual breakfast consumption.

Habitual breakfast consumption	Verbal SAS	Nonverbal SAS	Quantitative SAS	Overall SAS
Occasional [a]	-0.07	-0.05	0.05	-0.03
Rare [a]	-0.02	0.01	-0.05	-0.03

Values for Pearson's Product Moment correlation
[a] Frequent habitual breakfast consumption as reference

5.5.4.2 Verbal reasoning CAT SAS

There were missing data for three participants and therefore these data were not included in this analysis. Table 5.8 details the results of the hierarchical multiple regression analysis with verbal reasoning CAT SAS as the outcome variable and the crude (model 1) and adjusted (models 2 and 3) beta coefficients (β and B). Model 1 was non-significant, $F(2,286) = 1.08$, *ns*. In model 2, the inclusion of socio-demographic covariates (Table 5.8, model 2) resulted in a significant model which explained 6.0% of the variance in verbal reasoning CAT SAS, $R^2 = 0.06$; adjusted $R^2 = 0.03$; $F(7,281) = 2.36$, $p<0.05$. The change in variance (ΔR^2) accounted for was 5.0% reflecting the effects of the addition of socio-demographic covariates, $\Delta R^2 = 0.05$; $F(5,281) = 2.80$, $p<0.05$. However, occasional and rare habitual breakfast consumption were not significantly associated with verbal reasoning SAS. In model 3, the inclusion of interaction terms (Table 5.8, model 3) did not significantly improve the model and all interaction terms were non-significant, $R^2 = 0.08$; adjusted $R^2 = 0.02$; $F(17,271) = 1.26$, *ns*. Correspondingly, the change in variance accounted for in model 3 was non-significant, $\Delta R^2 = 0.01$; $F(10,271) = 0.51$, *ns*. The relationship between rare and occasional habitual breakfast consumption and verbal reasoning CAT performance remained non-significant.

Table 5.8: Hierarchical multiple regression analysis for verbal reasoning CAT SAS

Model	Explanatory Variables	R^2	ΔR^2	ANOVA	B	SE B	β
1[a]	**Habitual breakfast consumption**	0.01	0.01	$F(2,286) = 1.08$, $p=0.340$			
	Frequent (reference)						
	Occasional				-2.57	1.79	-0.10
	Rare				-1.47	1.70	-0.06
2[b]	**Habitual breakfast consumption**	0.06	0.05*	$F(7,281) = 2.36$, $p<0.05$			
	Frequent (reference)						
	Occasional				-1.72	1.78	-0.06
	Rare				-1.74	1.71	-0.07
3[c]	**Habitual breakfast consumption**	0.08	0.02	$F(17,271) = 1.26$, $p=0.222$			
	Frequent (reference)						
	Occasional				-1.50	1.85	-0.06
	Rare				-1.39	1.75	-0.05
	Interaction terms						
	Ethnicity * Occasional breakfast				1.39	3.87	0.03
	Ethnicity * Rare breakfast				-0.31	3.93	-0.01
	SES * Occasional breakfast				-0.49	3.87	-0.01
	SES * Rare breakfast				4.14	3.50	0.08
	Sex * Occasional breakfast				3.58	3.71	0.07
	Sex * Rare breakfast				0.08	3.48	0.00
	EAL* Occasional breakfast				-2.13	3.88	-0.04
	EAL* Rare breakfast				-3.72	3.99	-0.06
	BMI SDS* Occasional breakfast				1.06	1.50	0.05
	BMI SDS* Rare breakfast				-0.53	1.39	-0.03

[a] Crude (unadjusted) model
[b] Adjusted model: Includes habitual breakfast consumption adjusted for ethnicity, SES, sex, EAL and BMI SDS
[c] Fully adjusted model: Includes habitual breakfast consumption adjusted for ethnicity, SES, sex, EAL, BMI SDS and interaction terms
*p <0.05, ** p<0.01, ***p<0.001

5.5.4.3 Nonverbal, quantitative and overall reasoning CAT SAS

The same pattern of results was observed for nonverbal, quantitative, and overall reasoning CAT SAS. For brevity these results are reported together. Seven participants had missing nonverbal data and 5 participants had missing quantitative reasoning data. The hierarchical multiple regression analysis for each outcome variable is shown in tables 5.9-5.11. Model 1 was non-significant, smallest $F(2,284)=0.40$, *ns*. The addition of socio-demographic covariates in model 2 also resulted in a non-significant model, smallest $F(7,279)=1.61$, *ns*. Model 3 was also non-significant, $F(17,269)=0.97$, *ns*. In all models, the resulting β coefficients indicated that habitual breakfast consumption did not predict nonverbal, quantitative, and overall reasoning CAT SAS.

Table 5.9: **Hierarchical multiple regression analysis for nonverbal reasoning CAT SAS**

Model	Explanatory Variables	R^2	ΔR^2	ANOVA	B	SE B	β
1[a]	**Habitual breakfast consumption**	0.01	0.01	$F(2, 282)=0.41$ $p=0.667$			
	Frequent (reference)						
	Occasional				-1.76	1.96	-0.06
	Rare				-0.75	1.86	-0.03
2[b]	**Habitual breakfast consumption**	0.04	0.04	$F(7, 277)=1.65$ $p=0.122$			
	Frequent (reference)						
	Occasional				-1.85	1.96	-0.06
	Rare				-0.65	1.88	-0.02
3[c]	**Habitual breakfast consumption**	0.07	0.02	$F(17, 267)=1.02$ $p=0.436$			
	Frequent (reference)						
	Occasional				-2.20	2.03	-0.08
	Rare				-0.75	1.92	-0.03
	Interaction terms						
	Ethnicity * Occasional breakfast				6.02	4.28	0.10
	Ethnicity * Rare breakfast				-0.70	4.27	-0.01
	SES * Occasional breakfast				1.95	4.23	0.03
	SES * Rare breakfast				3.69	3.83	0.07
	Sex * Occasional breakfast				-3.04	4.07	-0.05
	Sex * Rare breakfast				-2.01	3.80	-0.04
	EAL* Occasional breakfast				-2.85	4.26	-0.05
	EAL* Rare breakfast				0.39	4.43	0.01
	BMI SDS* Occasional breakfast				1.68	1.65	0.07
	BMI SDS* Rare breakfast				1.60	1.54	0.07

[a] Crude (unadjusted) model
[b] Adjusted model: Includes habitual breakfast consumption adjusted for ethnicity, SES, sex, EAL, BMI SDS.
[c] Fully adjusted model: Includes habitual breakfast consumption adjusted for ethnicity, SES, sex, EAL, BMI SDS and interaction terms
*$p<0.05$, ** $p<0.01$, ***$p<0.001$

Table 5.10: Hierarchical multiple regression analysis for quantitative reasoning CAT SAS

Model	Explanatory Variables	R^2	ΔR^2	ANOVA	B	SE B	β
1[a]	**Habitual breakfast consumption**	0.01	0.01	$F(2,284)=0.40$, $p=0.668$			
	Frequent (reference)						
	Occasional				0.89	1.95	0.03
	Rare				-0.96	1.84	-0.04
2[b]	**Habitual breakfast consumption**	0.04	0.03	$F(7,279)=1.61$, $p=0.134$			
	Frequent (reference)						
	Occasional				1.37	1.95	0.05
	Rare				-0.60	1.86	-0.02
3[c]	**Habitual breakfast consumption**	0.06	0.02	$F(17,269)=0.97$, $p=0.490$			
	Frequent (reference)						
	Occasional				1.33	2.02	0.05
	Rare				-0.52	1.90	-0.02
	Interaction terms						
	Ethnicity * Occasional breakfast				3.81	4.23	0.07
	Ethnicity * Rare breakfast				-1.14	4.23	-0.02
	SES * Occasional breakfast				2.73	4.22	0.05
	SES * Rare breakfast				1.66	3.81	0.03
	Sex * Occasional breakfast				3.92	4.06	0.07
	Sex * Rare breakfast				0.15	3.79	0.00
	EAL* Occasional breakfast				-5.39	4.27	-0.09
	EAL* Rare breakfast				-2.67	4.38	-0.04
	BMI SDS * Occasional breakfast				1.73	1.63	0.07
	BMI SDS* Rare breakfast				0.80	1.52	0.04

[a] Crude (unadjusted) model
[b] Adjusted model: Includes habitual breakfast consumption adjusted for ethnicity, SES, sex, EAL and BMI SDS
[c] Fully adjusted model: Includes habitual breakfast consumption adjusted for ethnicity, SES, sex, EAL, BMI SDS and interaction terms
*$p<0.05$, ** $p<0.01$, ***$p<0.001$

Table 5.11: Hierarchical multiple regression analysis for overall CAT SAS

Model	Explanatory Variables	R^2	ΔR^2	ANOVA	B	SE B	β
1[a]	**Habitual breakfast consumption**	0.01	0.01	$F(2,289)=0.41$, $p=0.663$			
	Frequent (reference)						
	Occasional				-1.22	1.64	-0.05
	Rare				-1.20	1.54	-0.05
2[b]	**Habitual breakfast consumption**	0.05	0.04	$F(7,284)=1.92$, $p=0.093$			
	Frequent (reference)						
	Occasional				-0.77	1.64	-0.03
	Rare				-1.04	1.56	-0.05
3[c]	**Habitual breakfast consumption**	0.07	0.02	$F(17,274)=1.08$, $p=0.327$			
	Frequent (reference)						
	Occasional				-0.83	1.70	-0.03
	Rare				-0.89	1.60	-0.04
	Interaction terms						
	Ethnicity * Occasional breakfast				3.47	3.55	0.07
	Ethnicity * Rare breakfast				-0.78	3.56	-0.02
	SES * Occasional breakfast				1.51	3.56	0.03
	SES * Rare breakfast				3.59	3.18	0.08
	Sex * Occasional breakfast				1.89	3.41	0.04
	Sex * Rare breakfast				-0.93	3.16	-0.02
	EAL * Occasional breakfast				-3.47	3.56	-0.07
	EAL * Rare breakfast				-1.80	3.66	-0.03
	BMI SDS* Occasional breakfast				1.45	1.38	0.07
	BMI SDS* Rare breakfast				0.49	1.27	0.03

[a] Crude (unadjusted) model
[b] Adjusted model: Includes habitual breakfast consumption adjusted for ethnicity, SES, sex, EAL and BMI SDS.
[c] Fully adjusted model: Includes habitual breakfast consumption adjusted for ethnicity, SES, sex, EAL, BMI SDS and interaction terms
*$p<0.05$, ** $p<0.01$, ***$p<0.001$

5.6 Discussion

The study presented in this chapter examined the hypothesis that habitual breakfast skipping is negatively associated with CAT performance, a test of reasoning abilities taken by many school children in the UK in the first year of secondary education. The study extends previous work by exploring interaction effects of socio-demographic characteristics in the relationship between habitual breakfast consumption and CAT performance.

5.6.1 Overview of findings

Contrary to expectations, there was no evidence to support the hypothesis that habitual breakfast skipping is negatively associated with CAT performance in this sample of 11-13 year olds. The consistent null findings for verbal, nonverbal, quantitative and overall reasoning ability indicates that frequency of habitual breakfast consumption did not influence performance on any CAT subtest. This finding also did not vary by gender, ethnicity, SES, EAL status and BMI SDS. Therefore, factors other than frequency of habitual breakfast consumption are likely to have exerted a greater influence on CAT performance. Nearly all linear regression models were non-significant and explained a small amount of the variance in CAT performance. Similarly, even with the addition of socio-demographic covariates, only a small amount of variance in CAT performance was explained, implying that CAT performance is potentially explained by unmeasured variables.

The findings of the current study are inconsistent with the existing literature on the association between breakfast consumption and academic performance reviewed in Chapter 4. In this respect, it is helpful to compare the findings of the current study to those of other cross-sectional studies in young adolescents with similar socio-demographic characteristics. Two cross-sectional studies have demonstrated a consistent positive association between habitual breakfast consumption frequency and achievement test scores in children and adolescents. Associations were apparent in school children aged 9-15 years, from low SES backgrounds and/or of low academic ability. Hence the characteristics of these samples were comparable to those of the current study sample. Acham et al. (2012) demonstrated a positive association between breakfast intake frequency and achievement test scores in a sample of 645 Ugandan 9-15 year olds who were mostly of low academic ability and low SES. A positive association between breakfast eating frequency and achievement test scores was also reported by Edwards et al. (2011) in a sample of 800 American 11-13 year olds, of which 14% were eligible for FSMs.

Only one previous epidemiological study has reported findings that are consistent with the results reported in this chapter. Miller et al. (2012) failed to find a significant positive association between breakfast consumption frequency and scores on standardised achievement tests in a large sample of American 5-15 year olds. In their analyses, Miller et al. (2012) controlled for a more extensive set of covariates compared to the aforementioned studies. This suggests that the associations reported by these studies were driven by residual or unmeasured confounding. Taken together with the null findings of the current study, this suggests that the positive associations between breakfast consumption and academic performance reported in previous work should be viewed with some caution. Alternatively, there are possible factors which may explain the lack of significant associations found in the current study. These factors may also indicate important reasons for the discrepancy between the findings of the current study and other similar studies described above.

5.6.2 Possible explanations for the null findings

5.6.2.1 The proxy measurement of academic performance

Although the current study contributed to the existing literature, an important caveat to the results is that academic performance was measured by reasoning tests that do not directly assess actual academic performance based on the content of the taught curriculum. Educational assessments in British secondary schools are either made by achievement tests, such as NC key stage tests and GCSE examinations, or by reasoning tests such as the CAT (Strand, 2006). The majority of previous studies that report positive associations between habitual breakfast consumption and academic performance use school grades or achievement tests that assess content drawn from the taught curriculum (Chapter 4; Adolphus et al., 2013). Reasoning tests and achievement tests can be contrasted on a number of dimensions. This may provide possible explanations for the lack of associations found in the current study and account for the disagreement in findings compared with previous studies. These differences are discussed below in conjunction with other limitations relating to the academic performance measure used in the current study (the CAT).

5.6.2.1.1 The predictive validity of reasoning tests for academic performance

Achievement tests are designed to measure specific outcomes of learning from the taught curriculum. All test content is directly drawn from what pupils learn at school and their outcomes reflect how well pupils have acquired and retained knowledge in key areas of the curriculum. These tests can therefore be considered as direct measures of academic performance. In contrast, reasoning tests do not assess what is learned in school but contain more general assessments of content broadly similar to the taught curriculum using familiar and basic elements such as simple words, numbers and mathematical operators and shapes. Reasoning tests are considered to be valid predictors of academic performance. There is a strong correlation between CAT performance and subsequent attainment on NC key stage 3 tests (usually at age 14 years) and GCSE examinations (usually at age 16 years; Lohman et al., 2001; Strand, 2006). The CAT is typically used in schools to predict GCSE performance by providing GCSE indicated outcomes (Lohman et al., 2001). Hence, in the present study, the CAT was considered as a good proxy measure of academic performance. However, whilst the correlations between CAT performance and NC key stage 3 and GCSE performance are all highly significant, this does not indicate a deterministic relationship. The indicated outcomes give a typical or most frequent outcome for a particular age 11 CAT SAS and there will be a range of achievement around it. Strand (2006) demonstrated that approximately half of the variance in NC key stage 3 and GCSE outcomes is attributable to CAT performance at age 11 years. Clearly, other factors may influence performance on subsequent academic assessments. Such factors may include quality of teaching, opportunities to learn, parental support, motivation and effort of the pupil and their emotional and physical well-being including nutritional intake. Hence, from the current study it cannot be confidently concluded that habitual breakfast consumption has no association with academic performance given that a proxy indicator for direct measures of academic performance was used. Furthermore, the key differences in the content of the measures may account for the disparate findings in the current study compared with previous studies.

5.6.2.1.2 The consistency in reasoning test scores over time

Reasoning test scores tend to be more stable over time than achievement test scores. The CAT third edition has good test-retest reliability based on data from over 10,000 UK school children who were tested at age 10 years (school Year 6) and 13 years (school Year 9; Strand, 2004). The correlation coefficient for overall mean SAS at age 10 and 13 years was 0.89, suggesting a high degree of consistency in scores over time. Correlations were strongest for verbal and quantitative reasoning and lowest for nonverbal reasoning. This may be because of the relatively novel material in the nonverbal reasoning test battery which could be susceptible to practise effects. However, despite high reliability coefficients, pupils' scores between age 10 and 13 years can show significant progress over time (>10 standard score points; Strand, 2004).

In contrast, achievement tests, including NC tests and GCSE examinations, are used specifically to measure pupils' progress over time (Department for Children, Schools and Families, 2009b). Furthermore, secondary schools are often judged based on a measure of the amount of progress pupils make between NC tests and GCSE examinations. Pupils' NC key stage 3 tests and GCSE results are compared to their prior NC key stage 2 test scores to calculate a 'value-added' measure of pupil progress to indicate a school's effectiveness (Department for Education, 2012). Although, some authors have suggested that the small changes in reasoning scores can be used to measure pupils' progress and to measure the 'value-added' by a school given that the quality of teaching and learning opportunities should enhance transferable reasoning skills (Primrose, Fuller, & Littledyke, 2000).

The consistency in reasoning scores over time suggests that school reasoning tests may not be sensitive to the potential beneficial effects of breakfast since scores tend to remain stable over time. Instead, achievement tests may be more sensitive measures in detecting an association between habitual breakfast consumption and academic performance as pupils' performance generally progresses over time (Department for Children, Schools and Families, 2009b). Hence, achievement tests are likely to be influenced by the effects of habitually consuming breakfast to a greater degree than reasoning tests. The consistency in reasoning scores over time may account for the lack of associations reported in the current study, rather than the true absence of an association with academic performance. Hence CAT performance may have been an inappropriate measure considering that the immediate and cumulative effects of consuming breakfast on academic performance are likely to be subtle.

5.6.2.1.3 The transferability of reasoning scores to educational attainment

Reasoning tests assess transferable learning abilities that can be applied to a wide range of subjects (Lohman et al., 2001). However, the educational significance of reasoning tests is unclear and less obvious in comparison to achievement tests. An average CAT SAS cannot be directly interpreted in terms of more familiar educational standards such as grades and NC levels. Similarly, schools tend to have greater interest in the outcomes of achievement tests given their role in public accountability through their publication in "league tables" (Department for Education, 2013b). Furthermore, schools are set expected targets for key stage NC tests, GCSE examinations and value-added measures and are judged against meeting these targets. In contrast, for reasoning tests such as the CAT there are no specified targets and the results are not published or used to judge school quality. Consequently, secondary schools often consider the CAT as "low stakes" and NC key stage tests and GCSE examinations as "high stakes" (Strand, 2006). Thus, reasoning tests may not provide as meaningful and significant academic measures as achievement tests.

5.6.2.1.4 The anxiety-provoking nature of the CAT

Another factor to consider in relation to the null findings is the anxiety-provoking nature of the CAT. The CAT can cause considerable state anxiety (test anxiety) such as subjective feelings of tension, worry and apprehension. The CAT, or other school administered reasoning tests, may cause more test anxiety than achievement tests because the test content and format is unfamiliar and not based on the taught curriculum. Furthermore, the CAT does not require preparation. Therefore, school children may feel more anxious because they have not prepared and thus this lack of preparation could negatively affect their performance. Moreover, the CAT is most typically administered at the start of the first year of secondary education (Year 7), during the initial period of transition into secondary school which may further heighten test anxiety. The arousal caused by such anxiety may have both a motivational and detrimental effect on performance. Research has shown that test anxiety negatively correlates with cognitive performance outcomes (Reeve & Bonaccio, 2008). The debilitating effects of test anxiety may be because the subjective feelings of tension, worry and apprehension divert the test taker's attention away from the task (Reeve & Bonaccio, 2008). For example, the test taker may be unable to concentrate fully on the task because of a preoccupation with performance and/or consequences of failure. This may have partly contributed to the low CAT performance in this sample. Conversely, cortisol release during a stressful situation such as the CAT might present which has been shown to improve cognitive performance by increasing arousal (Abercrombie et al., 2003). Moreover, ingestion of carbohydrate has been shown to amplify the cortisol response in such situations (Kirschbaum et al., 1997). Therefore, high levels of test anxiety could have obscured and overridden the effects of breakfast on CAT performance.

It is apparent, therefore, that these measures of academic performance assess different domains and have different sensitivities. This suggests that the results of the present study may not permit conclusions about the association between habitual breakfast consumption and academic performance. By analysing the association between habitual breakfast consumption and a proxy measure of academic performance, rather than measures of specific curricular attainment, this study may be understood as an extension of previous research, rather than a refutation of the previous positive associations reported (e.g. Acham et al. 2012; Edwards et al. 2011; see Chapter 4). However, despite the issues surrounding the use of reasoning tests to measure academic performance, one previous study has demonstrated a positive association between breakfast consumption and performance on school reasoning tests (e.g. the scholastic aptitude test) in 9–11 year olds (Lopez-Sobaler et al., 2003). This suggests that factors other than the use of the CAT may account for the null findings reported in the current study. These possible factors are discussed below.

5.6.2.2 The definition of habitual breakfast consumption

One factor that may have affected the findings of the current study and contributed to the disagreement in findings compared with previous studies, is the classification of habitual breakfast consumption. The literature gives mixed definitions and cut-offs to define “frequent” habitual breakfast consumption (Rampersaud et al., 2005). In the present study, participants were classified into habitual breakfast consumption groups on a frequency basis where a specific number of days of breakfast intake per week was used to define rare, occasional or frequent habitual breakfast consumption. Previous studies have used various methods and classification systems to define habitual breakfast consumption. Twenty-four hour recalls or 1-day dietary surveys were used in previous studies where frequent habitual breakfast consumption was defined as having consumed breakfast on the day of the recall (Herrero Lozano & Fillat Ballesteros, 2006). This method was not used in the current study as a one-day reporting period would not adequately reflect habitual breakfast consumption.

Previous studies have also defined habitual breakfast consumption on a frequency basis. However, of the studies that do define habitual breakfast consumption on a frequency basis, there is variation in the frequency of breakfast intake to indicate the various consumption categories. For example, Lien et al. (2007) used a 5-group classification system which defined habitual breakfast consumption as never, 1-2 days per week, 3-4 days per week, 5-6 days per week and every day. So et al. (2013) and Miller et al. (2012) employed a 7-group classification system (0-7 days). Dichotomous classification systems are also employed to define habitual breakfast consumption as “regular” (≥ 5 days per week) or “irregular” (<5 days per week; Boschloo et al., 2012, Edwards et al., 2011). One previous study employed a three category classification system to define habitual breakfast consumption, comparable to the current study (Gajre et al., 2008). However, Gajre et al., (2008) used different frequencies of breakfast intake per week to indicate the various consumption categories (e.g. regular: ≥ 4 days per week, irregular: 2-3 days per week and never: 0-1 day per week). Whilst these are subtle differences in the frequency of breakfast intake, this may have affected the ability to detect a significant association with CAT performance in the present study.

5.6.2.3 The lack of distinction between school-day and weekend breakfast intake

The present study did not distinguish between school-day and weekend breakfast intake frequency in the classification of habitual breakfast consumption which may partly explain the non-significant associations with CAT performance. School-day breakfast intake may exert a greater influence on academic performance given that it is consumed before school and may have immediate effects on the subsequent experience in school lessons and possibly assessments or examinations occurring after consumption. Furthermore, differentiating between school-day and weekend breakfast intake is important because habits may differ (Alexy, Wicher, & Kersting, 2010; Cullen, Lara, & Moor, 2002). Weekend and school-day breakfast intake may also be different in terms of the time breakfast is consumed and the environment in which it is consumed because of different waking times and schedules. On weekends, more school children report consuming breakfast in general and more school children report eating breakfast with parents compared with school days (Vanelli et al., 2005).

In the current study, the lack of distinction between school-day and weekend breakfast intake frequency may have resulted in a less relevant and sensitive measure of habitual breakfast consumption in relation to academic performance. In addition, this lack of distinction will have resulted in variation in the pattern of breakfast intake on school days and weekend days within each habitual breakfast consumption category. For example, a participant classified as a frequent breakfast consumer could have consumed breakfast on 3 school days and 2 weekends or all 5 school days. An adolescent who habitually consumes breakfast on 3 school days is not indicative of frequent breakfast consumption on school days, which is most likely to influence academic performance. Moreover, adolescents within habitual breakfast consumption categories will not be entirely comparable in terms of their breakfast intake pattern. This variation in breakfast intake within the frequent, occasional and rare consumption categories may account for the lack of associations found in the current study.

5.6.2.4 The definition of a breakfast eating occasion

Participants were not given a clear definition of breakfast meaning that breakfast was subjectively interpreted by the individual. What was considered as “breakfast” may have varied between participants in terms of the type and amount of food consumed, and the time of day. Some participants may have considered food consumed later in the morning, for example at mid-morning break time, as breakfast, even though in these participants the overnight fasting period will have been extended for the majority of the morning lessons. Some participants may have also considered a small amount of food or drink as breakfast. In addition, some participants may not have considered more unhealthy food items, non-traditional breakfast foods, food consumed on the way to school or hand held food as breakfast.

The use of a questionnaire with a single item to measure habitual breakfast consumption as frequency per week did not allow for the assessment of the type and amount of food consumed, and the time of day it was consumed. Although participants were asked what they usually consumed at this time, this did not reflect daily differences in food intake at breakfast. Therefore, the data did not allow for the study to employ a standardised definition of breakfast post-hoc (e.g. threshold amount of food or energy and/or time of day). This may have caused inconsistencies in habitual breakfast patterns between participants and contributed to the lack of significant association with CAT performance. By employing a dietary assessment method that permitted the measurement of food intake at breakfast would have allowed the composition and time of breakfast to be considered when defining a breakfast eating occasion.

5.6.3 Considerations for future studies using academic performance outcomes

The present study's findings suggest that there are more comprehensive ways in which future studies might investigate the relationship between habitual breakfast consumption and academic performance. Hence, the following modifications were considered for the subsequent studies in this thesis evaluating academic performance outcomes:

I. *Employ achievement tests as measures of actual academic performance*

Future work should employ a measure of actual academic performance using achievement tests that assess outcomes of the taught curriculum. These measures may be more sensitive to the effects of habitual breakfast consumption. Assessing academic performance using measures of the taught curriculum would permit more confident conclusions about the relationship between habitual breakfast consumption and academic performance. The outcomes of achievement tests such as grades and NC levels are more familiar and established educational standards than outcomes of reasoning tests. These measures also have more educational significance to pupils, parents and teachers. Examining older adolescents is necessary if studies employ academic performance measures used in secondary education as outcomes. These include NC key stage tests (administered in school Year 9; ages 13-14 years) and GCSE examinations (administered in school Years 10-11; ages 15-16 years).

II. *Use food diaries, or variants, to measure frequency of breakfast intake, breakfast composition and time of intake*

Further work should employ a more comprehensive method to assess breakfast intake than the current study. The single item question to indicate the frequency of breakfast intake per week may not have provided an adequate assessment of breakfast and did not capture breakfast composition. A food diary or dietary recall method would allow for data on the composition of breakfast to be considered when classifying habitual breakfast consumption. These measures should include an adequate measurement period to reflect habitual breakfast consumption.

III. *Apply a consistent definition of a breakfast eating occasion*

A breakfast eating occasion should be specifically defined to all participants to attempt to reduce inconsistencies between participants. This definition should also specify the time of day for the eating episode to be considered as breakfast. This will ensure that breakfast is not consumed late-morning thus resulting in an extended overnight fasting period. To strengthen this definition, future studies should apply a threshold indicator to define a breakfast eating occasion. The energy content of breakfast would be a useful objective indicator of a breakfast eating occasion. Weight of food may not provide a good indicator as foods and drinks can be high in weight but provide little or no energy. If an energy content threshold is applied in the definition of breakfast, then this should take into account individual differences in energy needs given that BMI and consequently, energy need varies widely, particularly by gender. An appropriate estimation of energy needs for participants would be needed in this respect.

IV. *Distinguish between school-day and weekend breakfast intake*

School-day and weekend breakfast intake should be considered separately in the classification system used define habitual breakfast consumption. Previous studies, including the study reported in this chapter, have not isolated breakfast intake on school days and weekends despite the importance for academic performance. This would provide a more appropriate measure of habitual breakfast consumption in relation to academic performance and account for differences in school-day and weekend breakfast intakes. Within the categories representing frequent, occasional or rare breakfast consumption, there should be less variation in the frequency of breakfast intake. This would permit a more refined and relevant habitual breakfast consumption classification system in which adolescents within the same consumption category are more comparable in terms of their breakfast intake.

V. *Use a direct, individual-level measure of SES.*

Further work should continue to use individual level measures of SES in the analysis. The measure of SES used in the current study was FSM status. FSM status identifies those claiming, rather than their eligibility for FSM. Hence FSM status may incorrectly classify participants in families who do not claim support payments to which they are entitled, and/or participants in families who do not apply for FSMs but are eligible. Additionally, FSM status is a dynamic rather than a fixed quality with approximately 5-7% of pupils changing FSM status annually (Department for Children, Schools and Families, 2009a). Thus, at any time point, some participants' SES may be incorrectly classified on this basis. More direct and stable measures of SES, such as parental income, parent education level or occupation, could be more accurate measures of SES to include as covariates in the analysis.

5.6.4 Conclusion

To conclude, the present study provided no evidence that habitual breakfast consumption was associated with academic performance in the sample of 11-13 year old adolescents studied. In drawing conclusions from this study, it is important to consider the proxy measure of academic performance utilised (i.e. the CAT). Although this study found no association between habitual breakfast consumption and academic performance, and differs from previous studies methodologically, it is premature to make firm conclusions about the value of habitual breakfast consumption for academic performance from this study. However, the present study has highlighted important methodological considerations that were taken forward and applied to subsequent work presented in this thesis in order to better understand the relationship between habitual breakfast consumption and academic performance.

6 Study 3: Habitual school-day breakfast consumption in 16-18 year olds and the association with academic performance

Statement of Contribution

The candidate confirms that she was solely responsible for the conception and design of the study. The candidate was solely responsible for the statistical analysis and interpretation of the data in this chapter. The candidate was solely responsible for writing the chapter and the production of all tables and figures. Undergraduate project students assisted with data collection. Supervisors provided editing and proof-reading assistance with the chapter.

6.1 Introduction

Study 2 reported in the previous chapter (Chapter 5) examined the association between habitual breakfast consumption and CAT performance, an age-specific reasoning test routinely used to predict key stage 3 and GCSE examination results. The findings from this study indicated that there was no relationship between habitual breakfast consumption and CAT performance in 11-13 year olds. However, the possibility that habitual breakfast consumption may influence actual academic performance was not explored. Whilst CAT scores are highly correlated with subsequent examinations results (Lohman et al., 2001), it is more pertinent to measure actual academic performance using specific outcomes of learning from the national curriculum. The GCSE is a nationally administered course taken in a range of subjects by most 15-16 year olds during the final two years of secondary education in England, Wales and Northern Ireland. As recommended in Chapter 5, this study considers associations of breakfast and actual academic outcomes using GCSE assessments.

The SRR reported in Chapter 4 highlighted evidence that habitual breakfast consumption is positively associated with academic performance (Chapter 4; Adolphus et al., 2013). Some of the studies reviewed in Chapter 4, and Study 2 (Chapter 5), were criticised for their choice of method to assess and define habitual breakfast consumption. Nearly all studies included in the SRR, and Study 2 (Chapter 5), did not differentiate between school-day and weekend breakfast intake, despite the likely importance of school-day breakfast consumption in the relationship with academic attainment. Therefore, the study reported in this chapter intended to extend previous research by concentrating on the unique contribution of school-day breakfast eating to this relationship. The SRR highlighted the need for further work to employ an adequate measurement period of breakfast intake (e.g. at least 7 days) to sufficiently reflect habitual consumption. Study 2 (Chapter 5) also highlighted the need to apply a standard definition of breakfast and possible energy-based cut-off to define breakfast. The study reported in this chapter applies the methodological considerations and recommendations established in the previous study (Chapter 5; section 5.6.3) and in the SRR of the literature (Chapter 4). The study extends previous work to include a sample of adolescents attending a UK school and by examining the associations between breakfast consumption and national academic qualifications.

6.2 Study aims

The aims of the study reported in this chapter were as follows:

I. To examine the association between habitual school-day breakfast consumption frequency and GCSE performance in adolescents aged 16-18 years.
II. To investigate the effects of socio-demographic characteristics on the relationship between habitual school-day breakfast consumption frequency and GCSE performance.

The subsidiary aims of the study reported in this chapter were as follows:

I. To examine the nature of breakfast consumption including frequency, food type, macronutrient and micronutrient content, and the contribution to population RNIs in adolescents aged 16-18 years.
II. To examine the associations between habitual school-day breakfast consumption and socio-demographic characteristics

Previous research on breakfast consumption is inconsistent in terms of the frequency of breakfast intake reported (Chapter 1; see section 1.2). Often, data are not UK specific and do not include older adolescents. The present study, therefore, intended to complement and extend previous breakfast consumption data by including more in-depth descriptions of breakfast intake and differentiating between school-day and weekend breakfast habits.

6.3 Hypotheses

It was hypothesized that habitual school-day breakfast skipping would be negatively associated with GCSE performance in 16-18 year old adolescents, after adjustment for confounders. The examination of interactions between habitual school-day breakfast consumption frequency and socio-demographic characteristics in this relationship were exploratory given the limited and mixed findings reported in the literature (Chapter 4).

No specific predictions were hypothesized regarding the frequency or the nature of breakfast consumption in 16-18 year old adolescents due to the inconsistent findings reported in Chapter 1; section 1.2. The examination of breakfast consumption patterns was exploratory.

6.4 Methodology

6.4.1 Participants

Three hundred and eleven adolescents (males: 70 [22.5%]; females: 241 [77.5%]) aged 16-18 years (mean age ± SD: 17.32 ± 0.77) were recruited to take part in this study. Participants were in full time post-16 education attending sixth form schools or colleges in West Yorkshire. Ages 16-18 years correspond to post-16 education Years 12 (lower sixth) and 13 (upper sixth) in the British school system. Participation in post-16 education at age 16-18 years was non-compulsory at the time of the study. Of the 311 participants recruited to take part, 17 (5.5%) returned incomplete food diaries or questionnaires, or indicated that acute illness and/or circumstances had altered their 7-day food diary data. All 17 participants were excluded from the analysis. The final sample for analysis consisted of 294 participants, described in section 6.5.1.

6.4.2 Inclusion/exclusion criteria

Participants were recruited using the following inclusion and exclusion criteria.

6.4.2.1 Inclusion criteria

- Male or female, aged 16-18 years
- Completed GCSE examinations and obtained results
- Ability to follow verbal and written instructions in English
- Ability to understand and/or complete both the questionnaire and food diary

6.4.2.2 Exclusion criteria

- No GCSE examination grades available
- Acute illness, feeling unwell, and/or circumstances (e.g. holiday) within the week prior to data collection which could influence 7-day food diary data.

6.4.3 Design

The study conformed to an observational cross-sectional survey design. Primary cross-sectional survey data were collected through a self-administered questionnaire and retrospective 7-day food diary adapted specifically to measure breakfast intake. Data collection was carried out within sixth form schools and colleges or as part of the IPS Research Open Day. In both instances, data collection took place in a controlled research environment within an allocated teaching room.

6.4.4 Measures

6.4.4.1 Socio-demographic measures

Demographic information on age, gender and ethnicity were gathered via a self-report written questionnaire (see Appendix 9.52). For ethnicity, categories were dichotomised into ‘White British’ and ‘other ethnic background’ due to infrequent occurrence of many ethnic groups. The majority of adolescents coded as ‘other ethnic background’ were Asian and British Asian (84.9%).

Highest parent/guardian education level was used as a proxy for SES. Measuring SES in children and adolescents is usually based on parental socio-economic or educational characteristics. Agreement between adolescents’ and parents’ reports of measures of SES are generally good (Lien, Friestad, & Klepp, 2001; Perera & Ekanayake, 2009), with the highest degree of agreement for reports of parental education compared with occupation and income (Pu, Huang, & Chou, 2011). Parental education measures are also more likely to be provided than parental occupation by adolescents (Lien et al., 2001; Wardle, Robb, & Johnson, 2002). It was not feasible to measure family income, as adolescents are unlikely to accurately estimate the amount their parents or guardians earn. Similarly, adolescents’ reports of parental occupation have been shown to have the lowest completion rates and contain vague responses that are difficult or impossible to code to occupational classification scales (Wardle et al., 2002).

Participants were asked to report the highest level of their parents’/guardians’ education via the questionnaire shown in Appendix 9.52. Parental education level was classified into three SES groups (see Table 6.1) consistent with previous studies (Fielding, Yang, & Goldstein, 2003; Hallström et al., 2012; Hallström et al., 2011).

Table 6.1: SES classification

Reported parental education level	SES category
Completed primary school or less	Low SES
Completed part of secondary school	
Completed all of secondary school and/or college	Middle SES
Completed university or above	High SES

The SES variable was dichotomised into the categories of low/middle SES (completed primary school or less, part of secondary school, all of secondary school) and high SES (completed university or above) due to infrequent counts in the low SES category. Within the low/middle SES category, the majority (82.9%) of participants were in the middle SES category.

6.4.4.2 BMI

The height and weight of each participant was measured and recorded by trained researchers in order to determine BMI SDS and weight classification. The methods described in Chapter 3 were used to calculate BMI SDS (Chapter 3; section 3.4.5.2).

6.4.4.3 Basal metabolic rate estimation

Basal metabolic rate (BMR) was estimated using the paediatric height-weight equations proposed by Schofield (1985). There are numerous paediatric predictive equations available to estimate BMR in children and adolescents and there is debate regarding which is the most accurate method. The predictive equations proposed by Schofield (1985) are the most frequently used in energy recommendation reports by the Committee on the Medical Aspects of Food Policy (COMA) and WHO (COMA, 1991; WHO, 2004) and are recommended as valid estimations of BMR by The European Food Safety Authority (EFSA; EFSA, 2013). Validation studies show the Schofield (1985) height-weight equations have most agreement with measured BMR in adolescents (Rodríguez, Moreno, Sarría, Fleta, & Bueno, 2002).

Recently, the SACN adopted equations developed by Henry (2005) which have been shown to be more accurate in adults (SACN, 2011). These new equations, however, demonstrate improved accuracy in adults and older adults only, not in children or adolescents (Henry, 2005). Hence, the study sample of adolescents aged 16-18 years would not benefit from their use. For validation purposes, a comparison of mean estimated BMR for the current sample based on the prediction equations of Schofield (1985) and Henry (2005) was conducted (see Table 6.2). Mean estimated BMR for the current sample calculated using the Schofield (1985) equations was also compared to BMR values given in SACN (2011) and ESFA (2013) energy recommendation reports. A paired samples t-test indicated a significant difference between mean estimated BMR (Kcal/day) using the Schofield (1985) equations compared with the Henry (2005) equations, $t(293) = 38.94$, $p<0.001$. However, one sample t-tests indicated no significant differences between mean estimated BMR for the current sample using the Schofield (1985) equations compared with estimated BMR values prescribed by SACN (2011), $t(293) = 0.50$, *ns*, and by ESFA (2013) for EU children and adolescents, $t(293) = 0.83$, *ns*. As there were no differences in mean BMR values prescribed by SACN (2011) and ESFA (2013) compared with mean estimated BMR for the study sample using the equations of Schofield (1985), these BMR estimates were considered to be acceptable for the present study.

Table 6.2: Comparisons of a) estimated BMR values for the current sample calculated using Schofield (1985) and Henry (2005) equations and b) estimated BMR values from SACN (2011) and ESFA (2013) energy recommendation reports

	Female BMR Kcal/day		Male BMR Kcal/day		All BMR Kcal/day	
Sample	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Schofield (1985)[a]	1472.35	114.75	1951.19	215.84	1581.47	247.25
Henry (2005)[b]	1442.32	117.15	1916.28	209.92	1550.33	245.30
EARs						
SACN (2011)[c]	1398.18	-	1750.32	-	1574.25	-
EFSA (2013)[d]	1386.23	-	1752.71	-	1569.47	-

[a] BMR calculated using Schofield (1985) equations as Male: (16.25 x W) + (1.372 x H) + 515.5, Female: (8.365 x W) + (4.65 x H) + 200; [b] BMR calculated using Henry (2005) equations as Male: (15.6 x W) + (2.66 x H) + 299, Female: (9.40 x W) + (2.49 x H) + 462; [c] BMR values calculated using Henry (2005) equations using UK 1990 reference for children (Freeman et al., 1995); [d] BMR values calculated using Henry (2005) equations using growth curves of children in the EU.

