The Effect of Breakfast Consumption Prior to Exercise on Cognitive Performance, Mood and Appetite

Rachel C. Veasey

PhD

2013

The Effect of Breakfast Consumption Prior to Exercise on Cognitive Performance, Mood and Appetite

Rachel C. Veasey

A thesis submitted in partial fulfilment of the requirements of the University of Northumbria at Newcastle for the degree of Doctor of Philosophy

Research undertaken in the Faculty of Health and Life Sciences

November 2013

Abstract

Exercise can improve mood and some facets of cognitive performance acutely and may suppress appetite transiently. Breakfast consumption is associated with mood and memory enhancement and superior control of appetite and body weight. Beneficial pre-exercise nutritional practices for those who exercise for mood, cognitive and appetite benefits, rather than to improve physical performance, have not been well established. Therefore, the current PhD programme aimed to uncover the potential effects of breakfast consumption prior to exercising on cognitive function, mood and appetite later in the day, with a particular focus on recreationally active females, an under-represented population in this area of research.

The results from two intervention studies presented in this thesis determined that consuming, compared to omitting, breakfast prior to exercise reduced appetite until the next meal was consumed and abridged mental fatigue in the post-exercise recovery period in active males (Chapter 2) and females (Chapter 5). Active females may choose to undertake morning exercise in a fasted state to avoid discomfort during exercise and due to lack of time (Chapter 3), but post-exercise, overall mood positively correlated, and mental fatigue inversely correlated with breakfast size prior to exercise in active females when assessed in a field setting (Chapter 4); however, consuming a lower energy dense breakfast still elicited the aforementioned positive effects, and was preferential to consuming a larger breakfast to avoid cognitive detriments in the afternoon when measured in a laboratory setting (Chapter 5).

To conclude, the results from this thesis suggest that consuming breakfast prior to morning exercise is beneficial for post-exercise mood and appetite in both habitually active men and women, but consuming a large breakfast may impair cognitive function after exercise. Consuming a light breakfast pre-exercise may be a particularly beneficial practice for habitual female exercisers who chose to omit breakfast prior to exercise due to lack of time or to avoid discomfort during exercise.

Contents

List of Tables

List of Figures

List of Abbreviations

ANOVA	analysis of variance
ART	arrow reaction time
AUC	area under the curve
BCAAs	branched-chain amino acids
BDNF	brain-derived neurotrophic factor
BE	breakfast and exercise
BMI	body mass Index
BNE	breakfast and rest
CDR	cognitive drug research
CFB	change from baseline
CHO	carbohydrate
CRT	choice reaction time
COMPASS	computerised mental performance assessment system
CNS	central nervous system
EE	energy expenditure
EI	energy intake
EEG	electroencephalography
FCRT	four choice reaction time
g	grams
GI	glycaemic index
GIP	glucose-dependent insulinotropic peptide
GLP-1	glucagon-like peptide 1
HR	heart rate
HR max	maximum heart rate
HRR	heart rate reserve

h	hour/s
IPAQ	international physical activity questionnaire
kcal	kilocalorie
MPS VAS	mood and physical state visual analogue scales
min	minute/s
MJ	mega joules
NBE	no breakfast and exercise
NBNE	no breakfast and rest
OR	odds ratio
PE	physical education
PYY	peptide YY
RPE	rate of perceived exertion
RT	reaction time
RVIP	rapid visual information processing
sec	second/s
SEM	standard error of the mean
SRT	simple reaction time
TFEQ	three factor eating questionnaire
VAS	visual analogue scale
$\dot{V}O_2$	oxygen uptake
$\dot{V}O_2$ max	maximal oxygen uptake

Publications and Conference Proceedings

Data within this thesis has formed the basis of the following peer reviewed publications:

Veasey RC, Gonzalez JT, Kennedy DO, Haskell CF, Stevenson EJ (2013). Breakfast consumption and exercise interact to affect cognitive performance and mood later in the day. A randomized controlled trial. Appetite, 68(0):38-44

Gonzalez, J. T., Veasey, R. C., Rumbold, P. L. S. & Stevenson, E. J. (2013). Breakfast and exercise contingently affect postprandial metabolism and energy balance in physically active males. *British Journal of Nutrition, FirstView*, 1-12.

Conference Proceedings

The effect of breakfast size prior to morning exercise on cognitive performance, mood later in the day in habitually active women

Rachel Veasey, Crystal Haskell, David Kennedy, Brian Tiplady and Emma Stevenson

Oral presentation, PsyPAG 2013, Lancaster

Veasey, R. C., Kennedy, D. O. Haskell, C. F., Tiplady, B., Stevenson, E. (2013).

The effect of breakfast prior to morning exercise on cognition and mood in female habitual morning exercisers: an observational study (*Appetite*, abstract in press)

Poster presentation, British Feeding and Drinking Group Annual Conference 2013, Loughborough

Veasey, R. C., J. T. Gonzalez, Kennedy, D. O. Haskell, C. F. Stevenson, E. (2012). Breakfast consumption and exercise interact to affect appetite, cognitive performance and mood later in the day. *Appetite,* **59**(2): 636.

Oral presentation, British Feeding and Drinking Group Annual Conference 2012, Brighton

Acknowledgments

I would firstly like to thank my supervisory team Dr Emma Stevenson, Dr Crystal Haskell and Professor David Kennedy. I feel privileged to have been offered a PhD under their supervision and the guidance and support they have provided over the last few years has been instrumental in the completion of my PhD.

I would like to thank Brian Tiplady for his technical assistance and all of the participants who took part in my studies for their time and cooperation.

I would like to thank my colleagues in the BPNRC for their friendship, advice and excellent banter, all of which made my PhD journey a little easier.

Lastly, I would like to thank Rob and my family, whose continuous encouragement and support saw me through the tougher times.

Authors Declaration

I declare that the work contained in this thesis has not been submitted for any other award and that it is all my own work. I also confirm that this work fully acknowledges opinions, ideas and contributions from the work of others.

Ethical approval for the research presented in this thesis been sought and granted by the Faculty of Health and Life Sciences Ethics Committee at Northumbria University.

Name:

Signature:

Date:

Chapter 1: Introduction and Literature Review

1.1 General introduction

A large proportion of the general population exercise regularly for physical and psychological benefits, which are well documented in the literature (e.g. Miles, 2007). Acutely, exercise can improve mental function (Lambourne & Tomporowski, 2010; Tomporowski, 2003), psychological state (Lluch, Hubert, King & Blundell, 2000; Maroulakis & Zervas, 1993) and mood (Ströhle, 2009) and is also a popular method of weight control, particularly among women (Silliman, Rodas-Fortier & Neyman, 2004).

Subjective mental state and weight regulation can also be improved by following healthy dietary practices; one such practice is regular breakfast consumption (Barton et al., 2005; Pereira et al., 2011; Smith, 1998). If exercise is undertaken in the morning, breakfast is a likely source of pre-exercise nutrition and whilst there are nutritional guidelines available for athletes to follow with regards to improving exercise performance, for example, consuming carbohydrate (CHO) following an overnight fast and 2-4 h before exercise (Hargreaves, Hawley & Jeukendrup, 2004), these strategies may not be applicable to those exercising recreationally for benefits other than performance enhancement.

Little is known about how pre-exercise nutrition affects post-exercise mental performance, mood and appetite and the relationship between breakfast consumption and exercise has not been explored in depth. Eating breakfast prior to a morning physical education lesson has been shown to benefit children's cognitive performance before lunch (Vermorel, Bitar, Vernet, Verdier & Coudert, 2003), a finding that may arguably apply to adult morning exercisers. However, other studies have shown no effect of breakfast consumption prior to exercise on cognitive performance or mood (Hill, Whitehead & Goodwin, 2011; Paul, Rokusek, Dykstra, Boileau, & Layman, 1996). Breakfast is a commonly skipped meal for women (Ozdogan, Ozcelik, & Surucuoglu, 2010; Silliman et al., 2004), who are more likely to use this practice for weight control than men (Dundes, 2008) and it is generally understood that women are somewhat under-represented in exercise research.

Previous research, whilst providing some insight into the effects of pre-exercise breakfast consumption on post-exercise cognition, mood and appetite, does not as yet allow clear conclusions to be made. To begin to address this, the studies that form this PhD thesis started by investigating the effect of breakfast consumption or omission, prior to exercise or rest in an active male population (Chapter 2). In Chapter 3, a survey was designed to collect data on the dietary and exercise habits of an active female population, the observations from which were developed further in Chapter 4, when the effects of breakfast prior to morning exercise on cognitive performance, mood and appetite in a habitually active female sample were examined in a field setting. In Chapter 5, the final study investigated the effect of consuming either no breakfast or breakfasts differing in energy content prior to morning exercise on cognitive function, mood and appetite in an active female sample.

