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Breakfast consumption and cognitive function in adolescent schoolchildren

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1 **Abstract**

2 COOPER, S. B., S. BANDELOW AND M. E. NEVILL. Breakfast consumption and cognitive
3 function in adolescent schoolchildren. *PHYSIOL BEHAV* xx (x), xxx-xxx, 2010.

4 This study examined the effects of breakfast consumption on cognitive function, mood and blood
5 glucose concentration in adolescent schoolchildren.

6 With the institutions ethical advisory committee approval, 96 adolescents (12 to 15 years old)
7 completed two randomly assigned trials (one following breakfast consumption and one following
8 breakfast omission), scheduled 7 days apart. Cognitive function tests (visual search test, Stroop test
9 and Sternberg paradigm), a mood questionnaire and a finger prick blood sample (in a subgroup of 60
10 participants) were completed immediately following breakfast and 120 min after the baseline
11 measures.

12 Following breakfast consumption, accuracy on the more complex level of the visual search test was
13 higher than following breakfast omission ($p = 0.021$). Similarly, accuracy on the Stroop test was
14 better maintained across the morning following breakfast consumption when compared to breakfast
15 omission ($p = 0.022$). Furthermore, responses on the Sternberg paradigm were quicker later in the
16 morning following breakfast consumption, particularly on the more complex levels ($p = 0.012$).
17 Breakfast consumption also produced higher self-report energy and fullness, lower self-report
18 tiredness and hunger and higher blood glucose concentrations (all $p < 0.0005$).

19 Overall, the findings of the present study suggest that breakfast consumption enhances cognitive
20 function in an adolescent population when compared to breakfast omission.

21

22 **Keywords: BREAKFAST, ADOLESCENTS, COGNITIVE FUNCTION, MOOD**

23

24

1 **1. Introduction**

2 It is often stated that breakfast is the most important meal of the day. However, young people
3 are more likely to skip breakfast than any other meal [1], with only just over 50% of young people
4 aged 6 to 11 regularly eating breakfast [2]. Furthermore, breakfast skipping in young people and
5 adolescents is reported to be increasing in prevalence [3]. This is of particular concern because
6 breakfast consumption has a number of positive effects in young people including; improving dietary
7 adequacy, a decreased risk of being overweight or obese and improved cognitive function [4]. The
8 present study focuses on the effects of breakfast consumption and omission on cognitive function in
9 adolescent schoolchildren.

10 Although numerous studies have been conducted in younger children (typically 8-11 years
11 old) [2,5,6], only one previous study has examined the effects of breakfast consumption on cognitive
12 function in adolescents [7]. Based on a review of the literature relating to young people, but not
13 specifically adolescents, it has been concluded that breakfast consumption has a beneficial effect on
14 cognitive function when compared to breakfast omission [8]. However, other authors have suggested
15 there is ambiguity in the evidence regarding the effect of breakfast consumption on cognitive function
16 in young people, possibly stemming from the wide range of research designs employed, the varied
17 nature of the breakfasts provided and the age of the participants, thus making comparisons between
18 studies difficult [9].

19 The one study to date to examine the effects of breakfast consumption on cognitive function
20 in an adolescent population recruited 104 13-20 year old males and females, who either consumed a
21 standardised breakfast or omitted breakfast [7]. Whilst breakfast did not affect attention, it did have a
22 beneficial effect on the accuracy of visuo-spatial memory. Interestingly, there were also a number of
23 positive effects on mood following breakfast consumption, such as increases in self-report awareness
24 and males also reported feeling more positive [7]. However, the cognitive tests were conducted using
25 paper and pencil tests assessing memory and attention, thus limiting the analysis undertaken and the
26 elements of cognitive function examined. Furthermore, the use of a standardised breakfast may have

1 resulted in different effects between participants due to differences in palatability of the meal, food
2 preferences and in the nutritional content of the breakfasts provided, relative to body mass.

3 Despite the lack of studies conducted in adolescent populations, it is suggested adolescents
4 are particularly worthy of study for four main reasons. First, adolescents are undergoing rapid growth
5 and changes in metabolism due to puberty, thus their responses may be different to those of younger
6 children [10,11]. Second, the academic work completed by adolescents is of a greater complexity than
7 in younger children, thus the additional academic stress could compound any nutritional effects on
8 cognition [10]. Evidence also suggests that adolescents are a population more likely to skip breakfast
9 due to peer and media pressure to maintain a slender body [11]. Finally, it has also been reported that
10 young children (aged 3 – 11 years) have a larger brain relative to their body weight and a 50% greater
11 metabolic rate per unit of brain weight, thus the responses between adolescents and younger children
12 are likely to be different [8]. Therefore, adolescents require study in the field as their responses are
13 likely to be different to those of both adults and younger children.

14 Whilst some of the literature in adult populations has attempted to explain mechanistically the
15 improvement in cognitive function observed after breakfast consumption, such work has not been
16 conducted in children or adolescents. Glucose is the only fuel that can be used by the brain and thus is
17 crucial for cognitive function. Research in adults indeed suggests that higher blood glucose
18 concentrations improve memory [12] and performance on the Stroop test [13], but the effects of
19 breakfast consumption on blood glucose concentrations and subsequent cognitive function in an
20 adolescent population have not been examined.