6.4.4.4 Total energy expenditure estimation

Total energy expenditure (TEE) was estimated to provide a measure of energy requirement as: BMR x physical activity level, with physical activity level adjusted for energy needs for growth. The UK reference physical activity level value was used (physical activity level value 1.75; SACN, 2011). The mean estimated TEE was 2768 ± 432.68 Kcal/day for the current sample.

6.4.4.5 Assessment of habitual breakfast intake

6.4.4.5.1 Seven-day food diary

Participants completed a 7-day retrospective food diary record using household measures to estimate weights of foods consumed to determine habitual breakfast frequency and composition (see Appendix 9.53). Self-report methods are recommended to collect dietary intake data in studies on public health nutrition (Public Health England, 2010). This is because they usually use fewer resources and are more practical than alternative methods, such as the use of biomarkers (Public Health England, 2010). Participants were required to recall all food and drink consumed for breakfast over a 7-day period which included the day of testing and the previous 6 days. No other meals or drinks were reported. Participants were provided with instructions on how to complete the food diary (see Appendix 9.54). These instructions were read aloud to all participants. To ensure consistency of reporting, participants were instructed that breakfast is defined as the first eating occasion involving a solid food or a drink that occurred after waking, up to and including 1000 hours on school days/college days or 1100 hours on weekend days (Reeves, Halsey, McMeel, & Huber, 2013). This included all food eaten at home, on the way to school or at school prior to the start of lessons, including food not usually considered as conventional breakfast foods. Participants were instructed to report all food and drink consumed for breakfast, the type of food (e.g. skimmed milk), brand name (if appropriate), preparation or cooking method and the amount eaten. Participants estimated portion sizes using household measures (e.g. spoons/cups/bowls), natural unit size (e.g. slices of bread) and number of items consumed. Participants were told to only indicate the amount eaten, taking into consideration any leftovers. Where participants reported acute illness, or feeling unwell, and/or circumstances (e.g. holiday) during the 7-day recall period which may have influenced food diary data, these participants were excluded from the analyses (see section 6.4.2). Data collection occurred during school term time so that school holidays were not included within the 7-day diary reporting period. Participants completed the diary in the presence of a researcher. This allowed the opportunity to check compliance, clarify ambiguous items, respond to queries and facilitate food portion estimation. The food diary was piloted on a small sample (*n*=4) of 18-20 year old students to obtain information on completion times, acceptability, clarity and ability to recall breakfast, as recommended by Public Health England, 2010.

All food diaries were analysed using WinDiets nutritional analysis software (Research Version 2010; Robert Gordon University, Aberdeen, UK) to calculate energy, macronutrient and micronutrient content using the 2008 UK food tables. Estimated portion sizes were converted into weights using corresponding portion weights (in grams) indicated in the WinDiets 2008 UK food tables. Additionally, data from manufacturers on typical portion size and a photographic food atlas were used to calculate portion weights (Nelson, Atkinson, & Meyer, 1997). Where no data on portion size was provided, portion size was estimated from typical portion weights for adolescents aged 15-18 years (Wrieden, Longbottom, & Barton, 2003) and using data from manufacturers. Where no data was provided on type of a food (e.g. type of milk, type of bread), a standard code was used. For example, where type of milk was not reported, semi-skimmed milk was used as a standard code.

A database containing daily dietary totals for breakfast (energy, macronutrients and micronutrients) and listing each food item consumed by participants was created. Each food item and drink recorded was assigned to one of 24 food and drink groups. All food items were classified as being consumed (on at least one day of all recall days) or not consumed (no days of all recall days). Micronutrient and protein intakes were expressed as the percentage of RNI using UK population RNI values to determine the contribution of breakfast to daily micronutrient intake (COMA, 1991). The energy content of breakfast was expressed as the percentage of TEE to determine the contribution of breakfast to energy requirements.

6.4.4.5.2 Classification of habitual school-day breakfast consumption

A breakfast eating occasion was defined as any solid food or drink containing ≥5% of TEE consumed up to and including 1000 hours on school days/college days or 1100 hours on weekend days. The cut-off was adopted to represent a minimum amount of energy needed for classification as breakfast. This cut-off equates to approximately 100 Kcal which represents the threshold of detection of food and beverage ingestion on appetite visual analogue scales (Anderson & Woodend, 2003; Borer, 2010; Woodend & Anderson, 2001). Hence, the energy threshold for a breakfast eating occasion was at least capable of inducing changes in satiety and hunger. School-day (weekday) breakfast eating frequency was used to classify participants' habitual school-day breakfast consumption. Habitual school-day breakfast consumption frequency was categorised as rare (0-1 school days), occasional (2-3 school days) or frequent (4-5 school days).

6.4.4.6 Academic performance: GCSE attainment

Participants' GCSE grades obtained in key stage 4 were used to measure academic performance. Participants were required to report all GCSE (or equivalent) qualifications including the type of GCSE (e.g. short course, full course, double award) and the date the qualification was obtained via a self-report questionnaire (see Appendix 9.52). GCSE grades are awarded for each course subject, where pass grades include A*-G with U as ungraded/fail. Final grades are a result of coursework and examinations which are completed at specific times throughout the course (modular GCSEs) or completed in a single exam series at the end of the course (linear GCSEs). The GCSE subjects English and Mathematics are compulsory; all other GCSEs are optional.

6.4.4.6.1 Aggregated GCSE performance: GCSE point scores

To measure overall GCSE performance, aggregate point scores were created using the Department for Education GCSE point score system to transform individual subject grades into a continuous numerical point score (see Appendix 9.55). Point scores are routinely used as a method of combining GCSE grades in educational research (Birchwood & Daley, 2012; Fielding et al., 2003; O'Connell, 2006) and in annual GCSE performance tables (Department for Education, 2013b). Participants' grades for each subject were transformed into corresponding point scores (e.g. A* = 58, A = 52, B = 46 etc.) which were used to produce a measure of overall GCSE performance (see Appendix 9.55). A small proportion of participants reported Business and Technology Education Council (BTEC) First Level 2 qualifications which are graded on a 3-point or 4-point scale as Pass, Merit, Distinction, Distinction*. The score equivalencies were obtained from the Official Register of Regulated Qualifications website to calculate corresponding GCSE point scores. Three aggregate GCSE point scores were created:

total uncapped GCSE point score, total capped GCSE point score and mean GCSE point score per qualification (see Appendix 9.55).

Although there is some overlap, it was deemed necessary to perform separate analyses for each of these outcomes. Firstly, capped point score (best 8 GCSE results) is not sensitive to the total number of qualifications obtained but provides an indication of the quality of the grades achieved. Capping at the equivalent of 8 GCSEs provides a measure of attainment that does not favour participants who have studied a greater number of subjects at GCSE or equivalent. Uncapped point score reflects both quality and the number of GCSE attained and can be affected by ‘GCSE equivalent effects’ (Office for National Statistics, 2012). For example, BTEC qualifications can account for 2-4 GCSE A*-C grades and therefore a higher point score may be simply a function of having taken more GCSE or equivalent qualifications rather than a higher quality of grades achieved. Secondly, each measure may provide a result that is difficult to interpret in isolation. Thus, multiple measures of aggregated GCSE performance were considered.

6.4.4.6.2 Performance in compulsory GCSE subjects: Mathematics and English grades

To measure performance in Mathematics and English, participants’ grades for each subject were used. Where participants reported more than one grade for English or Mathematics (e.g. English literature and English language) their best eligible result was used. Performance in Mathematics and English were of particular interest as the evidence outlined in Chapter 4 indicated that habitual breakfast may affect performance in individual subject domains, particularly Mathematics. In addition, English and Mathematics are compulsory GCSE subjects and are included within threshold performance indicators (e.g. ≥5 GCSE A*-C including Mathematics and English).

6.4.5 Ethical considerations

6.4.5.1 Approval

Prior to commencement of the study, ethical approval was obtained from the IPS Ethics Research Committee at the University of Leeds, UK. Ethical approval was obtained separately for data collection which was carried out within sixth forms (Reference: 11-0087, Date: 15/06/2011, Appendix 9.56) and during Research Open Days at the IPS (Reference: 11-0182, Date 20/10/2011, Appendix 9.57). All researchers involved in the study were in possession of enhanced Criminal Records Bureau clearance. All participants were fully supervised during their testing session. At least one teacher was present during data collection; parents were not present during data collection. All data gathered were strictly confidential and anonymised.

6.4.5.2 Recruitment and assent

This study adopted a process of assent to determine whether potential participants and their parents/guardians were willing to take part in the study. This was in line with normal protocol at sixth form schools and colleges for extraordinary activities and excursions. Sixth form schools were recruited to take part in the study through invitation and coordination with a senior teacher. All teachers were made fully aware of the procedures and requirements for the study and gave voluntary permission for their sixth form to take part. Immediately following agreement to take part, a letter was sent home to the parents/guardians of the participating sixth form pupils, containing a cover letter and information sheet for the parent/guardian (see Appendix 9.58 and 9.60) and an information sheet for the adolescent participants (see Appendix 9.59 and 9.61). These letters provided parents and potential participants with written information about the purpose of the study and requirements for participation. These documents also stated that parents/participants should contact the researchers, via email or telephone, with any questions or queries regarding the study. Parents/guardians were informed that if they were happy for their child to take part in the study they did not need to respond to the letter or notify the researchers, and consent (by a process of assent) was assumed. Alternatively, if parents/guardians were not happy for their child to participate in the study, they were requested to return a reply slip to the sixth form teacher which was enclosed with the letter.

Study participants (adolescents) received a presentation to confirm understanding on the day of testing prior to any data collection. Information contained in the information sheet for the adolescent participants was reiterated during the presentation including a description of the research, its purpose, procedure and requirements for participation and could decline to participate if they wished at any stage, without having to give a reason. Participants were given the opportunity to ask questions to ensure they each had a full understanding of what the research entailed.

6.4.5.3 Study withdrawal and confidentiality

Participants and their parents/guardians were told that participants could withdraw at any point before or during the study without giving a reason. All information gathered remained strictly confidential and was anonymous. If a participant withdrew part way through, any data collected were excluded from the analysis.

6.4.5.4 Adverse events

Before the study began, research staff were instructed to document reported or observed AEs (defined in Chapter 3; section 3.4.7.4) at the time they were reported or observed using a standard form (see Appendix 9.27). Any AEs were to be reported to the IPS Ethics Committee, according to ethical requirements, and followed up until they were resolved. There were no AEs recorded in this study.

6.4.6 Statistical analysis

Statistical analyses were performed using SPSS version 21 (SPSS, Inc. Chicago, USA) and the significance level (α-level) was set as $p<0.05$.

6.4.6.1 Habitual breakfast consumption

Descriptive analyses of breakfast eating patterns including frequency, food type, macronutrient and micronutrient content are presented as daily mean intake for weekly total, school-day and weekend breakfast intake. All data were summarised and boxplots were produced to screen for outliers and check for normality of distribution. To assess differences in daily mean intake of macronutrients and micronutrients from school-day breakfast meals compared with weekend breakfast meals, paired samples t-tests were employed. Participants were then classified into three groups based on their school-day breakfast intake frequency. Habitual school-day breakfast consumption was classified as rare (0-1 weekdays), occasional (2-3 weekdays) or frequent (4-5 weekdays). To assess the association between socio-demographic characteristics and habitual school-day breakfast consumption, Pearson's chi-squared test was used with the following socio-demographic characteristics: gender (2 levels; male, female), ethnicity (2 levels; white British, other), SES (2 levels; high, low-middle). Differences between observed and expected values and standardised residuals that exceeded ±1.96 were used to identify cells driving effects where significant associations were observed (Tabachnick & Fidell, 2007). Age and BMI SDS were subjected to one-way ANOVAs with habitual-school day breakfast group as the between-subjects factor (3 levels; rare, occasional, frequent). Post-hoc pairwise comparisons were conducted using the Bonferroni correction.

6.4.6.2 Primary analysis of the association between habitual school-day breakfast consumption and GCSE performance

6.4.6.2.1 Aggregated GCSE performance: GCSE point scores

The analysis of aggregate GCSE performance followed the same format as the primary analysis in Study 2 (Chapter 5; see section 5.4.6.1). Three hierarchical multiple regression analyses were conducted for each aggregate point score measure: total uncapped point score, total capped point score and mean point score per qualification with adjustments for SES, ethnicity, sex, age and BMI SDS. The full regression models and the resulting coefficients (B and β) for habitual school-day breakfast consumption categories, socio-demographic covariates and interaction terms are shown in

Appendices 9.62-9.64. Plots of raw data according to habitual school-day breakfast consumption are shown in Appendix 9.65.

Categorical socio-demographic covariates were coded as follows: ethnicity: 0 (reference) = white British, 1 = other ethnic background; sex: 0 (reference) = male, 1 = female; SES: 0 (reference) = low/middle, 1 = high. Habitual school-day breakfast consumption was transformed into a binary categorical variable as described in the statistical analysis section (section 5.4.6.1) in Chapter 5. The testing of interaction terms followed the same format as the analysis of Study 2 (Chapter 5; see section 5.4.6.1). The analyses attempted to control for factors related to both breakfast consumption and GCSE attainment in school children. Sex, ethnicity and SES have been consistently shown to predict GCSE performance (Connolly, 2006; Department for Children, Schools and Families, 2009a; Sammons et al., 2014 ; Scott, 2004). Preliminary regression analyses indicated that age and BMI significantly predicted GCSE point scores, which has also been shown recently (Booth et al., 2014), and therefore, these were included in the analyses. All of these covariates are also related to breakfast consumption (Chapter 1; 1.2.2). To test the assumption that these covariates were indeed covariates in the relationship between habitual school-day breakfast consumption and GCSE point scores, Pearson's Product Moment correlation coefficients, produced as part of the multiple regression analyses, were examined. All socio-demographic covariates correlated significantly with aggregate GCSE point score measures (see Appendix 9.66), confirming that their inclusion in the analyses was appropriate (Tabachnick & Fidell, 2007).

The relevant assumptions of hierarchical multiple regression analyses were tested and confirmed as described in Chapter 5, section 5.4.6.1.

6.4.6.2.2 Mathematics and English grades

For the analysis of Mathematics and English grades, conversion to point scores and the use of linear models is inappropriate, hence ordinal logistic models are recommended (Fielding, 1999; Fielding et al., 2003). GCSEs are graded in discrete ordered categories. In the current sample, Mathematics and English grades ranged from A* to D, with A* being the highest grade. Transformation into point scores and normalising transformations did not result in a continuous outcome variable or improve error distributions and a limited number of discrete values were evident. Consequently, to analyse the association between habitual school-day breakfast consumption and the single subject domains of Mathematics and English, ordinal logistic regression (proportional odds model) with GCSE grade as the outcome variable was used (O'Connell, 2006). Two ordinal logistic regression analyses were computed for English and Mathematics grades to calculate cumulative crude and adjusted odds ratios (ORs) and 95% confidence intervals (CI) for higher grades, with and without controlling for socio-demographic variables and interaction terms. Ordinal logistic regression estimates cumulative ORs, modelling the probability of obtaining any higher grade category across the entire grade variable.

Ordinal regression estimates the probability of that event and all others above it in the ordinal ranking (cumulative probabilities) rather than probabilities for discrete categories. Therefore, for English and Mathematics grades, the ordinal outcome variable has 5 levels (D, C, B, A, A*) requiring four cut points to be modelled in a single model: D vs. C, B, A, A*; D, C vs. B, A, A*; D, C, B vs. A, A*; D, C, B, A vs. A* (O'Connell, 2006). This single model is used to estimate the odds of being at or above a given threshold or spilt across all cumulative splits in the outcome variable and offers greater parsimony compared with multiple binary logistic regression analyses. Odds ratios are therefore cumulative odds ratios and are constant across all possible cumulative splits of the outcome variable. Hence, for an ordinal logistic regression analysis to be valid, the proportional odds assumption must be met indicated by the test of parallel lines. The test of parallel lines was non-significant for both analyses ($p>0.05$) suggesting the explanatory variables have the same effect on the odds regardless of the cumulative split.

Model 1 included the crude cumulative ORs and 95% CIs and Models 2 & 3 included the adjusted cumulative ORs and 95% CIs, as per the analysis of aggregated GCSE performance. The full ordinal regression models are shown in Appendices 9.67-9.68. The percentage of participants obtaining each grade (A*-D) plotted according to habitual school-day breakfast consumption category is shown in Appendix 9.69. For all models, the likelihood ratio test was used to examine overall model fit. A significant χ^2 indicates that the model gives a statistically significant improvement in the prediction of English and Mathematics grades over the baseline intercept-only model. For parameter estimates, positive coefficients indicate an association with higher grades for that category in comparison to the reference category. An association with higher grades means larger cumulative odds for higher grades in comparison to the reference category. The pseudo-R^2 statistic employed was Nagelkerke's pseudo R^2 to provide an approximation of the proportion of variance accounted for by the predictor variables (Tabachnick & Fidell, 2007)

6.5 Results

6.5.1 Participant demographic characteristics

Participant demographic characteristics are shown in Table 6.3. The sample consisted of 294 participants aged 16-18 years (mean age ± SD: 17.25 ± 0.76). There were considerably more females than males (males: 67 [22.8%]; females: 227 [77.2%]) providing an uneven gender spilt in the study sample. The sample was not ethnically diverse. Most participants were White British (241 [82.0%]) with fewer participants of any other ethnic background (53 [18.0%]). Half of the participants were classified as high SES. The BMI SDS varied considerably with a mean BMI SDS of 0.49 ±1.08. Two hundred and four participants (69.4%) were classified as normal weight, 43 (14.6%) as overweight and 47 (16.0%) as obese.

Table 6.3: Participant demographic characteristics

Demographic characteristics	n (%)
Gender	
Male	67 (22.8)
Female	227 (77.2)
Ethnicity	
White British	241 (82.0)
Other ethnic background	53 (18.0)
SES	
High SES	148 (50.3)
Low/middle SES	146 (49.7)
	Mean (SD)
Age (years)	17.25 (0.76)
Height (cm)	167.41 (8.89)
Weight (kg)	63.61 (13.02)
BMI (SDS/z-scores)	0.49 (1.08)

6.5.2 Habitual breakfast consumption

6.5.2.1 Frequency of habitual breakfast intake

Frequency of breakfast intake, as defined in section 6.4.4.5.2, for weekly total, school-day and weekend breakfast intake is presented in Table 6.4. Ten percent of participants skipped breakfast every day during the 7-day measurement period. The prevalence of skipping breakfast was similar on weekends and school days. For school days, 51 (17.4%) participants skipped breakfast on all 5 days and for weekend days 64 (21.8%) participants skipped breakfast on both days. Sixty percent of the participants who skipped breakfast on all 5 school days also skipped breakfast on both weekend days. Approximately a third of participants ate breakfast every day during the 7-day measurement period. Overall, the mean frequency of breakfast intake was 4.42 (± 2.46) days during the 7-day measurement period.

Table 6.4: Frequency of breakfast intake (n; %) for weekly total, school-day and weekend breakfast intake.

Frequency of breakfast	Total		School-day		Weekend	
	N	%	N	%	N	%
0	30	10.2	51	17.4	64	21.8
1	21	7.1	33	11.2	71	24.2
2	27	9.2	27	9.2	159	54.1
3	25	8.5	27	9.2	-	-
4	27	9.2	37	12.6	-	-
5	37	12.6	119	40.5	-	-
6	32	10.9	-	-	-	-
7	95	32.3	-	-	-	-

6.5.2.2 Food choice at breakfast

Food and drinks consumed for weekly total, school-day and weekend breakfast meals and the mean portion size in grams for these foods are shown in Table 6.5 (N.B. some participants consumed more than one item at each breakfast meal). For all breakfast meals, bread was the most frequently consumed food (68.0%), with RTECs also popular (54.8%).Correspondingly, milk (61.2%) and added fat (39.8%), usually as spreads, were commonly consumed accompaniments. Food items considered less healthy were not frequently consumed, these included chocolate or sugar confectionary (3.7%), cakes, pastries and sweet buns (10.2%). However, a high proportion of participants consumed added sugar or sugary spreads at breakfast meals (38.1%). Approximately a quarter (26.5%) of participants consumed fruit at breakfast. Tea, coffee, fruit juice and water were the most frequent beverages consumed at breakfast. Supplement drinks (e.g. drinks fortified with vitamins and minerals) were consumed by 7.5% of the sample. These drinks contained large quantities of micronutrients (e.g. >900% of RNI for Thiamine and Riboflavin, and >500% of RNI for vitamin C).

A lower proportion of participants consumed RTECs at weekend breakfast meals compared with school-day breakfast meals (32.7% vs. 46.3% respectively). A higher proportion of participants consumed meat and eggs in various forms (e.g. processed meat products or boiled, scrambled, fried eggs) at weekend breakfast meals compared with school-day breakfast meals (33.0% vs. 22.4% respectively). Fewer adolescents consumed fruit at weekend breakfast meals compared with school-day breakfast meals (13.3% vs. 20.8% respectively). A higher proportion of adolescents consumed vegetables at weekend breakfast meals than at school-day breakfast meals (10.9% vs. 5.1% respectively) however; these items were typically cooked in fat (e.g. fried mushrooms, tomatoes) or were tinned vegetables (e.g. beans and pulses) with added salt and/or sugar.

Table 6.5: Number[a] and percentage of sample consuming twenty four food and drink groups and mean (SD) amount in grams[b] of the food consumed over the entire seven days (weekly total), on school days and at weekends.

Food group	Total				School-day				Weekend			
	N	%	Mean (g)	SD	N	%	Mean (g)	SD	N	%	Mean (g)	SD
Cereals and cereal products												
Bread (all types)	200	68.0	56.93	24.14	145	49.3	56.37	24.57	143	48.6	57.96	23.35
RTECs (including muesli)	161	54.8	42.31	18.12	136	46.3	42.32	17.36	96	32.7	42.30	20.38
Oats, porridge	14	4.8	211.63	61.12	10	3.4	224.35	51.86	8	2.7	179.11	73.67
Other cereals (pasta, rice, pizza)	11	3.7	307.86	52.17	5	1.7	297.50	36.84	8	2.7	315.63	62.65
Biscuits, breakfast biscuits or bars	38	12.9	42.91	21.76	31	10.5	37.31	9.74	14	4.8	62.35	36.85
Cakes, pastries, sweet buns	30	10.2	74.14	29.18	17	5.8	71.80	29.92	15	5.1	77.59	28.59
Meat, eggs												
Meat and meat products	79	26.9	56.89	21.08	38	12.9	56.64	17.62	54	18.4	57.03	22.98
Egg (in various forms)	60	20.4	95.24	35.07	28	9.5	93.95	33.09	43	14.6	96.23	36.83
Added fat and oil											14.40	18.05
Fat spreads and oil	117	39.8	13.38	12.54	127	43.2	12.84	8.33	120	40.8	14.40	18.05
Fruit and vegetables												
Fruit (including smoothies)	78	26.5	163.11	65.93	61	20.8	156.32	62.98	39	13.3	180.26	70.55
Vegetables (including beans & pulses)	42	14.3	181.15	97.62	15	5.1	205.25	111.68	32	10.9	170.44	89.96
Potatoes and products	14	4.8	101.11	40.71	4	1.4	80.00	0.00	11	3.7	111.67	46.87
Milk and milk products												
Milk	180	61.2	158.61	59.83	156	53.1	159.26	60.29	111	37.8	156.72	58.62
Yoghurt	31	10.5	142.07	39.60	27	9.2	145.69	41.52	13	4.4	130.56	31.08
Cheese	18	6.1	43.82	9.77	12	4.1	42.75	10.66	6	2.0	46.67	6.83
Snack food and confectionary												
Savoury snack (crisps)	6	2.0	45.00	53.71	5	1.7	46.11	59.99	2	0.7	40.00	0.00
Chocolates or sugar confectionary	11	3.7	53.28	38.21	9	3.1	50.75	39.74	3	1.0	61.50	36.78
Added table sugar, sweet spreads	112	38.1	15.31	12.73	87	29.6	14.59	12.15	77	26.2	16.87	13.85

[a] Consumed food for breakfast at least once on school days, weekends or the entire seven days. One participant can have more than one entry
[b] Grams consumed on consumption days.

Table 6.5 continued: Number[a] and percentage of sample consuming twenty four food and drink groups and mean (SD) amount in grams[b] of the food consumed over the entire seven days (weekly total), on school days and at weekends.

Food group	Total				School-day				Weekend			
	N	%	Mean (g)	SD	N	%	Mean (g)	SD	N	%	Mean (g)	SD
Beverages												
Tea and coffee	136	46.3	258.87	33.10	109	37.1	258.21	31.77	98	33.3	260.39	36.04
Fruit juices	106	36.1	238.33	79.24	87	29.6	238.86	78.99	64	21.8	237.00	80.35
Soft drinks	62	21.1	260.92	96.60	47	16.0	254.07	89.60	34	11.6	276.02	110.08
Supplement drinks (protein or fortified drinks)	22	7.5	147.65	89.35	16	5.4	146.12	90.61	16	5.4	151.11	88.76
Water	90	30.6	263.83	120.26	83	28.2	264.59	121.50	46	15.7	261.67	118.34
Other – Marmite, peanut butter condiments, soup	33	11.2	41.32	81.97	24	8.2	30.78	54.38	18	6.1	61.08	116.55

[a] Consumed food for breakfast at least once on school days, weekends or the entire seven days. One participant can have more than one entry
[b] Grams consumed on consumption days.

6.5.2.3 Macronutrient intake

Table 6.6 shows the mean daily intake of energy and macronutrients (total and percentage of food energy) for weekly total, school-day and weekend breakfast meals. The mean daily energy intake from all breakfast meals was 218 ± 140.48 Kcals. Mean daily macronutrient intake was: 32.39 ± 20.06 total carbohydrate (g), 7.37 ± 6.27 protein (g), 7.27 ± 6.34 total fat (g) and 1.30 ± 1.32 non-starch polysaccharides (g). The mean daily percentage of estimated TEE provided by breakfast was 7.95%. For all breakfast meals, most of the energy consumed came from total carbohydrate. For all breakfast meals, the mean daily percentage of energy consumed from total carbohydrate was 44.70%, of which 26.06% of energy was consumed from sugar. All breakfast meals provided a considerable proportion of the RNI for protein (mean daily intake of protein accounted for 19.00% of the RNI for males and 14.33% of the RNI for females aged 15-18 years). Mean daily intake of protein with complete digestibility was 10.49 ± 9.85 and 6.45 ± 4.34 protein (g) for males and females respectively. Mean daily intake of non-starch polysaccharides from breakfast, provided 7.22% of the RNI for males and females.

Mean daily energy intake (Kcal) from school-day breakfast meals was significantly lower compared with weekend breakfast meals, $t(293) = -6.45$, $p<0.001$. For all macronutrients excluding sugar, mean daily intake (in grams) was consistently and significantly lower from school-day breakfast meals compared with weekend breakfast meals, smallest $t(293) = -2.61$; all $p<0.01$, with largest differences occurring in total carbohydrate, protein, total fat, saturated fat and non-starch polysaccharides, smallest $t(293) = -3.70$; all $p<0.001$. Generally, there were fewer significant differences in mean daily percentage of energy consumed for each macronutrient compared with absolute intake. Although absolute mean daily intake (in grams) of total carbohydrate was significantly lower from school-day breakfast meals than weekend breakfast meals, $t(293) = -4.31$, $p<0.001$, the mean daily percentage of energy consumed from total carbohydrates was significantly higher from school-day breakfast meals than weekend breakfast meals, $t(293) = 2.32$, $p<0.05$. Similarly, the mean daily percentage of energy consumed from sugar was significantly higher from school-day breakfast meals compared with weekend breakfast meals, $t(293) = 2.70$, $p<0.01$ respectively. This is because a significantly lower mean daily percentage of energy was consumed as total fat from school-day breakfast meals compared with weekend meals, $t(293) = -3.14$, $p<0.01$. Daily macronutrient intakes from school-day vs. weekend breakfast meals as a proportion of energy were similar for protein, saturated fat and non-milk extrinsic sugars (all $p>0.05$).

Table 6.6: Mean (SD) daily energy and macronutrient consumption (g) and proportion (%) of energy from macronutrients from weekly total, school-day and weekend breakfast meals.

Energy, macronutrient	Total		School-day		Weekend		*t*-value, *df*, *p*-value[a]
	Mean	SD	Mean	SD	Mean	SD	
Energy (Kcal)	218	140.48	197	136.21	270	223.27	t(293) -6.45, p<0.001
Total Carbohydrate (g)	32.39	20.06	30.62	21.06	36.79	27.03	t(293) -4.31, p<0.001
% of food energy	44.70	21.57	45.65	23.70	42.31	25.70	t(293) 2.32, p<0.05
Sugar (g)	15.92	11.76	15.47	12.70	17.02	14.64	t(293) -1.94, p=0.053
% of food energy	26.06	18.68	26.06	18.68	22.78	20.40	t(293) 2.70, p<0.01
Non-milk extrinsic sugars (g)	8.67	8.52	8.23	9.11	9.77	10.93	t(293) -2.61, p<0.01
% of food energy	13.52	14.18	13.74	15.47	12.98	16.99	t(293) 0.82, p=0.415
Protein (g)	7.37	6.27	6.49	6.05	9.57	9.91	t(293) -6.17, p<0.001
% of food energy	9.73	6.08	9.62	6.86	10.01	6.87	t(293) -0.96, p=0.339
Total Fat (g)	7.27	6.34	6.08	5.77	10.27	11.63	t(293) -6.89, p<0.001
% of food energy	18.90	12.00	18.08	13.13	20.97	15.86	t(293) -3.14, p<0.01
Saturated fat (g)	3.41	2.88	2.95	2.77	4.57	5.01	t(293) -6.02, p<0.001
% of food energy	9.26	6.24	9.03	7.06	9.83	7.76	t(293) -1.66, p=0.098
Non-starch polysaccharides (g)	1.30	1.32	1.18	1.31	1.61	2.16	t(293) -3.70 p<0.001

[a] *p*-value (two tailed) for paired samples t-test comparing macronutrient intake (absolute intake in grams and as percentage of energy) from school-day vs. weekend breakfast meals for each macronutrient.

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6.5.2.4 Micronutrient intake and nutrient recommendations

Table 6.7 shows the mean daily intake of micronutrients for weekly total, school-day and weekend breakfast meals consumed by participants. Mean daily micronutrient intakes from all breakfast meals were high in relation to RNIs, particularly for Vitamin C (22.62 ± 41.05 mg), and for the B vitamins, Vitamin B^{12} (0.63 ± 0.85 µg), Thiamine (0.34 ± 0.70 mg), Riboflavin (0.45 ± 0.92 mg), and Niacin (4.38 ± 4.43 mg). However intake was variable. Mean daily intake of these micronutrients from breakfast provided over a third of the RNIs for males and females (Table 6.8). Mean daily intakes of Iron and Zinc from breakfast were lower than other micronutrients in relation to RNIs, but were nonetheless moderately high (1.69 ± 1.44 and 0.92 ± 0.96 respectively). Males achieved a higher proportion of the RNI for Vitamin B^{12} and a lower proportion of the RNI for Vitamin C from breakfast compared with females despite having the same RNIs. Mean daily intake of Calcium, Iron and Thiamine from breakfast in relation to RNIs differed slightly for males and females (Table 6.8) probably because the RNIs for these micronutrients are different for male and female adolescents.

Mean daily intakes of Vitamin B^{12}, Niacin, Calcium, Vitamin D, Zinc and Iron were significantly lower from school-day breakfast meals compared with weekend breakfast meals, smallest $t(293) = -2.52$; all $p<0.05$, with the largest differences occurring for Zinc and Vitamin D intakes, $t(293) = -4.47$, $p<0.001$ and $t(293) = -3.31$, $p<0.001$ respectively. Mean daily intakes of Vitamin C, Thiamine, Riboflavin, Vitamin B^{6} and Folate from school-day breakfast meals compared to weekend breakfast meals did not differ significantly (all $p>0.05$).

Table 6.7: Mean (SD) daily micronutrient consumption (mg;µg) according to weekly total, school-day and weekend breakfast meals.

Micronutrient	Total		School-day		Weekend		t-value, *df*, p-value
	Mean	SD	Mean	SD	Mean	SD	
Vitamin C (mg)	22.62	41.05	22.40	46.34	23.17	45.69	t(293) -0.28, p=0.777
Vitamin D (µg)	0.29	0.45	0.25	0.49	0.39	0.68	t(293) -3.31, p<0.001
Thiamine (mg)	0.34	0.70	0.33	0.82	0.37	0.79	t(293) -0.76, p=0.450
Riboflavin (mg)	0.45	0.92	0.45	1.07	0.45	1.04	t(293) 0.03, p=0.979
Vitamin B^6 (mg)	0.35	0.55	0.34	0.63	0.36	0.61	t(293) -0.40, p=0.693
Vitamin B^{12} (µg)	0.63	0.85	0.58	0.91	0.75	1.10	t(293) -2.71, p<0.01
Niacin (mg)	4.38	4.43	4.16	4.92	4.93	5.17	t(293) -2.60, p<0.01
Folate (µg)	49.11	49.01	48.22	53.17	51.34	54.52	t(293) -1.12, p=0.264
Calcium (mg)	143.74	111.61	138.45	122.89	156.97	131.25	t(293) -2.52, p<0.05
Iron (mg)	1.69	1.44	1.60	1.55	1.90	1.77	t(293) -3.14, p<0.01
Zinc (mg)	0.92	0.96	0.83	1.01	1.13	1.29	t(293) -4.47, p<0.001

[a] *p*-value (two tailed) for paired samples t-test comparing micronutrient intake (absolute intake in mg or µg) from school-day vs. weekend breakfast meals for each micronutrient.

Table 6.8: Mean daily micronutrient intake as a proportion (%) of RNI according to gender and weekly total, school-day and weekend breakfast meals.

Micronutrient	Total		School-day		Weekend	
	Male	Female	Male	Female	Male	Female
Vitamin C	46.65	59.47	48.01	58.35	43.26	62.26
Thiamine	31.24	42.55	30.59	41.00	32.87	46.42
Riboflavin	36.03	40.78	37.08	40.48	33.42	41.55
Vitamin B^6	24.84	28.19	24.95	27.68	24.55	29.47
Vitamin B^{12}	54.06	38.44	50.61	35.40	62.69	46.04
Niacin	30.11	29.06	28.52	27.62	34.09	32.64
Folate	26.88	23.87	26.72	23.34	27.29	25.19
Calcium	27.15	16.26	27.09	15.42	27.29	18.36
Iron	17.29	10.87	16.04	10.41	20.42	12.02
Zinc	10.83	12.66	9.45	11.61	14.28	15.27

6.5.2.5 Habitual school-day breakfast consumption

Participants were classified into three habitual school-day breakfast consumption categories based on school-day breakfast frequency (Table 6.9). Approximately a third (28.6%) of participants rarely ate breakfast on school days. Over half the participants frequently ate breakfast on school days (53.1%). The remaining participants (18.4%) ate breakfast occasionally on schooldays.

Table 6.9: Proportion of participants (n;%) who frequently, occasionally or rarely consume breakfast on school days

Habitual school-day breakfast consumption	Frequency per week	N	%
Rare	0-1	84	28.6
Occasional	2-3	54	18.4
Frequent	4-5	156	53.1

6.5.2.6 Associations between habitual school-day breakfast consumption and socio-demographic characteristics

Associations between habitual school-day breakfast consumption and socio-demographic characteristics are detailed in Table 6.10. Pearson's chi-squared analyses indicated that habitual school-day breakfast consumption was not significantly associated with gender, ethnicity or SES (all p>0.05). However, one-way ANOVA revealed significant differences between the age of participants across habitual school-day breakfast consumption, $F(2,291)=4.47$, $p<0.05$. Post-hoc comparisons indicated that participants who rarely ate breakfast were younger (17.05) compared to participants who frequently ate breakfast (17.36), although this difference was small given the narrow age range of the sample. There was no difference in BMI according to habitual school-day breakfast consumption.

Table 6.10: Habitual school-day breakfast consumption (n;%) according to socio-demographic characteristics

	Rare		Occasional		Frequent		χ^2, df, p-value
	N	%[a]	N	%[a]	N	%[a]	
Gender							χ^2=1.59,df=2, p=0.453
Male	19	28.4	9	13.4	39	58.2	
Female	65	28.6	45	19.8	117	51.5	
Ethnicity							χ^2=0.80,df=2, p=0.669
White British	70	29.1	42	17.4	129	53.5	
Other	14	26.4	12	22.6	27	50.9	
SES							X^2=0.93,df=2, p=0.628
Low/middle	41	28.1	30	20.5	75	51.4	
High	43	29.1	24	16.2	81	54.7	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	***F*, df, p-value**
Age	17.05	0.75	17.25	0.76	17.36	0.76	$F(2,291)=4.47$, $p<0.05$
BMI SDS	0.68	1.21	0.47	1.12	0.40	.99	$F(2,291)=1.81$, p=0.164

[a] Percentage within socio-demographic group.

6.5.3 GCSE performance

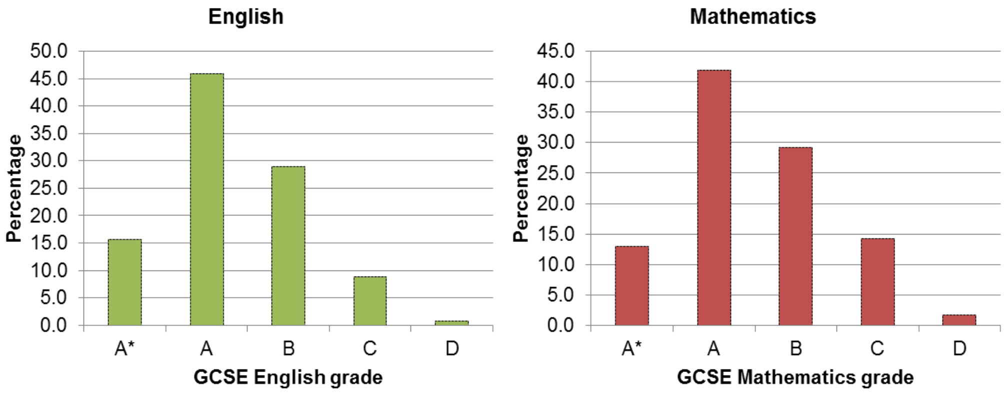
Mean GCSE point scores and number of qualifications for the study sample compared to performance in 2012 for all schools in England and in the Leeds LEA are shown in Table 6.11. Mean uncapped point score was 524.10 ± 99.20 which was higher than the national and Leeds LEA averages by 51.4 and 26.9 points respectively (Table 6.11). Mean capped point score was 401.07 ± 37.95 which was higher than the national and Leeds LEA averages by approximately 59 points (Table 6.11). Both mean uncapped and capped GCSE point scores were higher than the national average by a similar amount suggesting that the higher level of GCSE performance was not driven by the volume of GCSEs or GCSE equivalent effects, but by a higher quality of grades obtained by participants. This is also reflected in the mean point score per qualification and the mean number of GCSE qualifications attained by the sample compared with the national averages. The mean GCSE point score per qualification was 48.71 ± 3.93 which equates to a grade B+ (see Appendix 9.55). This is one grade higher than the national and Leeds LEA average grade per qualification (42 points per qualification/C+ for both national and Leeds LEA; Table 6.11). However, participants attained a mean of 10.73 ± 1.66 GCSE qualifications which is lower than the national and LEA averages (11.3 and 12.2 GCSE qualifications respectively).

Table 6.11: Mean (SD) GCSE point scores and number of qualifications for the study sample compared to performance in 2012 for all schools in England (state and independent) and in the Leeds LEA

GCSE point score	Study sample	National	LEA
Uncapped GCSE point score	524.10 (99.20)	472.7	497.2
Capped GCSE point score	401.07 (37.95)	341.5	342.3
Mean point score per qualification	48.71 (3.93)	42.0	42.0
Mean number of qualifications	10.73 (1.66)	11.3	12.2

Figure 6.1 illustrates the distribution of GCSE grades in English and Mathematics. GCSE attainment in Mathematics and English was high in this sample. Over half of the participants obtained grades A*-A in English and Mathematics. GCSE attainment was slightly higher for English than Mathematics with more participants obtaining A*-A in English than in Mathematics (61.6% vs. 54.8% respectively). No participant achieved lower than a grade D in both subjects.

Figure 6.1: Distribution of GCSE grades in (a) English and (b) Mathematics



6.5.4 The association between habitual school-day breakfast consumption and GCSE performance

6.5.4.1 Correlation between habitual school-day breakfast consumption and GCSE point scores

Correlations between habitual school-day breakfast consumption and GCSE point scores produced as part of the hierarchical multiple regression analyses are shown in Table 6.12. A significant negative correlation was observed between rare school-day breakfast consumption and total capped GCSE point score, r = -0.20, p<0.001, and mean GCSE point score per qualification, r = -0.21, p<0.001. There was a trend for a negative correlation between rare school-day breakfast consumption and total uncapped GCSE point score, r = -0.12, p=0.054. Occasional school-day breakfast consumption was not significantly correlated with any GCSE point score outcome.