1.2 The effect of breakfast on cognition, mood and appetite

Breakfast has been previously defined as "the first meal of the day, eaten before or at the start of daily activities (e.g. errands, travel, work), within 2 hours of waking, typically no later than 10:00 in the morning, and of an energy level between 20 and 35% of total daily energy needs" (Timlin & Pereira, 2007; page 6). A recently conducted survey reported that the foods most commonly consumed at breakfast in a UK population, particularly on weekdays, were cereals, porridge and muesli and bread and toast (Reeves, Halsey, McMeel & Huber, 2013).

The importance of breakfast as a meal has been studied comprehensively. It has received widespread attention over recent years and, generally, data associates regular breakfast consumption with numerous health benefits, including improved cognitive function, in particular memory, mood and appetite control. Appropriate to the studies conducted as part of this PhD, the focus of this review will be on data from adult populations.

1.2.1 Breakfast and cognition

Over recent years, extensive research has been conducted looking at the effect of breakfast consumption on cognition. Although results have varied, many researchers have reported an improvement in some facets of cognitive function following acute breakfast consumption compared to omission (for review see Hoyland, Dye & Lawton, 2009). Fairly robust evidence suggests that consumption of breakfast is associated with improved memory (Benton & Parker, 1998; Benton & Sargent, 1992; Benton, Slater and Donohoe, 2001; Smith, Clark & Gallagher, 1999; Smith, Kendrick, Maben & Salmon, 1994; Smith & Wilds, 2009), with results for other cognitive domains presenting a less clear picture.

Smith, Kendrick, Maben and Salmon (1994) conducted a between subjects study investigating the effect of no breakfast, a cereal breakfast or a cooked breakfast, both providing 450 kilocalories (kcal) consumed with caffeinated or decaffeinated coffee, on simple reaction time (SRT) and choice reaction time (CRT) and vigilance, measured using a repeated digits task. Forty eight young healthy adults (24 female) were assigned to one of the 6 conditions and completed the cognitive tasks 1 and 2 h after breakfast. There were no reported effects of breakfast condition on any of the cognitive tasks. It could be argued that 8 participants per group is a relatively low number for statistical analysis and may explain the lack of significant effects found. In a follow-up study, the same authors investigated the effect of no breakfast or a cooked breakfast (450 kcal) consumed with caffeinated or decaffeinated coffee on memory and logical reasoning. Memory was measured using a word recall and delayed word recall task to assess episodic memory and a sentence verification task to measure semantic memory. Forty eight healthy young adults (24 females) each participated in one of the 4 conditions, completing the tasks 1 and 2 h after breakfast. Contrary to the lack of effects on attention and vigilance in the previous study, consuming breakfast led to superior word recall performance 1 h post-breakfast and fewer errors on the recognition memory task but reduced accuracy on the logical reasoning task. Sentence verification performance was unaffected. These findings may suggest a specific effect on memory or may reflect the increase from 8 to 12 participants per cell due to the reduction in treatment arms.

In 1998, Benton and Parker reported the results from a series of three studies which investigated the effect of breakfast on cognitive performance. In the first study, 33 young healthy adults (16 women) who habitually consumed breakfast either fasted or consumed a milk-based energy drink for breakfast providing 327 kcal. Following a 2 h break, they completed a spatial memory task and a word recall task. Participants were slower at completing the spatial memory task, but spent longer trying to recall words on the word list task when fasted. In the second experiment, 80 young adult females participated in one of four experimental conditions; breakfast and glucose drink, breakfast and placebo drink, fasted and glucose drink and fasted and placebo drink. Participants selected and consumed their typical breakfast before attending the laboratory, the mean energy content of which was 251 kcal and consisted of cereal and milk, toast and condiments or a combination of both. The Brown-Peterson task (where participants remembered three letter sequences while counting backwards, in threes, for various lengths of time) was used to measure working memory and information processing 20 min after consumption of the drink. When breakfast was omitted, performance augmentation was seen only when the glucose drink was consumed. When breakfast was consumed, compared to omitted, performance was enhanced in both drink conditions. Whilst 80 participants is a reasonable number for a between subjects design, it should be noted that the number of participants who completed each condition was not equal. In their final experiment, 184 young healthy adults (137 women) again consumed their own breakfast before attending the laboratory and were assigned to one of four conditions as described in experiment 2. Twenty min after drink consumption, participants completed a word recall task, the Wechsler Memory Scale task (the recalling of a story) and the Graduate and Managerial Assessment of Abstract Reasoning task (participants are presented with problems, such as a sequence progression, that can be solved with logical reasoning). When breakfast was consumed, more words were recalled on the Wechsler Memory Scale task. Again, the glucose drink augmented performance in the fasted condition, but drink type did not influence performance amongst the breakfast consumers. The abstract reasoning and word recall tasks were unaffected by either breakfast condition. It should be noted that these experiments did not include baseline measures of task performance and whilst the number of participants included in these studies does somewhat compensate for the lack of a repeated measures design, the unbalanced group sizes is an undesirable practice in research.

Smith, Clark and Gallagher (1999) investigated the effect of breakfast or no breakfast consumed with a caffeinated or decaffeinated beverage on selective attention and CRT using a categoric search task, recall memory using a digit recall task and spatial memory performance using a computerised corsi blocks task. Participants (N=144, 72 female) were assigned to one of the 4 conditions, completing tasks at baseline and 2.5 h post-breakfast. They were allowed to select the type and amount of breakfast cereal they consumed (the average energy content of breakfast was 208 kcal). Breakfast improved spatial memory performance, but had no effect on selective attention, CRT or recall memory.

Benton, Slater and Donohoe (2001) assessed the effect of no breakfast and two cereal breakfasts (providing 51 and 253 kcal) using a word recall task completed 15 and 45 min post-breakfast. Participants (150 young healthy females) who consumed breakfast, as opposed to fasted, spent longer trying to recall words, but task accuracy was unaffected, with no differential effect for the breakfast groups. The authors speculated this was due to an increase in motivation following breakfast consumption.

More recently, Smith & Wilds (2009) assessed the effect of consuming a cereal bar for breakfast (providing 133 kcal) or no breakfast, when combined with a mid-morning snack or no snack on memory, logical reasoning and semantic processing. These were measured using an immediate word recall task, a delayed word recognition task, a letters logical reasoning task and a sentence verification task. Thirty two participants (16 female) took part in one of the four conditions. Consumption of the cereal bar for breakfast improved word recall performance compared to remaining fasted, but no other tasks were influenced. As mentioned previously, it would certainly be desirable to have a larger number of participants in each group when conducting a between subjects experiment. Smith and Stamakatis (2010) conducted a similar between-subjects experiment using a high-fibre cereal bar (144 kcal) and reported the same positive effects on word recall performance in 20 young healthy participants (15 male) when memory was assessed 40 min post-breakfast.

It is of course also important to consider that consuming, compared to omitting, breakfast has also been shown to have no effect, or even an unfavourable effect on cognition. A previous study has shown no detrimental effect on cognitive function of missing breakfast, or indeed both breakfast and lunch. Cognitive function was measured using the Bakan vigilance task, a finger tapping task to measure motor speed, a SRT task, immediate word recall to measure memory and a focussed attention task measuring distractibility in a young female adult population (N=21; Green, Elliman & Rogers, 1995). The same authors reported similar findings when a larger mixed gender sample (N=82) was assessed after missing breakfast or lunch. In this study, no effect of food deprivation was seen on rapid visual information processing (RVIP), SRT, motor speed, measured using a finger tapping task and episodic memory, measured using word recall (Green, Elliman &

Rogers, 1997). However, the participants were allowed to consume tea and coffee prior to the test sessions, a factor which could have influenced the findings given the known effect of caffeine on cognitive function (Nehlig, 2010) and the authors also failed to specify the number of males and female participants in their sample.

As previously described, Smith et al. (1994) reported no effect of consuming breakfast or remaining fasted on SRT and CRT, vigilance (measured using a repeated digits task) and semantic memory performance (involved in the speed of information retrieval) but did find reduced accuracy on a logical reasoning task when breakfast was consumed (Smith et al., 1994). Lloyd et al. (1996) assessed cognitive function 30, 90 and 150 min post-breakfast or post-fasting in 16 healthy young adults (14 female) who habitually consumed breakfast. The breakfast consisted of a bread roll with margarine and jam and a milkshake. They reported no effect of breakfast consumption on the RVIP, finger tapping or SRT tasks, and surprisingly, on the word recall task when compared to the fasted condition. However, whilst this study did administer bread and milk products for breakfast which are commonly consumed items at this meal, the study provided breakfast meals much higher in energy than that which their sample usually consumed, which could have influenced the results; perhaps if a breakfast is too large, any beneficial cognitive effects are negated.

