Investigating the time elapsed since the last food item was consumed as a factor affecting cognitive performance in young adults

Elizabeth R. Walters* and Azhar Khan

Division of Psychology, University of Bradford, Bradford, United Kingdom

Author Note

*Corresponding author:

Email: e.walters@bradford.ac.uk

Abstract

Cognitive ability is used in numerous everyday situations (for example, in the classroom, workplace and home) and can be measured using cognitive tests designed to target specific cognitive domains. Cognition can be influenced by external factors (for example, age, education, caffeine intake and time of day) which if not controlled for or noted could influence performance. Prior food intake has not received a direct focus in the cognition literature therefore this study aims to investigate the time elapsed since the last food item was consumed as a factor which may affect cognitive performance.

Fifty-two cognitively healthy adults with no reported cognitive impairment or diagnosis of any eating or metabolic disorder took part in the study. Participants completed a self-rated hunger scale and stated the time that they last consumed a food item. The time of day that the assessments were completed was also noted. All participants completed a brief cognitive battery consisting of a semantic recall assessment, digit span and parts A and B of the Trail Making Test. Results revealed a significant main effect of minutes since the last food item was consumed on semantic recall and both Trails A and B whereby performance was significantly worse as the time since the last food item was consumed increased.

These results suggest that information about when the participant consumed food prior to assessment should be gathered to check for any such affects. This could have implications for cognitive performance in educational settings and clinical environments where scores often determine academic progression and further interventions.

Key words: Hunger; cognitive performance; neuropsychological testing; food consumption.

Introduction

Neuropsychological testing

Neuropsychological testing (NPT) is a process used in the detection of cognitive impairment (Chapman et al. 2010) and in the diagnosis and monitoring of a number of neuropsychological conditions, including but not limited to, autism (Losh et al., 2009), Parkinson's disease (Claassen & Wylie, 2012), stroke (Suzuki et al., 2013) Traumatic Brain Injury (TBI) (Dean & Sterr, 2013) and dementia (Fields, Ferman, Boeve, & Smith, 2011; P. D. Harvey, 2012; Ralph et al., 2001). NPT assesses cognitive function using specialised tests designed to target specific cognitive domains or general cognitive function (Lezak, 2004). The results obtained can then be compared to normative data, be used to highlight cognitive deficits (Zamrini, De Santi, & Tolar, 2004), inform whether a patient is suitable for research trial inclusion (Gauthier, Leuzy, Racine, & Rosa-Neto, 2013) or may even influence treatment regimes. The testing process can be influenced by external factors which if not adequately controlled for may affect the reliability of any scores obtained which then has implications for diagnosis, treatment and care. Such factors can include the presence of caffeine, (Walters & Lesk, 2016) the time of day that tests are carried out (Borella, Ludwig, Dirk, & de Ribaupierre, 2011; Schmidt, Collette, Cajochen, & Peigneux, 2007), mood (Jacova, Kertesz, Blair, Fisk, & Feldman, 2007) age (Goh, An, & Resnick, 2012) and gender (Maguire, Burgess, & O'Keefe, 1999). Other subtle factors likely to be prevalent at a typical testing session are hunger and prior food consumption. There is limited literature regarding hunger/prior food intake at the time of testing and this has not received a direct focus in previous literature. Despite this, current hunger or the time elapsed since the last meal/food item was consumed may be important for cognitive performance and therefore should be investigated.

Hunger, food and cognitive performance

Whilst food is primarily perceived as an energy source for the body, there is growing literature linking food choices to the development and prevention of certain diseases (Gómez-Pinilla, 2008). Furthermore, some nutrients can be linked directly to brain function and cognitive performance. For example, omega-3 polyunsaturated fatty acids, namely docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA), are known constituents of neuronal membranes (Hashimoto & Hossain, 2011) and diets rich in these substrates have been linked with the upregulation of genes associated with synaptic plasticity and improved cognitive performance (McCann & Ames, 2005). Diets high in saturated fat lead to increased levels of serum cholesterol and have negative associations with cognitive performance, further, cholesterol excess is linked to increased amyloid Beta load in the elderly and subsequently increases the risk for developing Alzheimer's disease (Refolo et al., 2000; Shobab, Hsiung, & Feldman, 2005).