Table 6.12: Correlations between habitual school-day breakfast consumption categories and aggregate GCSE point scores relative to the reference category of frequent school-day breakfast consumption.

Habitual school-day breakfast consumption	Uncapped point score	Capped point score	Mean point score per qualification
Occasional[a]	-0.05	0.07	0.10
Rare[a]	-0.09	-0.20***	-0.21***

p<0.01;* p<0.001; Values for Pearson's Product Moment correlation
[a] Frequent habitual school-day breakfast consumption as the reference category

6.5.4.2 Hierarchical multiple regression: Total uncapped GCSE point score

Table 6.13 details the results of the hierarchical multiple regression with total uncapped GCSE point score as the outcome variable, and the crude (model 1) and adjusted (models 2 and 3) beta coefficients (β and B). In the initial analysis, four outliers were identified. The analysis was re-run excluding the outliers. The crude model (model 1) was not significant, $F(2,287) = 2.05$, *ns*, and the crude coefficients for both occasional and rare habitual school-day breakfast consumption were not significant.

In model 2, the inclusion of socio-demographic covariates (Table 6.13, model 2) resulted in a significant model which explained 12.0% of the variance in uncapped GCSE point score, $R^2=0.12$; adjusted $R^2=0.10$; $F(7, 282)=5.42$ $p<0.001$. Occasional and rare school-day breakfast consumption remained non-significant predictors of uncapped point score. The change in variance (ΔR^2) accounted for was 10% reflecting a significant increase in variance accounted for by the addition of socio-demographic covariates, $\Delta R^2=0.10$; $F(5,282) = 6.69$, $p<0.001$.

In model 3 with interaction effects included (Table 6.13, model 3) all interaction terms were non-significant. Although model 3 was significant, $F(17, 272)=2.84$ $p<0.01$, and accounted for 15% of the variance in uncapped point scores, the change in variance (ΔR^2) was non-significant. Including interaction terms did not alter the habitual school-day breakfast consumption coefficients, which remained non-significant.

Table 6.13: Hierarchical multiple regression analysis for total uncapped GCSE point score

Model	Explanatory Variables	R^2	ΔR^2	ANOVA	B	SE B	β
1[a]	**Habitual school-day breakfast**	0.01	0.01	$F(2, 287)=2.05$ $p=0.131$			
	Frequent (reference)						
	Occasional				-17.87	14.59	-0.08
	Rare				-23.96	12.57	-0.12
2[b]	**Habitual school-day breakfast**	0.12	0.10***	$F(7, 282)=5.42$ $p<0.001$			
	Frequent (reference)						
	Occasional				-20.79	14.01	-0.09
	Rare				-16.29	12.26	-0.08
3[c]	**Habitual school-day breakfast**	0.15	0.03	$F(17, 272)=2.84$ $p<0.01$			
	Frequent (reference)						
	Occasional				-25.01	14.37	-0.11
	Rare				-12.44	12.42	-0.06
	Interaction terms						
	Ethnicity * Occasional breakfast				5.54	36.24	0.01
	Ethnicity * Rare breakfast				-12.68	32.14	-0.02
	SES * Occasional breakfast				-22.76	28.83	-0.05
	SES * Rare breakfast				12.86	24.41	0.03
	Sex * Occasional breakfast				-2.16	38.48	0.00
	Sex * Rare breakfast				-54.96	29.37	-0.11
	Age * Occasional breakfast				-0.21	18.97	0.00
	Age * Rare breakfast				27.92	16.11	0.10
	BMI SDS * Occasional breakfast				2.18	13.14	0.01
	BMI SDS * Rare breakfast				-13.25	11.20	-0.07

[a] Crude (unadjusted) model
[b] Adjusted model: Includes habitual school-day breakfast consumption adjusted for ethnicity, SES, sex, age and BMI SDS.
[c] Fully adjusted model: Includes habitual school-day breakfast consumption adjusted for ethnicity, SES, sex, age and BMI SDS and interaction terms
*$p<0.05$, ** $p<0.01$, ***$p<0.001$

6.5.4.3 Hierarchical multiple regression: Total capped GCSE point score

Results of the hierarchical multiple regression with total capped GCSE point score as the outcome variable are illustrated in Table 6.14. Two outliers were identified and excluded from the analysis. In model 1, rare school-day breakfast consumption significantly predicted lower attainment in total capped point score. The crude β indicated that capped GCSE point scores were 0.20 SDs lower in adolescents who rarely eat breakfast on school days compared with those who frequently eat breakfast, β= -0.20, p<0.001. Translated in terms of actual point scores, capped GCSE point scores were on average 15.67 points lower in adolescents who rarely eat breakfast on school days compared to those who frequently eat breakfast, B= -15.67, 95% CI= -24.97- -6.37. Occasional school-day breakfast consumption did not significantly predict capped point score. Habitual school-day breakfast consumption accounted for only 4% of the variance in capped point scores, R^2=0.04; adjusted R^2 =0.03, which was a significant model, $F(2,289) = 6.22$, p<0.01, despite the small amount of variance accounted for.

The relationship between rare school-day breakfast consumption and capped point score remained significant following adjustment for covariates, β= -0.14, p<0.05, (Table 6.14 model 2). Regardless of SES, ethnicity, sex, age and BMI, adolescents who rarely eat breakfast on school days achieved lower capped point scores by on average 11.30 points, B= -11.30, 95% CI= -20.03- -2.57. Occasional school-day breakfast consumption was non-significant. Model 2 was highly significant, $F(7,284) = 10.58$, p<0.001, and accounted for 21% of the variance in capped point score, R^2=0.21; adjusted R^2 =0.19. The increase in variance accounted for with the addition of socio-demographic covariates was significant, ΔR^2= 0.17; $F(5,284) = 11.86$, p<0.001.

Model 3 (Table 6.14, model 3) was also highly significant, $F(17,274) = 4.65$, p<0.001, and accounted for 22% of the variance in capped GCSE point score, R^2=0.22; adjusted R^2 =0.18. The inclusion of interaction terms, however, did not result in a significant increase in explained variance and all interaction terms were non-significant. Interaction terms had little effect on the β coefficients for habitual school-day breakfast consumption categories compared to model 2. Rare school-day breakfast consumption significantly predicted lower attainment in total capped point score by 0.13 SDs compared with frequent school-day breakfast consumption, β= -0.13, p<0.05. This translates to a difference in capped point score of -10.25 points, B= -10.25, 95% CI= -19.16- -1.34. Occasional school-day breakfast consumption remained non-significant.

Table 6.14: Hierarchical multiple regression analysis for total capped GCSE point score

Model	Explanatory Variables	R^2	ΔR^2	ANOVA	B	SE B	β
1[a]	**Habitual school-day breakfast**	0.04	0.04**	$F(2,289) = 6.22$, $p<0.01$			
	Frequent (reference)						
	Occasional				0.82	5.49	0.01
	Rare				-15.67	4.73	-0.20***
2[b]	**Habitual school-day breakfast**	0.21	0.17***	$F(7,284) = 10.58$, $p<0.001$			
	Frequent (reference)						
	Occasional				-0.37	5.08	0.00
	Rare				-11.30	4.43	-0.14*
3[c]	**Habitual school-day breakfast**	0.22	0.02	$F(17,274) = 4.65$, $p<0.001$			
	Frequent (reference)						
	Occasional				-1.54	5.24	-0.02
	Rare				-10.25	4.53	-0.13*
	Interaction terms						
	Ethnicity * Occasional breakfast				1.72	13.23	0.01
	Ethnicity * Rare breakfast				7.47	11.73	0.04
	SES * Occasional breakfast				-1.27	10.52	-0.01
	SES * Rare breakfast				7.00	8.90	0.04
	Sex * Occasional breakfast				7.39	14.03	0.03
	Sex * Rare breakfast				-8.27	10.69	-0.04
	Age * Occasional breakfast				3.09	6.92	0.03
	Age * Rare breakfast				6.22	5.87	0.06
	BMI SDS * Occasional breakfast				0.55	4.79	0.01
	BMI SDS * Rare breakfast				-5.66	4.07	-0.08

[a] Crude (unadjusted) model
[b] Adjusted model: Includes habitual school-day breakfast consumption adjusted for ethnicity, SES, sex, age and BMI SDS.
[c] Fully adjusted model: Includes habitual school-day breakfast consumption adjusted for ethnicity, SES, sex, age and BMI SDS and interaction terms
*p <0.05, ** p<0.01, ***p<0.001

6.5.4.4 Hierarchical multiple regression: Mean GCSE point score per qualification

Table 6.15 shows the results of the hierarchical multiple regression with mean point score per qualification as the outcome variable. The crude β coefficients (model 1) suggest that mean point score per qualification was 0.20 SDs lower in adolescents who rarely eat breakfast on school days compared with those who frequently eat breakfast, β= -0.20, $p<0.001$, equivalent to 1.75 points in actual point scores, B= -1.75, 95% CI= -2.78- -0.72. Occasional school-day breakfast consumption did not significantly predict mean point score per qualification. Habitual school-day breakfast consumption accounted for 5% of the variance in mean point score per qualification, R^2=0.05; adjusted R^2 =0.04; $F(2,291) = 7.04$, $p<0.001$, which was a significant model.

The adjusted β coefficients for habitual school-day breakfast consumption remained significant following inclusion of covariates (Table 6.15, model 2). Mean point scores per qualification were 0.14 SDs lower in adolescents who rarely eat breakfast on school days compared with those who frequently eat breakfast, controlling for covariates, β= -0.14, $p<0.01$. Converted to actual point scores, adolescents who rarely eat breakfast on school days showed an average 1.25 points lower mean point score per qualification, controlling for covariates, B= -1.25, 95% CI= -2.20- -0.31. Occasional school-day breakfast consumption was non-significant. Twenty-four percent of the variance in mean point score per qualification was accounted for in model 2, R^2=0.24; adjusted R^2 =0.22; $F(7,286)$=12.76, $p<0.001$, which represented a significant increase in variance accounted for from model 1, ΔR^2= 0.19; $F(5,286) = 14.40$, $p<0.001$.

In model 3, the inclusion of interaction terms (Table 6.15, model 3) did not significantly improve the model and all interaction terms were non-significant. The change in variance accounted for in model 3 was non-significant and the relationship between rare school-day breakfast consumption and mean point score per qualification remained significant. Twenty-five of the variance in mean point score per qualification was accounted for, R^2=0.25; adjusted R^2 =0.20; $F(17,276)$= 5.41, $p<0.001$. The resulting adjusted β coefficients suggest that mean point score per qualification was 0.14 SDs lower in adolescents who rarely eat breakfast on school days compared with those who frequently eat breakfast, β= -0.14, $p<0.05$, equivalent to 1.20 points in actual point scores, B= -1.20, 95% CI= -2.17- -0.23. Occasional school-day breakfast consumption was non-significant.

Table 6.15: Hierarchical multiple regression analysis for mean GCSE point score per qualification

Model	Explanatory Variables	R^2	ΔR^2	ANOVA	B	SE B	β
1[a]	**Habitual school-day breakfast**	0.05	0.05***	$F(2,291)=7.04$, $p<0.001$			
	Frequent (reference)						
	Occasional				0.36	0.61	0.04
	Rare				-1.75	0.52	-0.20***
2[b]	**Habitual school-day breakfast**	0.24	0.19***	$F(7,286)=12.76$, $p<0.001$			
	Frequent (reference)						
	Occasional				0.21	0.55	0.02
	Rare				-1.25	0.48	-0.14**
3[c]	**Habitual school-day breakfast**	0.25	0.01	$F(17,276)=5.41$, $p<0.001$			
	Frequent (reference)						
	Occasional				0.09	0.57	0.01
	Rare				-1.20	0.49	-0.14*
	Interaction terms						
	Ethnicity * Occasional breakfast				0.54	1.45	0.02
	Ethnicity * Rare breakfast				1.02	1.28	0.04
	SES * Occasional breakfast				0.39	1.15	0.02
	SES * Rare breakfast				0.79	0.97	0.05
	Sex * Occasional breakfast				1.79	1.53	0.07
	Sex * Rare breakfast				-0.22	1.17	-0.01
	Age * Occasional breakfast				0.37	0.76	0.03
	Age * Rare breakfast				0.19	0.64	0.02
	BMI SDS * Occasional breakfast				0.02	0.52	0.00
	BMI SDS * Rare breakfast				-0.43	0.44	-0.06

[a] Crude (unadjusted) model
[b] Adjusted model: Includes habitual school-day breakfast consumption adjusted for ethnicity, SES, sex, age and BMI SDS.
[c] Fully adjusted model: Includes habitual school-day breakfast consumption adjusted for ethnicity, SES, sex, age and BMI SDS and interaction terms
*p <0.05, ** p<0.01, ***p<0.001

6.5.4.5 Ordinal logistic regression: GCSE English grades

Results of the ordinal logistic regression with GCSE English grade as the outcome variable are shown in Table 6.16 including beta coefficients and cumulative ORs with 95% CI for higher English grades. Model 1 shows the crude cumulative ORs for habitual school-day breakfast consumption categories before controlling for socio-demographic covariates. Model 1 was not a significant model compared to the baseline intercept-only model, χ^2=3.38, df=2, *ns*.

In the adjusted model (Table 6.16; model 2) inclusion of covariates resulted in a significant model compared to the baseline intercept-only model, χ^2=32.03, df=7, p<0.001, accounting for approximately 12% of the variance in English grades, Nagelkerke's pseudo R^2= 0.12. The relationship between rare school-day breakfast consumption and English grades was significant, such that adolescents who rarely ate breakfast on school days had significantly lower cumulative odds of achieving higher English grades than adolescents who frequently ate breakfast, controlling for socio-demographic covariates, adjusted OR= 0.57, 95% CI= 0.35-0.95, p<0.05. Occasional school-day breakfast consumption was not significantly associated with English grades.

Model 3 with interaction terms accounted for approximately 13% of the variance in English grades, Nagelkerke's pseudo R^2= 0.13, which was significant compared to the baseline intercept-only model, χ^2=37.70, df=17, p<0.01. No interaction terms were significantly associated with English grades. Neither occasional nor rare school-day breakfast consumption was significantly associated with English GCSE grades.

Table 6.16: Ordinal logistic regression for English grades. Shown are beta coefficients and cumulative ORs for higher grades

Model	Explanatory variables	B	SE	OR	95% CI of OR Lower	Upper
1[a]	**Habitual school-day breakfast**					
	Frequent (reference)			1.00		
	Occasional	-0.16	.29	0.85	0.48	1.52
	Rare	-0.47	.25	0.63	0.38	1.03
2[b]	**Habitual school-day breakfast**					
	Frequent (reference)			1.00		
	Occasional	-0.32	0.30	0.73	0.41	1.31
	Rare	-0.55*	0.26	0.57	0.35	0.95
3[c]	**Habitual school-day breakfast**					
	Frequent (reference)			1.00		
	Occasional	-0.56	0.83	0.57	0.11	2.91
	Rare	-0.71	0.63	0.49	0.14	1.69
	Interaction terms					
	Ethnicity * Occasional breakfast	0.29	0.78	1.34	0.29	6.15
	Ethnicity * Rare breakfast	0.75	0.69	2.11	0.55	8.16
	SES * Occasional breakfast	0.02	0.61	1.02	0.31	3.39
	SES * Rare breakfast	0.47	0.53	1.61	0.57	4.54
	Sex * Occasional breakfast	0.22	0.81	1.25	0.25	6.15
	Sex * Rare breakfast	-0.32	0.60	0.72	0.22	2.35
	Age * Occasional breakfast	-0.43	0.41	0.65	0.29	1.45
	Age * Rare breakfast	-0.32	0.32	0.72	0.38	1.37
	BMI SDS * Occasional	0.13	0.28	1.14	0.65	1.98
	BMI SDS * Rare breakfast	0.05	0.24	1.06	0.66	1.68

[a] Crude (unadjusted) model; Nagelkerke's pseudo R^2= 0.01 ; [b] Adjusted model: Includes habitual school-day breakfast consumption adjusted for ethnicity, SES, sex, age and BMI SDS; Nagelkerke's pseudo R^2=0.12; [c] Fully adjusted model: Includes habitual school-day breakfast consumption adjusted for ethnicity, SES, sex, age and BMI SDS and interaction terms; Nagelkerke's pseudo R^2=0.13
**p* <0.05, ** *p*<0.01, ****p*<0.001

6.5.4.6 Ordinal logistic regression: GCSE Mathematics grades

Results of the ordinal logistic regression with GCSE Mathematics grade as the outcome variable are shown in Table 6.17 with beta coefficients and cumulative ORs for higher Mathematics grades. The unadjusted model (model 1) was not a significant model compared to the baseline intercept-only model, χ^2=4.00, df=2, *ns*.

In the adjusted model (Table 6.17, model 2), inclusion of covariates resulted in a significant model, χ^2=26.89, df=7, *p*<0.001, accounting for approximately 9% of the variance in Mathematics grades, Nagelkerke's pseudo R^2= 0.09. Rare school-day breakfast consumption was marginally significantly associated with lower cumulative odds for higher Mathematics grades compared to adolescents who frequently ate breakfast, controlling for covariates, adjusted OR= 0.63, 95% CI= 0.39-1.03, *p*=0.06. Occasional school-day breakfast consumption was not significantly associated with Mathematics grades.

Model 3, including interaction terms, accounted for approximately 13% of the variance in Mathematics grades, Nagelkerke's pseudo R^2= 0.13, and was a significant model, χ^2=37.81, df=17, *p*<0.01. Occasional school-day breakfast consumption remained non-significant. The association between rare school-day breakfast consumption and Mathematics grades was significant such that the adjusted OR indicated that rare school-day breakfast consumption was associated with lower cumulative odds for higher Mathematics grades compared to frequent school-day breakfast consumption, adjusted cumulative OR= 0.26, 95% CI= 0.07-0.88, $p<0.05$. A significant interaction was observed between SES and rare school-day breakfast consumption, suggesting the association between rare habitual school-day breakfast consumption and Mathematics grades varied depending on SES group. To further explore this interaction, the analysis was stratified by SES group (Table 6.18). This indicated that the association was specific to low/middle SES adolescents. Only those adolescents from low/middle SES backgrounds who rarely ate breakfast on school days had significantly lower cumulative odds for higher Mathematics grades, adjusted OR= 0.35 95% CI= 0.17-0.72, $p<0.01$, compared to those who frequently ate breakfast. There were no significant associations between habitual school-day breakfast consumption categories and Mathematics grades in adolescents from higher SES backgrounds. All other interaction terms were non-significant.

Table 6.17: **Ordinal logistic regression for Mathematics grades. Shown are coefficients and cumulative ORs for higher grades**

Model	Explanatory variables	B	SE	OR	95% CI of OR Lower	Upper
1[a]	**Habitual school-day breakfast**					
	Frequent (reference)			1.00		
	Occasional	0.13	0.29	1.14	0.65	2.02
	Rare	-0.43	0.25	0.65	0.40	1.06
2[b]	**Habitual school-day breakfast**					
	Frequent (reference)			1.00		
	Occasional	0.03	0.29	1.04	0.58	1.84
	Rare	-0.46	0.25	0.63	0.39	1.03
3[c]	**Habitual school-day breakfast**					
	Frequent (reference)			1.00		
	Occasional	-0.31	0.83	0.74	0.15	3.72
	Rare	-1.36*	0.63	0.26	0.07	0.88
	Interaction terms					
	Ethnicity * Occasional breakfast	0.10	0.77	1.10	0.24	5.01
	Ethnicity * Rare breakfast	0.39	0.68	1.47	0.39	5.60
	SES * Occasional breakfast	0.21	0.61	1.24	0.38	4.06
	SES * Rare breakfast	1.38**	0.53	3.98	1.42	11.16
	Sex* Occasional breakfast	0.23	0.81	1.26	0.26	6.19
	Sex* Rare breakfast	0.08	0.59	1.09	0.34	3.48
	Age * Occasional breakfast	-0.07	0.40	0.93	0.42	2.06
	Age * Rare breakfast	-0.37	0.32	0.69	0.37	1.30
	BMI SDS * Occasional breakfast	-0.16	0.28	0.85	0.49	1.47
	BMI SDS * Rare breakfast	0.37	0.23	1.45	0.91	2.29

[a] Crude (unadjusted) model; Nagelkerke's pseudo R^2= 0.01; [b] Adjusted model: Includes habitual school-day breakfast consumption adjusted for ethnicity, SES sex, age, and BMI SDS; Nagelkerke's pseudo R^2=0.09; [c] Fully adjusted model: Includes habitual school-day breakfast consumption adjusted for ethnicity, SES, sex, age, and BMI SDS and interaction terms; Nagelkerke's pseudo R^2=0.13
*$p<0.05$, ** $p<0.01$, ***$p<0.001$

Table 6.18: Ordinal logistic regression for Mathematics grades stratified by SES. Shown are coefficients and adjusted[a] cumulative ORs for higher grades

Explanatory variable	Low/middle SES (n=146)				
	B	SE	OR	95% CI of OR Lower	Upper
Habitual school-day breakfast					
Frequent (reference)			1.00		
Occasional	-0.16	0.41	0.85	0.38	1.90
Rare	-1.05**	0.37	0.35	0.17	0.72
Explanatory variable	**High SES (n=148)**				
	B	**SE**	**OR**	**95% CI of OR Lower**	**Upper**
Habitual school-day breakfast					
Frequent (reference)			1.00		
Occasional	0.17	0.43	1.19	0.51	2.78
Rare	0.07	0.35	1.07	0.54	2.13

[a] Model adjusted for ethnicity, sex, BMI SDS and age.
*p <0.05, ** p<0.01, ***p<0.001

6.6 Interim summary of results

6.6.1 Habitual breakfast consumption

- Adolescents frequently skip breakfast on school days. Seventeen percent of adolescents skipped breakfast everyday on school days.
- Adolescents who skipped breakfast on school days were significantly younger than adolescents who frequently ate breakfast on school days.
- Where breakfast was eaten, the most frequently consumed foods for breakfast were breads and RTECs.
- The mean daily percentage of estimated TEE provided by breakfast was less than 10%.
- For all breakfast meals, most of the energy consumed came from total carbohydrate (approximately 50% of food energy).
- Breakfast meals made a large contribution to micronutrient RNIs. Mean daily intake of Vitamin C, Vitamin B^{12}, Thiamine, Riboflavin and Niacin from breakfast provided over a third of the RNIs for males and females.
- Intake of macronutrients and micronutrients from school-day meals and weekend meals were significantly different.
- A significantly higher mean daily percentage of food energy was consumed as total carbohydrate and a significantly lower mean daily percentage of food energy was consumed as fat from school-day breakfast meals than from weekend breakfast meals.
- Mean daily intakes of Vitamin B^{12}, Niacin, Calcium, Vitamin D, Zinc and Iron were significantly lower from school-day breakfast meals than weekend breakfast meals.

6.6.2 The association between habitual school-day breakfast consumption and GCSE performance

- School-day breakfast skipping was negatively associated with measures of aggregated (capped and average point scores) GCSE performance after controlling for a range of confounders.
- Linear regression models indicated that rarely eating breakfast on school days depressed total capped (best 8) GCSE point score by 10 points and mean point per qualification by 1 point. This association was consistent across gender, SES, ethnic group, age and BMI.
- There were no clear subject differences, but the association between habitual school-day breakfast consumption appeared stronger and more consistent for Mathematics grades than for English grades.
- A significant association was apparent only when rare school-day breakfast consumption (0-1 times/weekdays) and frequent school-day breakfast consumption (4-5 times/weekdays) categories were compared.
- Habitual school-day breakfast consumption amongst adolescents is a minor correlate of GCSE attainment, since only a small amount of variance was explained by habitual school-day breakfast consumption in all regression models.

6.7 Discussion

The study examined the hypothesis that habitual school-day breakfast skipping is negatively associated with GCSE attainment, a national academic qualification obtained by most school children in the UK in the final years of education. The study examined a sample of 16-18 year old adolescents from a generally high academic ability population. The study extends previous work to include the important GCSE phase of secondary schooling. GCSE attainment was assessed by three composite measures using the Department for Education point score system (Department for Education, 2013a, 2013d) and by grades achieved in Mathematics and English. These outcomes were chosen to reflect typical performance indicators used within the education system, performance tables and educational research. Attainment in Mathematics and English were considered separately as these represent compulsory subjects which are included as part of entry requirements for further education and as part of government targets for schools. The focus on school-day breakfast consumption in this relationship is novel.

The study examined the nature of habitual breakfast consumption in 16-18 year old adolescents. The breakfast consumption data reported in this chapter extends previous work by providing more in-depth descriptions of breakfast intake and by differentiating between school-day and weekend breakfast eating. Furthermore, ascertaining the extent of breakfast consumption in adolescents is the initial step in understanding the relationship between habitual school-day breakfast consumption and academic performance.

6.7.1 Habitual breakfast consumption

6.7.1.1 Prevalence of breakfast skipping

The findings indicated that breakfast skipping is highly prevalent among adolescents. These findings echo previous research, outlined in Chapter 1 (section 1.2). Taken together, the results of the current study and previous UK breakfast consumption data suggest that adolescents in particular, are more likely to skip breakfast compared to younger age groups. The proportion of adolescents who skipped breakfast on school days and on weekends was similar, suggesting that a large proportion of adolescents who skipped breakfast on school days continued to skip breakfast on weekends. Common reasons cited by adolescents for skipping breakfast include lack of time, lack of morning appetite, not having a breakfast routine or preferring more time to sleep (Affinita et al., 2013; Mullan et al., 2014; Reddan, Wahlstrom, & Reicks, 2002). Given that adolescents who skip breakfast on school days continue to do so on weekends, lack of time due to busy morning schedules on school days would not appear to be the key reason for breakfast skipping, even though perceived lack of time is a barrier to consumption.

Previous work has shown that a third of school children who skip breakfast also do not eat or drink anything at mid-morning break time (Hoyland et al., 2012). Hence it is plausible to assume that some adolescents who skip breakfast will continue to abstain from eating anything until lunchtime. In these adolescents, the overnight fasting period is therefore prolonged until lunchtime and includes the entire school morning. Furthermore, the energy deficit induced by breakfast omission may not be compensated for by a greater energy intake at lunchtime or throughout the day. However, school children who miss breakfast report significantly greater hunger and a greater desire to eat (Kral, Heo, Whiteford, & Faith, 2010; Nicklas, Bao, Webber, & Berenson, 1993). Alternatively, school children who skip breakfast may consume more unhealthy foods at mid-morning break time in an attempt to compensate for the energy deficit induced by missing breakfast. Previous research has shown that adolescents who skip breakfast and eat later in the morning (i.e. break time) choose more unhealthy foods including confectionary, crisps or high-sugar carbonated drinks (Hoyland et al., 2012; Savige, MacFarlane, Ball, Worsley, & Crawford, 2007). Either scenario presents the opportunity for schools to provide breakfast and/or healthier snacks at break time for those who usually skip breakfast.

6.7.1.2 Socio-demographic factors and breakfast consumption

Excluding age, the study failed to find any socio-demographic differences in the frequency of school-day breakfast consumption. Adolescents who skipped breakfast on school days were significantly younger than adolescents who frequently ate breakfast on school days. This is largely inconsistent with previous studies in adolescents which suggests that breakfast skipping increases with age (e.g. Vereecken et al., 2009; see Chapter 1, section 1.2.2). The narrow age range included in the present study could explain this contradictory finding.

The null findings for gender, SES, ethnicity and BMI suggest that there is no variation in the extent of breakfast skipping in the different subgroups of the sample. This contradicts a wealth of evidence that breakfast consumption differs according to SES, gender, ethnicity and weight status (Chapter 1, section 1.2.2). However, the failure to detect these associations in this study is most likely due to the unintended recruitment bias of a homogenous sample, in which male adolescents, lower SES and ethnic minority groups were underrepresented.

6.7.1.3 Macronutrient intake in habitual breakfast consumers

Where breakfast was consumed, on average, it provided inadequate energy. Other studies have reported slightly higher energy intakes from breakfast (15% of daily energy needs; Matthys, De Henauw, Bellemans, De Maeyer, & De Backer, 2007; Nicklas et al., 2000; Raaijmakers, Bessems, Kremers, & van Assema, 2013). The low mean energy intake at breakfast may be an artefact of underreporting or recall error. Despite this, breakfast meals typically had a favourable macronutrient profile, with most of the energy consumed from carbohydrate. Evidence from both child and adolescent samples has demonstrated similar macronutrient intakes from breakfast (Aranceta, Serra-Majem, Ribas, & Pérez-Rodrigo, 2001; Raaijmakers et al., 2013).

Macronutrient intake from breakfast may have positive effects on total daily macronutrient intake; however this was not assessed in the current study. Habitual breakfast consumers are more likely to have higher daily intakes of total carbohydrate and lower total fat (Deshmukh-Taskar et al., 2010; Min et al., 2011). The frequent consumption of RTECs for breakfast observed in the current study, and in previous studies (Hallström et al., 2012; Hoyland et al., 2012), may contribute to the more favourable daily macronutrient intakes in habitual breakfast consumers. Previous work indicates that RTEC consumption is independently associated with a higher proportion of daily energy from carbohydrate and lower proportion of daily energy from fat in adolescents (Preziosi et al., 1999). Alternatively, the more positive total daily macronutrient intake seen in habitual breakfast consumers may be because breakfast consumers are more likely to consume healthy food choices throughout the day. These include higher intakes of fruit, vegetables, and lower intakes of high-fat/high sugar snacks (Pedersen et al., 2012; Utter et al., 2007).

Mean daily intake of non-starch polysaccharides from breakfast, a food component that school children lack (Ruxton & Derbyshire, 2011), provided only 7% of the UK 18g/day dietary reference value. This is lower than reported intakes (14-16% of reference intake) from breakfast in recent studies (Grieger, Kim, & Cobiac, 2013; Raaijmakers et al., 2013). Moreover, evidence suggests that habitual breakfast consumers have higher daily intakes of fibre than non-consumers (Affenito et al., 2005; Deshmukh-Taskar et al., 2010).

6.7.1.4 Micronutrient intake in habitual breakfast consumers

Breakfast meals made a large contribution to RNIs of many micronutrients despite the relatively low mean energy consumed. This suggests that the energy provided by breakfast disproportionately, yet favourably, contributed to daily micronutrient intake. Breakfast meals typically have a higher nutrient-to-energy ratio than other meals (Magarey & Boulton, 1995) and common breakfast foods reported in the current study are normally considered nutrient-dense, providing substantial amounts of micronutrients in a small amount of energy (Rampersaud et al., 2005). These include whole-grain breads, fortified RTECs, milk and fruits. The relatively frequent consumption of vitamin fortified drinks for breakfast also accounted for the high daily micronutrient intake from breakfast in this study.

Similar results were reported from the 2001-2002 US NHANES illustrating that breakfast provides approximately 15-18% of energy but 15-40% of daily needs for Vitamin A, Thiamine, Riboflavin, Niacin, Vitamin B^{12}, Vitamin B^{6} , Folate, Vitamin C and Iron in adolescents aged 12-19 years (Rampersaud et al., 2005). Fortified RTECs may positively contribute to micronutrient intake particularly because they are normally consumed with milk. An increased frequency of RTEC consumption was significantly associated with increased intakes of Niacin, Vitamin B^{12}, Vitamin D, Calcium, Iron, Zinc in US school children (Balvin Frantzen, Treviño, Echon, Garcia-Dominic, & DiMarco, 2013). RTEC consumption is also positively associated with improved biochemical indices of nutritional status including serum concentrations of Thiamine in French school children (Preziosi et al., 1999). Gibson (2003) reported that RTECs provided only 5% of total energy intake yet 13-21% of Iron, Folate, Thiamine, Riboflavin, Niacin, Vitamin B^{6} and Vitamin D. Breakfast consumption is also related to higher calcium intake in adolescents, most likely attributable to the consumption of milk with RTECs (Peters, Verly, Marchioni, Fisberg, & Martini, 2012).

6.7.1.5 Differences in school-day and weekend breakfast intakes

The findings suggested that the frequency of breakfast intake remains relatively stable between school days and weekend days yet breakfast habits, in terms of macronutrient and micronutrient intake, differed. This was because low fat, carbohydrate based foods (e.g. RTECs, breads) were more frequently consumed for school-day breakfast meals and more high-fat foods (e.g. meat, eggs) and larger amounts of fat were more frequently consumed for weekend breakfast meals. Similar findings for the type of foods consumed at breakfast on school days and weekends were reported in Study 2 in a younger sample of adolescents aged 11-13 years (Chapter 5; see section 5.5.2.3). These findings suggest that school-day and weekend breakfast habits are different and reflect different behaviours and/or food choices which could particularly affect studies that assess breakfast on a single day or over a 3-day period only. This also highlights the importance of isolating school-day breakfast consumption in the relationship between habitual breakfast consumption and academic performance.

6.7.2 Habitual school-day breakfast consumption and academic performance

6.7.2.1 Aggregated GCSE attainment

The findings supported the hypothesis that habitual school-day breakfast skipping is negatively associated with GCSE performance in 16-18 year old adolescents, after adjustment for confounders. Linear regression models indicated that rarely eating breakfast on school days depressed capped GCSE point score by 10 points and average point per qualification by 1 point. Although it is difficult to translate these effects into grades, the magnitude of the associations suggests meaningful differences in GCSE grades (Department for Education point score scale increases by 6 points for each grade increase). The findings are also consistent with the cross-sectional evidence outlined in the SRR reported in Chapter 4.

Uncapped GCSE point scores were not associated with breakfast skipping on school days. However, capped point score (best 8) and mean point score per qualification were negatively associated with breakfast skipping on school days. These measures are not indicative of the number of GCSE qualifications, but reflect the quality of the results obtained. These findings suggest that habitual school-day breakfast consumption has greater effects on the quality of the grades rather than the number of GCSE qualifications achieved. It is unlikely that habitual school-day breakfast consumption has a strong effect on the number of GCSE qualifications attained. This may be because the number of qualifications a pupil obtains can be influenced by the opportunity to sit certain examinations. Factors other than habitual breakfast consumption are likely to have a greater influence on the number of GCSE qualifications achieved such as the school attended and the teachers' decision to enter pupils into examinations.

Aggregated GCSE attainment decreased with lower frequencies of school-day breakfast consumption suggestive of a possible dose-response relationship. However, a significant association was apparent only when comparing rare school-day breakfast consumption (0-1 times/week) to frequent (4-5 times/week). This suggests that significant effects on GCSE performance are more evident at the extremes of breakfast consumption. It may mean that the occasional school-day breakfast consumption group fell into the middle between rare and frequent school-day breakfast consumption in terms of its association with GCSE point scores and was not different from those frequently consuming breakfast, but the difference between the extreme groups was significant.

Whilst statistically significant associations were evident, a small amount (≈20%) of variance was explained by habitual school-day breakfast consumption and socio-demographic variables. This is not surprising given the multitude of other factors that influence academic achievement in adolescents. These factors alone cannot provide sufficient explanation of GCSE performance implying that unmeasured variables played a significant and larger part in GCSE performance. Another possible factor that may contribute to the small amount of explained variance could be the sample characteristics. The majority of adolescents were of high academic ability. It may be that in lower achieving adolescents more variance in GCSE performance is explained by breakfast.

6.7.2.2 Mathematics and English attainment

There were no clear subject differences for Mathematics and English. Rarely eating breakfast on school days was associated with poorer grades in both subjects, but this was slightly attenuated following adjustment for covariates and interaction terms. Both subject grade distributions ranged from A*-D meaning lower pass grades (E-G) did not occur. Both subject grade distributions were also sustainably skewed towards higher grades (A*-B). Performance in English was particularly high. This may have made it difficult to elucidate an association between habitual school-day breakfast consumption and GCSE grades since performance was within a very limited range of higher grade categories. This may have accounted for the lack of consistent associations between habitual school-day breakfast consumption and English and Mathematics grades. However, the association between habitual school-day breakfast consumption and GCSE attainment appeared stronger for Mathematics grades. Rarely consuming breakfast on school days was significantly associated with poorer Mathematics attainment. This is largely consistent with previous work examining the effects of habitual breakfast consumption on individual subject domains (Chapter 4; Adolphus et al., (2013).

6.7.2.3 Impact of socio-demographic characteristics on the relationship between breakfast and GCSE performance

The association between habitual school-day breakfast consumption and aggregated GCSE performance was consistent across gender, ethnicity, SES, age and BMI. No interaction terms were significant and the inclusion of interaction terms into the regression models did not improve the models. Moreover, the significant main effects of previously entered habitual school-day breakfast consumption variables remained in all models. Collectively, this suggests that in this sample of adolescents, there is no evidence of systematic variation in the effects of habitual school-day breakfast consumption on GCSE attainment across socio-demographic groups. However, this finding should be interpreted with caution as the sample was not sufficiently diverse to detect reliable interactions between socio-demographic variables and breakfast consumption patterns. Although, a previous cross-sectional study has examined possible interaction effects and demonstrated similar results to that of the current study in a large sample of Dutch adolescents (11-18 years) of high academic ability. Breakfast skipping (<5 days/week) was associated with lower average annual school grades, consistent across gender and age (Boschloo et al., 2012). Similarly, Lien (2007) demonstrated that adolescents who never ate breakfast were twice as likely to have lower self-reported school grades compared with those who consumed breakfast every day, an effect consistent in males and females. However, this association differed by immigration status with a significant association apparent only for native Norwegians compared with second-generation immigrant groups (Lien, 2007). This is inconsistent with the findings of the present study where no ethnic differences were observed in the association between habitual school-day breakfast consumption and aggregated GCSE performance.

An interaction between rare school-day breakfast consumption and SES was observed for Mathematics grades suggesting that SES modifies the association between habitual breakfast consumption and GCSE Mathematics attainment. Further examination of this interaction indicated that the negative association between skipping breakfast and Mathematics attainment was only apparent for adolescents from low/middle SES backgrounds. In high SES adolescents, overall quality of the diet (including evening intake) may be higher than in low SES adolescents which may offset any detrimental effects of skipping breakfast. For example, SES discrepancies in dietary intake are observed for intake of fruit, vegetables, fish, whole grains, fibre rich foods and high fat food (Weichselbaum & Buttriss, 2014). Previous work has also shown positive effects of breakfast consumption on academic performance in low SES groups (Kleinman et al., 2002; Murphy et al., 1998). Moreover, Cueto and Chinen (2008) demonstrated that the positive effects observed on achievement test scores following a SBP were specific to schools which tended to have higher levels of poverty. Yet, no study has directly compared the effects of breakfast on attainment in school children of differing SES and previous studies suggest that effects are evident in all SES groups (Chapter 4; Adolphus et al., 2013).

Caution should be exercised when interpreting this finding. The main effects of SES on GCSE attainment (full models shown in Appendices 9.62-9.64 and 9.67-9.68) for all GCSE outcomes were contradictory to previous research. High SES was associated with lower GCSE attainment in the current study. The positive link between SES and school children's attainment is well-established (Brooks-Gunn & Duncan, 1997; Machin & Vignoles, 2004; McLoyd, 1998). Higher SES is associated with better achievement in all key stages of schooling in the UK, including GCSE achievement (Department for Children, Schools and Families, 2009a). This positive association between SES and academic performance was also demonstrated in Study 2 in Chapter 5 (see Appendices 9.46-9.49). Moreover, high parental education specifically is associated with positive educational outcomes in school children (Davis-Kean, 2005; Dubow, Boxer, & Huesmann, 2009). The potentially spurious finding of an inverse relationship between SES and GCSE performance in the current study may be due to error in the measurement of SES or because low SES groups were unrepresented due to selection bias. Therefore, the association between rare school-day breakfast consumption and poorer Mathematics attainment in low/middle SES adolescents is unlikely to represent a valid finding.

