Breakfast consumption and cognitive function in adolescent schoolchildren

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Abstract

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

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

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

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

Keywords: BREAKFAST, ADOLESCENTS, COGNITIVE FUNCTION, MOOD

1. Introduction

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

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

The one study to date to examine the effects of breakfast consumption on cognitive function in an adolescent population recruited 104 13-20 year old males and females, who either consumed a standardised breakfast or omitted breakfast [7]. Whilst breakfast did not affect attention, it did have a beneficial effect on the accuracy of visuo-spatial memory. Interestingly, there were also a number of positive effects on mood following breakfast consumption, such as increases in self-report awareness and males also reported feeling more positive [7]. However, the cognitive tests were conducted using paper and pencil tests assessing memory and attention, thus limiting the analysis undertaken and the elements of cognitive function examined. Furthermore, the use of a standardised breakfast may have resulted in different effects between participants due to differences in palatability of the meal, food preferences and in the nutritional content of the breakfasts provided, relative to body mass.

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

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

Furthermore, a recent review indicates that there is a need for more studies which examine the effects of breakfast consumption across a range of dimensions of cognitive function, particularly in an adolescent population [8]. Therefore, the aim of the present study is to examine the effects of an ad libitum breakfast on the cognitive function, mood and blood glucose concentration of adolescents (12-15 years old) using a randomised crossover design. The use of an ad libitum breakfast should allow participants to consume a breakfast similar to their habitual breakfast intake, thus allowing the findings to be applied to everyday settings. The study will employ a battery of cognitive function tests across a wider range of dimensions than in previous studies (assessing visual perception, attention and working memory) and furthermore, by measuring blood glucose concentration, an insight into potential mechanisms for an effect of breakfast consumption on cognitive function in an adolescent population may be possible.

2. Methodology

2.1: Participant Characteristics

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

(Insert table 2.1 here)

2.2: Study Design

The study was approved by Loughborough University Ethical Advisory Committee. Participants were recruited through their schools and in accordance with the ethical guidelines of the British Education Research Association for school-based research, school-level consent was obtained from head teachers. In addition, written parental informed consent was obtained and a health screen questionnaire completed to ensure all participants were in good health. To ensure the children's willingness to participate, on each testing day they indicated assent by signing a willingness to participate form. Each participant undertook a familiarisation session which preceded the first of the two experimental trials seven days. During familiarisation, the protocol of the study was explained to participants and they were familiarised with the methods involved.

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

(Insert figure 2.1 here)

Participants were recruited from five local schools. For descriptive purposes, the Index of Multiple Deprivation (an indicator of socio economic status) for each of the schools can be seen in table 2.2. Upon arrival at school participants were provided with breakfast if completing the breakfast trial. Participants were given 15 minutes to consume breakfast. After breakfast (or after 15 minutes resting on the no breakfast trial), participants completed the mood questionnaire and cognitive function tests. Following the tests, the subgroup who were participating in the finger prick blood sample had this measure taken. Participants then returned to normal lessons for approximately 90 minutes, after which they reported back to investigators and repeated the mood questionnaire and cognitive function tests (120 minutes after baseline measures), along with the finger prick blood sample (if appropriate). The use of a 120 minute interval between testing sessions is based upon previous findings which indicate this is a sufficient period for the benefits of breakfast consumption to become apparent in young people [14, 15, 16]. All participants were then fed upon completion of the trial.

(Insert table 2.2 here)

2.3: Breakfast

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

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

(Insert table 2.3 here)

2.4: Mood Questionnaire

The mood questionnaire was a modified version of the 'Activation-Deactivation Check List' (AD ACL) short form [17]. The 20 item questionnaire was split into four components of mood; energy, tiredness, tension and calmness, each having five corresponding adjectives on the questionnaire. The original AD ACL short form was piloted in an adolescent population and subsequently five of the adjectives were changed to ensure suitability for the study population. The adjectives used and their corresponding components of mood were; energy: active, energetic, alert, lively and wide-awake; tiredness: sleepy, tired, drowsy, exhausted and fatigued; tension: anxious, nervous, fearful, worried and tense; and calmness: restful, calm, at-rest, laid-back and quiet. The scoring system was also slightly modified, with participants asked to respond on a scale of 1 to 5 regarding how they felt at that moment in time (where 1: definitely do not feel, 3: unsure, 5: definitely feel). The scores on the adjectives for each component of mood were summed, providing an overall score for each component.

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

2.5: Cognitive Function Tests

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

2.5.1: Visual Search Test

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

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

2.5.2: Stroop Test

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

The baseline level contained 20 stimuli, where the test word was printed in white on the centre of the screen and the participant had to select the target word, from the target and distractor, which were also printed in white. The colour-interference level contained 40 stimuli and involved the participant selecting the colour the test word was written in, rather than the actual word (which was an incongruent colour), again using the right and left arrow keys to identify the target. The choices remained on the screen until the participant responded. The variables of interest were the RT of correct responses (in ms) and the proportion of correct responses made.