The brain relies upon large amounts of energy relative to other bodily organs for optimal processing. Neuronal plasticity can be influenced by food intake and signalling factors, for example, Brain Derived Neurotrophic Factor (BDNF) can directly be affected by energy metabolism (Gómez-Pinilla, 2008) and therefore food intake.   Many signalling factors, such as BDNF, insulin like growth factor 1 (IGF1), insulin, leptin and ghrelin, are known to be associated with energy metabolism, hunger processes, appetite and nutrition. Importantly all have receptors in brain areas involved in cognitive performance for example, the hippocampus and pre-frontal circuits providing support for the direct effect of food on cognition (Islam et al., 1998).

Consequently alterations in nutrient and calorie intake have the capacity to directly influence cognitive performance. For example, excess calorific intake is associated with decreased synaptic plasticity (Vaynman, Ying, Wu, & Gomez-Pinilla, 2006) and moderate calorie restriction in rodents has shown positive effects on cognition in certain domains (Mattson, Duan, Wan, & Guo, 2004). In humans however, malnutrition (Boulos, Salameh, & Barberger-Gateau, 2016; Russell & Elia, 2010) and low body weight have been implicated as factors associated with poor cognitive performance. As a result frailty and weight loss, particularly in the elderly, are predictors of mortality (Formiga, Vidan, Ariza-Sole, & Martinez-Selles, 2016; Saka et al., 2016; Slee, Birch, & Stokoe, 2015) and further cognitive decline (Boulos et al., 2016).

Biological correlates of appetite and hunger

Hunger is a sensation which promotes feeding and ingestive behaviour (McKiernan, Houchins, & Mattes, 2008). However, humans often deliberately refrain from eating due to a variety of reasons which may include; diet plans, religious observance, busy lifestyles, forgetting and health related reasons including psychiatric and physical illnesses (Benau, Orloff, Janke, Serpell, & Timko, 2014). Likewise, humans may also over eat or choose to eat when energy is not necessarily required, for example, during periods of boredom or during sensory stimulation (McKiernan et al., 2008). In some instances hunger sensations may be actively ignored by diverting attention to other tasks or the biological hunger signal may be received and/or inhibited. This can make the concept of hunger difficult to quantify due to the potential for large individual differences.

Whilst some gut peptides are known to be associated with current hunger status and appetite regulation via direct hypothalamic actions, there is growing evidence to show that these can also directly stimulate molecular systems associated with plasticity, learning and cognition (J. Harvey, 2007; McNay, 2007; van der Lely, Tschop, Heiman, & Ghigo, 2004).

For example leptin, synthesised by adipose tissue, signals to the brain to reduce appetite and circulating levels have been shown to correlate with fat mass (J. Harvey, 2007). Peripheral leptin can cross the blood brain barrier and there is some evidence to suggest that the brain itself possesses the capacity to make and locally release leptin due to the find of leptin mRNA in some brain regions (Morash, Li, Murphy, Wilkinson, & Ur, 1999). Whilst leptin receptors are highly expressed in the hypothalamus in areas involved in the regulation of energy they are also located across the cortex and hippocampus (J. Harvey, 2007). Hippocampal excitability has been shown to relate to leptin binding as well as the modulation of long term depression associated with NMDA receptors (Durakoglugil, Irving, & Harvey, 2005).

Another gut peptide, ghrelin, is secreted by the stomach lining to increase appetite and initiate a meal (Dhurandhar, Allison, van Groen, & Kadish, 2013), therefore ghrelin levels are a physiological indication of current hunger levels. Furthermore, ghrelin has been shown to promote synapse formation in the hippocampus which accompanied enhanced spatial learning ability in rats (van der Lely et al., 2004).

Finally insulin, a hormone produced by the pancreas in response to a meal has also shown to influence synaptic activity and cognitive processing specifically in the hippocampus (McNay, 2007). Insulin delivered intranasally increased memory performance in Alzheimer's disease patients (Benedict et al., 2004; Reger et al., 2006) supporting the role of insulin in memory function.

Hunger and cognitive performance

Whilst there is a distinct lack of research specifically investigating the effect of hunger on cognitive performance there has been a large body of literature which investigates the influence of breakfast consumption on cognition particularly in children (for example, (Hoyland, Dye, & Lawton, 2009; Ingwersen, Defeyter, Kennedy, Wesnes, & Scholey, 2007;

Pivik, Tennal, Chapman, & Gu, 2012; Wesnes, Pincock, Richardson, Helm, & Hails, 2003) with a large focus on the impact this may have on education and learning in school environments. Usually in such studies there are experimental groupings relating to a 'breakfast condition' and a 'no breakfast condition'. The control participants in the 'no breakfast condition' have therefore not eaten since the previous evening and therefore it is logical to presume that this group of participants are more likely to be experiencing increased hunger. The results of many of these studies confirm poorer cognitive performance both at the time of testing and throughout the day in the no breakfast condition.