21 Furthermore, a recent review indicates that there is a need for more studies which examine the
22 effects of breakfast consumption across a range of dimensions of cognitive function, particularly in an
23 adolescent population [8]. Therefore, the aim of the present study is to examine the effects of an ad
24 libitum breakfast on the cognitive function, mood and blood glucose concentration of adolescents (12-
25 15 years old) using a randomised crossover design. The use of an ad libitum breakfast should allow
26 participants to consume a breakfast similar to their habitual breakfast intake, thus allowing the

1 findings to be applied to everyday settings. The study will employ a battery of cognitive function tests
2 across a wider range of dimensions than in previous studies (assessing visual perception, attention and
3 working memory) and furthermore, by measuring blood glucose concentration, an insight into
4 potential mechanisms for an effect of breakfast consumption on cognitive function in an adolescent
5 population may be possible.

6

7 **2. Methodology**

8 *2.1: Participant Characteristics*

9 Sixty children in year 8 (30 male and 30 female) and thirty-six children in year 10 (6 male
10 and 30 female) were recruited to participate in the study. Of the ninety-six participants, fifty-three
11 (55%) reported consuming breakfast every day, thirty-four (35%) reported consuming breakfast
12 regularly (between one and six times per week) and 9 (10%) reported that typically they did not
13 consume breakfast. During familiarisation, simple measures of height, body mass and waist
14 circumference were taken. Height was measured using a Leicester Height Measure (Seca, Hamburg,
15 Germany), accurate to 0.1 cm. Body mass was measured using a Seca 770 digital scale (Seca,
16 Hamburg, Germany), accurate to 0.1 kg. These measures allowed the determination of Body Mass
17 Index (BMI), calculated by dividing body mass [kg] by the square of the height [m^2]. Waist
18 circumference was measured at the narrowest part of the torso between the xiphoid process of the
19 sternum and the iliac crest, to the nearest 0.1 cm. For descriptive purposes, the anthropometric
20 characteristics of the participants can be seen in table 2.1.

21 (*Insert table 2.1 here*)

22 *2.2: Study Design*

23 The study was approved by Loughborough University Ethical Advisory Committee.
24 Participants were recruited through their schools and in accordance with the ethical guidelines of the
25 British Education Research Association for school-based research, school-level consent was obtained

1 from head teachers. In addition, written parental informed consent was obtained and a health screen
2 questionnaire completed to ensure all participants were in good health. To ensure the children’s
3 willingness to participate, on each testing day they indicated assent by signing a willingness to
4 participate form. Each participant undertook a familiarisation session which preceded the first of the
5 two experimental trials seven days. During familiarisation, the protocol of the study was explained to
6 participants and they were familiarised with the methods involved.

7 The study employed a randomised crossover design, with participants blind until arrival at
8 school on their first day of testing. The experimental trials consisted of one trial where breakfast was
9 provided upon arrival at school (breakfast trial) and one trial where no breakfast was provided until
10 completion of the protocol (no breakfast trial), thus participants acted as their own controls. Trials
11 were scheduled seven days apart and participants reported to school at the normal time, having
12 followed an overnight fast from 10 pm the evening before the trial. The experimental protocol is
13 shown in figure 2.1.

14 *(Insert figure 2.1 here)*

15 Participants were recruited from five local schools. For descriptive purposes, the Index of
16 Multiple Deprivation (an indicator of socio economic status) for each of the schools can be seen in
17 table 2.2. Upon arrival at school participants were provided with breakfast if completing the breakfast
18 trial. Participants were given 15 minutes to consume breakfast. After breakfast (or after 15 minutes
19 resting on the no breakfast trial), participants completed the mood questionnaire and cognitive
20 function tests. Following the tests, the subgroup who were participating in the finger prick blood
21 sample had this measure taken. Participants then returned to normal lessons for approximately 90
22 minutes, after which they reported back to investigators and repeated the mood questionnaire and
23 cognitive function tests (120 minutes after baseline measures), along with the finger prick blood
24 sample (if appropriate). The use of a 120 minute interval between testing sessions is based upon
25 previous findings which indicate this is a sufficient period for the benefits of breakfast consumption to

1 become apparent in young people [14, 15, 16]. All participants were then fed upon completion of the
2 trial.

3 *(Insert table 2.2 here)*

4 5 2.3: Breakfast

6 A range of breakfast foods were provided for participants, from which they chose ‘ad
7 libitum’. Broadly, the breakfast could be classified into; cereals (Cornflakes, Coco Pops, Frosties,
8 Bran Flakes, Muesli and Weetabix, all available with semi-skimmed milk), toast (a choice of white or
9 brown bread along with butter, margarine and strawberry, blackcurrant, raspberry and apricot jam),
10 fruit (apples, bananas and raisins), yoghurts (strawberry and raspberry) and fruit juices (orange, apple
11 and cranberry). The quantity of food taken by each participant was recorded and any leftovers were
12 weighed using a Salter 1029 WHDRT scale (Salter, Hamburg, Germany) to allow determination of
13 the breakfast consumed by each participant.