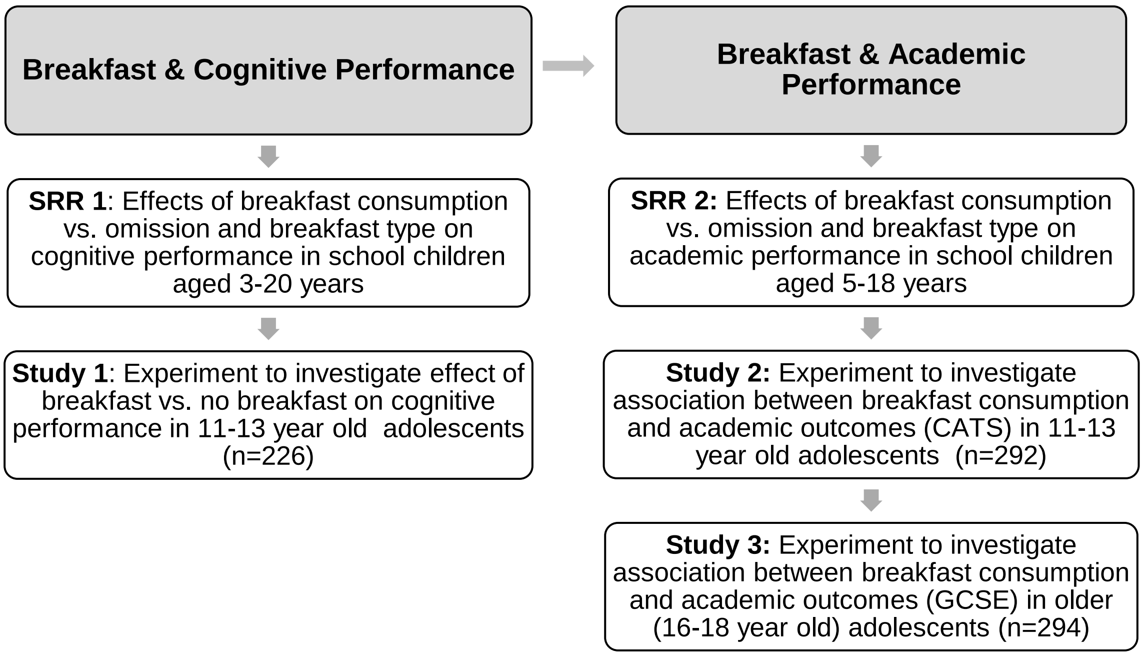
6.7.3 Conclusion

In conclusion, the findings show that breakfast skipping is a prevalent behaviour in adolescents. The study suggests that habitual breakfast consumption on school days is a minor, but significant correlate in adolescents' academic performance at age 16-18 years after controlling for gender, SES, ethnicity, age and BMI. However, the cross-sectional design only confirms the coexistence of these two conditions in the adolescents studied. Furthermore, these factors alone cannot provide sufficient explanation of GCSE performance. Nevertheless, the results offer promising associative evidence that breakfast consumption is linked to academic performance in adolescents which warrants further exploration in well controlled studies.

7 General Discussion

This final chapter summarises the key findings of this thesis in relation to the original aims set out in Chapter 1. Here, the strengths and limitations of this work are explored and original contributions to the field of breakfast, cognitive and academic performance are highlighted. The implications of the thesis findings, in terms of future research and real-word implications are also discussed alongside methodological recommendations for future research in this area. Figure 7.1 (below) shows the two main foci of the research presented in this thesis.

Figure 7.1: Schematic overview of the thesis



Each tenet was explored firstly by systematically reviewing the literature which identified both the strongest evidence for possible effects of breakfast on cognitive performance and academic outcomes and those areas in which evidence was weak or lacking. The subsequent studies were then designed to address the limitations and gaps in the evidence base. The main findings, strengths and limitations of the reviews and studies presented within this thesis are discussed for both cognitive and academic outcomes in turn below.

7.1 Breakfast and cognitive performance

7.1.1 Overview of the thesis findings

7.1.1.1 Effects of breakfast vs. breakfast omission on cognitive performance in children and adolescents

A key aim of this thesis was to systematically review the effects of breakfast vs. breakfast omission on cognitive performance in children and adolescents. The SRR presented in Chapter 2 provided an up to date SRR which evaluated the consistency of the effects across a range of cognitive domains, populations, settings, and breakfast manipulations and highlighted the areas ripe for future research. The SRR demonstrated modest evidence that breakfast consumption has a short-term positive effect on cognitive performance in school children aged 5-11 years. The available evidence was considerably mixed. Although it seems intuitive that consuming breakfast will have a positive impact on cognitive function, the data included in the SRR suggested that the effects can be positive, null and sometimes negative.

Sample sizes in these experimental investigations were rather small and tended to include middle class school children if studies were not conducted in the developing world. Beneficial effects of breakfast consumption were not consistently reported in well-nourished middle class children (e.g. Busch et al., 2002; Cromer et al., 1990; Dickie & Bender, 1982; Mahoney et al., 2005; Widenhorn-Müller et al., 2008) who may have better cognitive ability or greater cognitive reserve (McCulloch & Joshi, 2001). These samples may therefore have been fairly well-protected against any negative effects of breakfast omission. There was a lack of evidence for effects in adolescents in whom few studies have been conducted. There was also a lack of research employing naturalistic breakfast manipulations and contexts, which prevented generalisation to 'real-life' situations. This observation provided the motivation for Study 1 presented in Chapter 3 which examined the effects of breakfast vs. breakfast omission on cognitive performance in a large sample of adolescents from an inner city comprehensive school with a high proportion of pupils claiming FSMs and whose cognitive ability was shown to be somewhat lower than the general population average (Chapter 3, section 3.5.1, Table 3.5). The deliberate recruitment of an at-risk population in terms of cognitive ability and degree of relative deprivation was intended to increase the sensitivity of the intervention. The detection of a beneficial effect of breakfast ought to be more likely in adolescents who are not already performing at a high level on cognitive tasks and whose performance may not be well-protected when challenged by breakfast omission. Nevertheless, Study 1 provided only very modest support for the benefit of breakfast relative to breakfast omission on cognitive performance across the morning of consumption in 11-13 year old adolescents. This was a well-powered study with a sample size far larger than almost all the previous studies yet the findings were largely non-significant. Of the 19 cognitive outcome measures included in the analysis, only 2 showed significant positive effects of breakfast and by chance one of these could be considered a Type 1 error.

Despite the lack of clear cognitive effects of breakfast consumption in the whole sample examined in Study 1, there were suggestions that performance benefits were either more notable in, or limited to, adolescents who performed at a lower level at baseline. For these adolescents, breakfast was able to boost task performance to a greater extent. Similarly, when IQ was included as a covariate in previous studies included in the SRR, the findings suggested that the consumption of breakfast benefits those with a lower IQ to a greater extent (Hoyland, 2009; Pollitt et al., 1998; Pollitt et al., 1981). Furthermore, the SRR suggested that the positive effects of breakfast consumption relative to fasting tended to be more consistent in undernourished children. These children also performed more poorly on the cognitive tasks (Ghazi et al., 2012; López et al., 1993; Nasir et al., 2012) and therefore had greater scope for improvement. This highlights the importance of employing appropriate statistical analysis, in this case, an ANCOVA analysis with baseline cognitive performance included as a covariate. It also demonstrates the importance of choice of cognitive task such that floor and particularly ceiling effects are avoided as well as the importance of sampling so that adolescents with a broad range of cognitive ability are included rather than those at the upper end of the distribution whose cognitive reserve is likely to protect them from the detrimental effects of breakfast omission.

7.1.1.2 Domain specific effects of breakfast vs. breakfast omission on cognition

The SRR indicated that breakfast-induced cognitive effects were domain specific. Tasks which required attention, working memory and immediate visual-spatial memory were facilitated more reliably by breakfast consumption relative to fasting. Study 1 also demonstrated domain specific effects of breakfast consumption relative to breakfast omission; however, the findings were not consistent with those of the SRR. Breakfast-induced cognitive benefits were specific to reaction time in Study 1. Attention and immediate visual-spatial memory were not facilitated by breakfast, in contrast to the findings of the SRR (Chapter 2). However, the SRR revealed some evidence that reaction time was facilitated by breakfast consumption relative to fasting (Amiri et al., 2014; Cooper et al., 2011, Wesnes et al., 2003), but there were only six studies which examined this domain and those that did tended to be in younger children.

The discrepancies between the findings of Study 1 and the SRR suggest that the findings of domain specific effects of breakfast should be interpreted cautiously as they are likely to be attributable to the inter-study methodological variability. Further, it is likely that certain characteristics of cognitive tasks such as task sensitivity, task demand, duration of the task, whether the task is presented within a battery or unaccompanied by other tasks, duration of the cognitive battery, order of presentation within the battery and time of administration also influence whether an effect is observed or not. In Study 1, the order that the cognitive tasks were administered was not counterbalanced and test order was not included as a covariate in the analyses. Therefore, the influence of order effects on the findings of Study 1 must be acknowledged. Hence, it might not be that specific cognitive functions are facilitated more reliably by breakfast, but that the huge variety of testing situations causes the observed variation in effects across domains. Importantly, many cognitive tasks can reflect or require one or more aspect of cognitive function and many tasks are neither designed, nor capable, of assessing change within a single cognitive function with a great degree of precision (Wesnes, 2010).

The SRR and Study 1 suggest that the effects of breakfast consumption on cognitive performance are likely to be subtle, and demonstrable only under specific conditions or in particular samples. The functions assessed could have some wider impact for learning in the classroom and for educational achievement. Measures of cognitive performance provide a proxy for cognitive abilities such as the ability to concentrate, react and remember, all of which are key processes for effective learning in school. However, Study 1 suggests that it is unlikely that breakfast omission is associated with cognitive impairment that has meaningful detrimental effects on everyday functioning at school.

7.1.1.3 Effects of breakfast vs. no breakfast on subjective state

A further aim of this thesis was to examine the effects of breakfast vs. breakfast omission on concomitant measures of subjective state alongside cognitive function in adolescents. The SRR in Chapter 2 revealed that breakfast consumption may improve several aspects of subjective feelings of mood, mental alertness and motivation in the short-term. The SRR also highlighted the potential for subjective feelings and cognitive testing to reciprocally influence each other, but there were few studies employing age-appropriate subjective state measures. Improvements in subjective feelings of mood or alertness following breakfast could be a mechanism underlying the improvements in cognitive performance. This observation led to the examination of subjective state alongside cognitive function in Study 1. There were clear breakfast-induced benefits to mood, mental alertness, motivation and satiety in Study 1, similar to the findings of some studies included in the SRR (Cooper et al., 2011; Defeyter & Russo, 2013; Wesnes et al., 2003). A novel finding of Study 1 was that the propensity for breakfast to exert beneficial effects was greater in participants who experienced more intense negative levels of these subjective states at baseline. This further underlines the importance of using ANCOVA with baseline measures as covariates. Study 1, therefore, contributes new information on the effects of breakfast on the nature of subjective state.

The positive effects on feelings of satiety, mood, alertness and motivation following breakfast consumption are perhaps some of the most encouraging findings from this thesis. It is interesting to note that the pattern of results for cognitive outcomes did not map onto the pattern of subjective ratings in Study 1, suggesting that these outcomes are temporally distinct. Study 1 therefore provides evidence that the intake of breakfast can help adolescents to feel in a better mood, more motivated, more alert and less hungry compared to when breakfast is skipped, but this did not facilitate cognitive performance. However, it is important not to overemphasize this effect as expectancy effects and/or socially desirable responding could have influenced the subjective reports observed.

7.1.2 The contribution of extraneous variables

There are many factors which could have influenced the findings of Study 1, which also offer tentative explanations for the lack of clear effects of the study manipulation on cognitive performance. There are likely to be large inter-individual differences in the cognitive response to breakfast consumption; such that for some participants there may be deterioration in performance whereas for other participants performance may improve. There are also likely to be intra-individual differences, depending on the day or even time of testing. There were no differences in key characteristics of participants randomised to the breakfast and no breakfast conditions (e.g. gender, age, CAT scores, habitual breakfast intake, FSM status, EAL). Thus we can be confident that these factors were unlikely to have accounted for observed differences between the breakfast and no breakfast study conditions. However, it is still possible that these factors could have contributed to additional variation in the data. For example, if skipping breakfast is part of the participant’s typical routine, negative effects on cognitive performance may be minimal (Lloyd et al., 1996). However, positive effects of breakfast consumption relative to fasting on cognitive performance are observed in both habitual and non-habitual breakfast consumers (Defeyter & Russo, 2013; Kral et al., 2012).

7.1.2.1 Effects of prior nutrient/energy intake and physical activity levels

There are also many unmeasured factors which could have influenced the cognitive response to breakfast and fasting. Some of these are related to the testing environment (discussed in section 7.1.3.5). Other factors that may cause variation in the cognitive response to breakfast include differences in glycogen stores at the time of testing (Gibson and Green 2001). Similarly, the timing and content of the meal consumed prior to breakfast will have differed between participants and contributed to variations in glycogen stores with possible impact on response to breakfast and cognitive function (Lamport et al., 2011). Differing physical activity levels on the test morning and habitual physical activity levels may have also influenced the effects of breakfast on cognitive function. A meta-analysis showed that both acute and chronic physical activity interventions have a significant positive effect on cognitive function in school children (Sibley & Etnier, 2003). Recent evidence has also shown that adolescents who are more physically active (via an intervention) have superior cognitive performance to those who are less active (Ardoy et al., 2014). In active male adults, breakfast consumption has been shown to impair cognitive performance, but moderate to vigorous exercise reversed this effect (Veasey, Gonzalez, Kennedy, Haskell, & Stevenson, 2013). In contrast, physical activity may have a negative impact on performance by increasing fatigue and reducing glycogen stores. In Study 1 the test morning did not occur during mornings where Physical Education was scheduled to ensure that participants had similar levels of physical activity on the test morning. However, it is likely that there were between participant differences in the level of physical activity undertaken on the morning of testing (e.g. some participants may have walked to school or engaged in sport before school). This may have improved cognitive performance in the no breakfast condition, which lessened the effect of fasting on cognitive performance.

7.1.2.2 Effects of hydration

Another consideration is the possibility that hydration status and test day water intake may have influenced the effects of breakfast and no breakfast on cognitive function. Cognitive performance in adults shows a dose-response relationship with the degree of dehydration (Lieberman, 2007). Studies in school children living in hot climates have demonstrated that those who arrive at school dehydrated perform worse on cognitive tasks relative to school children who are better hydrated (Bar-David, Urkin, & Kozminsky, 2005; Fadda et al., 2012). This relationship has not been examined in more temperate climates, including the UK, but there is evidence to suggest that school children may arrive at school dehydrated (Barker et al., 2012). In adults, reaction time (decision time) on the CANTAB SRT task improved following water supplementation but the effect was moderated by baseline subjective feelings of thirst, such that the effects were only apparent in participants who were more thirsty (Edmonds, Crombie, & Gardner, 2013). There was, however, no effect of water supplementation on the CANTAB PAL and RVIP tasks. Furthermore, when thirst is low, the intake of water can result in worse RVIP performance (Rogers, Kainth, & Smith, 2001). There are also reports in school children that intake of water improves reaction time, attention, and verbal memory (Edmonds & Burford, 2009). In Study 1 water was provided ad-libitum in both breakfast conditions but very few participants consumed water. However, participants were allowed to drink water during the entire test morning (e.g. during lessons), which was not recorded. The act of offering additional drinking water and permitting ad-libitum water intake in the no breakfast condition may have improved cognitive performance and counteracted some of the effects of missing breakfast. This may have contributed to the lack of differences between conditions. It is also possible that water intake in the breakfast condition influenced cognitive performance via a separate mechanism, and so it is impossible to untangle the effect of breakfast from the effect of water intake on cognitive function. Furthermore, dehydration could have also influenced the findings given that only 32% of the sample reported having a drink at breakfast, although, this may represent underreporting.

7.1.2.3 Effects of prior or habitual caffeine consumption

In Study 1, it was observed (but not recorded) that caffeinated energy drink consumption was particularly common among the adolescents under study, and that energy drinks which contain large quantities of caffeine (e.g. RedBull©, Monster Energy Drink© and variants) were particularly favoured. Corroborative evidence from a SRR suggests that energy drinks are consumed by 30% to 50% of adolescents and young adults (Seifert, Schaechter, Hershorin, & Lipshultz, 2011). Further, 9% of the adolescents under study reported that they usually consumed tea/coffee at breakfast but these beverages were not permitted on test mornings (only water). Studies in school children have shown that habitual caffeine consumers show poorer cognitive performance than non-consumers when they have abstained from caffeine overnight (Heatherley, Hancock, & Rogers, 2006). In the breakfast condition, participants who were habitual caffeine consumers may have performed worse on the tasks despite consuming breakfast because of caffeine withdrawal. This may have reduced the ability to detect effects of breakfast on cognitive performance. However, there were more tea/coffee consumers in the no breakfast condition (16 [7.1%]) than the breakfast condition (5 [2.2%]), but this does not reflect consumption of other caffeinated drinks. Caffeine consumption on test days due to non-compliance in either study condition is unlikely to have had a substantial effect on the results as reports generally show no net-benefit on performance, rather an alleviation of the withdrawal in habitual consumers only (Heatherley et al., 2006).

7.1.2.4 Effects of personality characteristics and chronotype

Personality factors may have also produced variation in the cognitive response to breakfast. In male adolescents, glucose enhancement of verbal memory is modulated by trait anxiety, such that the effects are only observed in males who report higher trait anxiety (Smith, Hii, Foster, & van Eekelen, 2011). The effectiveness of the study manipulation may have also been affected by individual differences in circadian rhythms defined by chronotype (Smith, Reilly, & Midkiff, 1989). These individual circadian rhythms are commonly referred to as ‘morning-type’/‘morningness’ and ‘evening-type’/‘eveningness’ and describe personal preferences for morning or evening activities (Jankowski, 2014; Smith et al., 1989). Those who are more ‘evening types’ may show worse cognitive performance in the morning irrespective of breakfast consumption as testing occurs during times which do not synchronize with the individual’s peak circadian arousal periods. These evening-type circadian rhythms may have overridden the effects of the study manipulation. Similarly, chronotype is known to affect sleep-wake patterns, which may have also influenced cognitive performance. Evening-types tend to go to bed later but are forced to wake up early due to the school schedule and as a result report feeling more tired during the day (Tzischinsky & Shochat, 2011) and also collect sleep debts during the working (school-day) week (Giannotti, Cortesi, Sebastiani, & Ottaviano, 2002), both of which could have negatively influenced performance on the test day irrespective of condition. During adolescence, there is a transition to eveningness (Russo, Bruni, Lucidi, Ferri & Violani, 2007) which suggests that the sample in Study 1 may have included more evening-types, although this was not measured.

7.1.3 Methodological limitations of Study 1

7.1.3.1 Transparency of treatment condition

A major limitation of employing a breakfast vs. no breakfast comparison in Study 1 is the inherent inability to blind participants to the study conditions. It is likely that participants held preconceptions about the effects of breakfast. There is a general consensus, widely communicated, that breakfast has a role in aiding concentration at school. Participants therefore, may have anticipatory beliefs about the effects of breakfast, which may also be exacerbated in those who are habitual breakfast eaters. For example, habitual breakfast eaters may engage in a regular breakfast habit because of beneficial reports of the consumption of breakfast or personal experience of the subjective benefits which were demonstrated in Study 1. Therefore, habitual breakfast consumers may be more likely to believe that breakfast enhances concentration. The repeated consumption of breakfast and perceived benefits may also reinforce the breakfast habit. In participants in the no breakfast condition, these preconceptions could lead to an expectation of poorer cognitive performance in the absence of breakfast. In turn, this could have caused participants in the no breakfast condition to engage in compensatory efforts on cognitive tasks to attempt to counteract the expected poorer performance caused by skipping breakfast. This is supported by the findings on subjective alertness in Study 1, where participants in the no breakfast condition indicated that they felt less alert across the morning. However, this finding did not manifest itself in measures of objective cognitive performance and may have contributed to the lack of significant differences observed between conditions.

7.1.3.2 The Cognitive Test Battery

Another limitation and possible explanation for the lack of significant effects of condition on cognitive performance observed in Study 1, lies in the choice of cognitive tests utilised. The cognitive tests employed in Study 1 were chosen because they have previously shown sensitivity to nutritional intervention (Chapter 3, 3.4.5.5). However, these specific CANTAB tasks have not been employed in nutrient intervention studies in adolescents and therefore whether they would be sensitive to nutritional intervention in adolescents is unknown. It is therefore possible that the tasks were not sufficiently sensitive to nutrient manipulations in school children.

Furthermore, the cognitive tasks employed in Study 1 may not have been sufficiently demanding or long enough to show effects of breakfast consumption. The length of the test battery was approximately 20-25 minutes, which was limited due to the constraints of the school's timetable and the requirement to avoid encroaching upon participants' lessons. Also, the tasks may not have been demanding enough for the sample under study. Although pilot work indicated that school children found the tasks demanding, this pilot work was carried out in primary school children aged 11 years. In Study 1, the VAS used to evaluate subjective performance on the cognitive test battery indicated that the battery was not rated as very difficult. Hence, this suggests that it would be acceptable and possibly fruitful for future studies to increase the difficulty level of these tasks. Nevertheless, there was little evidence of ceiling effects. It is possible that increasing both the difficulty and length of the test battery would increase the capacity to differentiate subtle differences in performance induced by breakfast consumption vs. omission. However, the degree of test difficulty must be chosen with care since cognitive tasks which are too difficult could lead to frustration, disengagement and loss of motivation in children.

7.1.3.3 VAS measures of subjective state

Several issues also relate to the measurement of subjective state in Study 1. Firstly, the VAS to assess subjective state were not validated and were developed for the purpose of the research. Secondly, VAS are generally more difficult for children and adolescents to understand than Likert scales, which may have diminished the validity of the method (van Laerhoven et al., 2004). VAS were employed in Study 1 because they may have better discrimination capacity than Likert scales and do not force the respondent into fixed categories (Hasson & Arnetz, 2005; van Laerhoven et al., 2004). Advantageously, they produce continuous, rather than discrete data and can therefore be subjected to more powerful parametric analyses than Likert ratings. However, the ability of VAS to detect small changes may not be meaningful or clinically significant. Moreover, it is questionable whether school children, and adults, can actually grade how they feel so accurately. The VAS were presented electronically because the manual measurement and recording process of the pen and paper VAS is time consuming and susceptible to human error. However, when VAS are presented electronically, there is a tendency for participants to be more conservative and avoid the extreme ends of the scales (end-aversion bias; Stubbs et al., 2000), which may have influenced the findings.

7.1.3.4 Parallel groups design

It is likely that the use of a parallel groups design in Study 1 introduced additional variation between conditions. The detection of a breakfast induced cognitive effect must compete with other sources of variation in cognitive performance between conditions (e.g. age, gender and SES). The use of randomisation and statistically testing for differences in characteristics between breakfast and no breakfast groups attempted to control for this. Indeed, the participants assigned to breakfast and no breakfast conditions did not differ on many measured characteristics. However, other aspects of state or ability were not measured and could contribute inter-individual variation which would be eliminated by using a cross-over design where breakfast vs. no breakfast comparisons would be made within the same participant. This is a potentially more sensitive design to detect the effects of breakfast. On the other hand, exposing participants to both of the breakfast conditions would introduce different limitations. Increasing the number of visits would increase the burden to participants and consequently, the likelihood of attrition. It would also increase practise effects on the cognitive tests. Further, it could increase expectancy effects due to familiarity with the study procedures and the inability to blind the study conditions.

Another issue concerns the suitability of VAS for use in a parallel groups design. As VAS are subjective ratings and individuals vary in how they use this type of scale, these scales are of most value when looking at the change within individuals (i.e. via cross-over designs) because they will tend to use the scale in the same way on repeated occasions. Some studies show that children and adults tend to respond at the extremes of the scales or at the middle range (Stubbs et al., 2000; van Laerhoven et al., 2004). Therefore, VAS may be of less value for making comparisons between groups of individuals (parallel group designs). Further, the same rating by different adolescents may not necessarily convey that they experienced the same feeling to the same extent. However, the study provided post-hoc support that the subjective state VAS can discriminate between participant groups following a breakfast manipulation (Chapter 3; section 3.5.5).

7.1.3.5 Testing environment

The testing environment of Study 1 can be considered a key strength, but also a limitation. Adolescents were tested in their own familiar school environment within their normal school day schedule. The SRR (Chapter 2) revealed that more research has been conducted in controlled, laboratory environments than in naturalistic settings. The act of arriving at the research unit in novel environments might inflate cognitive performance by increased motivation or effort. On the other hand, the consumption of unfamiliar test meals in unfamiliar environments may affect cognitive performance and mood in a negative manner. Findings from laboratory-based studies have less applicability to real-life situations such as the effects of breakfast on cognitive performance in the classroom. Hence, a more realistic indication of the cognitive and subjective state response to breakfast is achieved through applied research environments. Study 1, therefore, benefits from good ecological validity and possible extrapolation to real-life settings. However, there is always a trade-off between experimental control and ecological validity. Whilst it was more informative to conduct testing during the school day in the school environment, this caused a significant loss of control over the study procedures and extraneous variables that existed in participants' normal daily routine. For example, there may have been differences in how cognitively demanding the participants' lessons were between test sessions, which could have impacted on performance during the test sessions. Most importantly, compliance with the fasting requirement of the study may have varied. A further disadvantage is that cognitive testing was conducted in a group testing situation, similar to a classroom situation, and therefore participants may have been distracted by each other. One-to-one testing would have provided a more controlled testing environment but this would have increased the time taken for data collection and therefore disruption to the school and its pupils.

Whilst the study was conducted as part of a normal school day in an attempt to increase the ecological validity of the study's findings, the potential for disruption to daily routine to impact the study's findings should not be underestimated. The presence of researchers and the novel testing procedures may have produced a degree of behaviour change. Participants were still partly removed from their normal daily routine and so there was potential for demand characteristics and experimenter effects to influence the study outcomes. Hence, participants may have been more motivated to improve their performance on the cognitive tasks simply due to being under investigation.

7.2 Breakfast and academic performance

7.2.1 Overview of the thesis findings

7.2.1.1 Effects of habitual breakfast consumption on academic performance

The second part of this thesis focussed on the effects of breakfast on academic outcomes. Increasing breakfast consumption could be a useful public health education enhancing intervention. However, far less research has considered the effects of breakfast on academic performance outcomes compared with the relatively plentiful publications on cognitive performance. The motivation for examining the association between breakfast and academic performance was to establish if the modest effects of breakfast on cognitive performance demonstrated in Study 1 and the associated SRR (Chapter 2) are mirrored by effects on academic performance. Therefore, a key aim of this thesis was to systematically review the effects of breakfast on academic performance in children and adolescents. The second SRR presented in Chapter 4 and the associated published article (Adolphus et al., 2013) is the first systematic review of this evidence. The SRR demonstrated consistent evidence that habitual breakfast consumption frequency is positively associated with adolescents' (11-18 years) school grades.

The SRR suggested potential for habitual breakfast consumption to impact upon meaningful and educationally significant outcomes. However, there were few studies overall and no studies had been carried out in British school children. Furthermore, a number of studies did not control for important confounders such as SES. These findings led to the examination of the association between habitual breakfast consumption frequency and CAT performance in 11-13 year olds in Study 2 (Chapter 5) and GCSE performance in 16-18 year olds in Study 3 (Chapter 6). Both studies incorporated statistical adjustment for important confounders. Study 2 is the first study within the field of breakfast and academic performance to report on a large sample of British school pupils, using outcomes of an assessment method widely used in the British school system, the CAT. The CAT is highly predictive of academic performance, including GCSEs (Lohman et al., 2001; Strand, 2006). Study 2 examined this association in the same participants recruited for Study 1, to establish if the modest cognitive effects are mirrored by effects on academic outcomes. However, Study 2 provided no evidence that habitual breakfast consumption frequency is associated with CAT performance, a proxy for academic performance, following adjustment for confounders. The findings were contradictory to the findings of the SRR (Chapter 4). However, methodological considerations were identified which could account for the disagreement with previous research (see Chapter 5, section 5.6.2). In particular, the isolation of school-day breakfast consumption, use of a standard definition of breakfast, and measurement of actual academic performance were factors examined in Study 3, as a result of the learning from Study 2. Study 2 also highlighted that the examination of older adolescents was required since these adolescents would have obtained results from academic performance measures used in secondary education. In addition, the low and narrow range of CAT scores in Study 2 may have prevented finding a relationship with breakfast consumption. Hence, adolescents who were not largely from the lower end of the performance distribution were required in Study 3.

Study 3 is the first UK study to examine the association between school-day breakfast consumption and GCSE performance. Study 3 recruited 16-18 year olds attending further education because this would permit access to a large population of adolescents who had already obtained GCSE results. However, this strategy also produced an unintended systematic recruitment bias. In contrast to the sample included in Study 2, the adolescents were from a generally mid-high SES and high academic ability population. Despite the homogeneity of the sample, Study 3 (Chapter 6) showed that school-day breakfast consumption is a small, but significant, correlate of adolescents’ academic performance at age 16-18 years. School-day breakfast skipping was negatively associated with measures of aggregated GCSE performance after controlling for covariates (Chapter 6, section 6.7.2.1).

The findings of Study 3 may have important implications given that breakfast skipping is common in adolescents and because academic attainment plays a fundamental role in young people’s education and employment trajectories. GCSE qualifications have a functional relevance to the pupil. The single strongest predictor of whether school pupils will stay in post-16 education (prior to September 2013) at age 16-19 years is their GCSE results (Gayle, Murray, & Connelly, 2013; Payne, 2001). These qualifications are fundamental for future employment, with a clear relationship evident between poor GCSE results and unemployment (Rice, 1999). However, a cross-sectional design makes it hard to conclude any aetiological role for habitual eating of breakfast and only confirms the coexistence of these two factors. Consequently, the public health relevance of, and implications of Study 3’s findings are restricted.

The findings of Study 3 are consistent with those of the previous research demonstrating that breakfast consumption is positively associated with academic performance in children and adolescents (SRR 2, Chapter 4). However, these findings are not consistent with those of Study 2. Although Study 2 found no association between habitual breakfast consumption and a proxy measure of academic performance (the CAT), it differed methodologically from Study 3 which may explain the inconsistencies. Importantly, the sample characteristics of Study 2 may have contributed towards the non-significant associations. The intention of recruiting a “high-risk” group of adolescents from a low SES and low academic ability population for Study 1 to potentially increase sensitivity to the intervention could have had the reverse effect on Study 2. The consequence of this recruitment strategy on Study 2 was that most participants performed below the national average on the CAT and therefore there may have been too little variance in this data to discriminate statistical associations. Study 3 found a significant association between breakfast and GCSE performance despite the fact that most of the adolescents included in the sample were performing above the national average GCSE performance, but the variance explained was small. Other factors could also account for the discrepancies in the findings of Studies 2 and 3, such as the measurement of breakfast and the choice of academic performance measure. Clearly, there are also other contributing factors which could account for unexplained variance in the data and which should be measured in future studies. These important methodological considerations for future research are discussed in section 7.6.

7.2.2 The contribution of confounding variables

The validity of the relationship between breakfast and academic performance observed in Study 3 may be threatened by both residual and unmeasured confounding. Residual confounding is due to measurement error in the confounder/s included in an analysis whereas unmeasured confounding is due to omission of a confounder from an analysis (McNamee, 2003). Confounding can be caused by variables that are associated with both academic performance and breakfast consumption and are not on the causal pathway between these variables (McNamee, 2003). As breakfast consumption and GCSE attainment is known to vary by ethnicity, age, sex and SES (see Chapter 1, section 1.2.2 and Chapter 6, section 6.4.6.2) an analysis approach which controlled for these confounders was employed. Furthermore, since BMI has been shown to be predictive of GCSE attainment (Booth et al., 2014) and because of its consistent relationship with breakfast consumption (de la Hunty et al., 2013), BMI SDS was also controlled for in the analyses. However, it is probable that there is some residual confounding in the results with respect to SES. Error in the measurement of SES is likely given that the relationship between SES and GCSE attainment was inverse (see

Appendix 9.62- 9.64 and 9.67-9.68 for full regression models), which is contradictory to a wealth of evidence (Connolly, 2006; Department for Children, Schools and Families, 2009a). It is worth noting here that Study 3 relied on adolescents' reports of parental SES (measured as highest parent/guardian education level) which may have introduced error in the measurement of SES.

Given the extensive variance left unexplained (unmeasured confounding), it is also possible that those who habitually skipped breakfast were different to those who typically consumed it in ways that were not measured which are also related to academic performance. Cross-sectional studies, such as Study 3, have shown positive associations between breakfast consumption and academic performance, while in contrast, an RCT employing a 1-year intervention has shown no effect (Ni Mhurchu et al., 2013). This disparity in findings may be attributed to confounding.

7.2.2.1 Confounding by family structure

Other potential confounding factors, less consistently associated with both breakfast consumption and academic performance, may have also influenced the study findings. Family structure may be one of these common underlying factors. An SRR reported that living in a two parent family was positively associated with breakfast eating in children and adolescents (Pearson, Biddle, & Gorely, 2009). More recent evidence has also shown that living in single parent families was associated with increased odds of irregular breakfast eating (≤3 weekdays per week) in Scottish adolescents, an effect which remained following adjustment for sex, ethnicity and age (Levin & Kirby, 2012). However, a significantly greater proportion of adolescents from single parent families were categorised as having low family affluence (proxy of SES), which was not adjusted for in the analyses, precluding conclusions on the independent effects of family structure on breakfast consumption. In contrast, the HELENA study in over 3000 European adolescents found that breakfast skipping was not associated with family structure, when family affluence was controlled for (Hallström et al., 2012). There is also some evidence that family structure is associated with GCSE attainment. Adolescents are advantaged if they come from two-parent families in terms of their GCSE performance although, whether or not having a single-parent family is detrimental to academic performance, when other factors such as income, parental education level and the parent-child communication quality are taken into account, is less clear (Scott, 2004).

7.2.2.2 Confounding by personality factors

Personality factors may have also confounded the results of Study 3. Conscientiousness, which represents one of the factors of the five-factor personality model (Goldberg, 1993) has been shown to positively correlate with breakfast consumption in adults (Reeves et al., 2013). However, other studies report no association in young adults (Fisher & Dube, 2011). There is also no evidence to date regarding this relationship in children or adolescents. The relationship between conscientiousness and academic performance, however, is well-established with evidence showing a consistent link between conscientiousness and academic success on a range of indicators of academic performance (Poropat, 2009).

7.2.2.3 Confounding by chronotype

Evening or morning chronotype may have also confounded the findings. There is some evidence from a small number of studies that adults and adolescents with a tendency towards an evening chronotype are more likely to skip breakfast (Boschloo et al., 2012; Huber, Reeves, McMeel, & Halsey, 2012; Meule, Roeser, Randler, & Kubler, 2012). This relationship may be because ‘evening-types’ get up later and have a reduced morning appetite or are short of time in the morning. Research has also reported consistent relationships between chronotype and academic performance, such that ‘eveningness’ and academic performance are negatively related and ‘morningness’ and academic performance are positively related (Preckel et al., 2013; Preckel, Lipnevich, Schneider, & Roberts, 2011). Moreover, ‘morningness’ has shown to negatively correlate with work avoidance in school and to positively correlate with conscientiousness (Huber et al., 2012; Preckel et al., 2013), both of which are likely to positively influence academic performance.

7.2.2.4 Confounding by other healthy lifestyle factors

There is also evidence that links breakfast skipping with other health-compromising behaviours in children and adolescents including physical inactivity and poorer cardio-respiratory fitness (Sandercock et al., 2010), low fruit and vegetable intake (Pedersen et al., 2012), poorer micro- and macronutrient intake (Deshmukh-Taskar et al., 2010; Gibson, 2003), and smoking (Keski-Rahkonen et al., 2003). There is also evidence of clustering patterns for certain healthy lifestyle behaviours, such that frequent physical activity, fruit and vegetable consumption and breakfast consumption cluster together in adolescents (Pearson, Atkin, Biddle, Gorely, & Edwardson, 2009). However, the relationship of these behaviours with academic performance is unclear. Some studies show physical activity is positively related to academic performance (Booth et al., 2013), others report no relationship (Ahamed et al., 2007) or a negative relationship (Daley & Ryan, 2000). Higher fruit and vegetable intake and diet quality indices including higher intake of iron and lower intake of fat are associated with lower odds of poorer academic performance in school children (Florence, Asbridge, & Veugelers, 2008), dietary indices which are also associated with regular breakfast consumption

(Gibson, 2003; Pedersen et al., 2012). However, other studies have found no association between fruit and vegetable intake and academic performance (Trockel, Barnes, & Egget, 2000). Evidence has also suggested that adolescents who smoke cigarettes frequently are significantly more likely to achieve lower GCSE point scores (Gregg & Washbrook, 2011).

In the studies that link other healthy behaviours with academic performance, the contribution of other healthy lifestyle factors, including breakfast eating, are rarely considered in the analyses. Similarly, the studies which associate breakfast and academic performance, including Studies 2 and 3 reported in this thesis, have not controlled for these healthy lifestyle factors. For example, Booth et al. (2013) have recently demonstrated that habitual physical activity level is positively related to GCSE point scores, however breakfast consumption was not controlled for. Equally, in Study 3 physical activity level was not controlled for, thus highlighting the potential of confounding in both of these studies' observed relationships. The fact that other studies, including Study 3, often do not adjust for other health-related variables may be because there is a lack of evidence, either from other sources, or from preliminary analyses, which significantly link these factors to academic performance and would therefore justify including the confounder in the analysis (Tabachnick & Fidell, 2007). Nevertheless, the observation that regular breakfast consumption can coexist with other healthy lifestyle behaviour highlights the need to statistically adjust for these variables in observational research.

7.3 Trends in breakfast consumption

7.3.1 Overview of the findings

Examining the association between habitual breakfast consumption and GCSE performance in Study 3 enabled the incidental examination of breakfast consumption patterns in 16-18 year olds, in whom there are limited studies. Therefore, a subsidiary aim of this thesis was to examine the nature of breakfast consumption in adolescents aged 16-18 years (Study 3, Chapter 6). Study 3 indicated that breakfast skipping is highly prevalent among adolescents aged 16-18 years. It is particularly concerning that approximately a third of adolescents rarely ate (0-1 times/week) breakfast on school days. Furthermore, adolescents who skip breakfast may continue to do so during adulthood (Merten et al., 2009). The majority of previous studies, including Study 3, show that the proportion of adolescents considered 'breakfast skippers' is around 20%-30% (see Chapter 1). Where breakfast was eaten, breakfast meals had a high nutrient-energy ratio. Breakfast meals provided over a third of the RNIs of many micronutrients (Vitamin C, Vitamin B^{12}, Thiamine, Riboflavin and Niacin) despite the relatively low energy provided. There is, therefore, a definite need to promote the intake of breakfast among adolescents aged 16-18 years, for nutritional and possible educational benefits. Interestingly, intake of macronutrients and micronutrients from school-day meals and weekend meals were significantly different and the foods typically consumed were different. This highlights the importance of isolating school-day breakfast consumption from weekend breakfast consumption. The findings of Study 3 suggest that, with the exception of age, there appeared to be no socio-demographic differences in breakfast consumption on school days. However, the failure to detect such associations in Study 3 was most likely due to the unintended recruitment bias resulting in a homogenous sample, in which males, lower SES and ethnic minority groups were underrepresented.

7.3.2 Adolescent development and breakfast skipping

The findings of the studies presented in this thesis support previous studies which indicate that breakfast skipping is common amongst adolescents. Skipping breakfast is more prevalent in adolescents than any other age group (Hoyland et al., 2012; Vereecken et al., 2009). Adolescence is one of the greatest periods of growth and change throughout the lifespan. There is a dramatic increase in energy and nutrient requirements which coincides with other factors that may affect adolescents' dietary choices. These factors include increased independence, a greater need for acceptance by peers, rebellious or non-conformist behaviour, increased time spent out of the home (e.g. for school, extracurricular, social or work activities), changes in sleep patterns, reduced parental control and preoccupation with appearance and body-image.

7.3.2.1 Adolescent autonomy

The increased autonomy and desire for independence during adolescence may contribute towards breakfast skipping. This could be because adolescents have more opportunities to make decisions about what and when to eat. Adolescents who make autonomous decisions about their diet and food intake are 25% more likely to skip breakfast (Videon & Manning, 2003). Adolescents spend more time out of the home as a result of social, school and extracurricular activities and often have money to purchase meals and snacks on their own. In addition, working parents may not be present in the morning before an adolescent leaves for school. Parents may be less able to encourage their children to eat breakfast if they are not present. However, Videon and Manning (2003) demonstrated that having a parent at home in the morning before adolescents left for school did not significantly influence breakfast consumption, which could be due to a resistance to, or decrease in, parental control over eating habits during adolescence.

7.3.2.2 Sleep patterns

Changes in sleep patterns and chronotype during adolescence are also likely to affect breakfast eating habits. Biological sleep patterns shift toward later times for both sleeping and waking during adolescence meaning that it is natural for adolescents to not be able to fall asleep before 23:00 (National Sleep Foundation, 2015; Russo et al., 2007). There is also a shift from morningness to eveningness during adolescence (Russo et al., 2007). Some sources have suggested there is a reduction in the intensity of sleep across adolescence (reduced deep slow wave sleep) which could make adolescents more lethargic in the morning (Buchmann et al., 2010). Combined with this, school start times for secondary schools are generally earlier than primary schools. Moreover, adolescents may be required to wake up earlier in order to independently travel to school. Late school-night bedtimes combined with early school-day rise times reduces the amount of sleep on school nights. Moreover, it has been suggested that adolescents should be allowed to start their school day later in the morning because of the transition to an evening-type chronotype and their greater sleep demands to allow them to sleep for longer to benefit concentration (Carskadon, Wolfson, Acebo, Tzischinsky & Seife, 1998).