Several of the aforementioned authors (Smith, Kendrick, Maben & Salmon, 1994; Benton & Parker, 1998; Benton, Slater & Donohoe, 2001; Smith & Wilds, 2009) have examined or speculated the role that glucose and/or insulin may have regarding the effect of breakfast on the cognitive improvements observed. Other mechanisms which could account for cognitive changes, positive and negative, following breakfast consumption included changes in serotonin, a neurotransmitter which can positively influence memory and learning (Buhot, 1997; Park et al., 1994; Schmitt, Wingen, Ramaekers, Evers & Riedel, 2006), but may increase reaction time (RT) (Silber & Schmitt, 2010) and an increase in cortisol concentration which can impair memory an effect which may be more likely to occur if the cognitive tasks administered are particularly stressful (Buchanan, Tranel, & Adolphs 2006). These possible mechanisms are discussed in further detail in section 1.2.1.6.

It could be speculated that some cognitive domains and tasks may be only be susceptible to change when a certain type of breakfast is consumed, at a certain time following breakfast consumption or in a particular population, which advocates additional research manipulating these variables before more definite conclusions can be drawn. Indeed, there are a number of possible factors that could impact on findings in this area: these will be considered in the following sections.

1.2.1.1 Participant characteristics

It is important to consider that the cognitive effects of breakfast do appear to vary depending on the population being studied. Positive breakfast effects are seen more clearly in children and adolescents (Hoyland et al., 2009), in particular in poorly nourished children (for review see Grantham-McGregor, 2005), which has led to a large number of research studies in these populations over recent years. Particular emphasis has been placed on this population due to the importance of, and opportunity for, maximising academic performance. The data does suggest that there is a link between breakfast habits and academic performance in this population (for review see Adolphus, Lawton and Dye, 2013) and it has been suggested that breakfast consumption may increase alertness and motivation to concentrate and learn (Hoyland et al., 2008). For example, Wesnes, Pincock, Richardson, Helm and Hails (2003) found that not consuming breakfast led to poorer attention and episodic memory when measured using the cognitive drug research (CDR) computerised assessment battery (which measures the speed of memory, accuracy of episodic and working memory and speed and accuracy of attention; Wesnes, Pincock, Richardson, Helm & Hails, 2003) in school children (N=19, 15 female), but these declines were abridged towards the end of the morning following consumption of a cereal breakfast 2.5 h earlier. Breakfast may not only influence academic performance in children; in a recent study, when young, healthy adults (N=6, 1 female, mean age 20.9 years) received a nutritionally balanced breakfast (in liquid form), they felt more able to concentrate up to 90 min after breakfast compared to when they consumed water only (Akitsuki et al., 2011). However, this study was only conducted using a very small number of participants and therefore these results should be viewed with some caution. A large proportion of breakfast and cognition studies that have used a young, healthy adult sample have recruited from university student populations. This is an issue which is often raised by researchers, but the convenience of recruiting from this population often supersedes addressing this problem. There are studies which have investigated these effects in an older adult population (e.g. Nilsson, Radeborg & Bjorck, 2012), but there does need to be a conscious effort to conduct more studies in this group to allow data to be applied to a larger proportion of the population.

With few exceptions (e.g. Benton & Parker, 1998; Nabb & Benton, 2006), the majority of research investigating the effects of breakfast on cognitive function in adults has been conducted in mixed gender samples. Studies, especially those conducted in recent years, have also tended to use a balanced gender design, although not exclusively (Benton & Parker, 1998; Lloyd, Rogers, Hedderley & Walker, 1996; Smith & Stamatakis, 2010). These methods have obvious benefits, the key one being that results can be applied to a larger percentage of the general population. Those using large balanced-gender samples also have the potential to directly compare between the genders, although this is rarely done. However, when measuring the effect of breakfast on cognitive function it could be speculated that there are indeed gender differences; for example, differences in how macronutrients, in particular fat (Jensen, 1995), are processed, differences in resting metabolic rate (Arciero, Goran & Poehlman, 1993) and greater insulin-sensitivity in women than men (Geer & Shen, 2009) are all factors which may potentially affect cognitive response to a meal. Indeed, there is some evidence which shows a stronger association between glucose tolerance and cognitive function in females compared to males (Lamport, Lawton, Mansfield and Dye, 2009) and women are also more likely to skip breakfast than men (Dundes, 2008), suggesting that information on the effect of this practice may be more relevant to this gender.

It has been reported that those who consume breakfast are more likely to be physically active (Reeves et al., 2013). However, the role of breakfast consumption on cognitive functioning in active populations specifically has not been explored in depth to date. It is possible that the effects of breakfast on cognition may be influenced by exercise undertaken, given the known effects of exercise on cognitive performance. This potential relationship is a main focus of this thesis and will be discussed in section 1.4 of this literature review.

1.2.1.2 Habitual behaviours

It has been considered that the effect of breakfast on cognitive function may differ depending on the regular breakfast habits of the studied population. In an early study by Richards

(1972) it was reported that in both habitual and non-habitual breakfast consumers, task performance was poorer when individuals deviated from their habitual breakfast practice. More recently, it has been suggested that if breakfast is consumed regularly, omitting breakfast occasionally may not have a negative impact on cognitive performance; rather these effects may only be seen if breakfast is omitted over a long period of time (Kral, Heo, Whiteford & Faith, 2012); Benton and colleagues (2003) also report that data from two of their laboratory studies suggest that habitual breakfast habits do not influence the effect of breakfast on cognitive function. In addition, when a meal closely resembles an individual's habitual diet (e.g. medium-fat, medium-CHO) optimal performance may be seen and vice versa (Lloyd, Green & Rogers, 1994; Lloyd et al., 1996). Some studies have addressed this problem by allowing participants to consume their own breakfast before attending the laboratory or by providing a variety of breakfasts from which participants can choose the type and amount they consume (Benton and Parker, 1998; Smith, Clark and Gallagher, 1999). It appears important to control, or at least account, for habitual behaviours in breakfast studies although it could be speculated that this factor would more likely influence subjective, rather than objective measures.

It has also been proposed that an overnight fast may not be sufficient to eradicate the effects of the evening meal consumed prior to a morning test session (Lamport, Hoyle, Lawton, Mansfield & Dye, 2011). Lamport et al. (2011) evaluated this in 14 healthy male participants and reported improved verbal memory the following morning when a high, rather than low, glycaemic index (GI) meal was consumed the previous evening. To date, very few studies in this area have controlled this factor, highlighting a possible flaw in many previous breakfast research studies, and a need to control or monitor dietary intake the evening prior to morning testing.

1.2.1.3 Methodological differences

It is of course important to consider the methodological differences between studies which have investigated the effect of breakfast on cognitive function. In particular, differences in the type of breakfast provided, the cognitive tasks administered and the time period between breakfast consumption and task completion can make comparisons between studies difficult. Whilst some studies have chosen to administer items which perhaps reflect more commonly consumed breakfasts, such as cereal-based products or toast (Smith et al., 1994; Smith et al., 1999; Smith & Wilds, 2009), others have used nutrient-rich beverages (Benton & Parker, 1998; Benton & Sargent, 1992), cooked breakfasts (Smith, et al., 1994) or even pure macronutrients in the form of creams (Fischer et al., 2001; Fischer et al., 2002; Zeng et al., 2011). Whilst these studies do add to knowledge in this area, the relevance of using breakfasts which are not ordinarily consumed in the general population can be questioned.

Some studies have allowed participants to choose how much cereal they consume (Smith et al., 1999) or asked them to consume their own breakfast before attending the laboratory (Benton & Parker, 1998). Benton and Parker (1998) gave details of the average EI and nutrient content of breakfast intake in only one of two studies where they applied this methodology, making it hard to ascertain how this procedure may have influenced the study results. However, these techniques do go some way to eradicate the possible influence of acceptability of the breakfast intervention and do give these studies some “real-life” validity.

The timing of post-breakfast task administration in previous studies has varied. For example, the effects of breakfast interventions have been assessed 60 min (Smith et al., 1994, 1999 and 2009), 90 min (Smith, 2009), 120 min (Smith, 1994; Benton and Parker, 1998), and 3-3.5 h (Smith, 1992) following consumption. It is of course useful to measure performance at different time points to determine when the effects of breakfast on cognitive function may be most prominent, but these inconsistencies can make it difficult to directly compare data between studies. Furthermore, changes in circadian rhythm leads to changes in an individual’s mood and memory as the morning progresses (Smith & Wilds, 2009); therefore the effect that breakfast has on these parameters may very well depend on what time it is administered. In addition, the timing of breakfast and task administration post- waking is another factor which is rarely considered, although some studies have attempted to control sleep quality by advising 8 h sleep the night before testing (Fischer et al., 2001; 2002; Zeng et al., 2011).