14 The breakfast consumed was analysed for total energy content (kcal) and for the amount of
15 carbohydrate (g), protein (g) and fat (g). The energy content and composition of the breakfast
16 consumed is shown in table 2.3.

17 *(Insert table 2.3 here)*

18 2.4: Mood Questionnaire

19 The mood questionnaire was a modified version of the ‘Activation-Deactivation Check List’
20 (AD ACL) short form [17]. The 20 item questionnaire was split into four components of mood;
21 energy, tiredness, tension and calmness, each having five corresponding adjectives on the
22 questionnaire. The original AD ACL short form was piloted in an adolescent population and
23 subsequently five of the adjectives were changed to ensure suitability for the study population. The
24 adjectives used and their corresponding components of mood were; energy: active, energetic, alert,

1 lively and wide-awake; tiredness: sleepy, tired, drowsy, exhausted and fatigued; tension: anxious,
2 nervous, fearful, worried and tense; and calmness: restful, calm, at-rest, laid-back and quiet. The
3 scoring system was also slightly modified, with participants asked to respond on a scale of 1 to 5
4 regarding how they felt at that moment in time (where 1: definitely do not feel, 3: unsure, 5: definitely
5 feel). The scores on the adjectives for each component of mood were summed, providing an overall
6 score for each component.

7 In addition, two visual analogue (VAS) scales were used to provide a measure of participants'
8 hunger and fullness. The VAS scales consisted of a 10 cm line from one extreme to the other (i.e. not
9 at all hungry to very hungry and not at all full to very full), with participants indicating the point on
10 the line that applied to them at that moment in time. Both the AD ACL and the VAS scales allow
11 comparisons between time points.

12

13 *2.5: Cognitive Function Tests*

14 The battery of cognitive function tests was administered via a laptop computer and lasted
15 approximately 15 minutes. The battery of tests included a test of visual search, a Stroop test and the
16 Sternberg Paradigm. Written instructions appeared on the screen at the start of each test, which were
17 repeated verbally by an investigator. Each cognitive function test was preceded by 3-6 practice
18 stimuli, where feedback was provided regarding whether the participants' response was correct or not.
19 This allowed the participants to re-familiarise themselves with each of the tests (negating any learning
20 effects) and fully focus on the task in hand. Data from these practice stimuli was discarded and once
21 the test started no feedback was provided. The cognitive function tests were found to be suitable for
22 the study population during familiarisation and were administered in the following order:

23

24 *2.5.1: Visual Search Test*

1 This test consisted of two levels, each consisting of 21 stimuli. On each level, participants
2 were instructed to respond as quickly as possible to the stimuli by pressing the space bar on the
3 keyboard. In both levels there were 21 different locations for the stimuli, with the order of the
4 locations randomised, thus allowing a standardised test.

5 The stimuli in the baseline level were triangles drawn in solid green lines on a black
6 background, providing a measure of simple visuo-motor speed. The complex level had random green
7 dots covering the screen, which were redrawn every 250 ms to induce the visual effect of a flickering
8 background, acting as a background distractor. The target triangles were drawn with a few dots on
9 each line and the density of these dots increased until the participant responded (the lines become
10 denser until a response is registered). This provided a measure of complex visual processing. The
11 variables of interest on both levels were the response time (RT, in ms) and the proportion of correct
12 responses made.

13

14 *2.5.2: Stroop Test*

15 The Stroop test measures the sensitivity to interference and the ability to suppress an
16 automated response (i.e. the time required to identify the colour rather than read the word) [18] and is
17 a classical measure of frontal lobe function [19]. The Stroop test consisted of two levels. Both levels
18 involved the test word being placed in the centre of the screen, with the target and distractor presented
19 randomly on the right or left of the test word. The target position was counterbalanced for the left and
20 right side within each test level. The participant was asked to respond as quickly as possible, using the
21 left and right arrow keys, to identify the position of the target word.

22 The baseline level contained 20 stimuli, where the test word was printed in white on the
23 centre of the screen and the participant had to select the target word, from the target and distractor,
24 which were also printed in white. The colour-interference level contained 40 stimuli and involved the
25 participant selecting the colour the test word was written in, rather than the actual word (which was an
26 incongruent colour), again using the right and left arrow keys to identify the target. The choices

1 remained on the screen until the participant responded. The variables of interest were the RT of
2 correct responses (in ms) and the proportion of correct responses made.

3

4 *2.5.3: Sternberg Paradigm*

5 The Sternberg Paradigm [20] is a test of working memory and has three levels. Each level
6 used a different working memory load; one, three or five items. On the baseline (number) level, the
7 target was always the number '3'. This level contained 16 stimuli and provides a measure of basic
8 information processing speed. The three- and five-item levels had target lists of three and five letters
9 respectively, each containing 32 stimuli.

10 At the start of each level, the target items were displayed together with instructions to press
11 the right arrow key if the stimulus was a target item and the left arrow key otherwise. The correct
12 responses were counterbalanced on each level between the right and left arrow keys. The choice
13 stimuli were presented on the centre of the screen with an inter-stimulus interval (ISI) of 1 second,
14 during which the screen was blank. The choices remained on the screen until the participant
15 responded. The variables of interest were the RT (in ms) and the proportion of correct responses
16 made.