For example, (Wesnes et al., 2003) investigated the consumption of breakfast (specifically breakfast cereals), a glucose drink or 'no breakfast' in 29 school children ranging in age from 12-16 years over a four-day period. Three cognitive functions were tested; specifically working memory, episodic memory and attention. The 'no breakfast condition' was important as those who did not eat breakfast had most likely consumed their previous meal at least 12 hours prior to testing though this was not recorded. Therefore, it is likely that this group would have increased hunger levels which may have contributed to their performance on cognitive tasks. Findings revealed that both the 'no breakfast condition' and the 'glucose condition' demonstrated declines in attention and memory scores and this increased in magnitude over the morning. In comparison no decline was seen in the cereal breakfast condition. Another study investigated breakfast consumption and cognitive performance in 96 adolescents aged 12-15 years (Cooper, Bandelow, Nute, Morris, & Nevill, 2012). Participants were randomly assigned to either a 'breakfast consumption condition' or a 'no breakfast condition'. Findings revealed that accuracy on a visual search task was improved in the breakfast group as well as overall Stroop performance. The authors concluded that breakfast enhances cognitive performance in an adolescent population. This study did ask participants to self-report their hunger levels and self-reported hunger was found to be higher in the no breakfast condition, as expected.

The present study

If food intake is a factor which affects cognitive performance this could have implications for research and diagnostics using neuropsychological assessment as well as the work place and education sector and should therefore be either controlled or noted. As mentioned previously a further complicating issue is that humans often ignore hunger signals and continue to carry on with their normal daily lives for some hours before they have the opportunity to eat a meal. Consequently, the time since the last food item was consumed may be a more accurate, objective way of investigating the influence of potential hunger on cognitive performance removing any subjective confounds of self-rated hunger which could have large inter and intra-individual differences. This study will therefore investigate prior food consumption, by recording time (in minutes) since the last food item was consumed as a factor which may influence cognitive performance in a population of young adults. It is hypothesised that participants who report a longer time since the last food item was consumed will perform significantly worse on the cognitive tests administered.

Methods

Participants

Participants were Psychology students from the Division of Psychology at the University of Bradford and other young adults (n=52). The sample consisted of 16 males and 36 females, the mean age of participants was 23.94 years (± 6.47 years). Details of the study were outlined in an information sheet which was advertised online via the Division of Psychology Research Participation system to all current Psychology students. Interested participants were able to sign up to the study and received study points after participation was complete. Additional participants were recruited through snowball sampling. All participants gave their full informed written consent to take part. Ethical approval was granted by the Division of Psychology ethics committee at the University of Bradford. Exclusion criteria specified that participants with a current diagnosis of an eating or metabolic disorder or cognitive impairment would not be able to take part.

Materials

A Likert scale was created to measure participants subjective hunger rating at the time of testing. Participants were asked to rate their current hunger on a line labelled from 1-10 [where 1 = not hungry at all and 10 = extremely hungry]. Line Likert scales of this nature are widely used in food behaviour and nutritional based research ((Feig, Piers, Kral, & Lowe, 2018; Sibilia, 2010) and offer good levels of within subject reliability and validity (Stubbs et al., 2000). Participants were also required to state the time that they last consumed a food item.

A short neuropsychological test battery assessing different cognitive domains comprising the following tests was administered to all participants. The researcher noted the time of day that testing commenced immediately prior to the administration of the first test.

Semantic Recall: Thirty images were presented to participants one at a time on a computerised monitor, each picture was presented for a period of three seconds. After viewing all images participants were asked to recall as many images as they could using a pen and paper. Score was calculated to be the number of images accurately recalled. Whilst in this instance the task was created by the researcher assessments of recall are commonly used to assess memory function with varying levels of reliability depending on additional factors such as the participants' age (Lezak, 2004).