The use of a wide variety of tasks to test the same cognitive attribute can also confound the data somewhat. Results from simple tasks which have fairly fixed rules, such as the word recall task which has been readily used (Benton and Parker, 1998; Michaud, 1991; Smith, 1999; Smith, Kendrik & Maben, 1994; Smith & Wilds, 2009), can be compared reasonably confidently. When considering task choice for a study, or a series of studies, it would be beneficial to select commonly used tasks such as this to allow for easier comparison between results.

1.2.1.4 Breakfast size and nutritional content

The health benefits of regular breakfast consumption are often attributed to its nutritional content; a meal which provides essential nutrients which can contribute to better overall nutritional status (Rampersaud, Pereira, Girard, Adams & Metzl, 2005; Ruxton & Kirk, 1997). Adults who regularly consume breakfast tend to have a diet higher in fibre and nutrients and an overall lower energy intake (EI) than those who skip breakfast (Timlin & Pereira, 2007). Past research investigated the effect of the nutritional content of breakfast on subsequent cognitive performance, with mixed results. In the aforementioned study by Lloyd et al. (1996), the authors reported no difference in cognitive performance for any of the tasks administered following no breakfast or the consumption of three breakfasts which differed in CHO and protein content. However, when Zeng et al. (2011) assessed the cognitive effect of two isoenergetic breakfasts (813 kcal) which differed in protein content in 13 healthy young males, they reported that performance on a continuous performance test was better after consumption of the breakfast containing a high (protein/CHO/fat ratio of 5:3:2), rather than just an adequate (1:7:2), amount of protein. It should be considered, however, that this study may lack validity by providing a breakfast that was both very high energy and in the form of a “cream”, neither of which likely reflect breakfasts that are normally consumed in the general population.

It should be recognised that impairments in cognitive performance following meal consumption, particularly one high in CHO which is often the case at breakfast, have been documented (Cunliffe, Obeid & Powell-Tuck, 1997; Fischer, Colombani, Langhans & Wenk, 2001). Cunliffe et al. (1997) administered three isoenergetic breakfasts (400 kcal) which differed in macronutrient content to 16 healthy adults. Cognitive function was measured hourly for 4 h post-consumption using a flicker fusion frequency task measuring central fatigue and RT. Subjective fatigue and RT were worse following the high-CHO breakfast. Fischer et al. (2001) assessed cognitive function, as measured using SRT and CRT tasks and a task combining measures of working memory and peripheral attention, in 15 young healthy male participants. Testing commenced 45 min after they had consumed one of three isoenergetic breakfasts (399 kcal) and occurred every 60 min for 3 h. The breakfasts differed in macronutrient content and were presented as “creams”. They reported cognitive detriments following both the CHO and protein-rich breakfasts but that fat ingestion at breakfast led to enhanced cognitive performance, likely due to the occurrence of a more stable post-prandial metabolic state. Despite a relatively small sample size, the alcohol, caffeine, dietary and physical activity restrictions that the authors placed on the participants for 24 h prior to testing is good practice and suggests the study was well controlled. In a later study, the same authors also found differences in cognitive performance in 15 male participants following the ingestion of meals with varied CHO:protein ratios. The same tasks were used as described in the previous study. Working memory performance was better after a protein rich meal at nearly every time point post-consumption, which was associated with the least fluctuations in glucose metabolism. This effect is associated with the GI of the meal provided and is discussed further in section 1.2.1.2. Central attention, as measured using the combined task, and CRT decision making times were superior after the CHO rich meal when measured immediately and 75 min post-consumption. However, this effect was transient and from 135 min post-ingestion performance was better after a protein rich or balanced protein/CHO meal (Fischer, Colombani, Langhans & Wenk, 2002). Cognitive impairment following a CHO-rich meal is often attributed to reduced alertness (Benton, 2002; Cunliffe et al., 1997). In relation to this, RT is a facet of cognitive function which appears to improve with increasing feelings of hunger, likely due to the positive relationship between hunger and alertness (Fischer, Colombani & Wenk, 2004).

These data perhaps suggest that consuming a smaller breakfast may lead to preferable cognitive responses to one which is both CHO and calorie dense which may be more likely to induce feelings of tiredness and reduced alertness. Nabb and Benton (2006) reported that performance on an immediate and delayed word recall test was better following consumption of low, rather than high, caloric breakfasts in healthy young females (N=189), although RT was unaffected. The breakfast they administered consisted of crisp breads served with one or more of jam, butter, cottage cheese or turkey breast, with an orange glucose or placebo drink. This effect was found despite both the low and high calorie breakfasts differing in macronutrient content, suggesting that overall energy content of breakfast may have a greater influence on cognitive function than its macronutrient content. Positive findings on cognitive function following consumption of a very low calorie breakfast have been found. In 2009, Smith and Wilds investigated the effect of consuming a small breakfast, in the form of a cereal bar, or no breakfast. They reported that volunteers (N=32; 16 female) who consumed a cereal bar (133 kcal) for breakfast recollected more words in a word recall task 60 min later. Similar findings on the same task were reported by Smith and Stamatakis (2010), when 20 healthy young adults (5 female) consumed a cereal bar similar in energy density (144 kcal) 40 min prior to testing (144 kcal; Smith & Stamatakis, 2010).

1.2.1.5 Glycaemic index (GI)

Over recent years, the effect of the GI of breakfast has also been studied. The GI of a food or meal represents its ability to increase blood glucose (Jenkins et al., 1981). Consuming a low, compared to high, GI breakfast appears more favourable for post-prandial glucose and insulin responses (Fischer et al., 2002; Liljeberg, Åkerberg, and Björck, 1999; Stevenson, Astbury, Simpson, Taylor & Macdonald, 2009). Liljeberg et al. (1999) assessed the effect of consuming seven cereal breakfasts which differed in GI on glucose response to a meal at lunch time. The participants (N=10, 6 female) were administered a standard lunch 4 h post-breakfast. Two of the four low-GI breakfasts administered led to a significantly lower glucose profile and improved insulin response post-lunch. In 2009, Stevenson et al. assessed the effect of consuming a low-GI (44) or high-GI (78) breakfast 3 h before walking for 60 min. Participants (8 sedentary females) were then given a standard lunch; post-lunch glucose and insulin responses were higher following the high-GI, compared to low-GI, breakfast.

The effect of GI on cognitive function has been studied in young healthy adults administered a glucose drink or similar, with the most obvious positive effects of a low-GI drink seen for delayed verbal memory (for review see Hoyland, Lawton and Dye, 2008). Benton et al. (2003) examined the effect of consuming a low (42.3) or high (65.9) GI breakfast on memory in 106 healthy young females. Memory performance, as calculated by combining scores from an immediate and delayed word recall task, was significantly better at 150 and 210 min post-consumption when the low, compared to high, GI breakfast was consumed. However, relatively little research on the effect of the GI of a typical breakfast meal on cognitive function has been conducted in young, healthy adults, with this theory more extensively evaluated in school children to date. It has been reported that a low-GI breakfast leads to superior cognitive function in this population when compared to a high-GI breakfast (Ingwersen, Defeyter, Kennedy, Wesnes & Scholey, 2007; Micha, Rogers & Nelson, 2010) although the evidence is not conclusive (Brindal et al., 2012). Ingwersen et al. (2007) investigated the effect of a high (77) or low (42) GI breakfast cereal on cognitive performance in school children (N=64; 38 females) aged 6-11 years. Cognitive function was assessed using the CDR computerised assessment battery immediately after and at 1 and 2 h post-breakfast. Their results showed that children's accuracy of attention and episodic memory declines throughout the morning, but that this decline can be attenuated by consumption of a low, rather than high, GI breakfast. However, in a more recent study, Brindal et al. (2012) reported no effect of breakfast (bread with condiments and milk or fruit juice) GI on 6 cognitive traits (speed of processing, working memory, perceptual speed, attention switching and inspection time) in children (N=39, 13 female) with an average age of 11.7 years. The timing of task administration was similar to that used by Ingwersen et al. (2007) but this inconsistency in results could reflect differences in the type of breakfast administered, the type of tasks administered and the slightly older age of the children tested.

Nilsson, Radeborg and Bjorck (2012) compared glucose response, working memory and selective attention in 40 healthy subjects (28 female) aged 49-71 years following consumption of a low-GI or high-GI meal (white wheat bread and a glucose drink either consumed as a bolus drink, or sipped slowly over a 150 min period). Selective attention was found to significantly improve following the low, compared to high, GI meal, although working memory was unaffected. The authors did use sentence verification and noun recall, a working memory task less common than others have often used in this area of research, and it may have been a lack of task sensitivity which elicited these null findings. It should be noted, however, that it is quite rare to see a breakfast and cognition study carried out in an older population, and studies such as this are useful to help to build an overall picture in this area of research.