17

18 *2.6: Finger Prick Blood Sample*

19 In a subgroup of 30 year 8 students (14 male and 16 female) and 30 year 10 students (4 male
20 and 26 female), a finger prick blood sample was taken and analysed for glucose concentration.
21 Separate parental consent was obtained prior to participation in the finger prick blood sample test. An
22 Accu-chek Safe-T-pro plus single use lancet (Roche, Mannheim, Germany) was used and the test strip
23 was placed into an Accutrend Plus GCTL analyser (Roche, Mannheim, Germany). The analyser was
24 calibrated using the Accutrend control solutions and was accurate to 0.1 mmol.l^{-1} in the range of 1.1 to
25 33.3 mmol.l^{-1} .

1

2 *2.7: Statistical Analysis*

3 The mood and blood glucose data were analysed using SPSS (Version 16, SPSS Inc.,
4 Chicago, IL, USA) via two-way Analysis of Variance (ANOVA) for repeated measures (trial by
5 session time). Data are reported as mean \pm standard deviation.

6 The cognitive function data were analysed using R (www.r-project.org, version 2.9.1). Linear
7 mixed effects models were used to analyse the data, corrected for repeated measures with a random
8 effect for each participant. Response time analyses were performed using the nlme package and
9 accuracy analyses were performed with the lme4 package with a binomial outcome data distribution.
10 All analyses were conducted using a trial by session time by test level interaction, with the year group
11 of the participants included as a covariate. For all analysis, significance was set as $p < 0.05$.

12

13 **3. Results**

14 For each dimension of mood and cognitive function, there was no effect of the year group of
15 the participants or the trial order on participants' responses (all $p > 0.05$); thus all participants'
16 responses were analysed together. Interestingly, despite differences in the schools' indices of multiple
17 deprivation, the responses of participants from each of the schools was not significantly different (all
18 $p > 0.05$); thus all participants responses were analysed together. Furthermore, order effects were
19 examined and were non-significant for each dimension of mood and cognitive function (all $p > 0.05$).

20

21 *3.1: Mood*

22 *3.1.1: Energy*

23 Analysis revealed a main effect of trial ($F(1,94) = 82.8, p < 0.0005$), with self-report energy
24 significantly higher on the breakfast trial compared to the no breakfast trial (18.1 vs. 14.1

1 respectively). However, there was no main effect of session time ($p = 0.097$) and there was no
2 difference in the change in self-report energy across the morning on the breakfast and no breakfast
3 trials (trial by session time interaction, $p = 0.097$).

4

5 *3.1.2: Tiredness*

6 Analysis revealed a main effect of trial ($F(1,95) = 41.8, p < 0.0005$), with self-report tiredness
7 higher on the no breakfast trial compared to the breakfast trial (13.7 vs. 10.8 respectively). There was
8 also a main effect of session time ($F(1,95) = 26.1, p < 0.0005$) with self-report tiredness higher early
9 in the morning when compared to the later morning session (13.0 vs. 11.5, respectively). However,
10 there was no difference in the change in self-report tiredness across the morning between the breakfast
11 and no breakfast trials (trial by session time interaction, $p = 0.076$).

12

13 *3.1.3: Tension*

14 Self-report tension was not different between the breakfast and no breakfast trials (main effect
15 of trial, $p = 0.100$), nor between the early and late morning sessions (main effect of session time, $p =$
16 0.123). Furthermore, the pattern of change in self-report tension across the morning was not different
17 between the breakfast and no breakfast trials (trial by session time interaction, $p = 0.278$).

18

19 *3.1.4: Calmness*

20 There was no difference in self-report calmness between the breakfast and no breakfast trials
21 (main effect of trial, $p = 0.215$). However, there was a main effect of session time ($F(1,95) = 24.2, p <$
22 0.0005) with participants reporting a greater level of calmness early in the morning, compared to later
23 in the morning (15.9 vs. 14.6 respectively). The pattern of change in self-report calmness across the

1 morning was similar between the breakfast and no breakfast trials (trial by session time interaction, p
2 = 0.397).

3

4 3.1.5: Hunger

5 Analysis revealed a main effect of trial on self-report hunger ($F(1,94) = 240.5, p < 0.0005$).

6 As expected, self-report hunger was higher on the no breakfast trial compared to the breakfast trial

7 (8.0 vs. 3.6 respectively). There was also a main effect of session time ($F(1,94) = 114.4, p < 0.0005$),

8 with self-report hunger higher later in the morning when compared to the early morning session (6.7

9 vs. 4.8 respectively). Furthermore, self-report hunger increased on both the breakfast and no breakfast

10 trials, though the increase was greater on the breakfast trial (trial by session time interaction, $F(1,94) =$

11 33.8, $p < 0.0005$, figure 3.1).