Trail Making test (TMT): this is a two-part assessment which assesses executive function and visual attention (Reitan, 1958). The TMT is widely used in neuropsychological assessment across the life span and is recognised as being highly reliable and valid for use in cognitively normal participants and in patients with neuropsychological disorders (Ashendorf et al., 2008; Bowie & Harvey, 2006; Lezak, 2004). In Part A the participant is required to join up correctly a series of circles containing numbers in ascending numerical order. This is timed and the participant is instructed to complete this section as quickly as they can. This part of the task assesses visual attention. In Part B of the task the participant is required to again join a series of circles containing either letters or numbers alternating between increasing numerical order and ascending alphabetical order. Part B assesses executive function, specifically flexibility and set switching (May & Hasher, 1998). Participants are timed and must complete the task as quickly as they can. The score for each part of the test is the time taken to complete the task in seconds (Ashendorf et al., 2008). The TMT has excellent interrater reliability (Bowie & Harvey, 2006). Reliability coefficients vary depending on the participants age and presentation and have been recorded in the literature with values between 0.60 – 0.90, with the majority of studies reporting values in the region of 0.80 (Lezak, 2004).

Digit Span forward: this task assesses working memory (Wechsler, 1981) and is a component of the widely used Wechsler Adult Intelligence Scale Revised battery. A series of numbers are read aloud to participants increasing in length from three digits to nine. The test ends when the subject is unable to recall two sets of digits of a certain length in the same order they were stated by the researcher. The digit span forward score is the number of digits in the last correct string recalled. Test-retest reliability coefficients range from between 0.66 to 0.89 and are dependent on additional factors such as age and education (Lezak, 2004; Woods et al., 2011).

Data analysis

The IBM® SPSS statistical software package version 23 was used to analyse the data collected. As the study used a cognitive battery consisting of four cognitive tests (semantic recall, trails A, trails B and digit span score) thereby creating four separate dependent variables, multivariate methods were employed in order to reduce the risk of type one error. As is recommended when carrying out a neuropsychological assessment, the data was checked for any main effects of demographic variables on test scores (Jacova et al., 2007, Lezak et al., 2004), specifically age, gender and time of day. A Multivariate Analysis of Covariance (MANCOVA) was carried out where test scores were entered as the dependent variables, age and time of day entered as covariates and gender as a fixed factor.

A second MANCOVA was carried out to address the research aim and investigate whether there was a significant effect of time since the last food item was consumed on any of the test scores. The four separate test scores were entered into the model as dependent variables and time since the last food item was consumed entered as a covariate. Multiple regression was employed to determine the direction of any significant main effects. These were visualised using scatter plots.

Results

The aim of the present study was to investigate whether the time elapsed since the last food item was consumed affects cognitive performance.

A MANCOVA was carried out to check for any significant main effects of participant demographics (age and gender) and time of day on the cognitive test scores obtained, age and time of day were entered into the model as covariates, gender as a fixed factor and all test scores as dependent variables. There was no significant main effect of age, gender, or time of day on any of the tests administered. Table one outlines the mean scores for the cognitive tests administered:

Table 1: Mean neuropsychological test scores and (±SD)

Cognitive domain	Test	Mean	Standard Deviation ±
Semantic memory	Recall	10.40	2.95
Working Memory	Digit span	5.40	0.89
Visual search/Processing Speed	Trail Making A (seconds)	26.28	10.60
Executive function	Trail Making B (seconds)	56.45	22.91

Table two outlines the descriptives for the covariate factors under investigation. As the data in table two demonstrates participants were tested at various time points across the day. All participants were asked to state the time that they last consumed a food item, this ranged from recently (10 minutes) prior to testing to 1080 minutes which equated to 18 hours prior to testing and represented an individual who had refrained from consuming breakfast therefore was in a fasting state since the previous day's evening meal. The large standard deviation of this variable was expected and reflects the wide scope for individual differences in eating patterns.

Table 2: Mean and (±SD) for factors under investigation

Factor	Range	Mean	Standard Deviation ±
Time of day	08.30am – 17.30pm	13.01	2.00
Time since the last food item was consumed (minutes)	10min – 1080mins	248.31	270.86
Subjective hunger rating as measured by Likert scale	1-9	5.23	1.83

Analysis for the main effects of subjective hunger on cognitive test scores

Due to the battery consisting of multiple cognitive tests a Multivariate Analysis of Covariance (MANCOVA) was used to analyse the findings in the present study.

In order to investigate time since the last food item was consumed as a factor influencing cognitive performance a MANCOVA included time since the last food item was consumed (minutes) as a covariate and the cognitive test scores as dependent variables.