Another index used to determine the glycaemic potential of a meal is the glycaemic load (GL), which describes the quantity and amount of CHO (Smith, 2011a). A recent review concluded that the evidence does not substantiate a reliable effect of GL on cognitive performance (Gilsenan, de Bruin & Dye, 2009). However, a study conducted more recently examined the effects of the glycaemic influence (both GI and GL) on cognitive performance of 60 children (aged 11-14 years, 36 girls) when they consumed their own breakfast at home before testing. The cognitive tasks consisted of a word generation task, immediate and delayed word recall, Stroop, a mathematics task, number search and serial seven subtractions. A low-GI/high-GL breakfast was associated with faster information processing and better serial seven subtraction performance, and a high-GI/low-GL breakfast was associated with superior performance on the immediate word recall task (Micha, Rogers & Nelson, 2010). These differing effects of opposite GI/GL profiles may explain the inconsistencies in tasks affected in the previously described breakfast studies.

The notion that a low GI-meal is beneficial for cognitive function is supported further when we consider that several aforementioned breakfast studies have reported superior cognitive performance following the ingestion of a meal containing higher protein or fat, both of which corresponded with a more consistent blood glucose response (Fischer et al., 2001; Fischer et al., 2002; Zeng, Li, Xiong, Su & Wan, 2011). Improved glucoregulation following macronutrient consumption is thought to be preferential for cognitive performance (Meikle, 2004; Messier, 1997), as a less fluctuating glucose profile may reflect lower metabolic stress (Hoyland, Dye and Lawton, 2008). Indeed, Nabb and Benton (2006) reported that memory performance was better following consumption of low caloric meals which led to only minor increases in blood glucose (details as previously described in section 1.2.1.1).

These metabolic effects are not only seen in the immediate breakfast post-prandial period; it appears that consumption of breakfast also favourably alters the glycaemic response to macronutrients consumed at a second meal a few hours later, which could provide longer lasting cognitive benefits (Liljeberg, Åkerberg & Björck, 1999; Astbury, Taylor and Macdonald, 2011). Consuming breakfast "breaks" the overnight fast and therefore the metabolic consequences of its consumption are important; the role that glucose metabolism may play in the effect of breakfast on cognitive function is discussed further in the following section.

1.2.1.6 Mechanisms of action of the effect of breakfast on cognition

The possible mechanisms for the effect of breakfast on cognitive function have been explored but are not yet fully established (Hoyland et al., 2008). As previously mentioned, regular breakfast consumption can contribute to an improved overall nutrient status (Rampersaud et al., 2005; Ruxton & Kirk, 1997), which may consequently lead to better brain function. However, the acute cognitive effects of breakfast have been mainly discussed with regards to glucose availability. It is well documented that the brain requires a continuous supply of glucose to function efficiently and an insufficient glucose supply can be detrimental for cognitive function (Amiel et al., 1991; Gold, MacLeod, Thomson, Frier & Deary, 1995). Following an overnight fast, liver glycogen stores are reduced, and must be replenished. When a meal is consumed, the pancreas releases insulin, a hormone which enables digestion of starches and sugars. Insulin acts as a key, effectively allowing the cell to take up glucose from the bloodstream via glucose transporter proteins (GLUT) in the cell's membrane. Of particular importance when considering glucose supply to the brain are the GLUT-4 transporters, which have been identified in several brain regions (Hopkins & Williams, 1997; McCall et al., 1997). GLUT-4 transporters are sensitive to insulin and play a central role in clearing the blood stream of excess glucose during the post-prandial period (Debons, Krimsky & From, 1970). After a meal, the number of GLUT-4 receptors on a cells surface rises, increasing glucose uptake. Within the cells, glucose is metabolised and produces heat and adenosine triphosphate (ATP) a molecule responsible for releasing energy as required. If inadequate insulin is produced, or insulin sensitivity in the cells is impaired (insulin resistance) this leads to an undesirable rise in circulating blood glucose and reduced uptake into the cells, such as those in the brain, where energy may be needed. Impaired glucose tolerance is a condition directly related to insulin resistance and is defined as having elevated blood glucose 2 h after a glucose load has been consumed (American Diabetes Association, 2013). Consuming any meal provides the brain with macronutrient energy in the form of glucose. However, it is perhaps the timing of breakfast compared to other meals, consumed in the morning to “break” the previous overnight fast and replenish depleted glucose concentrations, which elicits its benefits and therefore importance in the diet with regards to cognitive performance (Benton & Parker, 1998; Lieberman, Falco & Slade, 2002; Pollitt & Mathews, 1998). Consuming breakfast may influence brain function by altering an individual’s metabolism, increasing the preservation and availability of nutrients to the central nervous system (CNS), or by controlling the effectiveness of cognitive processing (Pollitt & Mathews, 1998). Indeed, it has been reported that omitting breakfast can impair insulin sensitivity acutely (Farshchi, Taylor, & Macdonald, 2005), which may negatively affect learning and memory (Park, 2001).

It has been reported that higher brain activation occurs in the pre-frontal cortex following consumption of a nutritionally balanced breakfast compared to breakfast omission (Akitsuki, Nakawaga, Sugiura & Kawashima, 2011). The relationship between glucose and cognitive function, in particular memory, following breakfast consumption or omission has been explored. Time to complete a spatial memory task (where participants were required to remember the location of 16 pictures on a grid) was reported to correlate with blood glucose concentrations; higher blood glucose was associated with a quicker task completion time (Benton & Sargent, 1992). In 1994, Benton, Owens and Parker reported that increases in blood glucose improved word recall performance and attention measured using an RVIP task and in a later study, a correlation between performance on the same spatial memory task and blood glucose was revealed (Benton & Parker, 1998). Falling blood glucose concentrations have been associated with lower energy levels after completing a hand-eye co-ordination task, Stroop and an RVIP task (Owens, Parker & Benton, 1997) and blood glucose concentration at the time of testing has been found to positively correlate with cognitive, particularly memory, performance (for reviews see Bellisle et al., 1998; Smith, Riby, Van Eekelen & Foster, 2011). However, it does appear that a healthy brain controls glucose uptake to satisfy metabolic load, therefore physiological disturbances due to low glucose availability in the brain are unlikely; this brings to question the role of increased glucose availability as a suggested mechanism for the positive cognitive effects of breakfast (Hoyland et al., 2008). It has more recently been suggested that better memory is associated with a lower blood glucose concentration, which reflects better glucose tolerance (Benton, Slater & Donohoe, 2001; Nabb & Benton, 2006). The glycaemic effect of breakfast, and the influence this factor may have on cognitive function has been previously discussed in this review in section 1.2.1.5.

Changes in blood glucose concentration can also influence levels of hormones which can affect cognitive function such as serotonin (Fischer et al., 2002) and cortisol (Gibson, 2007). Serotonin is a monoamine neurotransmitter produced in the CNS by conversion of the essential amino acid, tryptophan, which naturally occurs in many dietary sources (Fuller & Wong, 1990). If a protein-rich meal is consumed, containing a high amount of large neural amino acids (LNAA) and branched chained amino acids (BCAA), tryptophan has to compete with these amino acids for a transporter which allows it to cross the blood brain barrier (Jonnakuty & Gragnoli, 2008). In contrast, consuming a meal high in CHO and low in protein, increases tryptophan availability, resulting in a rise in brain serotonin (Wurtman & Wurtman, 1986). Serotonin is perhaps better known for its positive effect on mood and emotions, but has also been shown to influence some cognitive functions, in particular memory. Generally, data suggest that reduced serotonin synthesis is associated with impaired learning and long-term memory functioning (Buhot, 1997; Park et al., 1994; Schmitt, Wingen, Ramaekers, Evers & Riedel, 2006), although a recent review proposes that its effects may be limited to influencing episodic memory only (Mendelsohn, Riedel & Sambeth, 2009). Interestingly, this effect on episodic memory appears to be more pronounced in females than in males, although reasons for this are not yet clear (Sambeth et al., 2007). The effects of serotonin on cognitive function are often assessed by depleting tryptophan concentrations. This is achieved through the consumption of amino acids, by which protein synthesis is induced; proteins incorporate tryptophan, reducing its concentration in the blood and tissues (Young & Layton, 2002). However, reducing brain serotonin using this method does not appear to affect working memory, response inhibition or decision making (Mendelsohn et al., 2009). Serotonin is just one of multiple neurotransmitters which stimulate the pre-frontal cortex, a brain region responsible for attention, working memory and executive functions, and manipulation of serotonin alone may not compromise its function (Robbins, 2005). Attentional processes generally appear unsusceptible to acute tryptophan depletion, but have also been shown to improve using this procedure (Mendelsohn et al., 2009). Indeed, tryptophan loading can negatively impact RT performance which may be due to the sedative effect of an increase in serotonin (Silber & Schmitt, 2010). Associatively, memory impairment has also been found following tryptophan loading (Sobczak, Honig, Schmitt & Riedel, 2003). These were attributed to the positive correlation observed between tryptophan levels and drowsiness levels, thought to be caused by an associated increase in melatonin, a hormone that creates a sedative effect (Richardson, 2004; Vanecek, 1998). Following consumption of a low CHO/high protein breakfast, episodic memory performance was better when assessed in males

(N=15) than when a high CHO/low protein breakfast was consumed, which was attributed to a lesser increase in brain serotonin (Fischer et al., 2002).