This shift in sleep patterns may be influence by a number of psychosocial and biological changes during adolescence. Parental control over bedtimes may lessen for adolescents. Homework, extracurricular activities, part-time work, and socialising also contribute to late bedtimes (Crowley & Carskadon, 2010). Other stimulating environmental factors such as watching TV, playing video games, computer use, smart phone use, internet access and social media may also keep adolescents awake later at night. Biological changes in hormones are also implicated in this shift in sleeping patterns and could result in delayed sleep onset. A number of studies have noted alternations in melatonin secretions across adolescence, a hormone involved in inducing the onset of sleep, which typically shows a decline in the level of melatonin (Crowley & Carskadon, 2010).

It is likely that the changes in sleeping habits play a role in the decision to skip breakfast. When adolescents wake up before school they are likely to be sleep deprived due to later bedtimes and a reduced intensity of sleep. This may lead to a reduction in appetite in the morning due to tiredness. Adolescents may wake up as late as possible to allow time to sleep and therefore, may not allow sufficient time for breakfast or for appetite to increase before leaving for school. In addition, staying awake later may lead to food consumption later at night which may reduce morning appetite. In support of these proposed effects, Mullen et al (2014) indicated that common reasons for adolescent breakfast skipping were lack of time, desire to sleep longer in the morning, and lack of appetite.

7.3.2.3 Body image and appearance concerns

Concerns with appearance and body weight during adolescence may also contribute to breakfast skipping. The rapid physical changes and accelerated growth from hormonal changes during adolescence may cause increased interest in body shape, size, and appearance. In male adolescents, the physical changes such as growth in height and lean muscle mass and a more “bulkier” appearance are more likely to be viewed as positive changes (McCabe, Ricciardelli & Finemore, 2002). Conversely, female adolescents are more likely to view physical changes during adolescence as negative and can often feel uncomfortable during this growth phase because of the increase in body fat deposited in the body’s midsection (Felts, Parrillo, Chenier & Dunn, 1996). In addition, societal pressures that emphasise thinness particularly in females may contribute to the body weight concerns experienced by adolescent females. Some adolescents may reduce their food intake or skip meals altogether as a strategy to lose weight. This is likely to contribute to the increased prevalence of breakfast skipping in female adolescents (see section 1.2.2.1). Female adolescents who are dieting are more likely to skip breakfast than non-dieting female adolescents (Lattimore & Halford, 2003). However, this strategy may be ineffective given the consistent inverse relationship between breakfast consumption and BMI (see section 1.1.2).

7.3.3 Strategies to increase breakfast consumption

Although the findings suggest that breakfast skipping remains a considerable problem in adolescents, it is encouraging that the importance of breakfast is being acknowledged by schools and policy makers. The School Food Plan clearly states the importance of promoting breakfast consumption (Dimbleby & Vincent, 2013). Furthermore, the Department for Education is allocating £3.15 million towards increasing breakfast provision at school in the most deprived areas (Dimbleby & Vincent, 2013). School food provision has changed over recent years, with school food standards now in place in all UK nations. Numerous evaluations of the impact of school food standards have shown improvements in the diets of schoolchildren both at school and overall diet quality (Weichselbaum & Buttriss, 2014). However, there is room for improvement regarding breakfast provision in schools, particularly in secondary schools. In England, Scotland and Northern Ireland, breakfast provision at school is not mandatory and is largely self-funded or supported by charities (Defeyter, Graham, Walton, & Apicella, 2010). However, the Welsh Assembly Government has already committed to providing all primary school children with a free school breakfast since 2004 as part of The Primary School Free Breakfast Initiative. Breakfast clubs may offer an avenue by which to increase breakfast consumption by providing an opportunity to eat breakfast immediately before school with peers. Schools also have an important role to play as they present a setting to provide healthy food at breakfast and apply healthy eating messages as part of the curriculum. Moreover, a review of the benefits of school breakfast clubs reported that breakfast clubs offer benefits to cognitive and academic performance and social development, which may be more pronounced in breakfast clubs operating in deprived areas (Defeyter et al. 2010). Encouragingly, over half of schools in England have SBPs, but the availability of SBPs is greater in primary than secondary schools (Hoyland et al., 2012). Hence, a clear message from the findings of this thesis is that adolescents also represent an important target population for promoting breakfast consumption, possibly via the provision of breakfast clubs.

Whilst the School Food Plan is welcomed to encourage breakfast consumption in school children, the evidence underpinning the plan is not as clear-cut as it initially appears. The School Food Plan clearly states the importance of breakfast in terms of learning and raising attainment of school children (Dimbleby & Vincent, 2013). Furthermore, the plan states that hunger impedes concentration in school children. However, these claims are not fully supported by the studies presented in this thesis (Study 1), nor the existing literature (SRR 1). The plan selectively cites some acute cognitive studies which have shown beneficial effects of breakfast consumption on some cognitive measures. However, the plan does not state that these beneficial effects are usually very modest and are often coupled with null effects on other cognitive tasks or indeed, parameters of the same task. The evidence referred to in the School Food Plan has been selectively chosen which appears to suggest that the positive effects of breakfast on cognition are consistent. However, the entirety of literature is very contradictory (SRR 1). Although overall breakfast appears modestly beneficial for cognitive performance, the evidence also suggests that many children who are fasted perform as well on cognitive tasks as those who have eaten breakfast (SRR 1). Even school children who have low cognitive ability appear to compensate well when fasted on tasks of attention and visual-spatial memory and perform to a comparable level as those who have consumed breakfast (Study 1). Hence, the evidence suggests that the effects of skipping breakfast on concentration are not as deleterious as conveyed by the School Food Plan. Whilst the introduction of more breakfast clubs is extremely positive in terms of promoting healthy dietary behaviours, from the current literature, it is unclear whether this will have a profound effect on school children’s cognitive and academic performance. The School Food Plan also seems to overlook a recent review by the All Party Parliamentary Group on School Food which concluded that there is insufficient evidence to identify any effect of nutrition, diet and dietary change on learning, education or performance in school aged children in the developed world (Levy, 2013).

7.4 Methodological limitations of the studies relating breakfast consumption and academic performance

7.4.1 Dietary assessment issues

7.4.1.1 Underreporting of dietary intake in adolescents

The results of Studies 2 and 3 suggest that breakfast skipping is a prevalent problem in adolescents. However, because of the problems of assessing diet in adolescents, this may have biased reports in such a way that exaggerates the extent of breakfast skipping. Validation studies demonstrate that adolescents underreport dietary energy intake by approximately 20% (Bandini, Cyr, Must, & Dietz, 1997; Livingstone et al., 1992). Factors which may have contributed towards underreporting include more unstructured eating patterns, increased out-of-home eating, body image concerns, changing eating habits, and increased resistance to authority (Livingstone, Robson, & Wallace, 2004).

7.4.1.2 Choice of dietary assessment method

The validity of the findings of the cross-sectional studies in this thesis is also compromised because of the dietary assessment methods employed. In Study 2, it was noted that the single item question to indicate the frequency of breakfast intake per week may not have provided an adequate assessment of habitual breakfast consumption and did not capture breakfast composition. In order to improve the assessment of breakfast, a retrospective 7-day food diary record was employed in Study 3 to differentiate between school-day and weekend breakfast eating and to consider the composition of breakfast when classifying habitual breakfast consumption. Although the dietary assessment method employed in Study 3 was intended to improve the assessment of breakfast consumption, it still has limitations. Retrospective dietary assessment methods usually rely on a 24-hour recall period. A single 24-hour recall to assess breakfast was not considered to be representative of habitual breakfast consumption in Study 3 and would not reflect possible differences between school-day and weekend breakfast intake. A 7-day reporting period was, therefore, employed to provide an adequate representation of habitual breakfast intake and to account for differences in weekend and school-day breakfast intake (de Castro, 1991). This was deemed acceptable since participants were only required to recall breakfast meals. However, such a retrospective 7-day food diary record may have introduced recall error due to the reliance on participants' memory and accuracy and ability of recalling portion sizes, particularly for those days furthest away from the day of data collection. In contrast, a weighed prospective food diary may have resulted in more accurate intake data, less influenced by recall error, but could also have incurred considerable participant burden and increased attrition (Rankin, Hanekom, Wright, & Macintyre, 2010).

7.4.1.3 Definition of breakfast and the role of breakfast type

Another factor which may have affected the findings of Studies 2 and 3 is the definition of breakfast. In Study 2, a breakfast eating occasion was subjectively defined by the participants, which may have caused inter-individual variation in terms of what is considered to constitute breakfast. Similarly, almost all of the previous studies examining the association between habitual breakfast consumption frequency and academic performance included in the SRR (Chapter 4) did not state how breakfast was defined and this was subjectively interpreted by the respondent. Only one study on habitual breakfast consumption frequency included in the SRR applied a standard definition of breakfast (Gajre et al., 2008). Study 3, therefore, attempted to reduce inconsistencies between participants by adopting a standardised classification of a breakfast eating occasion as any food or drink providing a minimum of 5% TEE. The cut-off used in this study was adopted to represent a minimum amount of energy needed to be classified as breakfast. However, as in Study 2, breakfast quality was not fully considered in the analysis because the study was primarily concerned with the association between habitual breakfast consumption frequency and academic performance. Even when applying this cut-off of 5%, there is still a large amount of variance in terms of the nutritional composition of the breakfast meals which may influence the findings. There may be an association between different percentages of TEE, macronutrients and/or micronutrients or food groups and the GCSE point scores which would indicate the specific role of nutrients and/or food groups from breakfast for academic performance.

7.4.2 Academic performance measures

7.4.2.1 Aggregating GCSE grades

The challenge in measuring overall GCSE attainment is aggregating alphabetical grades from many subjects into a single composite score. As raw scores are typically unavailable, unlike the CAT, a standard convention in educational research is to transform GCSE grades into a continuous variable via an eight-point numerical scale and apply linear models for analysis (Birchwood & Daley, 2012; Fielding et al., 2003; O'Connell, 2006). An obvious constraint of aggregating GCSE results is that the numbers have been assumed to represent equal intervals on an achievement scale and the measurement unit has been artificially constructed to make a crude approximation of a continuous variable. This method ignores the hierarchical nature of GCSE grades and it is difficult to back translate to grades following analysis. For example, a predicted GCSE point score for a particular habitual school-day breakfast consumption category, even when taken in context with the samples' mean point score, is less readily interpretable as grades are used to express performance.

7.4.2.2 Self-reported academic attainment

The use of a self-report measure of academic performance in Study 3 may have introduced recall error and encouraged socially desirable responses for GCSE attainment. This method has lower validity compared to Study 2, where academic outcomes were obtained from school records. However, evidence suggests that whilst school children generally inflate their grades, self-report academic performance correlates highly with actual academic performance. A meta-analysis of 37 studies providing a pooled sample size of >61,000 adolescents (secondary school pupils) and young adults (university students) reported that self-reported grades are good reflections of actual grades, with an overall correlation of .84 (Kuncel, Credé & Thomas, 2005). This meta-analysis also showed that actual academic performance moderates the correlation between self-reported grades and actual grades, such that lower achieving students were more inaccurate and more likely to overestimate their grades. Higher achieving students, however, were consistently more accurate in reporting their grades, with the correlation between actual and self-reported grades reaching as high as .95. The authors argue that in situations where high achieving students are under investigation, self-reported grades are reasonably accurate (Kuncel et al., 2005). However, less than perfect correlations indicate at least some possibility of error. Hence, despite some possible reporting error, the self-reported GCSE grades are likely to be valid measures of actual GCSE performance, especially since the sample were in further education and so likely to have performed well in their GCSEs.

7.4.3 Sampling issues

In drawing conclusions from Studies 2 and 3, it is important to consider the unrepresentative sample characteristics. The sample in Study 2 was from a predominately low SES, low ability population. In Study 3 the selection of schools was not done systematically; it was a convenience sample and generalisation is therefore limited. The study examined a relatively homogenous sample. The sample size was fairly large but included adolescents who were largely white British, female, of high academic ability and from high SES backgrounds. It is therefore likely that the findings of these cross-sectional studies cannot be generalised to adolescents across different demographic population groups.

7.5 Ethical considerations

There are some limitations regarding the ethical practices of the research presented in this thesis. Informed consent was obtained from parents using passive consent (opt-out) rather than active consent (opt-in). Informed passive consent can be compromised by parents not receiving the information, not being able to read or understand the information, or by failing or forgetting to inform the researchers that participation has been refused. Another issue is that passive consent procedures can seem potentially coercive; opting-out involves taking some action (e.g. speaking to someone, or returning a letter) in order to avoid participating in a study. Certain parents may find it difficult to decline for a variety of reasons. For example, fear of causing themselves problems in relation to the school through which they have been recruited. Passive consent was deemed appropriate in the studies presented in this thesis for a number of reasons. Firstly, the research was school-based and therefore consent was obtained from a range of additional adult gatekeepers, including teachers, senior leadership and the SPTA directors. Secondly, the school routinely used, and recommended, the use of passive consent for extraordinary activities because of the reported parental disengagement in school related matters. In this respect, opt-in methods would have resulted in very low response rates and may have also caused a considerable sample bias. Thirdly, the topic was non-sensitive and low-risk. However, in order to strengthen the ethical practices of the research, further work should favour active consent procedures where only participants whose parents have formally consented are allowed to participate in the research. Using an active consent process allows researchers to feel confident that participants and their parents have intentionally and freely chosen to participate.

Another ethical consideration of the research presented in this thesis is the nature of the relationship between the researchers and the school's staff and pupils. This consideration can often be overlooked by researchers, but it is important for researchers to facilitate a reciprocal beneficial relationship. A great deal of co-operation is needed from the school's staff and pupils. A considerable amount of time is given up by participants, teachers and other school staff members for the benefit of the research. The research also causes a considerable amount of disruption to the school day. It was considered important to create a reciprocal relationship between the researchers and the SPTA by creating opportunities that offer benefit to the school pupils. This has included hosting a series of school assemblies on nutrition topics, hosting careers talks on higher education, developing display boards on the research and its impact, organising community events, hosting Research Open Days and providing opportunities for CV development in post-16 students. Further school-based research in this field should consider adopting a similar approach. However, a limitation of this partnership work was that no formal dissemination of the results was provided to the participants. This would have been a good opportunity to provide feedback to participants and assure them that their contribution was positive. A formal dissemination of the results would improve the ethical practices of the research. However, great caution should be exercised when discussing the results with parents and teachers, since evaluative statements may carry unintended weight with little opportunity to correct any misinterpretations once the research has concluded.

7.6 Directions for future research

The findings reported in this thesis suggest some interesting relationships between breakfast, cognition and academic performance which require further exploration. Further studies within the field of breakfast and cognitive performance might benefit from more adequate control over the extraneous variables discussed in sections 7.1.2 and 7.1.3.5. All of the aforementioned factors may have contributed towards inter and intra-individual differences in responsiveness to breakfast and therefore hampered a clear substantiation of the potential cognitive effect of breakfast consumption in Study 1. Future studies, particularly those where randomisation is not possible, could benefit from the inclusion of these factors as covariates in the statistical analyses to account for some of the error attributable to these factors, if they are significant predictors of performance. Future work with more control over these variables, where possible, might better isolate the effects of breakfast on cognitive performance. However, it is also questionable how useful this may be when interpreting the findings. If a breakfast-induced improvement in cognitive performance is only clearly apparent when all these factors are held constant, how meaningful this is to day-to-day functioning is debateable.

Another area of work which requires attention is the acute effect of breakfast composition on cognitive performance. The SRR revealed a shortage of studies and problematic designs. Further studies are needed with well-matched study conditions to establish the role of breakfast composition in school children’s cognitive performance. This may help make feasible recommendations on the type of breakfast that is beneficial for cognitive performance in school children. The acute effects of different breakfast meals on cognitive function may be difficult to decipher given subtle effects demonstrated following breakfast relative to fasting in Study 1. The null findings in relation to the effect of breakfast on the cognitive test results for attention and visual-spatial memory suggest potential for future investigation using different tests and cognitive domains. In this respect, the use of cognitive tests with proven sensitivity to nutritional manipulations will be imperative (de Jager et al., 2014).

Study 3 of this thesis has demonstrated promising associative evidence in adolescents which would be strengthened if replicated in further observational studies which adopt the following considerations. Isolating school-day breakfast consumption and using measures of academic performance which are directly related to the content of the curriculum appears to be beneficial in identifying an association, indicated by the discrepancies between the results of Studies 2 and 3. The interpretation of the findings would also be strengthened if future studies employed prospective designs, to offer a better indication of temporality or causality in this relationship. Better control over the confounders discussed in section 7.2.2 is needed. This would give greater confidence that the findings are not merely the result of a common underlying factor related to both breakfast and academic attainment. Further work would benefit from the measurement and inclusion of possible health-related covariates in the analysis of such data. Although health-related factors are not consistently associated with academic performance, studies would benefit from the inclusion of these in the analysis as they can cluster together in adolescents. Further work is also needed in large, representative samples to confirm whether these associations are constant across different socio-demographic groups. Finally, to improve the validity of the findings, GCSE grades, or other measures of academic performance, should be obtained from school records. A weighed prospective food diary would also offer the most valid assessment of breakfast consumption.

If the findings of Study 3 are supported by additional observational studies adopting the considerations discussed above, this would give greater confidence in the findings. These associations would then warrant further exploration in long-term intervention trials, to confirm whether such associative relationships are causal. As discussed in Chapter 4, relevant studies are generally SBPs which are not true comparisons of breakfast *per se*. Therefore, it might be insightful for interventions to target breakfast consumption both at home and at school. The lack of efficacy of these trials highlights the need to increase understanding of the personal and motivational factors affecting breakfast consumption. Indeed, a SRR of the efficacy of interventions aimed at increasing breakfast eating frequency showed that only 3 of the 11 included trials were successful in changing breakfast eating (Kothe & Mullan, 2011). The Theory of Planned Behaviour (Ajzen, 1991) offers a promising theoretical model for predicting breakfast consumption (both frequency and type) in British adolescents (Conner, Hugh-Jones, & Berg, 2011; Mullan, Wong, & Kothe, 2013; Mullan, Wong, Kothe, & Maccann, 2013). Interventions which adopt an evidence-based theoretical framework to produce change in breakfast eating behaviour may be more effective in changing breakfast eating and allow the researcher to more clearly interpret the effect of breakfast eating on the educational outcomes of interest.

Further work is also needed regarding the association between habitual breakfast consumption composition and academic performance. For example, further analyses of the data from Study 3 could reveal if there is an association between the composition of habitual school-day breakfast consumption and GCSE performance. These findings could be informative in terms of providing a rationale for the choice of food provided in a chronic intervention which aims to improve academic performance.

7.7 Overall conclusions

Through the use of different research methods, including two SRRs (Chapters 2 and 4), a randomised acute intervention study (Study 1) and two observational studies (Studies 2 and 3), this thesis has examined the effects of breakfast on cognitive function and academic performance. The strengths of the studies in this thesis include the large samples in each study which were focussed on specific age ranges to reflect key ages for learning. Educationally relevant cohorts were examined using appropriate and validated cognitive tests and ecologically valid academic related measures. In addition, this thesis has also considered the effects of breakfast on subjective satiety, mood, motivation and alertness. Current breakfast eating practices in adolescents were also explored. On balance, the findings of this thesis suggest that breakfast consumption has a very modest short-term beneficial effect on cognitive function measured within 4 hours post-ingestion. However, the evidence was extremely mixed. Study 1 showed that breakfast consumption relative to fasting specifically improved reaction time, with no improvements observed for attention or visual-spatial memory in adolescents. These findings both support and contradict previous research. The thesis findings, therefore, add to the mixed evidence in the literature. Clearer effects of breakfast consumption were, however, demonstrated on satiety, mood, motivation and mental alertness. Here improvements were consistently demonstrated in all of the subjective states assessed.

The findings of this thesis also contribute new information on the association between regular breakfast consumption and academic performance in adolescents from UK schools. Breakfast skipping was found to be negatively associated with GCSE performance (Study 3), a finding supported by previous observational research (Chapter 4). However, this thesis (Study 2) also showed no association between breakfast and academic performance when a proxy measure, albeit predictive of academic performance (the CAT), was considered in younger adolescents. Hence the thesis findings need to be treated with caution until they are supported by both further observational studies and well controlled randomised intervention trials to verify possible causal relationships. It is also important to consider for the potential of unmeasured and residual confounding. It is possible that adolescents who habitually eat breakfast and have high academic performance also share other characteristics (confounders) which are responsible for this relationship. Although trials are needed to establish whether altering the breakfast habits of adolescents can alter their academic attainment, the findings of this thesis (Study 3) are encouraging. However, given the multiplicity of interacting factors influencing academic attainment in adolescents, teasing out the independent effects of breakfast remains a considerable challenge and requires careful examination in further studies.

Taken together, the data presented in this thesis, on over 600 school children, make a significant contribution to our understanding of the importance of consuming breakfast on school days and its potential impact on learning. The thesis findings demonstrate very subtle but significant effects of breakfast consumption on the cognitive and academic performance of younger and older adolescents. Although more research is needed, a key message from the thesis is that breakfast consumption relative to breakfast skipping, can have a small positive effect on cognitive function and actual academic outcomes in adolescents. These findings have important implications because adolescents often skip breakfast on school days or consume an inadequate breakfast. Moreover, these findings have important implications because breakfast consumption represents a modifiable lifestyle factor which could be manipulated to enhance the learning of children and adolescents.

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9 APPENDICES

9.1 SRR 1: Literature search methods

Search terms and the number of articles identified

Search Terms	Number Identified
Breakfast AND cogniti* AND child* OR adolescent*	232
Breakfast AND memory AND child* OR adolescent*	115
Breakfast AND attention AND child* OR adolescent*	151
Breakfast AND visual-spatial AND child* OR adolescent*	3
Breakfast AND visuo-spatial AND child* OR adolescent*	0
Breakfast AND recall AND child* OR adolescent*	259
Breakfast AND recognition AND child* OR adolescent*	29
Breakfast AND problem solving AND child* OR adolescent*	16
Breakfast AND reaction time AND child* OR adolescent*	38
Breakfast AND vigilance AND child* OR adolescent*	13
Breakfast AND executive function AND child* OR adolescent*	11
Breakfast AND reasoning AND child* OR adolescent*	113
Breakfast AND psychomotor AND child* OR adolescent*	13
Breakfast program* AND cogniti* AND child* OR adolescent*	63
Breakfast program* AND memory AND child* OR adolescent*	20
Breakfast program* AND attention AND child* OR adolescent*	41
Breakfast program* AND visual-spatial AND child* OR adolescent*	1
Breakfast program* AND visuo-spatial AND child* OR adolescent*	0
Breakfast program* AND recall AND child* OR adolescent*	54
Breakfast program* AND recognition AND child* OR adolescent*	8
Breakfast program* AND problem solving AND child* OR adolescent*	3
Breakfast program* AND reaction time AND child* OR adolescent*	4
Breakfast program* AND vigilance AND child* OR adolescent*	2
Breakfast program* AND executive function AND child* OR adolescent*	1
Breakfast program* AND reasoning AND child* OR adolescent*	67
Breakfast program* AND psychomotor AND child* OR adolescent*	1

Inclusion and Exclusion Criteria

This review was limited to articles published in English in peer-reviewed journals.

Papers were included or excluded in this review using the following criteria:

Participants: Studies of children or adolescents (4-18 years old) of either sex were included. All studies using adult or elderly samples were excluded.

Manipulations: Any type of breakfast manipulation, including studies comparing breakfast with no breakfast and/or breakfast types. Studies investigating the effect of chronic interventions and habitual breakfast consumption were included. Studies of the effects of manipulations at other mealtimes were excluded. Breakfast was defined according to the definition applied within the studies reviewed. Studies were not excluded on the basis of the content of the meal; for example, studies that included interventions using drinks and/or snacks were included, studies that did not report breakfast composition were included.

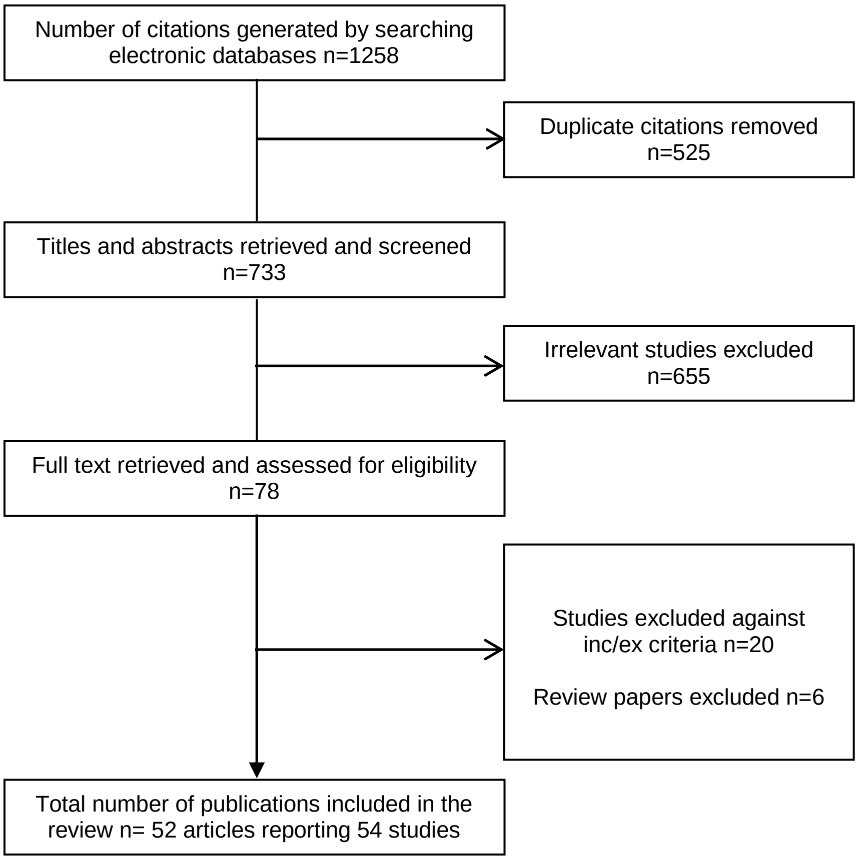
Outcome measures: Studies including any outcome measure of cognitive performance were included. Measures which were considered as scholastic or academic outcomes were not included.

Design: Intervention studies examining the acute and chronic effects of breakfast manipulations were included. Observational studies examining associations between breakfast consumption and cognitive performance were also included.

Study Selection Process

Figure 1 details the process for selecting studies for inclusion in this review and the number of articles excluded at each stage. The literature search yielded a total of 1258 citations. Following removal of 525 duplicates, a total of 733 citations were retrieved for possible inclusion in the review. Titles and abstracts were examined to remove obviously irrelevant reports (n=655). The full text versions of 78 articles were retrieved and examined for eligibility. A further 26 articles were excluded. A total of 54 studies reported in 52 articles were included in the review.

Figure 1: Flow diagram of the study selection process



9.2 SRR 1: Tabulated findings: Immediate verbal memory (20 studies)

Immediate verbal memory	Acute interventions		Chronic interventions	Habitual BF studies	
	BF vs. NO BF	BF type vs. BF type	SBPs	Frequency	Composition
Benton et al. (2007)		+			
Brindal et al. (2013)		+			
Brindal et al. (2012)		O			
Busch et al. (2002)	O				
Cromer et al. (1990)	O				
Gajre et al. (2008)				+	
Ingwersen et al. (2007)		+[a]			
Maffeis et al. (2012)	-				
Mahoney et al. (2005) Exp 1	O	O			
Mahoney et al. (2005) Exp 2	O	O			
Micha et al. (2010)					+
Micha et al. (2011)		O			
Moore et al. (2014)			O		
Murphy et al. (2011)			O		
Simeon & Grantham-McGregor (1989)	O				
Smith & Foster (2008)		O			
Vaisman et al. (1996)	+				
Wesnes et al. (2003)	+[a]	+[a]			
Widenhorn-Müller et al. (2008)	O				
Worobey & Worobey (1999) Exp 1			O		
Summary total[b]	**2/9**	**4/9**	**0/3**	**1/1**	**1/1**

a Based on factor scores; b No. of studies with positive effect/no. of studies in which test was applied; Key: + indicates positive effect of BF/association with BF. – indicates negative effect of breakfast. O indicates no effect/association. Blank cells indicate no measurement

9.3 SRR 1: Tabulated findings: Delayed verbal memory (10 studies)

Delayed verbal memory	Acute interventions		Chronic interventions	Habitual BF studies	
	BF vs. NO BF	BF type vs. BF type	SBPs	Frequency	Composition
Benton et al. (2007)		O			
Defeyter & Russo (2013)	+				
Ingwersen et al. (2007)		+[a]			
Mahoney et al. (2005) Exp 1	O	O			
Mahoney et al. (2005) Exp 2	O	O			
Micha et al. (2010)					O
Micha et al. (2011)		O			
Smith & Foster (2008)		+			
Vaisman et al. (1996)	+				
Wesnes et al. (2003)	+[a]	+[a]			
Summary total[b]	**3/5**	**3/7**	**0/0**	**0/0**	**0/1**

a Based on factor scores; b No. of studies with positive effect/no. of studies in which test was applied; Key: + indicates positive effect of BF/association with BF. O indicates no effect/association. Blank cells indicate no measurement

9.4 SRR 1: Tabulated findings: Immediate visual-spatial memory (19 studies)

Immediate visual-spatial memory	Acute interventions		Chronic interventions	Habitual BF studies	
	BF vs. NO BF	BF type vs. BF type	SBPs	Frequency	Composition
Amiri et al. (2014)	O	O			
Benton et al. (2007)		O			
Busch et al. (2002)	O				
Cueto and Chinen (2008)			+		
Ingwersen et al. (2007)		O[a]			
Kral et al. (2012)	O				
Maffeis et al. (2012)	O				
Mahoney et al. (2005) Exp 1	+	O			
Mahoney et al. (2005) Exp 2	+	O			
Michaud et al. (1991)		+			
Muthayya et al. (2007)		+			
Nkhoma et al (2013)			O		
Pollitt et al.(1981)	-				
Pollitt et al.(1982)	+				
Pollitt et al. (1998) Exp 1	+				
Simeon & Grantham-McGregor (1989)	O				
Vaisman et al. (1996)	+				
Wesnes et al. (2003)	O[a]	O[a]			
Widenhorn-Müller et al. (2008)	+				
Summary total[b]	**6/13**	**2/8**	**1/2**	**0/0**	**0/0**

a Based on factor scores; b No. of studies with positive effect/no. of studies in which test was applied; Key: + indicates positive effect of BF/association with BF. – indicates negative effect of breakfast. O indicates no effect/association. Blank cells indicate no measurement

9.5 SRR 1: Tabulated findings: Delayed visual-spatial memory (8 studies)

Delayed visual-spatial memory	**Acute interventions**		**Chronic interventions**	**Habitual BF studies**	
	BF vs. NO BF	**BF type vs. BF type**	**SBPs**	**Frequency**	**Composition**
Amiri et al. (2014)	O	O			
Benton et al. (2007)		O			
Ingwersen et al. (2007)		+[a]			
Mahoney et al. (2005) Exp 1	O	O			
Mahoney et al. (2005) Exp 2	O	O			
Muthayya et al. (2007)		+			
Wesnes et al. (2003)	+[a]	+[a]			
Wesnes et al. (2012)				+	
Summary total[b]	**1/4**	**3/7**	**0/0**	**1/1**	**0/0**

a Based on factor scores; b No. of studies with positive effect/no. of studies in which test was applied; Key: + indicates positive effect of BF/association with BF. O indicates no effect/association

9.6 SRR 1: Tabulated findings: Phonological working memory (26 studies)

Phonological working memory	Acute interventions		Chronic interventions	Habitual BF studies	
	BF vs. NO BF	BF type vs. BF type	SBPs	Frequency	Composition
Amiri et al. (2014)	O	O			
Brindal et al. (2013)		O			
Brindal et al. (2012)		O			
Busch et al. (2002)	O				
Chandler et al. (1995)	O				
Conners & Blouin, (1982/83)	+				
Cooper et al (2011)	+				
Cooper et al. (2012)	O	+			
Cueto et al. (1998)	+				
Defeyter & Russo (2013)	+				
Ingwersen et al. (2007)		O[a]			
Jacoby et al. (1996)			O		
Kral et al, (2012)	O				
López et al. (1993)	O				
Mahoney et al. (2005) Exp 1	+	+			
Mahoney et al. (2005) Exp 2	O	+			
Micha et al. (2010)					+
Micha et al. (2011)		+			
Morrell & Atkinson (1977)		O			
Pivik et al. (2012)	+				
Pollitt et al.(1982)	O				
Richter et al. (1997)			+		
Simeon & Grantham-McGregor (1989)	+				
Wesnes et al. (2003)	O[a]	O[a]			
Worobey & Worobey (1999) Exp 1			O		
Wyon et al. (1997)		O			
Summary total[b]	**7/16**	**4/11**	**1/3**	**0/0**	**1/1**

a Based on factor scores; b No. of studies with positive effect/no. of studies in which test was applied; Key: + indicates positive effect of BF/association with BF. O indicates no effect/association. Blank cells indicate no measurement

9.7 SRR 1: Tabulated findings: Attention (36 studies)

Attention	Acute interventions		Chronic interventions	Habitual BF studies	
	BF vs. NO BF	BF type vs. BF type	SBPs	Frequency	Composition
Amiri et al. (2014)	-[a]	+[a]			
Benton et al. (2007)		+			
Brindal et al. (2013)		O			
Brindal et al. (2012)		O			
Busch et al. (2002)	+				
Chandler et al. (1995)	O				
Conners & Blouin, (1982/83)	+				
Cooper et al. (2012)	+	+			
Cromer et al. (1990)	O				
Cueto and Chinen (2008)			O		
Cueto et al. (1998)	O				
Defeyter & Russo (2013)	O				
Dickie & Bender (1982) Exp 1				O	
Dickie & Bender (1982) Exp 2	O				
Gajre et al. (2008)				+	
Ingwersen et al. (2007)		+[a]			
Jacoby et al. (1996)			O		
Lieberman et al. (1976)			O		
López et al. (1993)	O				
Maffeis et al. (2012)	+				
Mahoney et al. (2005) Exp 1	+	O			
Mahoney et al. (2005) Exp 2	O	+			
Micha et al. (2010)					+
Micha et al. (2011)		+			
Michaud et al. (1991)		+			
Muthayya et al. (2007)		O			
Nkhoma et al (2013)			O		

9.8 SRR 1: Tabulated findings: Attention continued (36 studies)

Attention	Acute interventions		Chronic interventions	Habitual BF studies	
	BF vs. NO BF	BF type vs. BF type	SBPs	Frequency	Composition
Pivik & Dkyman (2007)	+				
Pollitt et al.(1981)	O				
Pollitt et al. (1998) Exp 1	O				
Richter et al. (1997)			+		
Simeon & Grantham-McGregor (1989)	+				
Wesnes et al. (2003)	+[a]	+[a]			
Wesnes et al. (2012)				+	
Widenhorn-Müller et al. (2008)	O				
Wyon et al. (1997)		O			
Summary total[b]	**8/19**	**8/13**	**1/5**	**2/3**	**1/1**

a Based on factor scores; b No. of studies with positive effect/no. of studies in which test was applied; Key: + indicates positive effect of BF/association with BF; O indicates no effect/association. Blank cells indicate no measurement

9.9 SRR 1: Tabulated findings: Reaction time (10 studies)

Reaction time	Acute interventions		Chronic interventions	Habitual BF studies	
	BF vs. NO BF	BF type vs. BF type	SBPs	Frequency	Composition
Amiri et al. (2014)	+	+			
Brindal et al. (2013)		O			
Brindal et al. (2012)		O			
Cooper et al (2011)	+				
Cueto et al. (1998)	O				
Defeyter & Russo (2013)	O				
Ingwersen et al. (2007)		+[a]			
Kral et al. (2012)	O				
Wesnes et al. (2003)	+[a]	+[a]			
Wesnes et al. (2012)				+[a]	
Summary total[b]	**3/6**	**3/5**	**0/0**	**1/1**	**0/0**

a Based on factor scores; b No. of studies with positive effect/no. of studies in which test was applied; Key: + indicates positive effect of BF/association with BF. O indicates no effect/association. Blank cells indicate no measurement

9.10 SRR 1: Tabulated findings: Psychomotor function (4 studies)

Psychomotor function	Acute interventions		Chronic interventions	Habitual BF studies	
	BF vs. NO BF	BF type vs. BF type	SBPs	Frequency	Composition
Baldinger et al. (2011)				O	
Kral et al. (2012)	O				
Muthayya et al. (2007)		O			
Worobey & Worobey (1999) Exp 2			+		
Summary total[a]	**0/1**	**0/1**	**1/1**	**0/1**	**0/0**

a No. of studies with positive effect/no. of studies in which test was applied; Key: + indicates positive effect of BF/association with BF. O indicates no effect/association. Blank cells indicate no measurement

9.11 SRR 1: Tabulated findings: Visual perception (14 studies)

Visual perception	Acute interventions		Chronic interventions	Habitual BF studies	
	BF vs. NO BF	BF type vs. BF type	SBPs	Frequency	Composition
Brindal et al. (2013)		O			
Brindal et al. (2012)		O			
Busch et al. (2002)	O				
Cromer et al. (1990)	O				
Cueto et al. (1998)	+				
Lieberman et al. (1976)			O		
Mahoney et al. (2005) Exp 1	+	O			
Mahoney et al. (2005) Exp 2	+	O			
Pollitt et al.(1981)	+				
Pollitt et al.(1982)	+				
Pollitt et al. (1998) Exp 1	+				
Simeon & Grantham-McGregor (1989)	+				
Worobey & Worobey (1999) Exp 1			+		
Worobey & Worobey (1999) Exp 2			+		
Summary total[a]	**7/9**	**0/4**	**2/3**	**0/0**	**0/0**

a No. of studies with positive effect/no. of studies in which test was applied; Key: + indicates positive effect of BF/association with BF. O indicates no effect/association. Blank cells indicate no measurement.

9.12 SRR 1: Tabulated findings: Executive function (14 studies)

Executive function	Acute interventions		Chronic interventions	Habitual BF studies	
	BF vs. NO BF	BF type vs. BF type	SBPs	Frequency	Composition
Chandler et al. (1995)	+				
Cooper et al (2011)	+				
Cooper et al. (2012)	+	+			
Defeyter & Russo (2013)	O				
Dickie & Bender (1982) Exp 2	O				
Kral et al. (2012)	O				
López et al. (1993)	O				
Micha et al. (2010)					+
Micha et al. (2011)		+			
Nkhoma et al (2013)			+		
Shemilt et al. (2004)			+		
Simeon & Grantham-McGregor (1989)	+				
Worobey & Worobey (1999) Exp 1			+		
Wyon et al. (1997)		+			
Summary total[a]	**4/8**	**3/3**	**3/3**	**0/0**	**1/1**

a No. of studies with positive effect/no. of studies in which test was applied; Key: + indicates positive effect of BF/association with BF. O indicates no effect/association. Blank cells indicate no measurement

9.13 SRR 1: Tabulated findings: Global function (9 studies)

Global function	Acute interventions		Chronic interventions	Habitual BF studies	
	BF vs. NO BF	BF type vs. BF type	SBPs	Frequency	Composition
Cueto et al. (1998)	-				
Ghazi et al. (2012)				+	
Lieberman et al. (1976)			O		
Liu et al. (2013)				+	
Nasir et al. (2012)				O	
Pollitt et al. (1998) Exp 1	O				
Pollitt et al.(1982)	O				
Rahmani et al. (2011)			+		
Taki et al. (2010)					+
Summary total[a]	**0/3**	**0/0**	**1/2**	**2/3**	**1/1**

a No. of studies with positive effect/no. of studies in which test was applied; Key: + indicates positive effect of BF/association with BF. O indicates no effect/association. Blank cells indicate no measurement

9.14 Study 1: Participant withdrawals or non-participation

Table 9.1: Breakdown of withdrawals and non-participation

Reason	Total	% of invited
Absent from ≥1 screening sessions	52	14.09
Participant withdrawal before study started	18	4.88
Absent from test day	12	3.25
Participant withdrawal during test day	8	2.17
Parental withdrawal	7	1.90
Participant left the school	7	1.90
Participant withdrawn by researchers (non-compliance or disruptive behaviour)	4	1.08
Medical condition	3	0.81

9.15 Study 1: Likert scales for RTEC taste testing at screening

1. On a scale of 1-10 how much did you like **Hoops** with **1 being not at all** and **10 being a lot**? (Please tick one star)

1	2	3	4	5	6	7	8	9	10
☆	☆	☆	☆	☆	☆	☆	☆	☆	☆

2. On a scale of 1-10 how much did you like **Cornflakes** with **1 being not at all** and **10 being a lot**? (Please tick one star)

1	2	3	4	5	6	7	8	9	10
☆	☆	☆	☆	☆	☆	☆	☆	☆	☆

3. On a scale of 1-10 how much did you like **Rice Bubbles** with **1 being not at all** and **10 being a lot**? (Please tick one star)

1	2	3	4	5	6	7	8	9	10
☆	☆	☆	☆	☆	☆	☆	☆	☆	☆

4. On a scale of 1-10 how much did you like **Frosted Squares** with **1 being not at all** and **10 being a lot**? (Please tick one star)

1	2	3	4	5	6	7	8	9	10
☆	☆	☆	☆	☆	☆	☆	☆	☆	☆

9.16 Study 1: Nutritional composition of the end of test day snacks

Table 9.2: Nutritional composition of the end of test day snacks per 100g/100ml.