There was a significant main effect of time since the last food item was consumed on semantic recall score [F (1, 50) = 14.26, p< 0.01], the time taken to complete part A of the trail making test [F (1, 50) = 5.24, p< 0.05] and the time taken to complete part B of the trail making test [F(1,50) = 5.46, p<0.05]. Regression analysis revealed a linear decrease in performance for all tests as the minutes since the participant consumed food increased [Recall: β = -0.005, F(1,50) = 14.26, p<0.05, y axis intercept = 11.70 with regression correlation coefficient r=0.47, p<0.01, Trails A: β= 0.31, F(1,50) = 5.24, p<0.05, y axis intercept = 23.30 with regression correlation coefficient r = 0.31, p<0.05], Trails B: β = 0.31, F(1,50) = 5.46, p<0.05, y axis intercept = 49.86 with regression correlation coefficient r = 0.31, p<0.05]. Scatter plots of these results can be seen in the figures below.

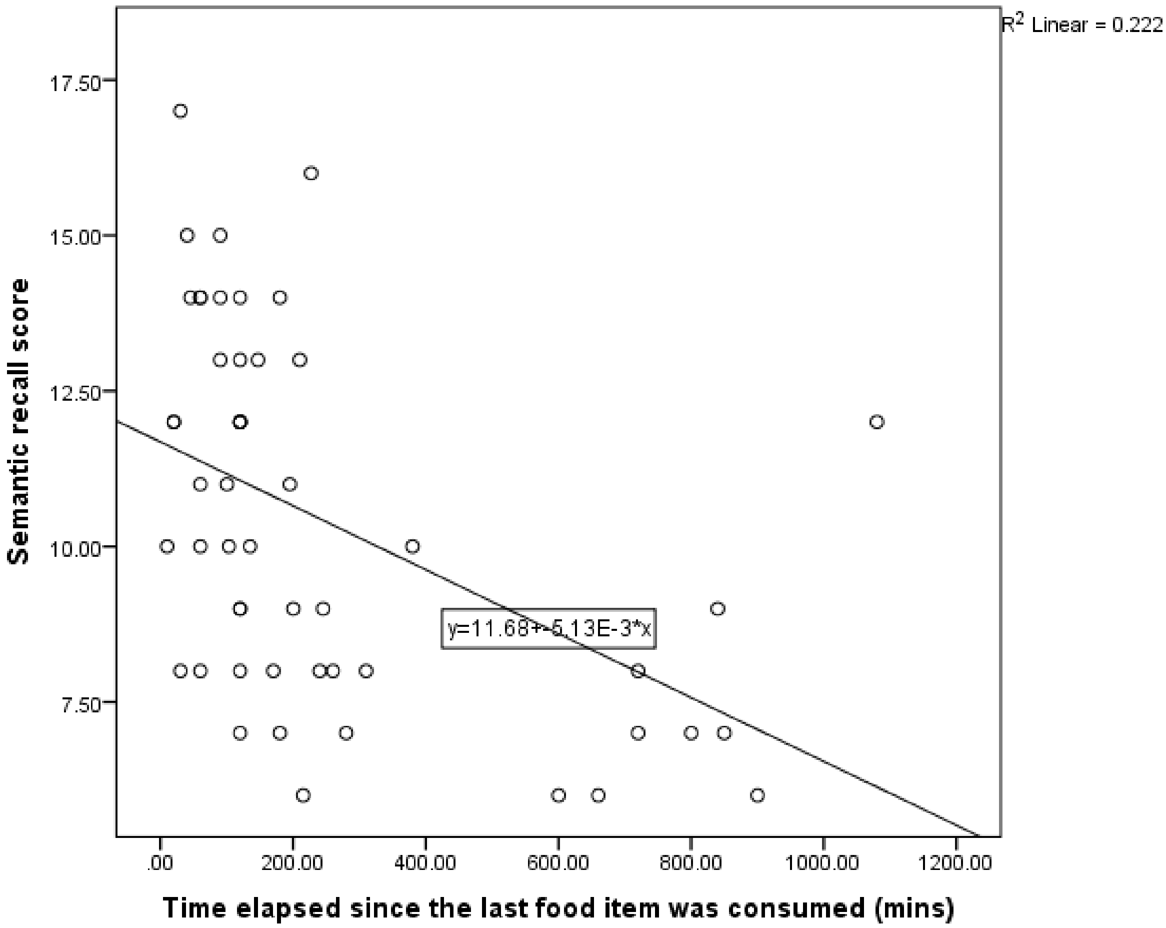

Figure 1: A linear decrease in performance is present whereby as the time since the last food item was consumed increases score on semantic recall decreases.