Cortisol is a glucocorticoid which has been identified as having a possible inverted-U relationship with cognitive function, in particular with memory performance (Abercrombie, Kalin, Thurow, Rosenkranz & Davidson, 2003). In response to a stressor, an increase in cortisol has been shown to impair memory performance (Buchanan, Tranel, & Adolphs 2006). Cortisol is thought to negatively influence cognitive function through its effect on the hippocampus, either through inhibiting glucose uptake (Horner, 1991) or reducing glucose metabolism (de Leon et al., 1997). Raised blood glucose levels can also enhance cortisol secretion during challenging cognitive tasks, leading to impaired performance (Gibson, 2007). Indeed, glucose intolerance is associated with elevated morning plasma cortisol levels (Reynolds et al., 2001), highlighting the key role that maintaining a stable glucose profile may have in relation to optimal cognitive function. Consuming breakfast may, especially a low-GI breakfast, may contribute positively to keeping blood glucose levels stable.

In summary, breakfast can improve cognitive function in healthy adults, although its effects are dependent on its nutritional content. In particular, data from studies measuring episodic memory measured using a word recall task provide the most convincing positive evidence for the effect of breakfast on cognitive performance. There is also some evidence that spatial memory improves post-breakfast, although semantic memory, logical reasoning, vigilance and RT do not appear sensitive to breakfast interventions. It could, however, be argued that the word recall task has been studied much more extensively than other tasks, and that more research is needed focussing on other cognitive domains and tasks before concrete conclusions can be drawn. Furthermore, it has been suggested that null findings in studies investigating the effect of breakfast on cognitive function may be due a lack of sensitivity in tasks measuring cognitive domains other than memory (Hoyland, Lawton & Dye, 2008). This advocates further exploration using different tasks, perhaps steering away from the very commonly used word recall task. Many studies choose to measure changes in subjective mood state alongside cognitive function and this is discussed in more detail in section 1.5.

1.2.2. Breakfast and Mood

Mood is an emotional state which is most often measured using visual analogue scales (VAS) such as those described in section 3.7.2 within this thesis. Whilst the effect of breakfast consumption on cognitive function appears to be fairly limited in healthy young adults, the evidence that breakfast consumption leads to mood enhancement is stronger. The results of epidemiological and observational studies show that regular breakfast consumption is generally reported as being beneficial for mental health and mood (Benton & Brock, 2010; Smith, 1998; Tanaka, Mizuno, Fukuda, Shigihara & Watanabe, 2008). Smith (1998) collected data from 126 participants (aged 20-79 years) using the perceived stress scale (Cohen & Williamson,1983), the Beck Depression Index (Beck, 1967), the Emotional distress scale of Profile of Fatigue Related States (Ray et al., 1992) and the Spielberger Trait-State Anxiety Inventory (Spielberger et al, 1970). Consuming breakfast cereal every day was associated with having lower depression, emotional distress and perceived stress. This relationship was still apparent when other lifestyle factors, such as smoking, alcohol consumption and overall diet quality, were accounted for.

Tanaka, Mizuno, Fukuda, Shigihara & Watanabe (2008) reported that skipping breakfast was associated with higher levels of fatigue in a student population (N=127) when measured using the Chalder Fatigue Scale (Chalder et al., 1993). In 2010, Benton and Brock conducted an observational study which comprised approaching individuals (N=686, 328 female) after they had chosen a meal in a cafeteria and measuring mood and motivation during the morning using a series of VAS. Both male and female participants who had consumed, compared to omitted, breakfast that morning (defined as the consumption of food in the hour following getting up in the morning) reported increased feelings of happiness and relaxation during the morning (Benton & Brock, 2010). Observational studies such as this are lacking in the literature and the use of such a large sample size certainly adds weight to these results.

Smith (2011) also reported lower stress levels (measured using a 5-point Likert scale) in a very large population (N=14,952) when breakfast, both cereal-based and other types, was consumed every day. Reduced anxiety was also associated with regular breakfast consumption, more so in those who consumed cereal regularly, a group who also reported lower depression (both measured using the Hospital Anxiety and Depression Scale; Zigmond & Snaith, 1983).

Furthermore, results from laboratory studies also suggest that consuming breakfast, compared to fasting, improves mood (Smith, Clark and Gallagher, 1999; Smith, Kendrick and Salmon, 1994; Smith & Wilds, 2009). Smith, Kendrik and Salmon (1994) assessed mood in forty eight young healthy adults (24 female) after consuming a cereal and toast breakfast, a cooked breakfast (both providing 450 kcal) or no breakfast. Participants reported feeling more contented, interested, sociable and out-going (as measured using 18 bi-polar VAS), 2 h, but not 1 h, after consuming the cooked breakfast as opposed to no breakfast or a cereal/toast breakfast.

In 1999, Smith, Clark and Gallagher investigated the effect of breakfast or no breakfast consumed with a caffeinated or decaffeinated drink on alertness, hedonic tone and anxiety as measured using a set of 18 VAS. Cognitive performance was also measured as described in section (1.2.1). Participants (N=144, 72 female) were assigned to one of the 4 conditions, completing the VAS at baseline and 2.5 h post-breakfast. They were allowed to select their own type and amount of breakfast cereal (the average energy content of breakfast was 208 kcal). Participants reported feeling more positive at the start of, and calmer at the end of, a cognitive test session when they had consumed, compared to omitted, breakfast.

Smith & Wilds (2009) examined the effect of consuming a cereal bar for breakfast (providing 133 kcal) or no breakfast on a number of mood states measured using 18 bi-polar visual analogue scales). Thirty two participants (16 female) were assessed. Consumption of the cereal bar for breakfast improved alertness, happiness and sociability and reduced anxiety 1 h post-consumption. Smith and Stamakatis (2010) conducted a similar between-subjects experiment using a high-fibre cereal bar (144 kcal) and reported greater alertness, happiness, sociability and calmness in 20 young healthy participants (15 male) when mood (measured using bi-polar VAS) was assessed 40 min post-breakfast.

Conversely, Benton, Slater and Donohoe (2001; study as described in section 1.2.2) reported no mood effects of fasting or consuming one of two cereal breakfasts (consisting either 50 or 253 kcal) up to 90 min post-breakfast, but found that the larger breakfast led to higher feelings of confusion and anxiety later in the morning, whilst those that fasted felt more elated. It was speculated that this detriment in mood following the larger breakfast may have been due to an increase in drowsiness (a concept discussed further in section 1.2.2.2). As these results were not in agreement with those previously reported, the authors also discussed the possible impact that the nature of the overall study design may have on mood. It may be difficult to compare studies where participants are only asked to rate mood and are left to rest and relax in between measures to those who have asked participants to complete demanding cognitive tasks multiple times, which could induce fatigue. It is important to consider methodological differences such as these, when evaluating the effect of breakfast on mood. Furthermore, several other factors are thought to moderate the relationship between breakfast and mood, including breakfast size and composition and habitual breakfast behaviours: these will be discussed in the following sections.

1.2.2.1 Habitual behaviours and gender

It is possible that variances in mood states following breakfast of differing compositions are in fact reflective of acceptability (Smith, 2011a) and the similarities or differences in the breakfast provided from what is habitually consumed (Lloyd et al., 1996). There is some evidence to suggest that long-term breakfast habits may influence mood responses to acute breakfast consumption. For example, Lloyd et al. (1996) reported that a more positive mood was seen following consumption of a low-fat, high-CHO breakfast which was similar in macronutrient composition to that eaten habitually than after consuming a breakfast of equal energy content, but higher in fat and lower in CHO. However, it has also been suggested that breakfast habits do not influence the effect of acute breakfast consumption on mood (Benton and Sargent, 1992; Smith, Kendrick and Maben, 1992; Smith, Kendrick, Maben and Salmon, 1994). Still, it seems wise to gather such information from participant samples used in breakfast studies, so this can be controlled for or assessed further.

In addition, the influence of food on mood may be moderated by how healthy the food is perceived to be (Lattimore, Walton, Bartlett, Hackett & Stevenson, 2010). Lattimore et al. (2010) assessed mood responses (using 100 mm VAS) after the consumption of two isoenergetic breakfasts, a bowl of cereal or a muffin in 123 obese females. The cereal breakfast was perceived to be lower in energy and its consumption led to increased feelings of happiness and relaxation compared to the muffin breakfast. Whilst perceived food “healthiness” is a factor which may only need to be measured when looking at obese or dieting populations, it is advisable to measure acceptability when conducting studies involving food administration.