12 *(Insert figure 3.1 here)*

13 3.1.6: Fullness

14 As expected, the results from the fullness VAS scale show the opposite effects to that of

15 hunger. Analysis revealed a main effect of trial ($F(1,94) = 290.3, p < 0.0005$) with self-report fullness

16 higher on the breakfast trial when compared to the no breakfast trial (6.0 vs. 1.6 respectively). There

17 was also a significant main effect of session time ($F(1,94) = 112.1, p < 0.0005$) with higher self-report

18 fullness early in the morning compared to later in the morning (4.5 vs. 3.0 respectively). Furthermore,

19 self-report fullness decreased across the morning on both the breakfast and no breakfast trials, though

20 the decrease was greater on the breakfast trial (trial by session time interaction, $F(1,94) = 36.4, p <$

21 0.0005, figure 3.2).

22 *(Insert figure 3.2 here)*

23 3.2: Cognitive Function Tests

1 For all timed cognitive tests the response times were first log-transformed to normalise the
2 distributions, which exhibited the right-hand skew typical of human response times. Minimum
3 response time cut-offs were then chosen based on what may reasonably be expected to be the fastest
4 possible human response to the given stimuli (200 - 300ms, depending on task complexity) to exclude
5 unreasonably fast responses, which relate to response key presses before stimuli have even been
6 perceived. Maximum response time cut-offs were determined so as to remove unreasonably long
7 right-hand tails for a normal distribution, corresponding to five standard deviations for each test and
8 test level. This procedure resulted in the removal of less than 2% of responses for all tests (1.7% for
9 Sternberg, 1% for the visual search and 0.1% for the Stroop test) and preserves more of the data than
10 strict standard deviation-based cut-offs, whilst at the same time approximating normally distributed
11 response time outcomes as closely as possible.

12

13 *3.2.1: Visual Search Test*

14 *Response Times:* Only response times of correct responses were used for analysis. Using the methods
15 previously described, responses faster than 300 ms for both test levels and slower than 1500 ms for
16 the baseline level and 10000 ms for the complex level were removed.

17 There was no main effect of breakfast on response times on the visual search test (main effect
18 of trial, $p = 0.792$). As expected, students performed quicker on the baseline level than the complex
19 level, on average by 1463 ms (main effect of test level, $t(1,15507) = 55.1$, $p < 0.0005$). However,
20 there was no difference in response times between the early and late morning sessions (main effect of
21 session time, $p = 0.134$).

22 The pattern of change of response times across the morning was not different between trials
23 (trial by session time interaction, $p = 0.268$) and the effects of breakfast were not different between
24 test levels (trial by test level interaction, $p = 0.173$). There was also no difference in the response
25 times between trials across the morning on either test level (3-way trial by session time by test level
26 interaction, $p = 0.766$).

1

2 *Accuracy:* There was no main effect of breakfast on accuracy on the visual search test (main effect of
3 trial, $p = 0.196$), however participants achieved more correct responses early in the morning compared
4 to later in the morning (main effect of session time, effect size = 0.010, $z(1,16427) = -2.0$, $p = 0.050$).
5 However, there was no main effect of test level on the proportion of correct responses (main effect of
6 test level, $p = 0.496$).

7 Accuracy on the baseline level of the visual search test was similar with and without
8 breakfast, but accuracy on the complex level was greater following breakfast consumption (trial by
9 test level interaction, effect size = -0.029, $z(1,16427) = -2.7$, $p = 0.007$). However, accuracy across the
10 morning was not affected differently by breakfast consumption and breakfast omission (trial by
11 session time interaction, $p = 0.505$). The results also suggest that accuracy on the baseline level was
12 not different between the trials or across session times (figure 3.3a). However, accuracy on the
13 complex level on the early morning test on the no breakfast trial was lower than at any other time
14 point on either trial (trial by test level by session time interaction, effect size = 0.032, $z(1,16427) =$
15 2.3, $p = 0.021$, figure 3.3b).

16 *(Insert figure 3.3 here)*

17

18 3.2.2: Stroop Test

19 *Response Times:* Incorrect responses were filtered out for the analysis of response times. Using the
20 methods previously described, responses quicker than 250 ms on both test levels and responses slower
21 than 2500 ms on the baseline level and slower than 4000 ms on the complex level were removed.

22 There was no main effect of breakfast on response times on the Stroop test (main effect of
23 trial, $p = 0.558$). However, students responded on average 11 ms faster later in the morning compared
24 to earlier in the morning (main effect of session time, $t(1,21630) = -2.8$, $p = 0.005$) and as expected,

1 students responded faster on the baseline than the complex level, on average by 347 ms (main effect
2 of test level, $t(1,21630) = 17.2, p < 0.0005$).

3 Response times across the morning were not different when breakfast was or was not
4 consumed (trial by session time interaction, $p = 0.249$). Furthermore, there were no differences when
5 breakfast was or was not consumed between test levels (trial by test level interaction, $p = 0.560$).
6 There was also no difference in the response times between trials across the morning on either test
7 level (3-way trial by session time by test level interaction, $p = 0.210$).

8

9 *Accuracy:* Students achieved more correct responses on the breakfast trial compared to the no
10 breakfast trial (main effect of trial, effect size = 0.010, $z(1,22973) = 2.0, p = 0.041$). However, there
11 was no difference between the proportion of correct responses made early and later in the morning
12 (main effect of session time, $p = 0.923$). As expected, students achieved more correct responses on the
13 baseline level than the complex level (main effect of test level, effect size = 0.024, $z(1,22973) = -4.2,$
14 $p < 0.0005$).