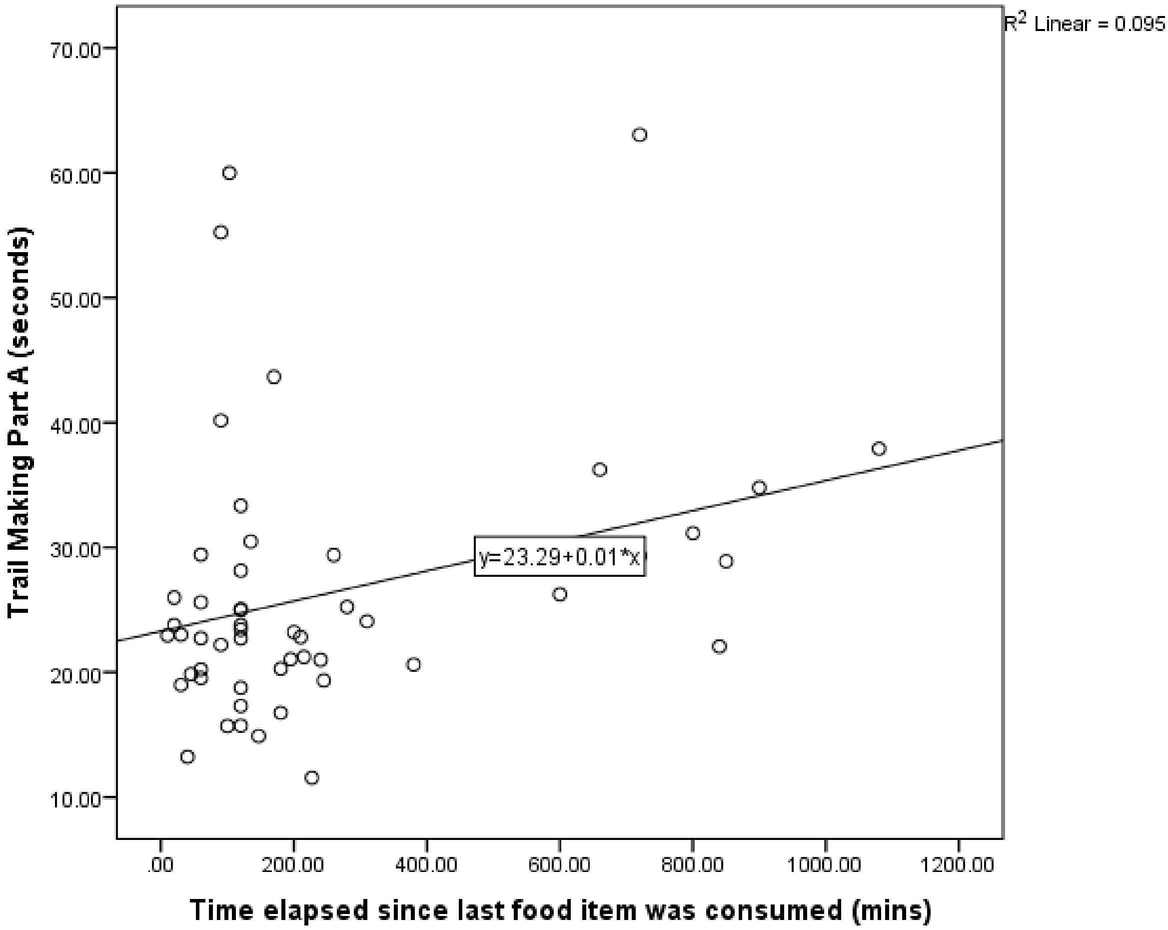

Figure 2: A positive correlation is present whereby as the time since the last food item was consumed increases the time taken to complete Trail Making part A increases equating to poorer performance.