As discussed previously, (section 1.2.1.1), breakfast studies are largely conducted using mixed-gender samples therefore more studies focussing on single gender samples would be useful.

1.2.2.2 Breakfast size and nutrient content

Consumption of a small breakfast (with regards to energy content) such as a cereal bar containing 133 or 144 kcal, has been shown to enhance alertness, happiness and sociability and reduce anxiety compared to omitting breakfast (Smith & Wilds, 2009; Smith and Stamakatis, 2010; studies as described in section 1.2.2). Interestingly, consuming a smaller breakfast (51 kcal, 10 g CHO) has been shown to lead to a more positive mood than consuming a larger breakfast (253 kcal, 51g CHO; Benton et al., 2001; study as described in section 1.2.2). Lloyd et al. (1996) found positive mood effects when administering a low-fat, high-CHO breakfast providing on average 350 kcal more than the subjects' usual intake, but still speculated that a smaller meal may have led to optimal mood.

In relation to this, there appears to be a positive relationship between hunger (which is likely to be higher following consumption of a small, rather than large breakfast) and alertness (Fischer, Colombani & Wenk, 2004). However, participants (11 young, healthy females) have also reported that a large breakfast (500 kcal, 93g CHO) led to higher feelings of contentment and less lethargy in the morning than when a smaller breakfast (64 kcal, 15g CHO) was consumed. The authors suggested this was due to the larger amount of CHO and/ or greater total energy content (Lluch et al., 2000).

It has been suggested that changes in mood following breakfast consumption depend on its nutrient composition (Holt, 1999; Lloyd et al., 1996; O'Sullivan et al., 2009; Pasman, et al., 2003; Smith et al., 1994; Zeng et al., 2011). Data from a large epidemiological study showed that improvements in well-being (as measured using the Child Behaviour Checklist) appeared to be more pronounced in adolescents (N=836) when a breakfast consisted of a combination of cereal and dairy products (O'Sullivan et al., 2009).

In 1994, Smith et al. (study described in section 1.2.2) reported that consuming a cooked breakfast (eggs, bacon and toast), as opposed to no breakfast or a cereal/toast breakfast, led to participants feeling more contented, interested, sociable and out-going. Whilst the breakfasts were reportedly isoenergetic (451 kcal), the authors did not provide a detailed description of the macronutrient content of the breakfasts, differences in which may have influenced these results. It could also be speculated that a cooked breakfast, whilst perhaps less reflective of a typically consumed breakfast than the cereal/toast breakfast, may have been seen as a “treat” by the participants and therefore associated with increased mood states.

Lloyd, Rogers and Hedderley (1996) assessed the mood effects of three breakfasts varying in nutritional composition (consisting of bread rolls with margarine and jam and a milkshake). Mood (measured using 16 VAS assessing dimensions of alertness, anxiety and depression) was recorded 30, 90 and 150 min post-breakfast in 16 participants (14 female). A reduction in fatigue and dysphoria was reported following consumption of a low-fat/high-CHO compared to no breakfast. The authors speculated that this may be due to the low-fat/high-CHO breakfast being more reflective of that which the participants would usually consume.

Holt, Delargy, Lawton and Blundell (1999) assessed the effect of four breakfasts (consisting of All-Bran cereal, Cornflakes, eggs and bacon or croissants) on alertness in 14 healthy young participants (7 female). Participants consumed the breakfast and completed the first VAS in the laboratory and all subsequent measures were taken in the participants own environment. Consumption of a breakfast high in both fibre and CHO was associated with higher alertness ratings (measured using a single VAS) following consumption. Conducting part of the study in a field setting is a design which is lacking in the literature, and gives this data good real-life applicability. The study used a repeated measures design and was well-controlled with participants asked to eat the same meal on the evening before each test day.

Smith, Bazzoni, Beale, Elliott-Smith, & Tiley (2001) reported that consumption of a high, rather than low, fibre wheat bran cereal for a 14 day period led to lower fatigue ratings in a large adult population (N=139, aged 30-80). Pasman, Blokdijk, Bertina, Hopman & Hendriks (2003) examined the effect of two bread-based breakfasts, either high in simple or complex CHO. The mood of 26 male participants (average age 34 years) was assessed 3 h post-breakfast using the Profile of Mood States (POMS; McNair, Lorr & Droppleman, 1971) questionnaire which measures depression, anger, fatigue, vigour and tension. Participants reported feeling more fatigued when the simple CHO breakfast was consumed. This was a well-controlled study, where the pre-study day evening meal was provided by the researcher and physical activity was kept constant the day prior to testing. The use of a slightly older population adds positively to data from many the studies that have assessed younger adult populations.

Zeng et al. (2011) reported higher positive mood scores (as measured on the VGZ mood assessment scale; Feist & Stephan, 2004) in young healthy males (N=13) after consumption of a high protein breakfast compared to one which contained only adequate protein (Zeng et al., 2011). It should be considered, however, that this study may lack validity by providing a breakfast that was both very high energy (813 kcal) and in the form of a "cream", neither of which likely reflect breakfasts that are normally consumed in the general population. .

A factor to consider when evaluating the effect of the nutritional content of breakfast on mood is the GI of the meals administered, although this marker is often not reported in the description of study methods. Breakfasts which vary in the amount of CHO they contain, particular those which differ in simple and complex CHO content (e.g. Pasman et al., 2003), will have differing GIs and will therefore elicit diverse glycaemic responses after consumption. Metabolic response following breakfast consumption may of course influence mood states, just as it may influence cognitive function (as discussed in section 1.2.1.5). The role of glucose as a mechanism for the effect of breakfast on mood is discussed in the following section.

1.2.2.3 Mechanisms of action of the effect of breakfast on mood

The physiological mechanisms responsible for the positive effects of breakfast consumption on mood and mental state are not entirely clear. It is recognised that CHO intake can lead to variations in neurotransmitters that are known to influence mood (Hoyland, Dye & Lawton, 2009). It has been suggested that a meal high in CHO, and low in protein will increase tryptophan availability, resulting in a rise in brain serotonin and an increase in mood (Smith & Stamatakis, 2010; Wurtman & Wurtman, 1986), and in particular females appear to be particularly sensitive to changes in mood caused by serotonin manipulation via acute tryptophan depletion (Booij et al., 2002), although the reasons for this are not yet known (Mendelsohn et al., 2009). Indeed, it has been reported that a high-CHO breakfast (93g CHO) led to higher feelings of contentment and less lethargy than when a breakfast much lower in CHO (15g CHO) was consumed (Lluch et al., 2000). These data somewhat contradict the results of an earlier study by Cunliffe et al. (1997) when fatigue, measured using the POMS and the Stanford Sleepiness Scale, was higher following consumption of a high-CHO breakfast compared to two breakfasts containing less CHO (Cunliffe et al., 1997). This effect was attributed to reduced alertness via serotonin synthesis.

However, it has also been suggested that as some effects on mood of a high-CHO, low-protein meal are seen before nutrients would have been fully absorbed, other mechanisms are likely involved (Lloyd et al., 1994; Lloyd et al., 1996). Also, it is generally accepted that meals would need to be almost exclusively CHO, containing < 5% protein to see an increase in tryptophan availability and therefore an increase in serotonin synthesis; meals such as these are rarely consumed in a normal diet (Benton, 2002).

The digestive benefits of consuming breakfast and the subsequent positive effects on wellbeing have been explored (Lawton, et al., 2011). It was recently reported that regular consumption of a breakfast containing 5.4 g fibre improved digestive health, comfort and wellbeing (Lawton et al., 2013). Smith (2011) suggested that the long-term mood benefits of regular breakfast consumption may be due to positive changes in digestive health, which can influence mental health (study described in section 1.2.2). However, this theory was not substantiated; it was found that the effects of breakfast and digestive health on mental health were present, but were independent of one another (Smith, 2011b).

The association between breakfast and mood appears to be particularly strong when the brain is placed under mental demand (Owens, Parker & Benton, 1997; for review see Benton, 2002) or stress (Macht, 1996). Indeed, the brain has a relatively high metabolic rate and its need for glucose increases during demanding tasks, therefore mood may be more influenced by glucose supply at this time (Benton, 2002). The biology of glucose availability and its effect on the brain has been discussed in section 1.2.1.6.

Owens, Parker and Benton (1997) conducted a series of three studies assessing the effect of blood glucose on energy levels whilst completing cognitively demanding tasks [Stroop (N=50, all male), a RVIP task (N=70, all female) and a hand-eye coordination computer game task (N=98, 48 female)]. Mood was measured using the Activation-Deactivation Adjective Check List, a questionnaire which measures the dimensions tired/energetic and relaxed/tense, 20 min following consumption of a glucose or placebo drink and before and after task completion. The authors reported that falling blood glucose during task completion was associated with feeling less energetic. In conjunction, participants (56 young healthy males) consuming a high (1700 kcal), compared to low (260 kcal), energy diet (combined breakfast and lunch EI) showed a lower stress response to white noise (Macht, 1996).