Energy, macronutrient	Kellogg's© Elevenses[a]			Kellogg's© Nutri-Grain[a]			Frube Yogurt[b]	Carton of raisins (small)[b]	Carton of orange juice (from concentrate)[b]
	Ginger	Golden Oat	Raisin	Apple	Strawberry	Blueberry			
GSA (g)	45	50	45	37	37	37	40	14	200(ml)
Energy (kcal)	377	413	374	359	359	359	102	290	42
Total Carbohydrate (g)	66	63	68	69	69	69	13.4	69.3	9.1
Sugar (g)	37	31	40	33	33	33	12.9	69.3	9.1
Protein (g)	4.5	5	5	3.5	3.5	3.5	4.9	2.1	0.5
Total Fat (g)	10	15	9	8	8	8	2.8	0.4	0.1
Saturated fat (g)	0.9	1.5	0.8	3	3	3	1.9	0	Trace
Non-starch	2.5	3	2.5	3.5	3.5	3.5	0.1	2.0	0.1
Sodium (g)	0.2	0.1	0.2	0.3	0.3	0.3	0.05	0.1	Trace

[a] Kellogg's©. Macronutrient nutritional information from www.kelloggs.co.uk.
[b] Sainsbury's©. Macronutrient information from www.sainsburys.co.uk.

9.17 Study 1: Questionnaire

Participant number	
D.O.B	_ _ / _ _ / _ _ _ _

Do you **normally** have breakfast?

☐ Yes
☐ No
☐ Sometimes

How **many times a week** do you have breakfast?

☐ 0
☐ 1-2
☐ 3-4
☐ 5-6
☐ 7

What do you **normally** eat and/or drink at this time?

In the week I normally have: ____

At the weekend I normally have: ____________________________________

Are you taking any **medication** or **vitamin tablets**?

☐ Yes
☐ No

If **yes**, please tell us what you are taking: _______________________

Do you have any **food allergies** or **food intolerances**? For example, are you allergic to nuts or cannot have milk?

☐ Yes
☐ No

If **yes**, please tell us what they are: ____________________________

Are there any foods you **cannot** eat? For example, food that is not **Halal** or **Kosher**.

☐ Yes
☐ No

If **yes**, please tell us what they are: ____________________________

Do you feel unwell now or have you felt unwell during the past few days?

☐ Yes
☐ No

If **yes**, please tell us what was/is wrong with you: _______________

____

Now, we will ask you to taste some cereals

What was your **favourite cereal** that you tasted today? Please tick **one**

☐ Cornflakes
☐ Rice bubbles
☐ Hoops
☐ Frosted squares

Now please hand your questionnaire back to one of the researchers

Measure height	
Measured weight	
BMI	
Colour blind	
Ethnicity	
EAL	
SEN	
BD	
Gender	

9.18 Study 1: CANTAB rater certificate

Valid From 10 January 2011 Certificate Number: LEFMTCZGD8GG

CANTABelect

Training Certificate

This is to certify that

Katie Adolphus

has attended training on the administration of the **Cambridge Neuropsychological Test Automated Battery (CANTAB)** customised for the **University of Leeds** study on **15th December 2010**

Gary Conway
Project Manager for Clinical Trials

Cambridge Cognition

9.19 Study 1: SRT and 5-CRT outcome variables

Outcome variables	Description	Unit	Scoring	Repeated measures	Max Score
SRT/5-CRT reaction time	The mean duration between the onset of the stimulus and the time at which the participant released the button in correct, assessed trials.	ms	-	3	N/A
SRT/5-CRT movement time	The mean time taken to touch the stimulus after the button has been released in correct, assessed trials.	ms	-	3	N/A
SRT/5-CRT total number of errors (ALL)	The total number of occasions where the response status is any error (inaccurate, premature, no response)	#	-	3	14

N.B. Outcome variables for the two reaction time tasks are identical. Negative (-) means that higher scores indicate poorer performance. Positive (+) means that higher scores indicate better performance

9.20 Study 1: RVIP outcome variables

Outcome Variable	Description	Units	Scoring	Repeated measures	Max score
RVP number correct	The total number of target sequences that were responded to within the allowed time (1700ms) during assessment sequence blocks	#	+	3	54
RVP number correct (Blocks; 1,2,3,4,5,6)	The total number of target sequences that were responded to within the allowed time (1700ms) during each block (duration 1 minute)	#	+	3	9 per block
RVP total false alarms	The count of the stimulus presentations during assessment blocks that were false alarms (pressing the response button outside of the 1700ms response window, or more than once during the response window)	#	-	3	n/a
RVP total correct rejections	The number of stimuli that were correctly rejected i.e. The number of stimuli that were not part of a target sequence and were not responded to. 91 stimuli per block do not require a response.	#	+	3	546
RVP mean reaction time	The mean response latency during assessment sequence blocks where the participant responded correctly. Response latency refers to the time between when the stimulus was presented and when the participant responded.	ms	-	3	n/a

N.B. Negative (-) means that higher scores indicate poorer performance. Positive (+) means that higher scores indicate better performance

9.21 Study 1: PAL outcome variables

Outcome variable	Description	Units	Scoring	Repeated measures	Max score
PAL total errors (adjusted)	The number of times the participant chose the incorrect box for a stimulus on assessment problems plus an adjustment for the estimated number of errors they would have made on any problems they did not reach. The adjustment is based on the participant choosing boxes at random on each recall. The chance of making an error on any recall is 1-1/number of boxes. The adjustment simply multiples the probability error by the maximum number of recalls (boxes) that the participant would have had if the test had not terminated early.	#	-	3	103
PAL total trials (adjusted)	The total number of trials (attempts not levels) reached (but not necessarily completed) by the participant during assessment problems with an adjustment for assessment problems that they did not reach. The adjustment scores if calculated by adding the maximum scores of 6 trials for each stage not attempted due to an earlier failure.	#	-	3	24
PAL first trial memory score	The number of correct pattern choices that were made on the first attempt at each difficulty level of the task, summed across levels.	#	+	3	19

N.B. Negative (-) means that higher scores indicate poorer performance. Positive (+) means that higher scores indicate better performance

9.22 Study 1: VAS 8-Item

How **hungry** do you feel right now?

Not at all hungry	______________________________	Very hungry

How **cheerful** do you feel right now?

Not at all cheerful	______________________________	Very cheerful

How much **energy** do you have right now**?**

No energy at all	______________________________	A lot of energy

How keen are you to **try hard** right now?

Not at all keen	______________________________	Very keen

Would you be **easily distracted** right now?

Not at all	______________________________	Very easily

How easy are you finding it to **focus** right now?

Not at all easy	______________________________	Very easy

How **awake** do you feel right now?

Not at all awake	______________________________	Very awake

How **bad tempered** do you feel right now?

Not at all bad	______________________________	Very bad tempered

9.23 Study 1: VAS 12-Item

Additional 4 items administered post cognitive testing only

How **hard** did you find these tests you just completed?

Not at all hard	________________________________	Extremely hard

How much did you **concentrate** in the tests that you just completed?

A small amount	________________________________	A large amount

How **well** do you think you did in the tests that you just completed?

Not at all well	________________________________	Extremely well

How **frustrating** did you find the tests that you just completed?

Not at all frustrating	________________________________	Extremely frustrating

9.24 Study 1: Ethical approval certificate

9.25 Study 1: Letter to parents and parent information sheet

Institute of Psychological Sciences
University of Leeds
Leeds
LS2 9JT
Tel: (0113) 343 5719
Date: XX/XX/XXXX

UNIVERSITY OF LEEDS

Dear Parent/Guardian,

We are a team of researchers from the University of Leeds and we are interested in the effect of breakfast on children's mental performance and mood. We would like to invite your child to take part in an exciting scientific study relating to the possible benefits of breakfast. Enclosed are two information sheets providing detailed explanations of what the study involves. One is for you and one for your child. They are designed to provide you and your child with enough information so that you can decide whether you would like to take part in the study.

The study will take place at The South Leeds Academy and will be conducted according to the ethical guidelines set out by the British Psychological Society. All researchers have been fully CRB checked.

The study will examine whether children perform differently on computerised mental performance tasks when they have not had breakfast compared with when they have eaten breakfast, which we will provide.

If you decide you are happy for your child to take part, they will attend two screening sessions (during form time) followed by one test day (at different points over one school morning). On the test day, your child will either receive breakfast or not receive breakfast **at school**. We ask that on this single occasion, **you <u>do not</u> feed your child breakfast at home before they go to school.** Please see the information sheet for more details.

If you **do not** wish for your child to take part in the study, please do one of the following:

1) Return the enclosed slip in this letter to the school with your child. They should give the slip back to reception.
2) Contact me via email: slastudy@leeds.ac.uk
3) Telephone or text me on 07XXXXXXXXX.

If you are happy for your child to take part, you do not have to do anything.

If you have any questions or just want to know more about the study, please do not hesitate to contact me by either the email address or telephone number provided above. If you would prefer to text or leave a voicemail, I will return your call as soon as possible.

Yours Faithfully,

Miss Katie Adolphus

University of Leeds Breakfast Study: Information for parents.

What will my child have to do?

Screening:

Your child will be asked to attend two screening sessions which will both take place at form time. The screening sessions will involve:

- Explaining exactly what is involved in the study, so that your child can decide whether they would like to take part.
- The tasting of four different breakfast cereals with milk. Your child will then choose which cereal they would like to eat on the test day.
- Measurement of your child's height and weight by a trained researcher.
- Filling in a brief questionnaire regarding their health, breakfast eating habits and food allergies or intolerances. The breakfast eating habits from this questionnaire will be used to look at the relationship between eating breakfast regularly and performance on the CAT, which your child has already completed. If you allow your child to participate, participant consent will be indicated by the act of completing and returning the questionnaire at screening.
- A simple and quick test for colour vision (your child will need to be able to distinguish between colours to do the tests).
- Practising the computer tasks that will be used in the study.

Unfortunately, your child may not be able to participate in the study if they have a food intolerance or allergy, any medical conditions, any learning difficulties or any behavioural/attention difficulties. These criteria apply in order to keep your child safe and to prevent any unnecessary stress.

The test day:
If your child has met the study criteria and both you and your child have decided that they would like to take part, they will be invited to **one** test morning. On that day, children will attend classes and the study. Disruption to normal class time has been minimised. The test morning involves three sessions:

Session	**Time**	**School period affected**
1	8.30-9.30	Whole of period 1
2	10.15-10.45	Last 15 minutes of period 2 and the whole of break.
3	12.40-1.10	Last 5 minutes of period 4 and the first 20 minutes of lunch or form time

Session 1:

- Your child will complete 25 minutes of memory, attention and reaction time tasks on a touch screen computer. These tests are engaging for children and can be challenging in places. However, the tests are not intended to be stressful and the children will be supported by us.
- They will be provided with either breakfast **or** no breakfast. Your child will not know whether they will be given breakfast until 9am that morning. This decision is completely random.
- If your child is given breakfast, they will be provided with the cereal they chose at screening and semi-skimmed milk, from which they can help themselves to as little or as much as they like. After this, your child will **not** be allowed to eat until lunch time.
- If your child is not given breakfast, they will be provided with a glass of water and will **not** be allowed to eat until lunchtime.
- Your child will also be asked to complete a simple questionnaire asking them about their mood and how they found the computer tasks.

Session 2:

- They will complete 25 minutes of the same computer tasks.
- They will fill in a questionnaire about their mood and how they found the tasks.

Session 3:

- They will complete 25 minutes of the same computer tasks.
- They will fill in a questionnaire about their mood and how they found the tasks.
- At the end of this session, your child will be offered a snack and a carton of fruit juice and they will then go straight to lunch.
- They will be given an extra 20 minutes at lunchtime so that they have plenty of time to eat and have a break.

What will my child do during testing if I do not want them to take part or if they can't take part?

If your child does not meet the criteria or does not wish to take part in the study, they will stay in their normal timetabled classes during the test sessions.

What will my child get for taking part?

They will have had the opportunity to take part and contribute to real scientific research. Your child will be presented with a certificate and a merit during assembly for taking part. They will also have the opportunity to enter a competition to create the most inventive cereal box.

Do I have to do anything?

The night before the test day we request that your child does not eat or drink anything apart from water after 9pm that evening or on the morning of the test day. You will be reminded that your child is due to take part in the study the night before via text and by a reminder slip given to your child during form time.

Will anybody know my child has taken part?

All of the information collected from your child during the study will be kept strictly confidential and will only be used for the purpose of this research. Taking part in the study is completely voluntary and your child may withdraw at any time without providing a reason. All results from the study will be kept strictly anonymous and at no point will any identifiable personal information be linked with the results. During the study, your child's data may be looked at by collaborators on the research project (both within and outside Europe) and by individuals from the University of Leeds for the purposes of research governance. All such data will, however, be anonymised (with the exception of personal data).

For the attention of <<Name of teacher>>

UNIVERSITY OF LEEDS BREAKFAST STUDY

Please fill in this slip, and return it to school if you do **not** want your child to take part in the study. **If you are happy for your child to take part, you do not need to do anything.**

I do **NOT** want my child to take part in the breakfast study.

Name	

Year	

Form	

Signed		Date	

9.26 Study 1: Pupil information sheet

Breakfast Study

You are invited to take part in an exciting scientific experiment carried out by researchers from the University of Leeds. You will have already heard about this experiment in assembly.

What is the experiment trying to find out?
The experiment is trying to find out if eating breakfast helps you to get a better score on computer tests/puzzles and if it changes the way you are feeling. You will do the tests on a small touch screen computer. The tests are similar to ones you might play on a computer or games console (such as a Playstation or Nintendo Wii). Some of the tests will be looking at your memory and concentration, and some will see how quickly you can react. You will also be asked to complete some simple questions to see what sort of mood you are in.

Who else will be asked to take part in the project?
We are asking most of the children in year 7 and 8 at South Leeds Academy to take part. You will take part with your classmates.

Do I have to take part?
You do not have to take part in the study if you don't want to, and you do not have to give a reason as to why you don't want to take part. If you do decide to take part, you can still decide to leave the study at any time.

What will I have to do if I agree to take part?
You will have to come to two introduction sessions, which will be in form time, and one test morning. On the test morning, you will take part in the study from the start of school at 8:30am until lunchtime. During this time, you will also go to some of your normal classes.

Introduction session 1: We will explain to you what you have to do and we will check you understand. We will ask you to try four different breakfast cereals and choose your favourite. We will ask you to complete a short questionnaire to check that there are no health reasons to stop you taking part. We will also give you a simple test to check you can see different colours. Finally, we will take your weight and height. We will give you the chance to ask questions if you are unsure of anything.

Introduction session 2: We will show you the types of computer tests we are using and you will get to have a practice on them.
After these introduction sessions, and if you decide that you would like to join the study, you will then take part in a real test day.

IMPORTANT: On the evening before the test day, we ask that you do not eat or drink anything after 9pm (but you can drink water if you are thirsty). We ask that you do not eat or drink anything before you come to school or when you arrive at school on the test day (but you can drink water if you are thirsty). Also, it is important that you do not eat or drink anything other than what we give you for breakfast during the test morning (but you can drink water if you are thirsty). If you do eat something, you will not be able to take part in the study and will return to lessons as normal.

Test morning:
First period: You will go to your usual class to be registered. A researcher will come and collect you at 8.35am from your class and take you to 1D6. You will miss the whole of period 1. If you are late that morning, you must go to your usual lesson and classroom. Next, you will do the computer tasks for 20 minutes and answer questions about your mood. After you have finished, you may be given breakfast or you may only be given a glass of water. You will not know if you will be given breakfast until the test day. If you are given breakfast, it will be the cereal you chose at the introduction session a week before, served with milk.

Second period: You will go to your lesson as usual where you will be registered. At 10:15am, 15 minutes before the lesson finishes, a researcher will come and pick you up and take you to 1D6. The test session will be from 10:15am till 10:45am (1/2 an hour), so you will miss break. You will do the computer tasks for 20 minutes and answer questions about your mood.

Third period: You will go to your normal lesson.

Fourth period: You will go to your lesson as normal. Five minutes before the lesson ends at 12:40pm, a researcher will come and pick you up and take you to room 1D6. The test session will be from 12:40pm to 1:10pm so you may miss 25 minutes of your lunch break. You will do the computer tasks for 25 minutes and answer questions about your mood. Once you have finished, you will be offered a carton of fruit juice and a snack bar. You do not have to have these. You will also get an extra 20 minutes of lunch, so you will have time to go and get something to eat. If your form time is 12.45-1.15pm, go straight to form class to get registered in the last 5 minutes and then go to lunch until 2.00pm. Don't worry, your form tutor will know that you are going to be late. If your form time is 1.30-2.00pm, go straight to lunch first then go to form time in the last 5 minutes to get registered. Don't worry, your form tutor will know that you are going to be late.

What do I do if I cannot or do not want to take part in the study?
If you do not take part in the study, you will go to your classes like on a normal school day while your classmates are involved in the study.

Will anyone be able to tell I have taken part?
Any information we collect from you will be kept secret. Please try and do your best on the computer tests but don't worry about it because we won't tell anyone else your scores. If the results of the study are published, this information will be kept anonymous. This means that your results will not be linked to your name and nobody (except the researchers and some teachers) will know you have taken part.

Do I get anything for taking part?
You get to take part in a real life, important and exciting scientific study. You will get a certificate in assembly and if behaviour is excellent you will receive a merit. You will also get the chance to enter a competition to design the best cereal box. The winner and runner ups of this will receive merits.

9.27 Study 1: AE reporting form

Study:

Participant number:

Date of report: Name of reporter:

Source of information:

Description of event:

Dates of event: Start: End:

Still on-going: Yes No

Any medication taken for this AE? Yes No

If YES, please specify: -

____

____

9.28 Study 1: Statistical comparison of baseline cognitive and VAS outcomes by condition

Table 9.3: Baseline cognitive performance by condition

Baseline parameter	No Breakfast		Breakfast		Statistic
	Mean	SD	Mean	SD	T-value, df, p-value[a]
SRT					
Reaction time (ms;log transformed)	2.49	0.07	2.48	0.07	t(223) 1.21 p=0.227
Movement time (ms)	289.44	99.28	269.85	67.97	t(223) 1.74 p=0.054
Total number of errors	1.34	1.28	1.64	1.49	t(223) -1.68 p=0.095
5-CRT					
Reaction time (ms;log transformed)	2.53	0.07	2.51	0.06	t(223) 1.53 p=0.068
Movement time (ms)	302.03	90.83	283.32	69.78	t(223) 1.75 p=0.043
Total number of errors	0.88	1.30	0.88	1.05	t(223) -0.01 p=0.992
RVP					
Number correct block 1	7.69	1.53	7.48	1.65	t(224) 0.99 p=0.319
Number correct block 2	7.60	1.59	7.56	1.43	t(224) 0.19 p=0.850
Number correct block 3	7.49	1.53	7.42	1.69	t(224) 0.29 p=0.765
Number correct block 4	7.50	1.64	7.37	1.62	t(224) 0.58 p=0.560
Number correct block 5	7.27	1.64	7.58	1.64	t(224) -1.45 p=0.148
Number correct block 6	7.28	1.71	7.39	1.61	t(224) -0.49 p=0.619
Total number correct	44.82	7.56	44.81	7.63	t(224) 0.01 p=0.990
Total number of correct rejections	520.92	20.44	520.33	20.79	t(224) 0.22 p=0.828
Total number of false alarms	5.62	6.53	6.04	6.78	t(224) -0.49 p=0.626
Reaction time (ms)	319.80	74.05	321.66	76.21	t(224) -0.19 p=0.850
PAL					
First trial memory score	14.11	3.84	14.36	3.25	t(224) -0.55 p=0.585
Total number of trials (adjusted)	7.52	2.85	7.30	2.53	t(224) 0.62 p=0.534
Total number of errors (adjusted)	11.41	14.86	9.32	12.24	t(224) 1.17 p=0.242

[a] *p*-value (two tailed) for independent samples t-test.

Table 9.4: Baseline VAS outcomes by condition

Baseline parameter	No Breakfast		Breakfast		Statistic
	Mean	SD	Mean	SD	T-value, df, p-value[a]
Satiety					
Hunger	66.02	31.65	66.70	30.80	t(224) -0.17 p=0.868
Mood					
Cheerfulness	55.01	29.28	51.34	31.48	t(224) 0.93 p=0.356
Bad temper	23.24	27.46	26.99	25.58	t(224) -1.08 p=0.282
Motivation					
Energy	45.77	25.37	44.59	28.28	t(224) 0.34 p=0.738
Keen to try hard	63.77	28.69	63.34	26.60	t(224) 0.12 p=0.905
Alertness					
Distracted	45.21	30.35	45.27	31.71	t(224) -0.02 p=0.998
Ability to focus	65.09	29.64	63.03	28.20	t(224) 0.55 p=0.586
Awake	49.05	30.58	48.37	31.94	t(224) 0.17 p=0.868
Cognitive test evaluation					
Test battery difficulty	38.40	26.68	33.84	26.11	t(224) 1.32 p=0.189
Perceived concentration	74.57	23.09	71.86	23.49	t(224) 0.89 p=0.375
Perceived performance	62.52	25.46	65.56	23.90	t(224) -0.92 p=0.349
Frustration	37.34	28.39	37.96	26.44	t(224) -0.17 p=0.864

[a] *p-value (two tailed) for independent samples t-test.*

9.29 Study 1: Final ANCOVA models for the SRT and 5-CRT task

Table 9.5: ANCOVA models for the SRT task

	Reaction time	**Movement time**	**Total number of errors**
Main effect terms			
Session	F[1,212]=0.03, *p*=0.957	F[1,215]=3.48,*p*=0.063	F[1,221]=0.39,*p*=0.535
Condition	F[1,212]=2.03, *p*=0.156	F[1,215]=0.50,*p*=0.821	F[1,221]=0.25,*p*=0.621
Covariate			
Baseline	F[1,212]=110.02, *p*<0.001	F[1,215]=129.63,*p*<0.001	F[1,221]=28.14,*p*<0.001
Interaction terms			
Condition*Session	F[1,212]=4.30, *p*<0.05	F[1,215]=4.00,*p*<0.05	F[1,221]=0.37,*p*=0.541
Baseline*Condition	F[1,212]=2.05, *p*=0.154	F[1,215]=0.71,*p*=0.402	F[1,221]=1.62,*p*=0.205
Baseline*Session	F[1,212]=0.02, *p*=0.881	F[1,215]=3.01,*p*=0.084	F[1,221]=0.01,*p*=0.944
Baseline*Session*Condition	F[1,212]=4.21, *p*<0.05	F[1,215]=3.43,*p*=0.064	F[1,221]=2.48,*p*=0.117

Table 9.6: ANCOVA models for the 5-CRT task

	Reaction time	**Movement time**	**Total number of errors**
Main effect terms			
Session	F[1,214]=2.47, *p*=0.117	F[1,211]=7.41,*p*<0.01	F[1,218]=9.39,*p*<0.05
Condition	F[1,214]=0.19, *p*=0.665	F[1,211]=5.32,*p*<0.05	F[1,218]=2.09,*p*=0.150
Covariate			
Baseline	F[1,214]=148.65, *p*<0.001	F[1,211]=235.59,*p*<0.001	F[1,218]=44.81,*p*<0.001
Interaction terms			
Condition*Session	F[1,214]=6.89, *p*<0.01	F[1,211]=0.40,*p*=0.527	F[1,218]=1.45,*p*=0.230
Baseline*Condition	F[1,214]=0.22, *p*=0.637	F[1,211]=0.16,*p*=0.688	F[1,218]=0.97,*p*=0.327
Baseline*Session	F[1,214]=2.56, *p*=0.111	F[1,211]=6.68,*p*<0.01	F[1,218]=0.01,*p*=0.977
Baseline*Session*Condition	F[1,214]=7.21, *p*<0.01	F[1,211]=0.24,*p*=0.625	F[1,218]=0.05,*p*=0.832

9.30 Study 1: Final ANCOVA models for the RVIP task

	Number correct block 1	**Number correct block 2**	**Number correct block 3**
Main effect terms			
Session	F[1,222]=1.69, *p*=0.194	F[1,220]=0.60, *p*=0.439	F[1,219]=0.19,*p*=0.661
Condition	F[1,222]=3.34,*p*=0.065	F[1,220]=0.16,*p*=0.691	F[1,219]=0.15,*p*=0.696
Covariate			
Baseline	F[1,222]=64.41,*p*<0.001	F[1,220]=68.04,*p*<0.001	F[1,219]=75.49,*p*<0.001
Interaction terms			
Condition*Session	F[1,222]=0.46, *p*=0.500	F[1,220]=2.39,*p*=0.123	F[1,219]=0.16,*p*=0.692
Baseline*Condition	F[1,222]=2.91,*p*=0.089	F[2,220]=0.45,*p*=0.502	F[1,219]=2.41,*p*=0.122
Baseline*Session	F[1,222]=2.40,*p*=0.123	F[2,220]=0.86,*p*=0.354	F[1,219]=0.45,*p*=0.505
Baseline*Session*Condition	F[1,222]=0.51,*p*=0.474	F[2,220]=2.47,*p*=0.117	F[1,219]=0.43,*p*=0.511

	Number correct block 4	**Number correct block 5**	**Number correct block 6**
Main effect terms			
Session	F[1,222]=3.22, *p*=0.074	F[1,222]=0.33, *p*=0.569	F[1, 222]=0.01, *p*=0.933
Condition	F[1,222]=0.17, *p*=0.685	F[1,222]=0.40, *p*=0.525	F[1, 222]=0.06,*p*=0.800
Covariate			
Baseline	F[1,222]=89.74,*p*<0.001	F[1,222]=58.08,*p*<0.001	F[1,222]=104.89,*p*<0.001
Interaction terms			
Condition*Session	F[1,222]=0.15,*p*=0.702	F[1,222]=0.09, *p*=0.760	F[1,222]=0.01,*p*=0.931
Baseline*Condition	F[1,222]=0.56,*p*=0.456	F[1,222]=0.86, *p*=0.354	F[1,222]=0.30,*p*=0.585
Baseline*Session	F[1,222]=4.11,*p*<0.05	F[1,222]=0.16, *p*=0.686	F[1,222]=0.32,*p*=0.574
Baseline*Session*Condition	F[1,222]=2.42,*p*=0.12	F[1,222]=0.34, *p*=0.563	F[1,222]=0.28,*p*=0.596

9.31 Study 1: Final ANCOVA models for the RVIP task continued

	Total number correct	Total number of correct rejections	Total number of false alarms	Reaction time
Main effect terms				
Session	F[1,218]=0.92,*p*=0.339	F[1,214]=1.03, *p*=0.311	F[1,214]=3.15, *p*=0.078	F[1,216]=2.84, *p*=0.096
Condition	F[1,218]=0.02,*p*=0.879	F[1,214]=0.28,*p*=0.595	F[1,214]=3.62, *p*=0.058	F[1,216]=0.01, *p*=0.959
Covariate				
Baseline	F[1,218]=253.56,*p*<0.001	F[1,214]=294.93,*p*<0.001	F[1,214]=213.71,*p*<0.001	F[1,216]=287.42,*p*<0.001
Interaction terms				
Condition*Session	F[1,218]=0.10,*p*=0.757	F[1,214]=0.16,*p*=0.686	F[1,214]=1.00, *p*=0.318	F[1,216]=0.03, *p*=0.862
Baseline*Condition	F[1,218]=0.65,*p*=0.420	F[1,214]=0.43,*p*=0.511	F[1,214]=6.50, *p*<0.01	F[1,216]=2.70, *p*=0.102
Baseline*Session	F[1,218]=1.80,*p*=0.181	F[1,214]=1.53,*p*=0.217	F[1,214]=0.13, *p*=0.722	F[1,216]=3.12, *p*=0.079
Baseline*Session*Condition	F[1,218]=0.12,*p*=0.709	F[1,214]=2.29,*p*=0.132	F[1,214]=1.57, *p*=0.212	F[1,216]=2.24, *p*=0.136

9.32 Study 1: Final ANCOVA models for the PAL task

	First trial memory score	Total number of trials (adjusted)	Total number of errors (adjusted)
Main effect terms			
Session	F[1,222]=0.36, *p*=0.549	F[1,216]=2.53,*p*=0.114	F[1,218]=0.83,*p*=0.363
Condition	F[1,222]=0.81, *p*=0.370	F[1,216]=6.90,*p*<0.01	F[1,218]=2.34,*p*=0.128
Covariate			
Baseline	F[1,222]=75.44, *p*<0.001	F[1,216]=111.88,*p*<0.001	F[1,218]=100.03,*p*<0.001
Interaction terms			
Condition*Session	F[1,222]=0.23, *p*=0.638	F[1,216]=0.49,*p*=0.483	F[1,218]=0.61,*p*=0.437
Baseline*Condition	F[1,222]=1.07, *p*=0.302	F[1,216]=5.84,*p*<0.05	F[1,218]=6.00,*p*<0.05
Baseline*Session	F[1,222]=0.47, *p*=0.496	F[1,216]=1.44,*p*=0.232	F[1,218]=3.31,*p*=0.070
Baseline*Session*Condition	F[1,222]=1.15, *p*=0.284	F[1,216]=0.09,*p*=0.770	F[1,218]=0.01,*p*=0.939

9.33 Study 1: Final ANCOVA models for the subjective state VAS outcomes

	Satiety	Cheerfulness	Bad temper	Energy
Main effect terms				
Time	F[3.22,702.88]=30.37, *p*<0.001	F[3.56,777.92]=0.59,*p*=0.651	F[4,872]=1.03,*p*=0.383	F[3.14,685.01]=3.76,*p*<0.01
Condition	F[1,218]=18.92, *p*<0.001	F[1,218]=4.59,*p*<0.05	F[1,218]=2.71,*p*=0.101	F[1,218]=36.61,*p*<0.001
Covariate				
Baseline	F[1,218]=88.84, *p*<0.001	F[1,218]=54.22,*p*<0.001	F[1,218]=87.41,*p*<0.001	F[1,218]=48.78,*p*<0.001
Interaction terms				
Condition*Time	F[3.22,702.88]=2.32, *p*=0.069	F[3.56,777.92]=4.34,*p*<0.01	F[4,872]=1.12,*p*=0.342	F[3.14,685.01]=12.18,*p*<0.001
Baseline*Condition	F[1,218]=0.02, *p*=0.889	F[1,218]=0.01,*p*=0.923	F[1,218]=0.04,*p*=0.841	F[1,218]=4.44,*p*<0.05
Baseline*Time	F[3.22,702.88]=2.54, *p*=0.051	F[3.56,777.92]=0.87,*p*=0.474	F[4,872]=0.90,*p*=0.452	F[3.14,685.01]=0.48,*p*=0.706
Baseline*Time* Condition	F[3.22,702.88]=4.03, *p*<0.01	F[3.56,777.92]=0.49,*p*=0.297	F[4,872]=4.60,*p*<0.01	F[3.14,685.01]=4.31,*p*<0.01

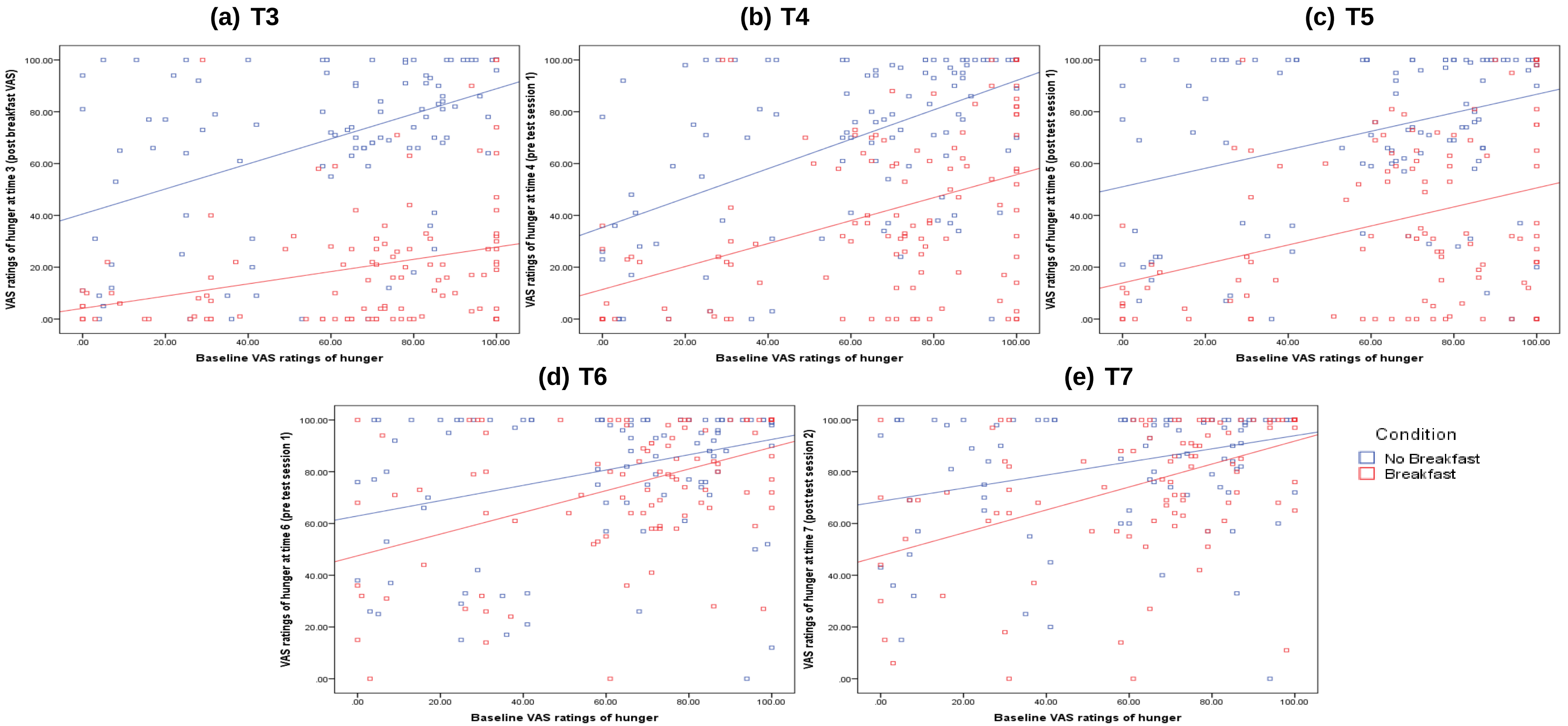
	Keen to try hard	Distracted	Ability to focus	Awake
Main effect terms				
Time	F[3.28,715.34]=0.60,*p*=0.632	F[3.79,825.51]=0.82,*p*=0.515	F[3.69,803.54]=0.44, *p*=0.765	F[3.49,760.12]=1.11, *p*=0.352
Condition	F[1,218]=13.54,*p*<0.001	F[1,218]=2.19,*p*=0.141	F[1,218]=15.65, *p*<0.001	F[1,218]=14.90, *p*<0.001
Covariate				
Baseline	F[1,218]=116.71,*p*<0.001	F[1,218]=75.05,*p*<0.001	F[1,218]=68.74, *p*<0.001	F[1,218]=38.83, *p*<0.001
Interaction terms				
Condition*Time	F[3.28,715.34]=5.17,*p*<0.001	F[3.79,825.51]=1.25,*p*=0.289	F[3.69,803.54]=3.33, *p*<0.05	F[3.49,760.12]=8.36, *p*<0.001
Baseline*Condition	F[1,218]=6.36,*p*<0.05	F[1,218]=9.32,*p*<0.001	F[1,218]=8.21, *p*<0.01	F[1,218]=1.70, *p*=0.194
Baseline*Time	F[3.28,715.34]=0.32,*p*=0.827	F[3.79,825.51]=0.35,*p*=0.833	F[3.69,803.54]=1.01, *p*=0.396	F[3.49,760.12]=1.55, *p*=0.193
Baseline*Time* Condition	F[3.28,715.34]=1.85,*p*=0.131	F[3.79,825.51]=3.02,*p*<0.05	F[3.69,803.54]=1.38, *p*=0.241	F[3.49,760.12]=2.70, *p*<0.05

9.34 Study 1: Final ANCOVA models for the cognitive test evaluation VAS outcomes

	Test battery difficulty	**Concentration**	**Performance**	**Frustration**
Main effect terms				
Time	F[1,219]=2.24, *p*=0.136	F[1,219]=2.83,*p*=0.094	F[1,219]=1.82,*p*=0.179	F[1,219]=0.29,*p*=0.591
Condition	F[1,219]=1.68, *p*=0.196	F[1,219]=4.74,*p*<0.05	F[1,219]=0.88,*p*=0.348	F[1,219]=0.37,*p*=0.543
Covariate				
Baseline	F[1,219]=84.98, *p*<0.001	F[1,219]=112.45,*p*<0.001	F[1,219]=149.87,*p*<0.001	F[1,219]=104.97,*p*<0.001
Interaction terms				
Condition*Time	F[1,219]=0.37, *p*=0.542	F[1,219]=3.31,*p*=0.070	F[1,219]=1.28,*p*=0.259	F[1,219]=8.99,*p*<0.01
Baseline*Condition	F[1,219]=1.86, *p*=0.174	F[1,219]=2.07,*p*=0.151	F[1,219]=0.01,*p*=0.977	F[1,219]=0.12,*p*=0.727
Baseline*Time	F[1,219]=0.40, *p*=0.527	F[1,219]=3.94,*p*<0.05	F[1,219]=2.52,*p*=0.114	F[1,219]=0.03,*p*=0.845
Baseline*Time*Condition	F[1,219]=0.46, *p*=0.499	F[1,219]=2.30,*p*=0.131	F[1,219]=1.99,*p*=0.159	F[1,219]=1.81,*p*=0.179

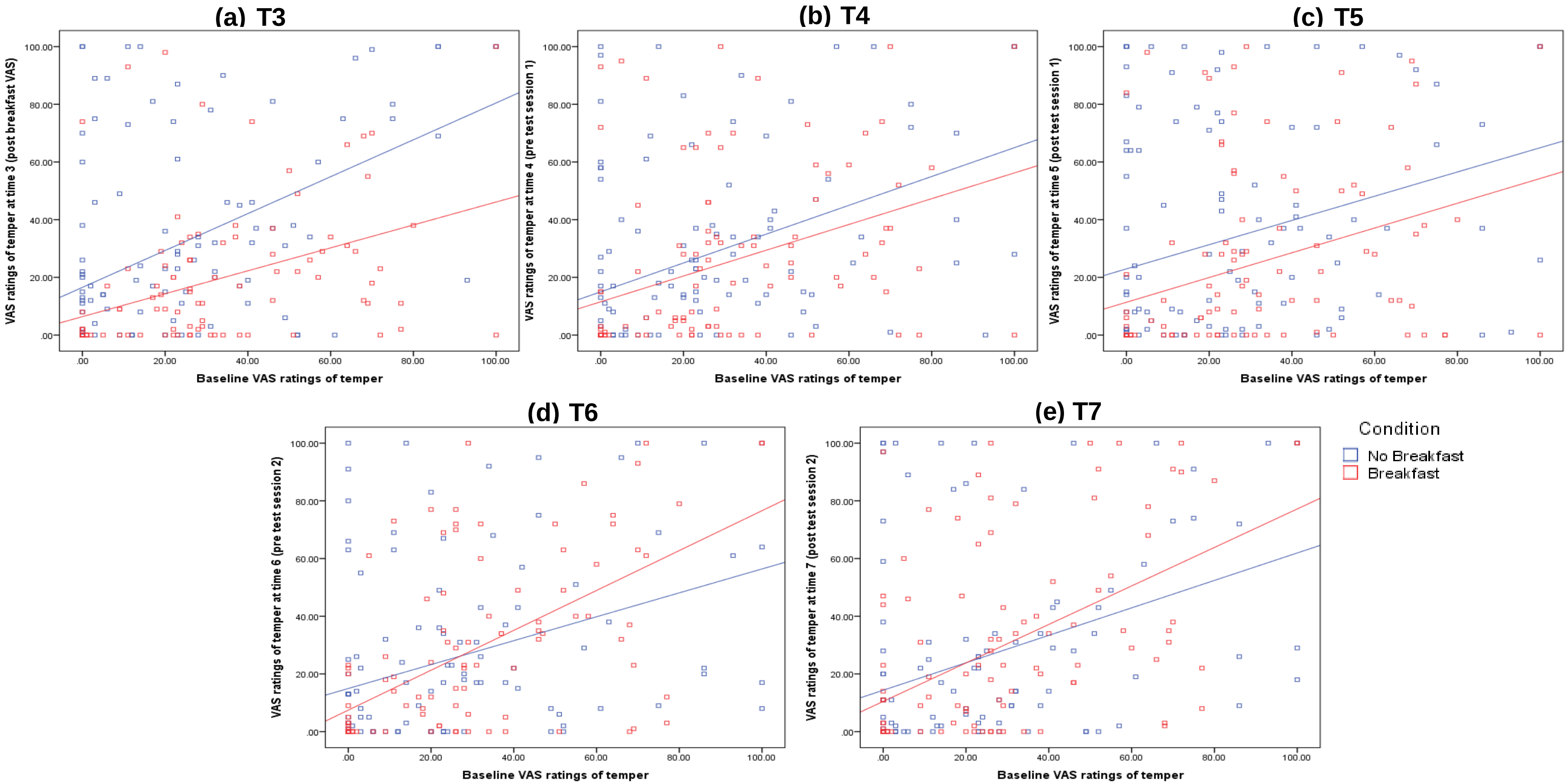
9.35 Study 1: Regression plots

Figure 9.1: Regression plots of baseline VAS ratings of hunger on post-intervention VAS ratings of hunger at T3-7.