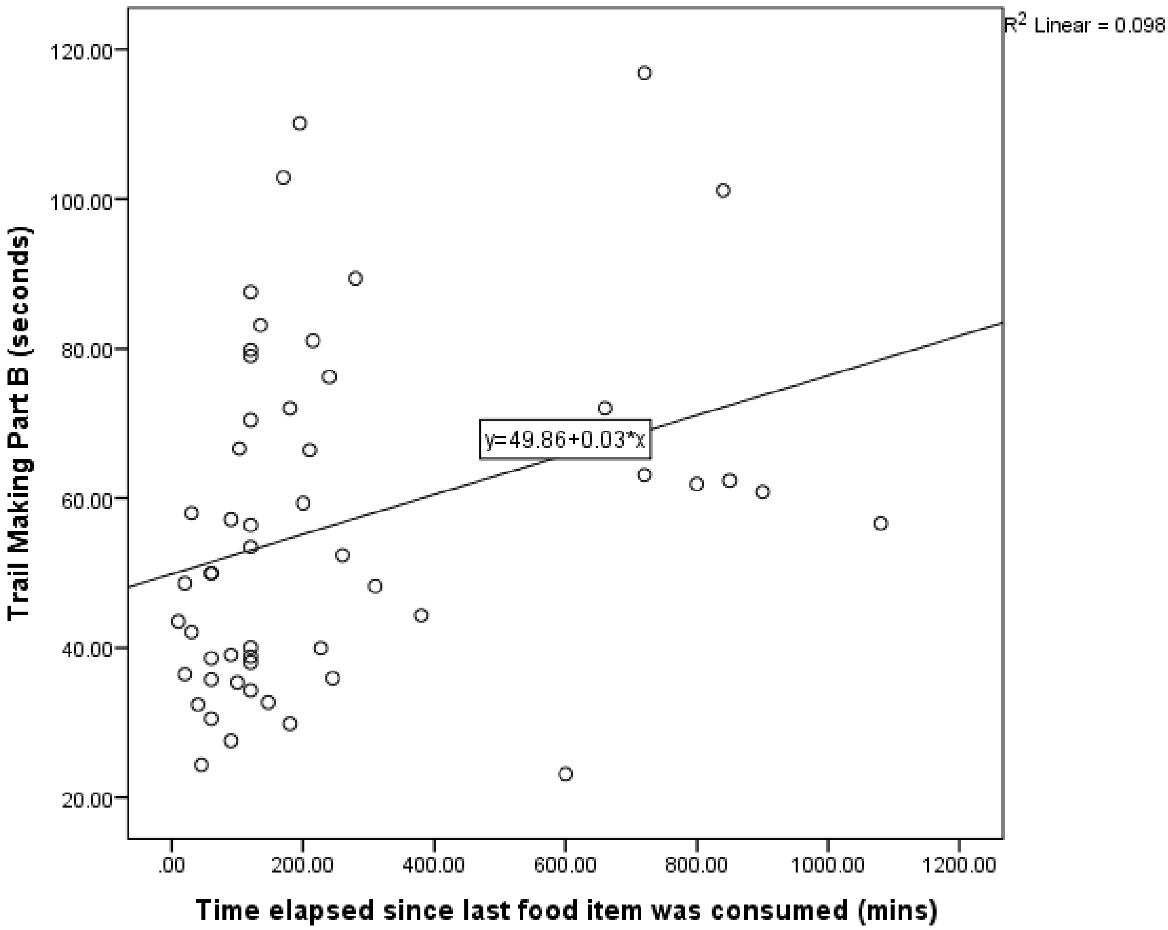

Figure 3*:* A positive correlation is present whereby as the time since the last food item was consumed increases the time to complete the Trail Making part B also increases equating to poorer performance.

Discussions

This study investigated the effect of prior food intake (recorded as minutes since the last food item was consumed) as a potential factor affecting cognitive performance in young adults. The analysis revealed a significant main effect of minutes since the last food item was consumed on recall, visual attention and executive function as measured by a semantic recall task and Parts A and B of the TMT. For all of these assessments, as the time since the last food item was consumed increased performance on all assessments declined.

The results of the current study reveal that the time elapsed since the last food item was consumed was a factor which affected performance on semantic recall, visual attention and executive function whereby performance on these domains declined as the time since the last food item was eaten increased.

The TMT is a commonly used neuropsychological assessment which assess multiple cognitive domains and can be applied to many neuropsychological conditions for monitoring and diagnosis (Lezak, 2004). The TMT, shown in the current study to be affected by the time in minutes since last eaten, assesses visual search and processing speed in Part A and executive function, specifically the ability to switch between two components in part B of the task (O'Rourke et al., 2011).

These findings have potential implications for educational settings particularly the scheduling of classes and examinations. University students are regularly required to recall information, scan texts for relevant information (visual search) and multi task by switching between multiple sources, three such skills assessed in the present study by the TMT and a semantic recall task. The findings of the current study show that these tasks are affected by prior food intake; specifically that performance is poorer in those students who have not eaten for a longer period of time.