15 Accuracy on the no breakfast trial decreased across the morning whereas on the breakfast trial
16 accuracy was better maintained across the morning (trial by session time interaction, effect size =
17 0.016, $z(1,22973) = -2.3, p = 0.022$, figure 3.4). Accuracy was similar on the baseline level on both
18 the breakfast and no breakfast trials, but accuracy on the complex level tended to be lower on the no
19 breakfast trial compared to the breakfast trial. However, this did not quite reach statistical significance
20 (trial by test level interaction, effect size = 0.011, $z(1,22973) = -2.0, p = 0.051$). There was also no
21 significant difference in accuracy between trials across the morning between test levels (3-way trial
22 by session time by test level interaction, $p = 0.260$).

23 *(Insert figure 3.4 here)*

24

25 *3.2.3: Sternberg Paradigm*

1 *Response Times:* Only response times of correct responses were used for analysis. A minimum
2 response time cut-off of 200 ms and a maximum response time cut off of 2000 ms was set for all
3 levels using the methods previously described.

4 There was a tendency for response times to be on average 53 ms quicker on the breakfast
5 trial, though this did not reach statistical significance (main effect of trial, $t(1,28225) = 2.0$, $p =$
6 0.051). There was no difference in response times between early and later in the morning (main effect
7 of session time, $p = 0.782$) but as expected, response times were slower with greater memory loads
8 (main effect of memory load, $t(1,28225) = 17.8$, $p < 0.0005$).

9 On the number level, response times were quicker on the breakfast trial compared to the no
10 breakfast trial. However, on the 3 letter level there was no difference in response times between the
11 breakfast and no breakfast trials, whereas on the 5 letter level response times were quicker on the no
12 breakfast trial compared to the breakfast trial (trial by load interaction, $t(1,28225) = -2.6$, $p = 0.010$).
13 However, the pattern of change in response times across the morning was not different between the
14 trials (trial by session time interaction, $t(1,28225) = -1.8$, $p = 0.066$).

15 There was however a significant, three-way trial by session time by memory load interaction
16 ($t(1,28225) = 2.5$, $p = 0.012$, figure 3.5). On the least cognitively demanding number level, the
17 improvement in response times across the morning was greatest on the no breakfast trial (figure 3.5a).
18 On the intermediate (3 letter level), the improvement in response times across the morning was
19 similar on the breakfast and no breakfast trials. On the most cognitively demanding 5 letter level,
20 response times improved considerably more across the morning on the breakfast trial (figure 3.5c).
21 This reversal of the trial effect on the lowest and highest working memory loads over time causes the
22 three-way interaction.

23 *(Insert figure 3.5 here)*

24

1 *Accuracy:* There was no main effect of breakfast (main effect of trial, $p = 0.643$) or the time of the
2 morning (main effect of session time, $p = 0.139$) on accuracy during the Sternberg test. However,
3 there was a significant effect of memory load on accuracy, with students achieving more correct
4 responses on the number level than the three letter level, where in turn they achieved more correct
5 responses than the five letter level (main effect of memory load, effect size = 0.013, $z(1,31089) = -$
6 3.6, $p < 0.0005$).

7 There was no difference in the pattern of change of accuracy across the morning between the
8 breakfast and no breakfast trials (trial by session time interaction, $p = 0.997$), nor did the memory load
9 influence the effect of breakfast on the accuracy of responses (trial by memory load interaction, $p =$
10 0.341). Also, there was no difference in accuracy between trials across the morning between the test
11 levels (3-way trial by session time by memory load interaction, $p = 0.781$).

12

13 *3.3: Blood Glucose Concentrations*

14 Analysis revealed that blood glucose concentrations were significantly higher on the breakfast
15 trial compared to the no breakfast trial (5.08 vs. 4.17 mmol.l⁻¹ respectively) (main effect of trial,
16 $F(1,59) = 57.1$, $p < 0.0005$). As expected, blood glucose concentrations were also significantly higher
17 early in the morning when compared to later in the morning (5.01 vs. 4.24 mmol.l⁻¹ respectively)
18 (main effect of session time, $F(1,59) = 55.9$, $p < 0.0005$). On the breakfast trial, blood glucose
19 concentration was highest immediately following feeding and decreased during the morning. In
20 contrast, on the no breakfast trial, there was also a decrease in blood glucose concentrations across the
21 morning, but at a much slower rate than seen on the breakfast trial (trial by session time interaction,
22 $F(1,59) = 17.0$, $p < 0.0005$, figure 3.6).

23

(Insert figure 3.6 here)

24

25

1 **4. Discussion**

2 The main finding of the present study was that breakfast consumption improved the accuracy
3 of responses on the cognitive function tests, particularly on the more cognitively demanding tasks
4 (e.g. Stroop test and the complex level of the visual search test). Breakfast consumption also
5 improved response times on the more complex levels of the Sternberg paradigm, but did not have
6 consistent effects on response times on the other tests conducted. Breakfast consumption also resulted
7 in higher self-reported energy and fullness, lower self-reported tiredness and hunger and as expected,
8 higher blood glucose concentrations.