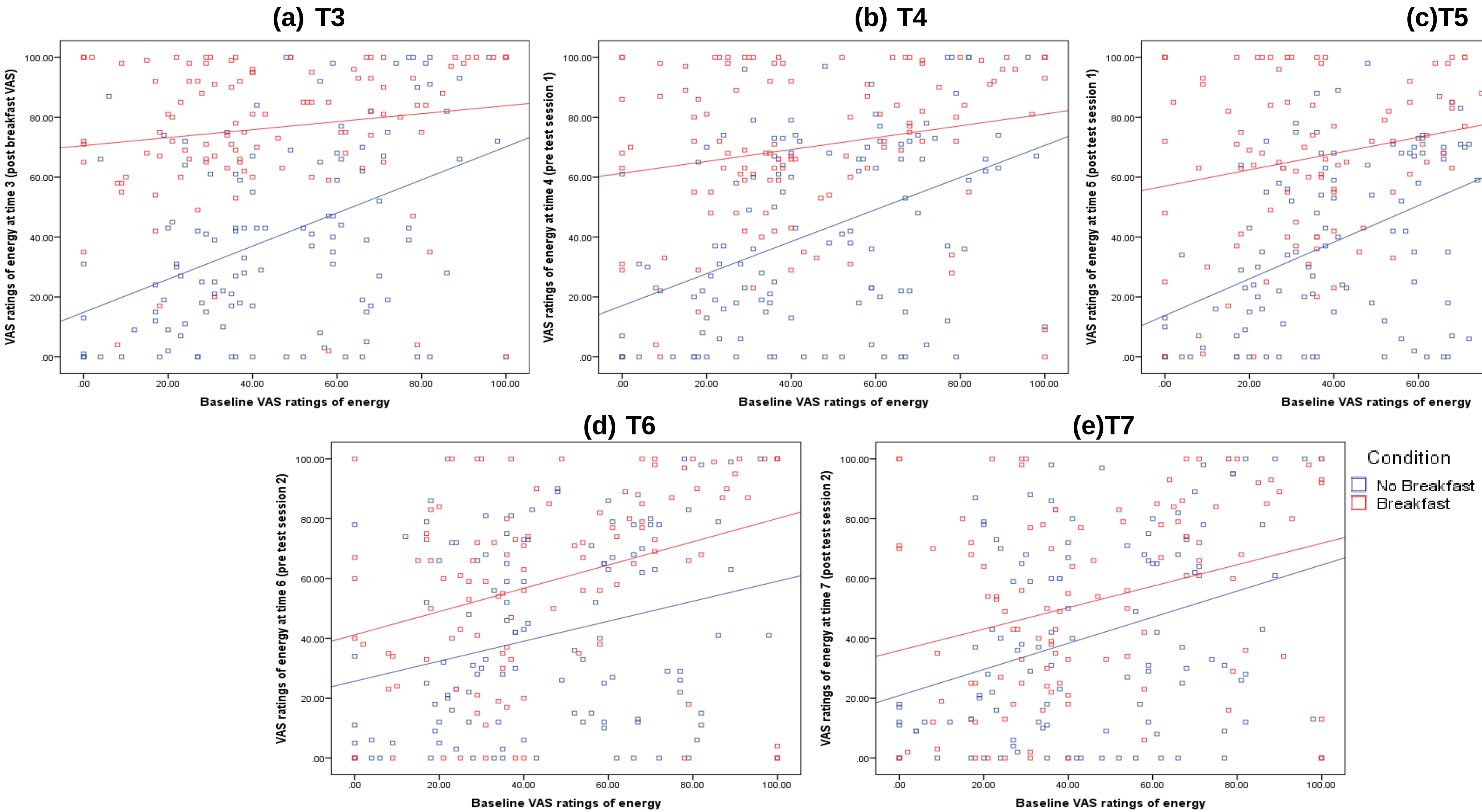
9.36 Study 1: Regression plots

Figure 9.2: Regression plots of baseline VAS ratings of bad temper on post-intervention VAS ratings of bad temper at T3-7



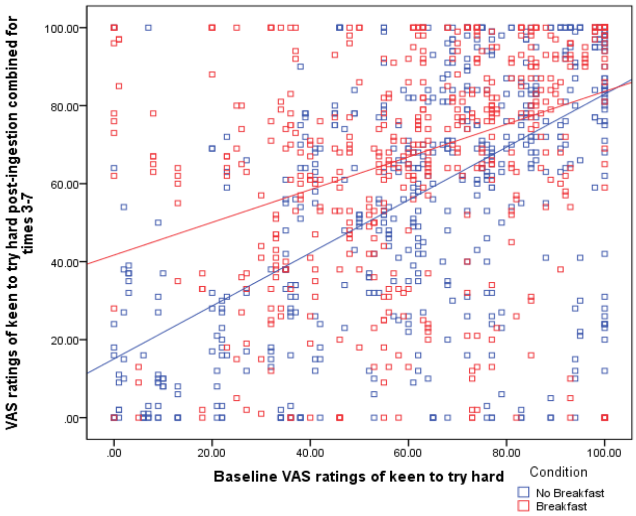
9.37 Study 1: Regression plots

Figure 9.3: Regression plots of baseline VAS ratings of energy on post-intervention VAS ratings of energy at T3-7



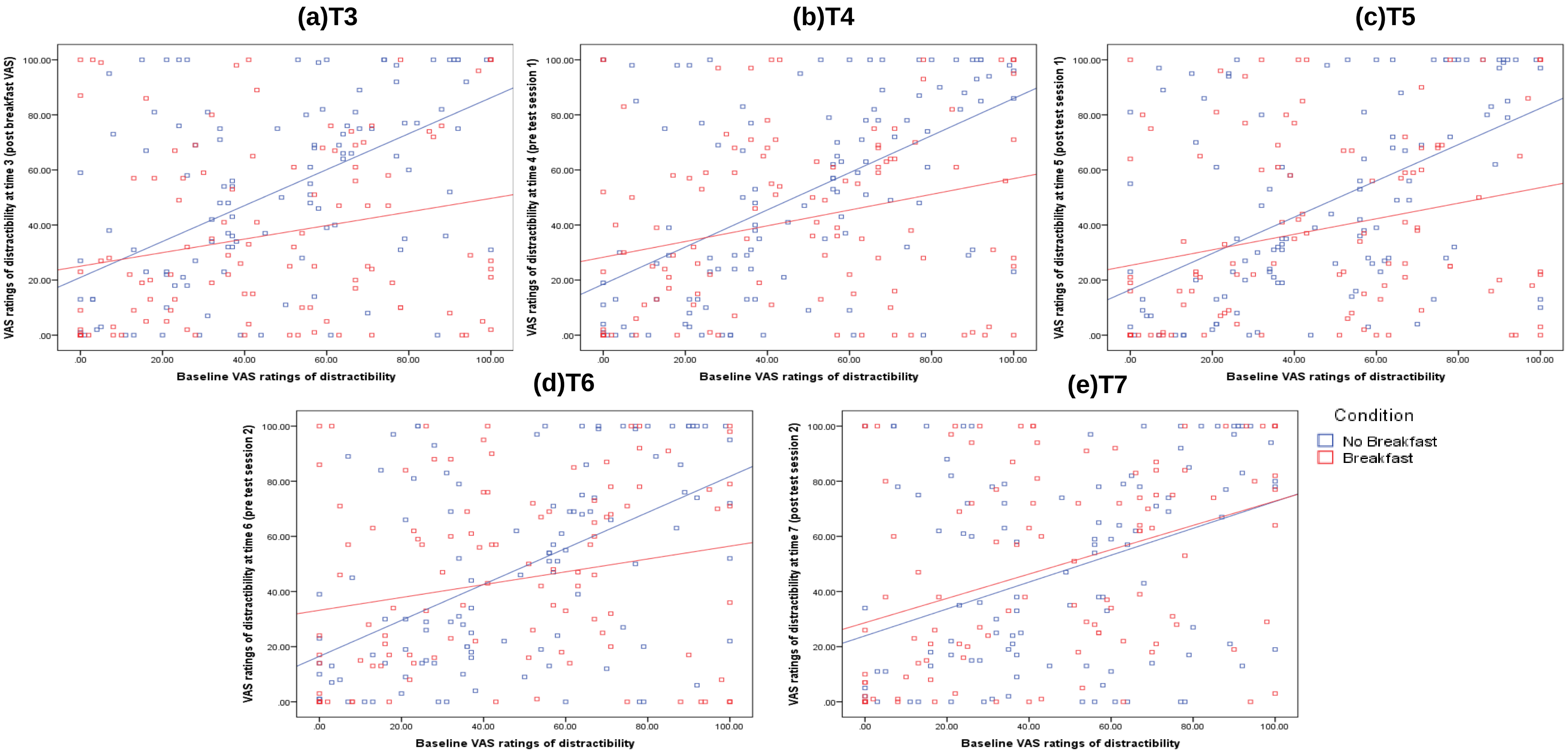
9.38 Study 1: Regression plot

Figure 9.4: Regression plot of baseline VAS ratings of keen to try hard on post-intervention VAS ratings of keen to try hard at T3-7 combined by condition



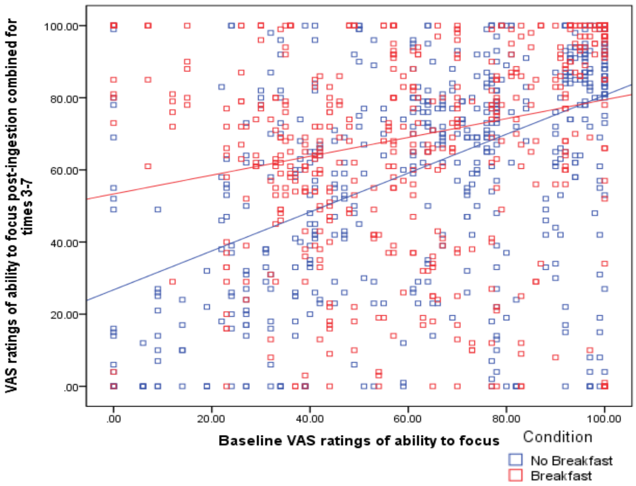
9.39 Study 1: Regression plots

Figure 9.5: Regression plots of baseline VAS ratings of distracted on post-intervention VAS ratings of distracted at T3-7



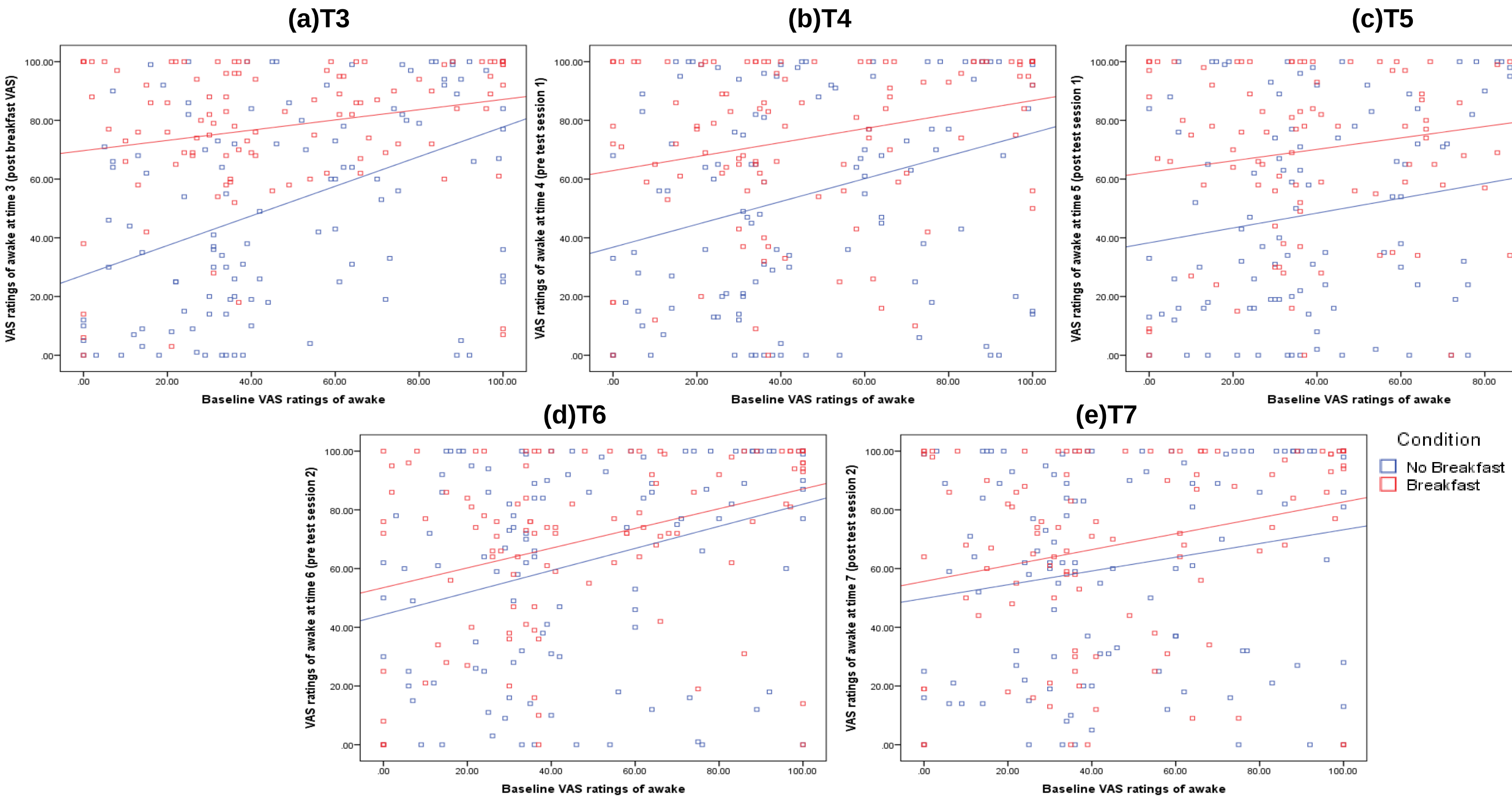
9.40 Study 1: Regression plot

Figure 9.6: Regression plot of baseline VAS ratings of ability to focus on post-intervention VAS ratings of ability to focus at T3-7 combined by condition



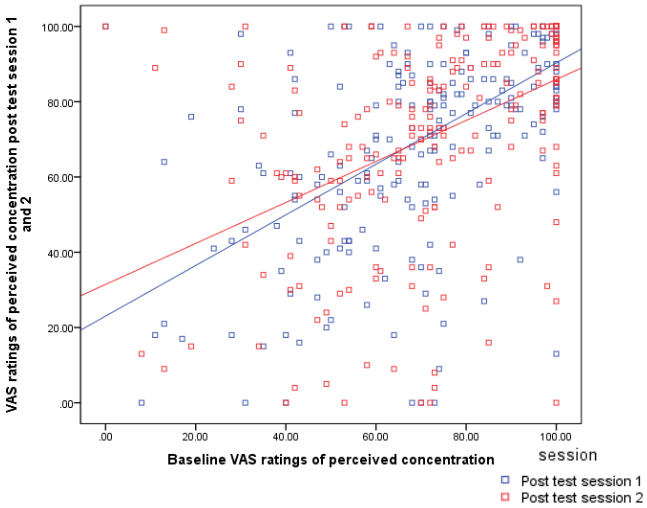
9.41 Study 1: Regression plots

Figure 9.7: Regression plots of baseline VAS ratings of awake on post-intervention VAS ratings of awake at T3-7



9.42 Study 1: Regression plot

Figure 9.8: Regression plot of baseline VAS ratings of perceived concentration during the test battery on post-intervention VAS ratings of perceived concentration during the test battery by session



9.43 Study 1: Summary of baseline*condition interactions

Table 9.7: Summary baseline*condition interactions according to task and test session

Outcome group	Variable	Baseline*condition interaction	
		Mid-morning	Late-morning
		TS1	TS2
Simple Reaction Time task			
Reaction time	Reaction time (ms)	O	Greater + effect of BF at better baseline CP
Movement time	Movement time (ms)	Greater + effect of BF at worse baseline CP	O
Errors	Total number of errors	O	O
5-Choice Reaction Time task			
Reaction time	Reaction time (ms)	Greater + effect of BF at worse baseline CP	Greater + effect of BF at better baseline CP
Movement time	Movement time (ms)	O	O
Errors	Total number of errors	O	O
Rapid Visual Information Processing task			
Accuracy	Number correct block 1	Greater + effect of BF at worse baseline CP	Greater + effect of BF at worse baseline CP
	Number correct block 2	O	O
	Number correct block 3	O	O
	Number correct block 4	O	O
	Number correct block 5	O	O
	Number correct block 6	O	O
	Number correct across blocks	O	O
	Number of correct rejections	O	O
	Number of false alarms	Greater + effect of BF at worse baseline CP	Greater + effect of BF at worse baseline CP
Reaction time	Reaction time (ms)	O	O
Paired Associates Learning task			
Immediate recall	First trial memory score	O	O
Learning	Number of trial attempts	Greater + effect of BF at worse baseline CP	Greater + effect of BF at worse baseline CP
Errors	Number of errors	Greater + effect of BF at worse baseline CP	Greater + effect of BF at worse baseline CP

Key: + indicates positive effect of breakfast. *Abbreviations: CP: Cognitive performance TS: test session*

9.44 SRR 2: Literature search methods

Search terms and the number of articles identified

Search Terms	Number Identified
Breakfast AND school performance AND child* OR adolescent*	197
Breakfast AND academic performance AND child* OR adolescent*	84
Breakfast AND scholastic performance AND child* OR adolescent*	4
Breakfast AND academic achievement AND child* OR adolescent*	60
Breakfast AND school achievement AND child* OR adolescent*	62
Breakfast AND scholastic achievement AND child* OR adolescent*	2
Breakfast AND education* achievement AND child* OR adolescent*	38
Breakfast AND education* performance AND child* OR adolescent*	75
Breakfast AND school grades AND child* OR adolescent*	262
Breakfast AND test scores AND child* OR adolescent*	104
Breakfast AND achievement test AND child* OR adolescent*	18
Breakfast program* AND school performance AND child* OR adolescent*	70
Breakfast program* AND academic performance AND child* OR adolescent*	29
Breakfast program* AND scholastic performance AND child* OR adolescent*	1
Breakfast program* AND academic achievement AND child* OR adolescent*	19
Breakfast program* AND school achievement AND child* OR adolescent*	28
Breakfast program* AND scholastic achievement AND child* OR adolescent*	1
Breakfast program* AND education* achievement AND child* OR adolescent*	21
Breakfast program* AND education* performance AND child* OR adolescent*	30
Breakfast program* AND school grades AND child* OR adolescent*	122
Breakfast program* AND test scores AND child* OR adolescent*	22
Breakfast program* AND achievement test AND child* OR adolescent*	7

Inclusion and Exclusion Criteria

This review was limited to articles published in English in peer-reviewed journals.

Papers were included or excluded in this review using the following criteria:

Participants: Studies of children or adolescents (4-18 years old) of either sex were included. All studies using adult or elderly samples were excluded.

Manipulations: Any type of breakfast manipulation, including studies comparing breakfast with no breakfast and/or different breakfast types. Studies investigating the effect of chronic interventions and habitual breakfast consumption were included. Studies of the effects of manipulations at other mealtimes were excluded. Breakfast was defined according to the definition applied within the studies reviewed. Studies were not excluded on the basis of the content of the meal; for example, studies that included interventions using drinks and/or snacks were included, studies that did not report breakfast composition were included.

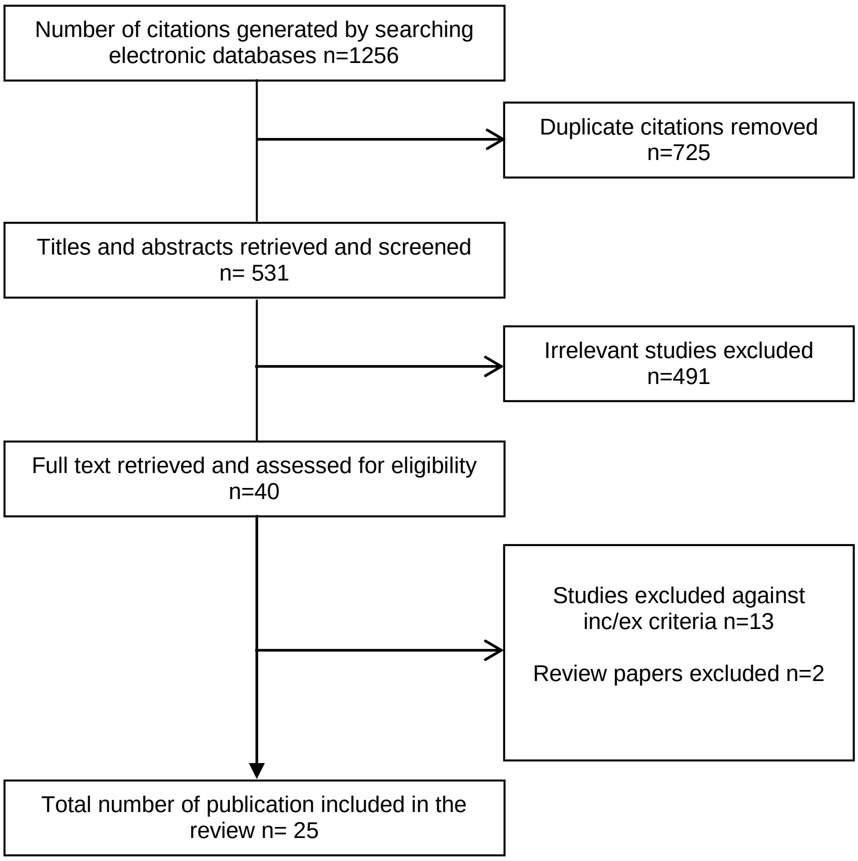
Outcome measures: Studies including any outcome measures of academic performance were included. These include measures that assess outcomes of a taught curriculum or content similar to the taught curriculum.

Design: Intervention studies examining the acute and chronic effects of breakfast manipulations were included. Observational studies examining associations between breakfast consumption and academic performance were also included.

Study Selection Process

Figure 1 details the process for selecting studies for inclusion in this review and the number of articles excluded at each stage. The literature search yielded a total of 1256 citations. Following removal of 725 duplicates, a total of 531 citations were retrieved for possible inclusion in the review. Titles and abstracts were examined to remove obviously irrelevant reports (n=491). The full text versions of 40 articles were retrieved and examined for eligibility. A further 15 studies were excluded. A total of 25 studies were included in the review.

Figure 1: Flow diagram of the study selection process



9.45 Study 2: CAT scoring

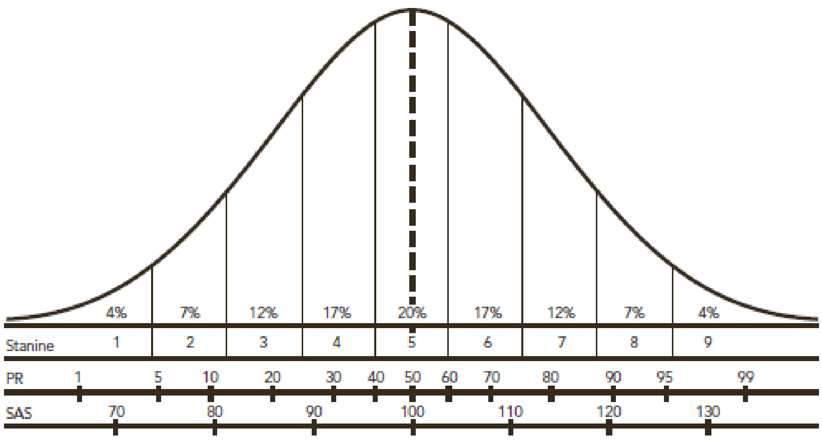
Recommended levels for year groups and corresponding ages.

CAT Level	Standardised age Group	School year group		
		England and Wales	Northern Ireland	Scotland
Level A	7:06-9:11	Y4	P5	P5
Level B	8:06-10:11	Y5	P6	P6
Level C	9:06-11:11	Y6	P7	P7
Level D	10:06-12:11	Y7	F1	S1
Level E	11:06-13:11	Y8	F2	S2
Level F	12:06-14:11	Y9	F3	S3
Level G	13:06-15:11	Y10	F4	S4
Level H	14:06-17:00+	Y11+	F5+	S5+

Raw score
The raw score is the total number of correct answers obtained by the pupil. The raw score is calculated for each battery. These scores are converted to normative scores described below. This allows comparison of scores with a national representative sample of pupils of a similar age.

Standard Age Scores (SASs)
Raw scores are converted to normative standard age scores (SASs). SASs are calculated by comparing a subject's raw scores with the national standardisation sample adjusted for age. SASs range from 60 to 140 and give discriminated, finely-graded information on the performance of each pupil compared to a national sample. Each subtest and overall mean performance is UK standardised to a mean of 100 and standard deviation of 15 based on national normative population data from the CAT which was administered in October and November (2000) in a representative sample of 16,000 school children across the age range of 7.6-15.9 from 566 schools in the UK. The SAS is key to monitoring progress and allows comparisons to be made across tests and year groups. The properties of SASs means that approximately two thirds of pupils in a particularly age group achieve a score between 85-115 and 95% of pupils score between 70-130, and 99% score between 60-140. The figure below illustrates the frequency distribution for SASs, stanines and percentiles.

Normal distribution curve showing the relationship between stanines, national percentile ranks and SASs (Lohman et al 2001)



Stanines

The SASs comprises of nine bands known as standard nines or “stanines”. Stanines are nine summary score bands calculated directly from the standard scores shown in the table below. Based on the national standardisation, the expected proportion in each band is shown. This can be compared to the proportion of pupils in each stanine in the sample. Although stanines are broad, stanines are frequently used in reporting test information to pupils and parents as they are easy to understand and interpret.

Stanine score bands for CAT SASs

Rating	Stanine	Percentage of cases	Corresponding percentiles	Corresponding SASs
Very high	9	4	>97	>127
Above average	8	7	90-96	119-126
	7	12	78-89	112-118
Average	6	17	59-77	104-111
	5	20	41-58	97-103
	4	17	23-40	89-96
Below average	3	12	12-22	82-88
	2	7	5-11	74-81
Very low	1	4	<4	<73

9.46 Study 2: Hierarchical multiple regression analysis for verbal reasoning CAT

Model	Explanatory Variables	R^2	ΔR^2	ANOVA	B	SE B	β
1[a]	**Habitual breakfast** (reference = Frequent)	0.01	0.01	$F(2,286) = 1.08$, p=0.340			
	Occasional				-2.57	1.79	-0.10
	Rare				-1.47	1.70	-0.06
2[b]	**Habitual breakfast** (reference = Frequent)	0.06	0.05*	$F(7,281) = 2.36$, p<0.05			
	Occasional				-1.72	1.78	-0.06
	Rare				-1.74	1.71	-0.07
	Ethnicity (reference = White British)				-4.38	1.58	-0.17**
	SES (reference = Low)				1.99	1.48	0.08
	Sex (reference = Male)				0.98	1.46	0.04
	EAL (reference = No)				1.54	1.60	0.06
	BMI				1.20	0.59	0.13*
3[c]	**Habitual breakfast** (reference = Frequent)	0.08	0.02	$F(17,271) = 1.26$, p=0.222			
	Occasional				-1.50	1.85	-0.06
	Rare				-1.39	1.75	-0.05
	Ethnicity (reference = White British)				-4.52	1.62	-0.18**
	SES (reference = Low)				1.96	1.52	0.08
	Sex (reference = Male)				0.85	1.48	0.04
	EAL (reference = No)				1.46	1.64	0.06
	BMI				1.26	0.60	0.13*
	Ethnicity * Occasional breakfast				1.39	3.87	0.03
	Ethnicity * Rare breakfast				-0.31	3.93	-0.01
	SES * Occasional breakfast				-0.49	3.87	-0.01
	SES * Rare breakfast				4.14	3.50	0.08
	Sex * Occasional breakfast				3.58	3.71	0.07
	Sex * Rare breakfast				0.08	3.48	0.00
	EAL* Occasional breakfast				-2.13	3.88	-0.04
	EAL * Rare breakfast				-3.72	3.99	-0.06
	BMI SDS* Occasional breakfast				1.06	1.50	0.05
	BMI SDS* Rare breakfast				-0.53	1.39	-0.03

[a] Crude (unadjusted) model; [b] Adjusted model; [c] Fully adjusted model; *p<0.05, ** p<0.01, ***p<0.001

9.47 Study 2: Hierarchical multiple regression analysis for nonverbal reasoning CAT

Model	Explanatory Variables	R^2	ΔR^2	ANOVA	B	SE B	β
1[a]	**Habitual breakfast** (reference = Frequent)	0.01	0.01	*F*(2, 282)=0.41 *p*=0.667			
	Occasional				-1.76	1.96	-0.06
	Rare				-0.75	1.86	-0.03
2[b]	**Habitual breakfast** (reference = Frequent)	0.04	0.04	*F*(7, 277)=1.65 *p*=0.122			
	Occasional				-1.85	1.96	-0.06
	Rare				-0.65	1.88	-0.02
	Ethnicity (reference =White British)				0.94	1.73	0.03
	SES (reference = Low)				2.90	1.62	0.11
	Sex (reference = Male)				1.58	1.60	0.06
	EAL (reference = No)				2.40	1.76	0.09
	BMI				1.32	0.65	0.13*
3[c]	**Habitual breakfast** (Reference = Frequent)	0.07	0.02	*F*(17, 267)=1.02 *p*=0.436			
	Occasional				-2.20	2.03	-0.08
	Rare				-0.75	1.92	-0.03
	Ethnicity (reference =White British)				0.71	1.77	0.03
	SES (reference = Low)				2.51	1.66	0.10
	Sex (reference = Male)				1.35	1.63	0.05
	EAL (reference = No)				2.16	1.81	0.08
	BMI				1.26	0.66	0.12
	Ethnicity * Occasional breakfast				6.02	4.28	0.10
	Ethnicity * Rare breakfast				-0.70	4.27	-0.01
	SES * Occasional breakfast				1.95	4.23	0.03
	SES * Rare breakfast				3.69	3.83	0.07
	Sex * Occasional breakfast				-3.04	4.07	-0.05
	Sex * Rare breakfast				-2.01	3.80	-0.04
	EAL* Occasional breakfast				-2.85	4.26	-0.05
	EAL * Rare breakfast				0.39	4.43	0.01
	BMI SDS* Occasional breakfast				1.68	1.65	0.07
	BMI SDS* Rare breakfast				1.60	1.54	0.07

[a] Crude (unadjusted) model; [b] Adjusted model; [c] Fully adjusted model; *$p<0.05$, ** $p<0.01$, ***$p<0.001$

9.48 Study 2: Hierarchical multiple regression analysis for quantitative reasoning CAT

Model	Explanatory Variables	R^2	ΔR^2	ANOVA	B	SE B	β
1[a]	**Habitual breakfast** (reference = Frequent)	0.01	0.01	*F*(2,284)=0.40, *p*=0.668			
	Occasional				0.89	1.95	0.03
	Rare				-0.96	1.84	-0.04
2[b]	**Habitual breakfast** (reference = Frequent)	0.04	0.03	*F*(7,279)=1.61, *p*=0.134			
	Occasional				1.37	1.95	0.05
	Rare				-0.60	1.86	-0.02
	Ethnicity (reference =White British)				-2.29	1.71	-0.08
	SES (reference = Low)				3.52	1.62	0.14*
	Sex (reference = Male)				0.02	1.59	0.00
	EAL (reference = No)				2.34	1.76	0.08
	BMI				0.92	0.64	0.09
3[c]	**Habitual breakfast** (Reference = Frequent)	0.06	0.02	*F*(17,269)=0.97, *p*=0.490			
	Occasional				1.33	2.02	0.05
	Rare				-0.52	1.90	-0.02
	Ethnicity (reference =White British)				-2.67	1.76	-0.10
	SES (reference = Low)				3.53	1.65	0.14*
	Sex (reference = Male)				-0.18	1.62	-0.01
	EAL (reference = No)				2.22	1.80	0.08
	BMI				0.88	0.65	0.09
	Ethnicity * Occasional breakfast				3.81	4.23	0.07
	Ethnicity * Rare breakfast				-1.14	4.23	-0.02
	SES * Occasional breakfast				2.73	4.22	0.05
	SES * Rare breakfast				1.66	3.81	0.03
	Sex * Occasional breakfast				3.92	4.06	0.07
	Sex * Rare breakfast				0.15	3.79	0.00
	EAL* Occasional breakfast				-5.39	4.27	-0.09
	EAL * Rare breakfast				-2.67	4.38	-0.04
	BMI SDS* Occasional breakfast				1.73	1.63	0.07
	BMI SDS* Rare breakfast				0.80	1.52	0.04

[a] Crude (unadjusted) model; [b] Adjusted model; [c] Fully adjusted model; *$p<0.05$, ** $p<0.01$, ***$p<0.001$

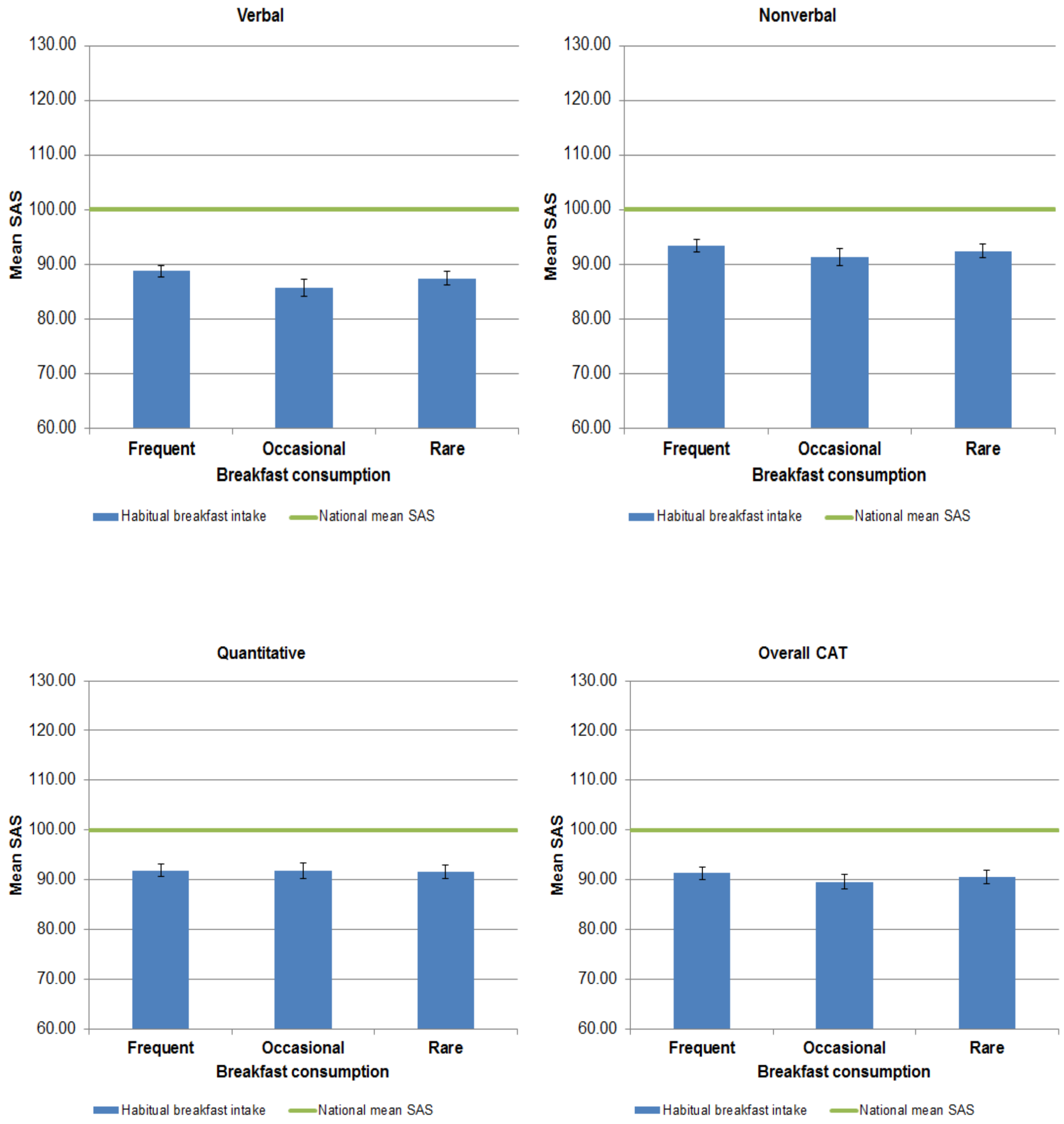
9.49 Study 2: Hierarchical multiple regression analysis for overall CAT

Model	Explanatory Variables	R^2	ΔR^2	ANOVA	B	SE B	β
1[a]	**Habitual breakfast** (reference = Frequent)	0.01	0.01	*F*(2,289)=0.41, *p*=0.663			
	Occasional				-1.22	1.64	-0.05
	Rare				-1.20	1.54	-0.05
2[b]	**Habitual breakfast** (reference = Frequent)	0.05	0.04	*F*(7,284)=1.92, *p*=0.093			
	Occasional				-0.77	1.64	-0.03
	Rare				-1.04	1.56	-0.05
	Ethnicity (reference =White British)				-2.10	1.44	-0.09
	SES (reference = Low)				2.83	1.35	0.13*
	Sex (reference = Male)				0.79	1.33	0.04
	EAL (reference = No)				2.13	1.47	0.09
	BMI				1.08	0.53	0.13*
3[c]	**Habitual breakfast** (Reference = Frequent)	0.07	0.02	*F*(17,274)=1.08, *p*=0.327			
	Occasional				-0.83	1.70	-0.03
	Rare				-0.89	1.60	-0.04
	Ethnicity (reference =White British)				-2.41	1.48	-0.10
	SES (reference = Low)				2.70	1.39	0.12*
	Sex (reference = Male)				0.65	1.36	0.03
	EAL (reference = No)				2.00	1.50	0.08
	BMI				1.07	0.55	0.12*
	Ethnicity * Occasional breakfast				3.47	3.55	0.07
	Ethnicity * Rare breakfast				-0.78	3.56	-0.02
	SES * Occasional breakfast				1.51	3.56	0.03
	SES * Rare breakfast				3.59	3.18	0.08
	Sex * Occasional breakfast				1.89	3.41	0.04
	Sex * Rare breakfast				-0.93	3.16	-0.02
	EAL* Occasional breakfast				-3.47	3.56	-0.07
	EAL * Rare breakfast				-1.80	3.66	-0.03
	BMI SDS * Occasional breakfast				1.45	1.38	0.07
	BMI SDS* Rare breakfast				0.49	1.27	0.03

[a] Crude (unadjusted) model; [b] Adjusted model; [c] Fully adjusted model; *p<0.05, ** p<0.01, ***p<0.001

9.50 Study 2: Plots of raw data

Figure 9.9: Mean SAS plotted according to habitual breakfast consumption for CAT (a) verbal (b) nonverbal (c) quantitative reasoning and (d) overall CAT reasoning



9.51 Study 2: Correlations and inter-correlations between predictor variables and CAT SAS

Variable	Verbal CAT SAS	Nonverbal CAT SAS	Quantitative CAT SAS	Overall CAT SAS
Occasional breakfast (reference = Frequent)	-0.07	-0.05	0.05	-0.03
Rare breakfast (reference = Frequent)	-0.02	0.01	-0.05	-0.03
Ethnicity (reference = White British)	-0.17**	0.06	-0.04	-0.06
SES (reference = Low)	0.07	0.12*	0.15**	0.13**
Sex (reference = Male)	0.01	0.06	-0.02	0.02
EAL (reference = No)	0.03	0.11*	0.05	0.07
BMI SDS	0.13*	0.12*	0.10*	0.13*

* *p*<0.05, ***p*<0.01;*** *p*<0.001
Values for Pearson's product moment correlation

Inter-correlations among socio-demographic and habitual breakfast consumption variables

	Variable	1	2	3	4	5	6	7
1	Ethnicity	-						
2	SES	0.10*	-					
3	Sex	0.05*	-0.11	-				
4	EAL	0.18***	0.04	-0.05	-			
5	BMI SDS	-0.09	0.03	-0.15**	0.00	-		
6	Occasional breakfast	0.18***	0.05	0.01	0.05	-0.10*	-	
7	Rare breakfast	-0.11*	-0.13**	0.06	-0.09	0.15**	-0.41***	-

* *p*<0.05, ***p*<0.01;*** *p*<0.001
Values for Pearson's product moment correlation

9.52 Study 3: Questionnaire

Participant number: ______________________________

Date of Birth: ______________________________

Sex:

☐ Male

☐ Female

What is your ethnic group?