There is a substantial body of literature which has investigated the impact of food intake on cognition. The majority of these studies recruit younger children and specifically look at breakfast consumption (Bellisle, Hebel, Salmon-Legagneur, & Vieux, 2018; Hoyland et al., 2009; Wesnes et al., 2003). In addition there is also a focus on the type of food item consumed. The findings of this preliminary study indicate that the time elapsed since the last food item was consumed could be just as important as the nutritional content of the food item. University students differ to school children in many demographical aspects but particularly in their lifestyle, eating patterns, food choice and daily schedules. As a cohort they are more independent and more able to make their own decisions particularly when to actually consume food. This can differ significantly from a school environment where the timing of meals and snack periods is predetermined by the school itself. Whilst further research is needed to build upon these preliminary findings, Universities' and educational institutions may wish to consider offering advice on the importance of maintaining regular food intake during study especially during intensive study periods. University students may not be aware of the impact that the timing of food intake can have on their cognitive performance.

The TMT and assessments of semantic recall are also used across the lifespan to assess cognitive performance and recent research has highlighted strong links between under eating and cognitive decline (Boulos et al., 2016; Slee et al., 2015) it may therefore be useful for researchers to consider noting the time the last food item was consumed in order to gain a more accurate representation of cognitive performance at the time of testing.

As mentioned in the introduction section of this paper, gut hormones and signalling factors associated with food intake and nutrient availability directly influence specific brain regions through direct receptor interaction and also through downstream signalling. For example, the hippocampus, an area heavily relied upon for the retrieval of information from memory, contains receptors for ghrelin and IGF, known gut hormones involved in the initiation of a meal which are correlated with hunger perceptions and ultimately food intake. In the current study when time since the last food item was eaten increased, performance on a semantic recall task (a measure of memory requiring hippocampal recruitment) declined. Likewise, processing speed and attention rely upon the pre frontal cortex and executive circuits, areas which have also been found to be directly influenced by signalling factors relating to nutrient intake and availability particularly in relation to synaptic plasticity and dendritic spine density. In the current study when time since the last food item was eaten increased participants took longer to complete part A and B of the TMT. The preliminary findings therefore provide support that food intake does affect performance on cognitive tests and further research using larger samples and varied populations is now needed to investigate this further.

Methodological Considerations

This study recorded two hunger related concepts, current subjective hunger and the time since the last food item was consumed (in minutes). There was no significant correlation between the two measures suggesting that use of a single item measure of self-reported hunger was not the most appropriate method to employ. Whilst other researchers have also measured subjective hunger in the form of a likert scale they too have reported similar issues, particularly the large amount of individual difference that can be associated with hunger perception (Stevenson, Mahmut, & Rooney, 2015) and the potential pitfalls of using singular self-report scales (Arsenault et al., 2009; Bowman et al., 2012; Liu et al., 2013). Physiological measurements of hunger would offer a more accurate picture of the participant’s actual hunger levels e.g. serum ghrelin and insulin concentration however this would be unrealistic to implement in a clinical setting during the administration of NPT for diagnostic purposes.

The researchers acknowledge the potential bias in the recruitment of the sample, i.e. that participants were known to the researchers as students at the institution that the study took place and further continuation of this research should consider widening participation to a more general sample to reduce bias and the possibility of demand characteristics. It is also important to consider other variables which influence hunger perception and eating patterns, whilst the study did not recruit participants who had a diagnosed eating disorder no information was collected about exercise patterns, diet observance or other lifestyle factors and this would be necessary in further continuations of this research.

Conclusion

The observations in the present paper which demonstrate that time in minutes since the last food item was consumed can significantly affect performance on assessments of semantic recall, visual attention and executive function could have important implications for cognition and NPT in both educational and potentially clinical environments. To our knowledge previous research has not investigated the influence of prior food intake on cognitive performance at the time of testing. Whilst the present study has investigated this in a population of young adults the findings may have implications for other age groups. Further study is needed to investigate this concept further.

The findings of the present paper are also important for researchers, clinicians and educators who may use cognitive assessment as a part of their methodologies, diagnostic procedures or daily tasks. Obtaining an accurate representation of cognitive function is important for clinical trials, monitoring of cognitive performance, diagnosis and educational outcomes.

Conflict of interest: there are no reported conflicts of interest.

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