9

10 *4.1: Visual Search*

11 In the present study, the findings indicate that following breakfast consumption participants
12 achieved a greater proportion of correct responses on the complex level of the visual search test,
13 particularly early in the morning (figure 3.3b). These findings suggest that breakfast consumption is
14 particularly beneficial for the more cognitively demanding task, whereas performance on the more
15 simple task (the baseline level) is similar with or without breakfast consumption (figure 3.3a).

16 Another study to suggest a beneficial effect of breakfast consumption on visual perception
17 indicates that in 6 to 8 year old boys, accuracy on the Rey complex figure copy and recall test was
18 improved following a ready to eat cereal when compared to breakfast omission, but in 6 to 8 year old
19 girls accuracy was improved following breakfast omission compared to a ready to eat cereal.
20 However, in the 9 to 11 year olds, breakfast consumption improved accuracy in both sexes regardless
21 of composition (i.e. accuracy was improved following both the ready to eat cereal and oatmeal
22 breakfasts compared to the no breakfast condition) [2]. Overall, the authors concluded that children
23 tended to perform better on a visual perception task following breakfast consumption compared to
24 breakfast omission, but both the age group of the young people and breakfast composition appear to
25 play mediating roles. Interestingly, in accordance with the present study, the effects of breakfast were

1 only evident when looking at the accuracy of visual perception, with no effects on response times on
2 the test of visual perception.

3 A study conducted in 9 to 12 year old males also reported that there was no effect of breakfast
4 consumption on response times (in accordance with the present study) or accuracy (in contrast to the
5 present study) during the same Rey complex figure copy and recall test [21]. A potential explanation
6 for this variation in findings could be that whilst the present study and the study of Mahoney et al [2]
7 compared breakfast consumption and breakfast omission, the study of Busch et al [21] compared
8 consumption of a confectionary snack and a non-calorie snack (control condition). Furthermore, the
9 Rey complex figure copy and recall test used in the study of Busch et al [21] was perhaps not
10 cognitively demanding enough for the study population, thus would not elucidate the beneficial
11 effects of breakfast consumption (similar to the baseline level of the visual search test employed in the
12 present study). However, Mahoney et al [2] tested a younger population (6-11 year olds) and thus the
13 test may have been cognitively demanding enough for these children.

14

15 *4.2: Stroop Test*

16 In the present study accuracy on the Stroop test declined across the morning following
17 breakfast omission but was better maintained across the morning following breakfast consumption
18 (figure 3.4). However, response times on the Stroop test were not affected by breakfast consumption.
19 To the author's knowledge, the effects of breakfast consumption and/or omission on adolescents'
20 performance on the Stroop test have not previously been published. However, the Stroop test was
21 included in the testing battery of a study looking at the effects of the glycaemic load (GL) and
22 glycaemic index (GI) of breakfast in an adolescent population [22]. Their findings indicated that a
23 high GL and high GI breakfast tended to produce better performance on the Stroop test compared to a
24 low GL and low GI breakfast. It was further suggested that this may be due to a high GL and high GI
25 breakfast resulting in a higher blood glucose concentration and consequently greater activation of the
26 hypothalamic-pituitary-adrenal (HPA) axis, resulting in better performance on the Stroop test [13,22].

1 Glucose is a key substrate used by the brain for cognitive activity [23] and higher blood
2 glucose concentrations increase the delivery of glucose to the brain and as a result, increase frontal
3 lobe functioning [13]. Due to the key role of the frontal lobe in determining performance on the
4 Stroop test [19] it is unsurprising that in the present study accuracy was better maintained following
5 breakfast consumption (and its associated higher blood glucose levels) . However, the present study is
6 the first to report the effects of breakfast consumption on performance on the Stroop test in
7 adolescents, with a limited number of other studies focussing on blood glucose concentrations rather
8 than breakfast consumption per se.

9

10 *4.3: Sternberg Paradigm*

11 In the present study, the effect of breakfast consumption on response times on the Sternberg
12 paradigm depended upon the test level (figure 3.5). On the simplest level, response times showed a
13 greater improvement across the morning on the no breakfast trial, whereas on the more cognitively
14 demanding levels there was a greater improvement in response times across the morning following
15 breakfast consumption. These observations imply that response speed on basic cognitive tasks (i.e.
16 those with a low working memory load) is slow directly after missing breakfast, but can improve over
17 time even without additional meals. In contrast, response speed for demanding cognitive tasks (i.e.
18 those with a high working memory load) is improved to a far greater extent two hours after having
19 breakfast, after which time presumably the meal was digested. These results are consistent with the
20 notion that breakfast consumption is most beneficial for cognitively demanding tasks, particularly
21 later in the morning.

22 In contrast to the other tests employed, when examining accuracy on the Sternberg paradigm
23 there was no effect of breakfast consumption, with a similar proportion of correct responses on the
24 breakfast and no breakfast trials across the morning. Comparisons between the findings of the present
25 study and those in the literature are limited due to the studies in the literature only assessing the
26 accuracy of memory, not accuracy and response times separately (as is the case in the present study).