☐ White British	☐ Indian
☐ White Irish	☐ Pakistani
☐ Any other white background	☐ Bangladeshi
☐ White and Black Caribbean	☐ Any other Asian background
☐ White and Asian	☐ Caribbean
☐ White and Black African	☐ African
☐ Any other mixed background	☐ Any other black background
☐ Chinese	☐ Other

Have you felt so unwell today and/or during the past week that this has affected your appetite?

☐ Yes

☐ No

If yes, please tell us what was/is wrong with you

____

Have you been on holiday during the past week which has changed what you have eaten a lot?

☐ Yes

☐ No

What is the **highest** level of education completed by either of your parents/guardians?

☐ Completed primary school or less

☐ Completed part of secondary school

☐ Completed all of secondary school and/or college

☐ Completed university or above

When did you attend secondary school?

From: ☐☐/☐☐☐☐ To: ☐☐/☐☐☐☐

M M / Y Y Y Y M M / Y Y Y Y

Please write down all your GCSE or equivalent qualifications that you obtained whilst in Key Stage 4 (Years 10 and 11).

- ✓ Please write down ALL GCSE qualifications or equivalents.
- ✓ Please write down the subject
- ✓ Please write down the level or type of qualification. For example, if it was a GCSE, GCSE short course, GCSE double award.
- ✓ Please include equivalent qualifications such as BTEC firsts, if you have them.
- ✓ Remember to include Maths and English.
- ✓ State the grade you were awarded and the year of examination

Subject	Type and level (E.g. GCSE, GCSE double award, BTEC)	Grade (s)	Year of examination (YYYY)			

9.53 Study 3: Seven-day food diary record

SEVEN-DAY FOOD AND DRINK DIARY FOR BREAKFAST MEALS

WHAT HAVE YOU EATEN AND DRANK FOR BREAKFAST DURING THE PAST SEVEN DAYS

Participant number:	

Example page

Day	**MONDAY (Today)**							
Date	**0**	**3**	**1**	**0**	**2**	**0**	**1**	**1**
Time of breakfast:								

Breakfast	**Description and preparation (E.g. type of milk or bread, how cooked)**	**Brand name (if any)**	**Portion size or amount eaten**
Food:			
Drink:			

9.54 Study 3: Seven-day food diary record instructions

We would like you to remember and write down everything you ate and drank for breakfast during the past seven days, including today. Please only report what you ate and drank for breakfast. It is very important that you do not change or report anything different from what you ate and drank. If you never eat breakfast, just tell us by writing on the front page of your food diary. If you didn’t eat breakfast on a particular day, tell us by writing at the top of the page for the day that you didn’t eat breakfast.

What is breakfast?

Breakfast is the first thing you eat or drink that is consumed soon after waking. This includes all food and drink consumed up to and including 10:00am on school days/college days or 11:00am on weekend days. This includes all food that was eaten at home, on the way to school or at school prior to that start of lessons. This includes **all food**, even if it’s not a usual breakfast food.

Date and day: The date and day are already printed at the top of the page for you. These are the days we want you to report what you had for breakfast. You will need to report your breakfast meals for today, and the previous 6 days in that order. For example, today (Monday) then yesterday (Sunday) then Saturday etc.

Time: Please write down the time you ate or drank anything for breakfast.

What did you eat? Please write down in as much detail as possible what food you ate for breakfast. Be as detailed as you can. The example on the following page will help you.

What did you drink? Please write down in as much detail as possible what you drank for (or with) your breakfast. Be as detailed as you can.

Description and preparation: Please include the cooking method if there was any (e.g. fried, grilled, baked, boiled) and anything you added (added sugar, butter, sweetener, spreads) and the type of food (e.g. type of cereal, bread, milk). The example on the following page will help you.

Brand name: Please write down the brand name if you know it, but don’t worry if not.

Portion size/amount you ate: Please tell us the amount of food and/or drink you had. Please only tell us how much you consumed and tell us if there were any leftovers. Please estimate your portion size using things like bowls, cups, glasses, teaspoons/tablespoons or number of items (one slice, one banana, one biscuit). If you are struggling, please ask a researcher to help you. We have some pictures that could help.

If you are struggling to remember what you had for breakfast, try and think what you were doing that day. We know it’s hard to remember everything, so just try and remember as much as you can.

On the next page, you will see an example page that has been filled in. This example shows you how we would like you to fill in the food diary to report your breakfast meals.

If you need help, please ask a researcher.

9.55 Study 3: GCSE point score allocation

GCSE point score scale

GCSE Qualification	Point score
Grade A*	58
Grade A	52
Grade B	46
Grade C	40
Grade D	34
Grade E	28
Grade F	22
Grade G	16
Grade U	0

Volume indicators

GCSE course type	Volume Indicator
GCSE Full course	1.0
GCSE Short Course	0.5
GCSE Double award	2.0

The grading structure, points and volume indictors for BTEC qualifications vary depending on the qualification type. The OFQUAL register was used for reference: http://register.ofqual.gov.uk/

Calculation of total uncapped GCSE point score

Total sum of all GCSE point scores obtained for all qualifications.

Calculation of capped point score

Qualifications are compared to the size of a GCSE to determine a volume indicator (i.e. how many GCSE is a qualification worth). The points value for each qualification is divided by the volume indicator to arrive at a standardised points figure. The qualifications are then ranked in descending standardised points order and volume indicator summed until a cap of 8 is reached. The total points for qualifications included in the cap is then summed to arrive at the capped point score. Maximum capped point score is 464 (i.e. 8 x 58).

Average point score per qualification.

Total uncapped point score divided by number of entries. To equate this to grades, the grade boundaries are use below.

Average point score per qualification	**Equivalent grade**
57.0+	A*
55.0-56.9	A*-
53.0-54.9	A+
51.0-52.9	A
49.0 - 50.9	A-
47.0 - 48.9	B+
45.0 - 46.9	B
43.0 - 44.9	B-
41.0 - 42.9	C+
39.0 - 40.9	C
37.0 - 38.9	C-
35.0 - 36.9	D+
33.0 - 34.9	D
31.0 - 32.9	D-
29.0 - 30.9	E+
27.0 - 28.9	E
25.0 - 26.9	E-
23.0 - 24.9	F+
21.0 - 22.9	F
19.0 - 20.9	F-
17.0 - 18.9	G+
15.0 - 16.9	G
8.0 - 14.9	G-
7.9 or below	U

Sources:

Department for Education GCSE point score system (Department for Education, 2013d)
Department for Education GCSE average point score per qualification (Department for Education, 2013a)

9.56 Study 3: Ethical approval certificate


Certificate of ethical approval
#11-0087

Title: The relationship between habitual breakfast intake, academic performance and cognitive failures

Researcher(s):

Supervisor: Clare Lawton

Date of approval: 15 June 2011

Ethics committee of the Institute of Psychological Sciences, Leeds University

9.57 Study 3: Ethical approval certificate


Certificate of ethical approval
#11-0182

Title: Amendment to 11-0087 to repeat the study with a new cohort of 6th form students: The

Researcher(s):

Supervisor: Clare Lawton

Date of approval: 20 October 2011

Ethics committee of the Institute of Psychological Sciences, Leeds University

9.58 Study 3: Letter to parents and parent information sheet

Data collection procedure: Visits to sixth form schools.

Institute of Psychological Sciences
University of Leeds
Leeds
LS2 9JT
Tel: (0113) 343 5719
Date: XX/XX/XXXX

UNIVERSITY OF LEEDS

Dear Parent/Guardian,

We are a team of researchers from the University of Leeds and we are interested in the effect of breakfast on children's academic performance. In association with <<Name of teacher>>, Head of Psychology at <<Name of Sixth form>>, we would like to invite your child to take part in a survey study relating to the possible benefits of breakfast on academic grades, which will take place on <<Date of data collection>>. Enclosed are two information sheets providing detailed explanations of what the study involves. One is for you and one for your child. They are designed to provide you and your child with enough information so that you can decide whether you would like to take part in the study.

The study will take place at <<Name of Sixth Form>> and will be conducted according to the ethical guidelines set out by the British Psychological Society. All researchers have been fully CRB checked.

The study will examine the relationship between eating breakfast regularly and academic performance in adolescents. The study will also examine how often adolescents consume breakfast and what food they consume. If you decide you are happy for your child to take part, he/she will complete a 7-day food diary to measure their breakfast intake during the previous 7 days and a questionnaire to measure their academic performance. Your child will take part on a single occasion during their usual psychology lesson with their teachers. The study will be integrated within their psychology teaching to learn about nutrition and psychology, research procedures and ethical considerations in research. This has been organised in association with <<Name of Teacher>>, Head of Psychology.

If you **do not** wish for your child to take part in the study, please do one of the following:

- Complete and return the enclosed slip in this letter to sixth form with your child. They should give the slip back to <<Name of teacher>>, Head of Psychology.
- Contact via email: pskad@leeds.ac.uk
- Telephone or text on: 07XXXXXXXXX

If you are happy for your child to take part, you do not have to do anything.

Yours Faithfully,

Miss Katie Adolphus
PhD Research Student
Human Appetite Research Unit
Institute of Psychological Sciences
University of Leeds,
LS2 9JT

University of Leeds Breakfast Study: Information for parents.

Research project title
A study to investigate trends in breakfast eating and the relationship between habitual breakfast eating and academic performance in 16-18 year olds.

What is the aim of the research study?
The study is investigating if habitual breakfast eating is associated with academic performance in adolescents. The study is also trying to establish trends in breakfast consumption including regularity, food type and the nutritional composition.

What happens if I decide to take part?
Your child will take part in a test session during their usual psychology lesson. Your child will receive a presentation given by the lead researcher to reiterate the study, its requirements and procedures. They will be given the opportunity to ask any questions about the study. Your child will then be required to complete a simple written questionnaire to obtain some information about them including their age, gender and ethnicity. They will also be required to report all of their GCSE qualifications and the grades obtained to measure academic performance. Your child will be given instructions for a 7-day food diary and will be asked to complete the diary during the lesson to indicate everything they have eaten and drank for breakfast only during the past seven days, including the day of testing. Your child's height and weight will be measured and recorded by a trained researcher. If they have any problems or queries, they will be able to ask the researchers present at any point.

Why has my child been selected to participate?
Males and females aged between 16-18 years have been recruited to take part. Your child has been chosen to participate on a single occasion as part of their psychology lesson. The study will be integrated within their psychology teaching to learn about nutrition and psychology, research procedures and ethical considerations in research. This has been organised in association with their psychology teacher.

Voluntary participation
Participation in the study is completely voluntary. If you decide to allow your child to take part they are free to withdraw at any time without providing a reason.

What will my child do if I do not want them to take part or if they are unable to take part?
If you and/or your child do not want to participate in the survey, they will still take part in the lesson as normal, but they will not complete the food diary, questionnaire or have their height and weight measured. If your child cannot take part due to an inability to adequately complete the food diary and/or questionnaire, they will still be able to take part if they wish but their data will be excluded from the analysis and report.

What are the possible disadvantages or risks of taking part?
There are no disadvantages or risks involved in taking part in the study.

What are the advantages of taking part?
Your child will take part in a real life, important scientific study and have the opportunity to learn about psychological research design, ethical considerations and nutrition and psychology.

Confidentiality
All of the information collected from your child during the study will be kept strictly confidential and will only be used for the purposes of this research. All results from the study will be kept strictly anonymous and at no point will any identifiable personal information be linked with the results.

Contact us:

If you have any questions or just want to know more about the study, please do not hesitate to contact me by either the email address or telephone number provided below. If you would prefer to text or leave a voicemail, I can return your call as soon as possible.
Contact via email: pskad@leeds.ac.uk
Telephone or text: on 07XXXXXXXXX

For the attention of <<Name of teacher>>

UNIVERSITY OF LEEDS BREAKFAST STUDY

Please fill in this slip, and return it to school if you do **not** want your child to take part in the study. **If you are happy for your child to take part, you do not need to do anything.**

I do **NOT** want my child to take part in the breakfast study.

Name	

Year	

Form	

Signed		Date	

9.59 Study 3: Adolescent information sheet

Data collection procedure: Visits to sixth form schools

What is the experiment trying to find out?
We are trying to find out if eating breakfast regularly is related to school performance in 16-18 year olds. We are also trying to find out if young adults normally eat breakfast, how often they eat breakfast and what they have for breakfast, such as the type of food and the amount.

What will I need to do?
You will take part in the experiment during one of your psychology lessons. In your lesson, you will also learn about research designs, ethical guidelines and about nutrition and psychology. Your teacher will tell you when this will be. Before you take part, you will watch a presentation given by the researchers to explain what you have to do. You can ask questions if you are not sure about anything. You will then complete a simple questionnaire to tell us about yourself such as your age, gender, and ethnicity. You will also be required to write down all of your GCSE grades you obtained in the last two years of secondary school. This will measure your school performance. Your height and weight will be measured and recorded by one of the researchers. You will get some instructions about how to complete a food diary and then fill in the diary to tell us everything you have eaten or drank for breakfast during the previous 7 days, including that day. Don't worry if you don't eat breakfast, you can just tell us. If you have any problems or queries, you can ask the researchers or your teacher at any point.

Why have I been chosen?
We are asking sixth form students aged 16-18 years to take part. You have been chosen to take part as part of one of your psychology lessons. The survey has been included in a special psychology lesson to help you learn about nutrition and psychology, research designs and ethical guidelines. You will take part with your classmates.

Do I have to take part?
You do not have to take part in the experiment if you do not want to, and you do not have to give a reason as to why you don't want to take part. If you decide to take part, you can still leave the experiment at any time without giving a reason.

What will I do if I do not take part or if I can't take part?
If you do not want to take part, you will still attend the lesson as normal, but you won't have to complete the food diary, questionnaire or have your height and weight measured. If you can't take part because you cannot fill in the questionnaire or food diary properly then you can still take part if you wish but we will not include your results in our report.

What are the possible disadvantages or risks of taking part?
There are no disadvantages or risks involved in taking part in the study.

What are the advantages of taking part?
You will take part in a real life, important scientific study and have the opportunity to learn about psychological research design, ethical guidelines and nutrition and psychology in action!

Will anyone know if I have taken part?
All of the information we collect from you will kept confidential and private. Your name will not be on any of the information we collect about you so no one else will know you have taken part. All of the information we collect about you will only be used for our research. It is really important that you are honest as possible in your answers and you don't need to worry because they are all kept private.

Remember that before you take part, you can ask the researchers any questions if you still want to know more.

9.60 Study 3: Letter to parents and parent information sheet

Data collection procedure: Institute of Psychological Sciences Research Open Day

Institute of Psychological Sciences
University of Leeds
Leeds
LS2 9JT
Tel: (0113) 343 5719
Date: XX/XX/XXXX

UNIVERSITY OF LEEDS

Dear Parent/Guardian,

My name is Dr Keon West. I am a Psychological Research Fellow at the University of Leeds. Together with Katie Adolphus, a doctoral researcher at the University of Leeds and <<Name of Teacher>>, Head of Psychology at <<Name of sixth form/college>>, I have organised a Research Open Day in which students are allowed to experience psychological research first-hand, see presentations on cutting-edge psychological research, and ask real psychologists questions about the research. This will take place at the Institute of Psychological Sciences. The students may be invited to take part in a number of studies (see the reverse of this sheet for descriptions and information sheets enclosed). For every study, participants are always told that all honest answers are ok, that they can withdraw from any study at any time without penalty, and that participation is strictly on a voluntary basis.

The Research Open Day is supported by the University of Leeds, Institute of Psychological science, and the individual projects are funded by numerous sources, including, but not limited to national and international research councils. The students will be escorted throughout the day by their regular teachers, and all the research will be carried out in accordance with the strict ethical guidelines as laid out by the British Psychological Society, which includes complete anonymity and confidentiality of the responses and giving each student the opportunity not to take part if they do not wish to be involved.

If you have any questions about the research, please feel free to contact me at: K.west@leeds.ac.uk

If you would prefer your child NOT to participate in the Research Open Day, please complete the enclosed form and return it to <<Name of teacher >> at <<Name of sixth form>>. If you are happy for your child to take part, you do not have to do anything.

Yours Faithfully,

Dr Keon West, University of Leeds

I do **NOT** want my child to take part in the Leeds University Research Open Day

Name of child: ____

Name of parent/guardian: ____________________________________

Signature of parent/ guardian: ________________ Date: _________

Breakfast Study: Information for parents.

Research project title
A study to investigate trends in breakfast eating and the relationship between habitual breakfast eating and academic performance in 16-18 year olds.

What is the aim of the research study?
The study is investigating if habitual breakfast eating is associated with academic performance in adolescents. The study is also trying to establish trends in breakfast consumption including regularity, food type, and the nutritional composition.

What happens if I decide to take part?
Your child will take part in a test session during a Research Open Day at The Institute of Psychological Sciences, University of Leeds. Your child will receive a presentation given by the lead researcher to reiterate the study, its requirements and procedures. They will be given the opportunity to ask any questions about the study. Your child will then be required to complete a simple written questionnaire to obtain some information about them including their age, gender and ethnicity. They will also be required to report all of their GCSE qualifications and the grades obtained to measure academic performance. Your child will be given instructions for a 7-day food diary and will be asked to complete the diary during the lesson to indicate everything they have eaten and drank for breakfast during the past seven days, including the day of testing. Your child's height and weight will be measured and recorded by a trained researcher. If they have any problems or queries, they will be able to ask the researchers present at any point.

Why has my child been selected to participate?
Males and females aged between 16-18 years have been recruited to take part. Your child has been chosen to participate on a single occasion as part of an extracurricular excursion to learn about nutrition and psychology, research procedures and ethical considerations in research. They will also learn about studying psychology at university. This has been organised in association with their psychology teacher.

Voluntary participation
Participation in the study is completely voluntary. If you decide to allow your child to take part they are free to withdraw at any time without providing a reason.

What will my child do if I do not want them to take part or if they are unable to take part?
If you and/or your child do not want to participate in this study during the Research Open Day, he/she can sit quietly in the test session or outside the room if they wish. If your child cannot take part due to an inability to adequately complete the food diary and/or questionnaire, they will still be able to take part if they wish but their data will be excluded from the analysis and report.

What are the possible disadvantages or risks of taking part?
There are no disadvantages or risks involved in taking part in the study.

What are the advantages of taking part?
Your child will take part in a real life, important scientific study and have the opportunity to visit the Psychology department at the University of Leeds. They will also learn about psychological research designs, ethical considerations and nutrition and psychology.

Confidentiality
All of the information collected from your child during the study will be kept strictly confidential and will only be used for the purposes of this research. All results from the study will be kept strictly anonymous and at no point will any identifiable personal information be linked with the results.

Contact us: If you have any questions or just want to know more about the study, please do not hesitate to contact me via email: Katie Adolphus pskad@leeds.ac.uk

9.61 Study 3: Adolescent information sheet

Data collection procedure: Institute of Psychological Sciences Research Open Day

What is the experiment trying to find out?
We are trying to find out if eating breakfast regularly is related to school performance in 16- 18 year olds. We are also trying to find out if young adults normally eat breakfast, how often they eat breakfast and what they have for breakfast, such as the type of food and the amount.

What will I need to do?
You will take part in the experiment during a visit to the psychology department at the University of Leeds for a Research Open Day. During the open day you will also learn about research designs, ethical guidelines and about nutrition and psychology. You will also be able to ask questions about university life and psychology. Your teacher will tell you when this should be. Before you take part, you will watch a presentation given by the researchers to explain what you have to do. You can ask questions if you are not sure about anything. You will then complete a simple questionnaire to tell us about yourself such as your age, gender and ethnicity. You will also be required to write down all of your GCSE grades you obtained in the last two years of secondary school. This will measure your school performance. Your height and weight will also be measured and recorded by one of the researchers. You will get some instructions about how to complete the food diary and fill in the diary to tell us everything you have eaten or drank for breakfast during the previous 7 days, including that day. Don’t worry if you don’t eat breakfast, you can just tell us. If you have any problems or queries, you can ask the researchers or your teacher at any point.

Why have I been chosen?
We are asking sixth form students aged 16-18 years to take part. You have been chosen to take part as part as part of an extracurricular trip to learn about nutrition and psychology, research designs and ethical considerations in research. You can also learn about what it’s like to study psychology at university. You will take part with your classmates.

Do I have to take part?
You do not have to take part in the survey if you do not want to, and you do not have to give a reason as to why you don’t want to take part. If you decide to take part, you can still leave the experiment at any time without giving a reason.

What will I do if I do not take part or if I can’t take part?
If you do not want to take part in this particular experiment during the Research Open Day, you can sit quietly in the test session or outside the room if you wish. If you can’t take part because you cannot fill in the questionnaire or food diary properly, you will still be able to take part if you wish but we will not include your results in our report.

What are the possible disadvantages or risks of taking part?
There are no disadvantages or risks involved in taking part in the study.

What are the advantages of taking part?
You will take part in a real life, important scientific study and have the opportunity to learn about psychological research design, ethical guidelines and nutrition and psychology in action!

Will anyone know if I have taken part.
All of the information we collect from you will kept confidential and private. Your name will not be on any of the information we collect about you so no one else will know you have taken part. All of the information we collect about you will only be used for our research. It is really important that you are honest as possible in your answers and you don’t need to worry because they are all kept private.

Remember that before you take part, you can ask the researchers any questions if you still want to know more.

9.62 Study 3: Hierarchical multiple regression analysis for total uncapped point score

Model	Explanatory Variables	R^2	ΔR^2	ANOVA	B	SE B	β
1[a]	**Habitual school-day breakfast**	0.01	0.01	$F(2, 287)=2.05$ $p=0.131$			
	Frequent (reference)						
	Occasional				-17.87	14.59	-0.08
	Rare				-23.96	12.57	-0.12
2[b]	**Habitual school-day breakfast**	0.12	0.10***	$F(7, 282)=5.42$ $p<0.001$			
	Frequent (reference)						
	Occasional				-20.79	14.01	-0.09
	Rare				-16.29	12.26	-0.08
	Ethnicity (reference = White British)				56.43	13.43	0.24***
	SES (reference = Low/middle)				-19.15	10.44	-0.10
	Sex (reference = Male)				18.55	12.52	0.08
	Age				16.92	6.87	0.14*
	BMI SDS				-6.90	4.88	-0.08
3[c]	**Habitual school-day breakfast**	0.15	0.03	$F(17, 272)=2.84$ $p<0.01$			
	Frequent (reference)						
	Occasional				-25.01	14.37	-0.11
	Rare				-12.44	12.42	-0.06
	Ethnicity (reference = White British)				56.32	13.67	0.24***
	SES (reference = Low/middle)				-20.03	10.56	-0.11
	Sex (reference = Male)				19.44	12.92	0.09
	Age				15.72	6.92	0.13*
	BMI SDS				-6.81	4.99	-0.08
	Ethnicity * Occasional breakfast				5.54	36.24	0.01
	Ethnicity * Rare breakfast				-12.68	32.14	-0.02
	SES * Occasional breakfast				-22.76	28.83	-0.05
	SES * Rare breakfast				12.86	24.41	0.03
	Sex * Occasional breakfast				-2.16	38.48	0.00
	Sex * Rare breakfast				-54.96	29.37	-0.11
	Age * Occasional breakfast				-0.21	18.97	0.00
	Age * Rare breakfast				27.92	16.11	0.10
	BMI SDS * Occasional breakfast				2.18	13.14	0.01
	BMI SDS * Rare breakfast				-13.25	11.20	-0.07

[a] Crude (unadjusted) model; [b] Adjusted model; [c] Fully adjusted model; *$p<0.05$, ** $p<0.01$, ***$p<0.001$

9.63 Study 3: Hierarchical multiple regression analysis for total capped point score

Model	Explanatory Variables	R^2	ΔR^2	ANOVA	B	SE B	β
1[a]	**Habitual school-day breakfast**	0.04	0.04**	$F(2,289) = 6.22, p<0.01$			
	Frequent (reference)						
	Occasional				0.82	5.49	0.01
	Rare				-15.67	4.73	-0.20***
2[b]	**Habitual school-day breakfast**	0.21	0.17***	$F(7,284) = 10.58, p<0.001$			
	Frequent (reference)						
	Occasional				-0.37	5.08	0.00
	Rare				-11.30	4.43	-0.14*
	Ethnicity (reference =White British)				19.05	4.87	0.21***
	SES (reference = Low/middle)				-9.09	3.78	-0.13*
	Sex (reference = Male)				11.76	4.51	0.14**
	Age				9.78	2.48	0.21***
	BMI SDS				-5.10	1.76	-0.16**
3[c]	**Habitual school-day breakfast**	0.22	0.02	$F(17,274) = 4.65, p<0.001$			
	Frequent (reference)						
	Occasional				-1.54	5.24	-0.02
	Rare				-10.25	4.53	-0.13*
	Ethnicity (reference = White British)				19.69	4.99	0.21***
	SES (reference = Low/middle)				-9.28	3.85	-0.13*
	Sex (reference = Male)				11.83	4.70	0.14*
	Age				9.64	2.52	0.21***
	BMI SDS				-4.78	1.81	-0.15**
	Ethnicity * Occasional breakfast				1.72	13.23	0.01
	Ethnicity * Rare breakfast				7.47	11.73	0.04
	SES * Occasional breakfast				-1.27	10.52	-0.01
	SES * Rare breakfast				7.00	8.90	0.04
	Sex * Occasional breakfast				7.39	14.03	0.03
	Sex * Rare breakfast				-8.27	10.69	-0.04
	Age * Occasional breakfast				3.09	6.92	0.03
	Age * Rare breakfast				6.22	5.87	0.06
	BMI SDS * Occasional breakfast				0.55	4.79	0.01
	BMI SDS * Rare breakfast				-5.66	4.07	-0.08

[a] Crude (unadjusted) model; [b] Adjusted model; [c] Fully adjusted model; *$p<0.05$, ** $p<0.01$, ***$p<0.001$

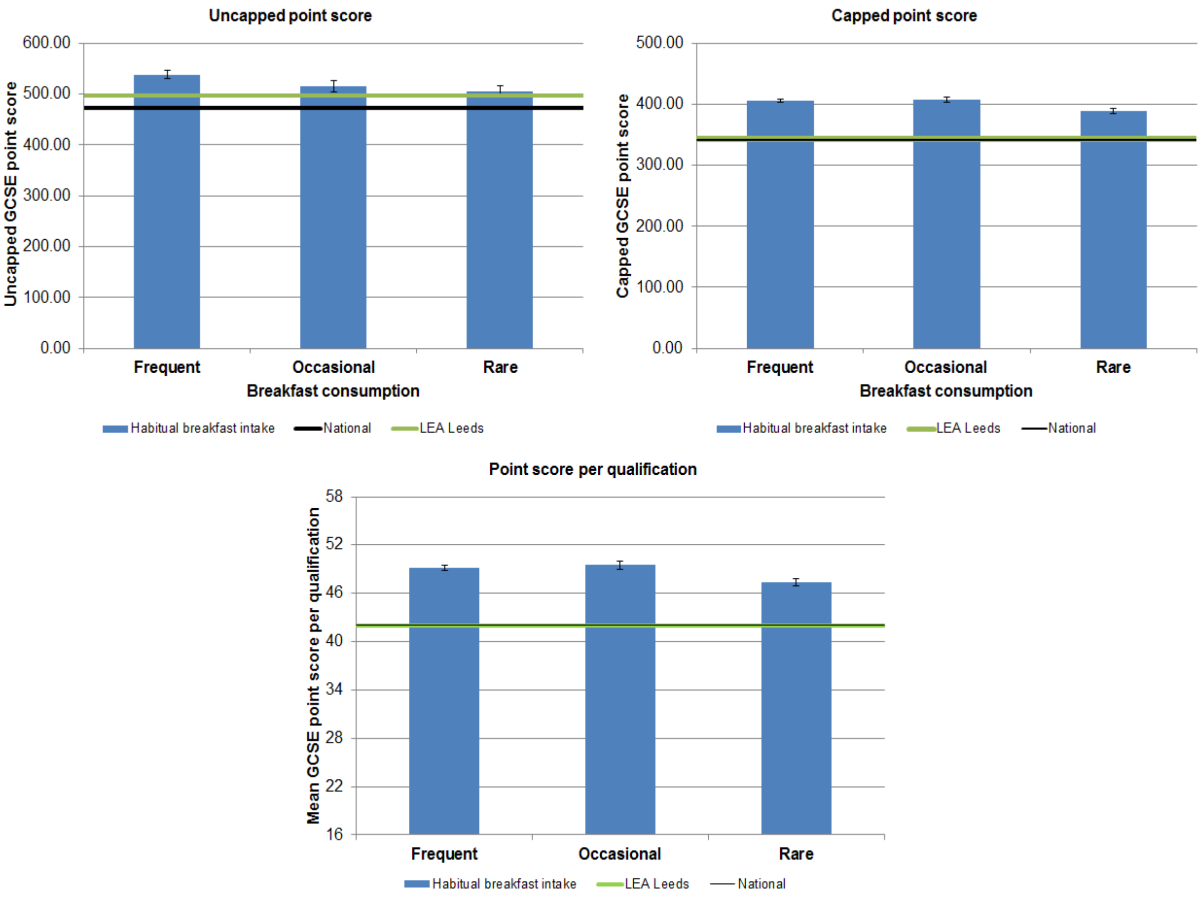
9.64 Study 3: Hierarchical multiple regression analysis for mean point score per qualification

Model	Explanatory Variables	R^2	ΔR^2	ANOVA	B	SE B	β
1[a]	**Habitual school-day breakfast**	0.05	0.05***	$F(2,291)=7.04$, $p<0.001$			
	Frequent (reference)						
	Occasional				0.36	0.61	0.04
	Rare				-1.75	0.52	-0.20***
2[b]	**Habitual school-day breakfast**	0.24	0.19***	$F(2,286)=12.76$, $p<0.001$			
	Frequent (reference)						
	Occasional				0.21	0.55	0.02
	Rare				-1.25	0.48	-0.14**
	Ethnicity (reference =White British)				2.18	0.53	0.21**
	SES (reference = Low/middle)				-1.05	0.41	-0.13*
	Sex (reference = Male)				1.51	0.49	0.16**
	Age				1.11	0.27	0.22***
	BMI SDS				-0.67	0.19	-0.18**
3[c]	**Habitual school-day breakfast**	0.25	0.01	$F(17,276)=5.41$, $p<0.001$			
	Frequent (reference)						
	Occasional				0.09	0.57	0.01
	Rare				-1.20	0.49	-0.14*
	Ethnicity (reference =White British)				2.31	0.54	0.23***
	SES (reference = Low/middle)				-1.08	0.42	-0.14*
	Sex (reference = Male)				1.55	0.51	0.17**
	Age				1.12	0.28	0.22***
	BMI SDS				-0.65	0.20	-0.18***
	Ethnicity * Occasional breakfast				0.54	1.45	0.02
	Ethnicity * Rare breakfast				1.02	1.28	0.04
	SES * Occasional breakfast				0.39	1.15	0.02
	SES * Rare breakfast				0.79	0.97	0.05
	Sex * Occasional breakfast				1.79	1.53	0.07
	Sex * Rare breakfast				-0.22	1.17	-0.01
	Age * Occasional breakfast				0.37	0.76	0.03
	Age * Rare breakfast				0.19	0.64	0.02
	BMI SDS * Occasional breakfast				0.02	0.52	0.00
	BMI SDS * Rare breakfast				-0.43	0.44	-0.06

[a] Crude (unadjusted) model; [b] Adjusted model; [c] Fully adjusted model; *$p<0.05$, ** $p<0.01$, ***$p<0.001$

9.65 Study 3: Plots of raw data

Figure 9.10: GCSE point scores plotted according to habitual school-day breakfast consumption for (a) uncapped (b) capped and (c) point score per qualification



9.66 Study 3: Correlations and inter-correlations between predictor variables and aggregate GCSE point scores

Variable	Total uncapped point score	Total capped point score	Point score per qualification
Ethnicity (reference = White British)	0.23***	0.20***	0.21***
SES (reference = Low/middle)	-0.13	-0.17***	-0.18***
Sex (reference = Male)	0.09	0.17***	0.19***
Age	0.16**	0.25***	0.26***
BMI SDS	-0.13*	-0.23***	-0.26***
Occasional breakfast (reference = Frequent)	-0.05	0.07	0.10
Rare breakfast (reference = Frequent)	-0.09	-0.20***	-0.21***

*p<0.01, **p<0.01;*** p<0.001
Values for Pearson's product moment correlation

	Variable	1	2	3	4	5	6	7
1	Ethnicity	-						
2	SES	0.01	-					
3	Sex	-0.04	-0.10*	-				
4	Age	-0.05	-0.09	0.01	-			
5	BMI SDS	-0.05	0.07	-0.13*	-0.09	-		
6	Occasional breakfast	0.05	-0.05	0.07	0.00	-0.01	-	
7	Rare breakfast	-0.02	0.02	0.00	-0.17***	0.12*	-0.30***	-

*p<0.01,**p<0.01;*** p<0.001
Values for Pearson's product moment correlation

9.67 Study 3: Ordinal logistic regression for English grade

Model	Explanatory variables	B	SE	OR	95% CI OR	
					Lower	Upper
1[a]	**School-day breakfast** : Frequent (reference)			1.00		
	Occasional	-0.16	.29	0.85	0.48	1.52
	Rare	-0.47	.25	0.63	0.38	1.03
2[b]	**School-day breakfast** : Frequent (reference)			1.00		
	Occasional	-0.32	0.30	0.73	0.41	1.31
	Rare	-0.55*	0.26	0.57	0.35	0.95
	Ethnicity: White British (reference)			1.00		
	Any other	0.67*	0.29	1.95	1.11	3.45
	SES: Low/middle (reference)			1.00		
	High	-0.53*	0.23	0.59	0.38	0.92
	Sex : Male (reference)			1.00		
	Female	1.05***	0.27	2.85	1.69	4.81
	Age	-0.17	0.14	0.84	0.63	1.12
	BMI SDS	-0.01	0.10	0.99	0.81	1.21
3[c]	**School-day breakfast** : Frequent (reference)			1.00		
	Occasional	-0.56	0.83	0.57	0.11	2.91
	Rare	-0.71	0.63	0.49	0.14	1.69
	Ethnicity: White British (reference)			1.00		
	Any other	0.46	0.40	1.58	0.72	3.48
	SES: Low/middle (reference)			1.00		
	High	-0.69*	0.32	0.50	0.27	0.94
	Sex : Male (reference)			1.00		
	Female	1.14***	0.35	3.12	1.56	6.25
	Age	0.02	0.20	1.02	0.68	1.52
	BMI SDS	-0.05	0.15	0.95	0.71	1.28
	Interaction terms					
	Ethnicity * Occasional breakfast	0.29	0.78	1.34	0.29	6.15
	Ethnicity * Rare breakfast	0.75	0.69	2.11	0.55	8.16
	SES * Occasional breakfast	0.02	0.61	1.02	0.31	3.39
	SES * Rare breakfast	0.47	0.53	1.61	0.57	4.54
	Sex * Occasional breakfast	0.22	0.81	1.25	0.25	6.15
	Sex * Rare breakfast	-0.32	0.60	0.72	0.22	2.35
	Age * Occasional breakfast	-0.43	0.41	0.65	0.29	1.45
	Age * Rare breakfast	-0.32	0.32	0.72	0.38	1.37
	BMI SDS* Occasional breakfast	0.13	0.28	1.14	0.65	1.98
	BMI SDS* Rare breakfast	0.05	0.24	1.06	0.66	1.68

[a] Crude (unadjusted) model; Nagelkerke pseudo $R^2 = 0.01$; [b] Adjusted model; Nagelkerke pseudo $R^2 = 0.11$; [c] Fully adjusted model; Nagelkerke pseudo $R^2 = 0.12$; **p*<0.05, ** *p*<0.01, ****p*<0.001

9.68 Study 3: Ordinal logistic regression for Mathematics grade

Model	Explanatory variables	B	SE	OR	95% CI OR Lower	Upper
1[a]	**School-day breakfast** : Frequent (reference)			1.00		
	Occasional	0.13	0.29	1.14	0.65	2.02
	Rare	-0.43	0.25	0.65	0.40	1.06
2[b]	**School-day breakfast** : Frequent (reference)			1.00		
	Occasional	0.03	0.29	1.04	0.58	1.84
	Rare	-0.46	0.25	0.63	0.39	1.03
	Ethnicity: White British (reference)			1.00		
	Any other	0.92***	0.29	2.50	1.42	4.40
	SES: Low/middle (reference)			1.00		
	High	-0.68***	0.22	0.51	0.33	0.79
	Sex : Male (reference)			1.00		
	Female	0.21	0.26	1.23	0.74	2.04
	Age	-0.15	0.14	0.86	0.65	1.13
	BMI SDS	-0.17	0.10	0.84	0.69	1.03
3[c]	**School-day breakfast** : Frequent (reference)			1.00		
	Occasional	-0.31	0.83	0.74	0.15	3.72
	Rare	-1.36*	0.63	0.26	0.07	0.88
	Ethnicity: White British (reference)			1.00		
	Any other	0.90*	0.40	2.45	1.12	5.39
	SES: Low/middle (reference)			1.00		
	High	-1.14***	0.32	0.32	0.17	0.60
	Sex : Male (reference)			1.00		
	Female	0.14	0.35	1.16	0.59	2.27
	Age	-0.02	0.20	0.98	0.66	1.46
	BMI SDS	-0.25	0.15	0.78	0.58	1.05
	Interaction terms					
	Ethnicity * Occasional breakfast	0.10	0.77	1.10	0.24	5.01
	Ethnicity * Rare breakfast	0.39	0.68	1.47	0.39	5.60
	SES * Occasional breakfast	0.21	0.61	1.24	0.38	4.06
	SES * Rare breakfast	1.38**	0.53	3.98	1.42	11.16
	Sex* Occasional breakfast	0.23	0.81	1.26	0.26	6.19
	Sex* Rare breakfast	0.08	0.59	1.09	0.34	3.48
	Age * Occasional breakfast	-0.07	0.40	0.93	0.42	2.06
	Age * Rare breakfast	-0.37	0.32	0.69	0.37	1.30
	BMI SDS* Occasional breakfast	-0.16	0.28	0.85	0.49	1.47
	BMI SDS* Rare breakfast	0.37	0.23	1.45	0.91	2.29

[a] Crude (unadjusted) model; Nagelkerke pseudo $R^2 = 0.01$; [b] Adjusted model; Nagelkerke pseudo $R^2 = 0.08$; [c] Fully adjusted model; Nagelkerke pseudo $R^2 = 0.10$; *$p<0.05$, ** $p<0.01$, ***$p<0.001$

9.69 Study 3: Plots of raw data

Figure 9.11: Percentage of pupils achieving grades A*-D plotted according to habitual school-day breakfast consumption for (a) English and (b) Mathematics.