2.5.3: Sternberg Paradigm

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

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

2.6: Finger Prick Blood Sample

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

2.7: Statistical Analysis

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

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

3. Results

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

3.1: Mood

3.1.1: Energy

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

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

3.1.2: Tiredness

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

3.1.3: Tension

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

3.1.4: Calmness

There was no difference in self-report calmness between the breakfast and no breakfast trials (main effect of trial, $p = 0.215$). However, there was a main effect of session time ($F(1,95) = 24.2$, $p < 0.0005$) with participants reporting a greater level of calmness early in the morning, compared to later in the morning (15.9 vs. 14.6 respectively). The pattern of change in self-report calmness across the morning was similar between the breakfast and no breakfast trials (trial by session time interaction, $p = 0.397$).

3.1.5: Hunger

Analysis revealed a main effect of trial on self-report hunger ($F(1,94) = 240.5$, $p < 0.0005$). As expected, self-report hunger was higher on the no breakfast trial compared to the breakfast trial (8.0 vs. 3.6 respectively). There was also a main effect of session time ($F(1,94) = 114.4$, $p < 0.0005$), with self-report hunger higher later in the morning when compared to the early morning session (6.7 vs. 4.8 respectively). Furthermore, self-report hunger increased on both the breakfast and no breakfast trials, though the increase was greater on the breakfast trial (trial by session time interaction, $F(1,94) = 33.8$, $p < 0.0005$, figure 3.1).

(Insert figure 3.1 here)

3.1.6: Fullness

As expected, the results from the fullness VAS scale show the opposite effects to that of hunger. Analysis revealed a main effect of trial ($F(1,94) = 290.3$, $p < 0.0005$) with self-report fullness higher on the breakfast trial when compared to the no breakfast trial (6.0 vs. 1.6 respectively). There was also a significant main effect of session time ($F(1,94) = 112.1$, $p < 0.0005$) with higher self-report fullness early in the morning compared to later in the morning (4.5 vs. 3.0 respectively). Furthermore, self-report fullness decreased across the morning on both the breakfast and no breakfast trials, though the decrease was greater on the breakfast trial (trial by session time interaction, $F(1,94) = 36.4$, $p < 0.0005$, figure 3.2).

(Insert figure 3.2 here)

3.2: Cognitive Function Tests

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

3.2.1: Visual Search Test

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

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

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

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

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

(Insert figure 3.3 here)

3.2.2: Stroop Test

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

There was no main effect of breakfast on response times on the Stroop test (main effect of trial, $p = 0.558$). However, students responded on average 11 ms faster later in the morning compared to earlier in the morning (main effect of session time, $t(1,21630) = -2.8$, $p = 0.005$) and as expected, students responded faster on the baseline than the complex level, on average by 347 ms (main effect of test level, $t(1,21630) = 17.2$, $p < 0.0005$).

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

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

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

(Insert figure 3.4 here)

3.2.3: Sternberg Paradigm

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

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

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

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

(Insert figure 3.5 here)

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

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

3.3: Blood Glucose Concentrations

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

(Insert figure 3.6 here)

4. Discussion

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

4.1: Visual Search

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

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

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

4.2: Stroop Test

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

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

4.3: Sternberg Paradigm

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

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

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.

4.4: Mood

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

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

Comparisons between the present study and those detailed above should be made cautiously for a number of reasons. First, the above studies have all used different methods of assessing mood and are therefore assessing different dimensions of mood. Furthermore, the above studies have tended to use mood questionnaires designed for use in adults, thus their suitability for use in young people must be questioned. Interestingly, the studies where a consistent effect of breakfast consumption on mood has been demonstrated have been conducted in adolescents, rather than younger children. This could be explained in two ways; firstly it could be that breakfast consumption does not affect mood in younger children but does so in adolescents, or it could be that younger children are unable to understand the construct of mood and/or use the mood questionnaires accurately because they were designed to be used in adults, highlighting the need for any mood questionnaire that is used to be suitable for the study population.

4.5: Summary and Future Research Directions

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

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

In summary, the findings of the present study suggest that breakfast consumption does improve cognitive function in an adolescent population. Therefore, because of this improvement in cognitive function and the other suggested health benefits of breakfast consumption [4] it is a practice that should be promoted in adolescent populations. However, further work is required to examine the optimal composition of breakfast (with particular interest in the glycaemic index), the optimal timing of breakfast, and to suggest potential mechanisms for an effect of breakfast consumption on cognitive function.

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