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In accordance with the present study, several early studies in the area also found there was no effect of breakfast consumption on accuracy of memory [10,24]. However, such studies suffer from methodological weaknesses, as both studies employed a cross-sectional design, with no crossover between conditions for participants and thus their results must be interpreted cautiously. However, the results of these studies [10,24] are in accordance with the present study which employed a randomised crossover design in an adolescent population.

One study to employ an adolescent population assessed the accuracy of verbal and visuospatial memory following breakfast consumption and breakfast omission [7]. The findings indicated that the accuracy of visuospatial memory was improved following breakfast consumption, with no effects of breakfast consumption on the accuracy of verbal memory. However, comparisons with the present study are limited because the study in question only assessed the accuracy of verbal and visuospatial memory, not speed and accuracy of working memory separately as in the present study.

To the authors knowledge, the present study is the first to assess the effects of breakfast consumption on performance of the Sternberg paradigm, thus comparisons with previous studies are difficult. Furthermore, comparisons are made even more difficult due to the different components of memory measured and the different age groups of the populations tested throughout the literature. Tentative conclusions have been drawn in the literature to suggest that breakfast omission adversely affects memory processes in young people, though the evidence in adolescent populations is limited and it is suggested more work should be conducted in this population [23]. The present study partly addresses this void in the literature, with the findings suggesting that breakfast consumption tended to improve the speed of working memory (especially on the more cognitively demanding levels of the Sternberg paradigm later in the morning), but there was no effect on the accuracy of working memory.

1 4.4: Mood

2 The findings of the present study indicate that following breakfast consumption self-report
3 energy and fullness were higher and self-report tiredness and hunger were lower when compared to
4 breakfast omission. A number of studies which have examined the effects of breakfast consumption
5 on cognitive function in young people have also measured the effect on mood. Not only is the effect
6 on mood states interesting in its own right, but it is also suggested that mood can influence cognitive
7 function, thus should be measured in studies assessing cognitive function. Furthermore, researchers
8 must ensure that the tools used to assess mood are appropriate for use in the study population, with the
9 modified version of the AD ACL short form used in the present study found to be suitable for use in
10 an adolescent population.

11 One study assessing mood and cognitive function in an adolescent population assessed the
12 effects of breakfast consumption on information uptake, positive affect, negative affect, alertness and
13 arousal in 13 to 20 year olds [7]. The findings indicate that following breakfast consumption, the
14 overall study population reported greater positive affect, information uptake and alertness, along with
15 lower negative affect, compared to the no breakfast condition. Similarly, it has been reported that
16 breakfast consumption produced greater self-rated alertness and contentment compared to breakfast
17 omission in 9 to 16 year olds [14]. These findings are in accordance with the present study, which also
18 showed increased energy and decreased tiredness following breakfast consumption, indicative of a
19 more positive mood state.

20 Comparisons between the present study and those detailed above should be made cautiously
21 for a number of reasons. First, the above studies have all used different methods of assessing mood
22 and are therefore assessing different dimensions of mood. Furthermore, the above studies have tended
23 to use mood questionnaires designed for use in adults, thus their suitability for use in young people
24 must be questioned. Interestingly, the studies where a consistent effect of breakfast consumption on
25 mood has been demonstrated have been conducted in adolescents, rather than younger children. This
26 could be explained in two ways; firstly it could be that breakfast consumption does not affect mood in

1 younger children but does so in adolescents, or it could be that younger children are unable to
2 understand the construct of mood and/or use the mood questionnaires accurately because they were
3 designed to be used in adults, highlighting the need for any mood questionnaire that is used to be
4 suitable for the study population.

5

6 *4.5: Summary and Future Research Directions*

7 The main finding of the present study was that breakfast consumption improved the accuracy
8 of responses on the visual search and Stroop tests. Breakfast consumption also improved response
9 times on the more complex levels of the Sternberg paradigm, but did not have consistent effects on
10 response times on the other tests conducted. Overall, it would appear that breakfast consumption was
11 particularly beneficial on the more cognitively demanding tasks, whereas the simpler tasks could be
12 performed to a similar level following breakfast omission.

13 The present study is unique in its findings for a number of reasons. First, the present study
14 employed an adolescent population, whereas much of the literature to date has used either younger
15 children or an adult population. Second, the number of participants in the present study is larger than
16 many other studies in the literature, particularly in adolescent populations. Furthermore, the present
17 study provided participants with breakfast ad libitum, allowing for a breakfast meal similar to habitual
18 breakfast intake. Many other studies have used fixed amounts of breakfast, possibly accounting for a
19 lack of an effect of breakfast on cognitive function in such studies. Finally, the present study also
20 measured blood glucose concentrations, providing a biochemical marker that is not available in many
21 of the studies in the literature to date, allowing an insight into the potential mechanisms for the effect
22 of breakfast consumption on cognitive function in adolescents.

23 In summary, the findings of the present study suggest that breakfast consumption does
24 improve cognitive function in an adolescent population. Therefore, because of this improvement in
25 cognitive function and the other suggested health benefits of breakfast consumption [4] it is a practice
26 that should be promoted in adolescent populations. However, further work is required to examine the

1 optimal composition of breakfast (with particular interest in the glycaemic index), the optimal timing
2 of breakfast, and to suggest potential mechanisms for an effect of breakfast consumption on cognitive
3 function.

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7 **5. References**

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