To summarise, breakfast consumption compared to omission appears to be beneficial for several aspects of mood. Regular, but not acute, breakfast consumption can reduce depression. When consumed acutely, there is evidence that breakfast can have a positive influence on stress and anxiety, fatigue and lethargy, happiness and contentment, relaxation and calmness and alertness and energy. Anger is a mood state which does not appear sensitive to breakfast interventions, although this may be because it has not been as commonly assessed. Mood is generally measured using validated questionnaires or bi-polar VAS which is good practice; the latter in particular allows for easy comparison between studies. The effects of breakfast on mood are moderated by its size and nutrient content, and despite the extensive research conducted so far, there is still scope to assess the manipulation of both these factors in future studies.

1.2.3 Breakfast, Appetite and Energy Intake (EI)

Mood and cognitive function are not the only factors affected by breakfast consumption; consuming breakfast is also an advocated method of appetite and weight control.

Appetite, the psychological desire to eat (for detailed definition see Blundell et al., 2010), is usually measured using VAS (such as those described in section 2.2.2.3 of this thesis) and by measuring EI, which is the total kcal consumed by an individual, through the intake of food and drink, during a single meal or over a certain period of time. A typical method of measuring EI is to ask participants to complete a self-report food diary, such as that described in section 3.9 or to record how much participants eat when they are provided with a meal, or several meals. Two terms used frequently when measuring appetite and EI are satiation (the process that leads to the cessation of eating) and satiety (the state of inhibition over further food intake once a period of eating has ended) (Blundell et al., 2010).

A decline in those consuming breakfast has accompanied an increase in obesity in the general population (Timlin & Pereira, 2007). Those who regularly consume breakfast are more likely to have a lower daily EI, body mass index (BMI) and better weight control (Barton et al., 2005; Cho, Dietrich, Brown, Clark & Block, 2003; de la Hunty, Gibson & Ashwell, 2013; Pereira et al., 2011; Schlundt, Hill, Sbrocco, Pope-Cordle & Sharp, 1992; Song, Chun, Obayashi, Cho & Chung, 2005; Wyatt et al., 2002).

In a recent study it was reported that those who consumed breakfast every day gained significantly less weight over an 18 year period compared to those who consumed breakfast infrequently (0-3 days per week) and daily breakfast consumers also had a lowered risk of metabolic syndrome and hypertension (Odegaard et al., 2013). In addition, Mekary and colleagues identified a significantly higher risk of developing type 2 diabetes in men (N=29,206) who skipped, compared to consumed, breakfast (Mekary, Giovannucci, Willett, van Dam & Hu, 2012). Regular breakfast consumers are also more likely to keep their fat and CHO intake to the recommended values and breakfast consumption appears to be important even if overall EI is adequate and has been found to reduce hunger and cravings for the rest of the day (for review see Ruxton & Kirk, 1997). Previous studies have assessed the effect of breakfast consumption on appetite and EI (Farshchi et al., 2005; Levitsky & Paconowski, 2013).

In 2005, Farshchi et al. reported that total daily EI assessed in a free-living situation was significantly lower when women (N=10) consumed, compared to omitted, a controlled breakfast (whole-grain cereal) or no breakfast over a 14-day period. However, there were no differences in hunger ratings between the eating breakfast and the omitting breakfast conditions (Farshchi et al., 2005). The assessment of only 10 participants, particularly in a field-study such as this, could be considered insufficient. Astbury, Taylor & Macdonald (2011) reported that male breakfast eaters (N=12) who skipped, rather than consumed, breakfast (cereal and milk; 10% of each participants daily energy requirement) increased their consumption at an *ad libitum* lunch meal and that hunger was significantly lower when breakfast was consumed, compared to omitted, immediately after a preload (a vanilla-flavoured drink). This study was well-controlled by standardizing the evening meal consumed the day prior to testing.

However, the effect of breakfast consumption on EI is not conclusive. In a recent study, Levitsky and Paconowski (2013) found no effect on EI at lunch of consuming or omitting a high-CHO or high-fibre breakfast (bread, jam and juice (335 kcal), or cereal and milk (338 kcal) respectively), even though breakfast reduced hunger (N=24,19 females). In a second study by the same authors (N=18, genders not reported), they did see an increase in both hunger ratings and EI at lunch when breakfast (served as a buffet) was omitted, but only a partial compensation which still resulted in an overall net calorie deficit (Levitsky & Pacanowski, 2013). Participants were required to fast from 23.00 h the night prior to testing but food consumed the evening prior to testing was not controlled. The authors report having both habitual and non-habitual breakfast consumers in the sample for the second study, but did not mention this factor when reporting details of the first. Methodological differences between the two studies such as this could explain the variation in findings.

1.2.3.1 Breakfast size and nutrient content

The content of breakfast appears to moderate the relationship between breakfast and appetite. Leidy and Racki (2010) reported that a high-protein (48 g) breakfast reduced subjective appetite more so than a normal protein (18 g) isoenergetic breakfast which, in addition, also reduced EI at an *ad libitum* lunch in adolescents who usually skipped breakfast (N=13).

Over recent years, particular attention has been paid to the GI of meals consumed at breakfast (discussed in section 1.2.1.5), and generally results have supported the theory that a low-GI breakfast, which releases energy at a slower rate, is superior at suppressing appetite than a high-GI breakfast (Liljeberg et al., 1999). Pasman et al. (2003; as described in section 1.2.2) reported higher satiety for 90 min when a breakfast contained complex, rather than simple, CHO, although Flint et al. (2006) reported that the glycaemic and insulinemic responses to breakfast affected EI, but not subjective appetite sensations. In 2009, Stevenson et al. assessed the effect of consuming a low or high-GI breakfast 3 h before a 60 min walk. Participants (8 sedentary females) were then given a standard lunch; post-lunch appetite was higher following the high-GI, compared to low-GI, breakfast.

A nutritional component that contributes greatly to the GI of a meal is the fibre content; meals high in fibre generally present a low-GI rating. The consumption of fibre may delay the next eating episode (i.e. increase satiety) by reducing the rate of gastric emptying (Benini et al., 1995). Holt et al. (1999; study as described in section 1.2.2.2) reported consumption of a breakfast high in both fibre and CHO (rather than high in fat) was associated with higher satiety and lower EI in the morning and at lunch in a mixed gender sample (N=14). The study used a repeated measures design and was well-controlled with participants asked to eat the same meal on the evening before each test day. Delargy et al. (1998) investigated the effects of three breakfasts (minimal fibre, 90 kcal; low fibre (3g), 555 kcal and high fibre (20g), 554 kcal) on satiety and EI in 12 healthy males. The high, but not low, fibre breakfast, reduced EI at lunch but overall daily EI was not significantly affected by breakfast condition. In a second study (N=16), the same authors reported that consumption of a breakfast containing a greater amount of soluble fibre led to the highest satiety 13.5 h post-breakfast but did not affect EI. This suggests that fibre amount may influence EI more so than fibre quality.

In addition, breakfast size also appears to influence the relationship between breakfast and EI. Consuming a larger breakfast (highest quintile of percentage of daily energy consumed at breakfast) has been shown to be associated with a lower BMI and less weight gain over a five year period, than consuming a smaller breakfast (Purslow et al., 2008). Hubert et al. (1998) reported that EI at lunch was higher in 11 young healthy females when a low-energy (64 kcal), compared to high energy (500 kcal), breakfast was consumed, but this energy difference was not compensated for completely. However, the type of breakfast administered was not specified. It has also been suggested that the effect of breakfast on satiety and EI is likely affected by habitual breakfast behaviours; Halsey et al. (2012) observed the dietary habits of 49 young healthy adults (26 female) over a 14 day period when they consumed, or omitted, breakfast (cereal and toast, amount self-selected) and reported that female, but not male, habitual breakfast consumers ate more during the day when they did not consume breakfast compared to non-habitual consumers. This again calls to attention to the issue of breakfast habits when selecting a sample. Whilst regulating this factor does not seem overly important when assessing the effect of breakfast on mood and cognitive performance (1.2.1.2 and 1.2.2.1), it may need to be controlled, or at least accounted for, when measuring the effect of appetite and EI. It also perhaps highlights differences in EI habits between the genders; the different phases of the female menstrual cycle are also known to affect appetite (Dye and Blundell, 1997), and both of these factors could bring to question the use of mixed gender samples in this area of research and advocate more controlled trials in single gender samples. In addition, the literature suggests that eating restraint (the monitoring and limiting of food intake to control body weight; Stunkard & Messick, 1985) is more prevalent in females (Conner, Johnson & Grogan, 2004). Although there is evidence to suggest that eating restraint should be accounted for in studies measuring appetite, it has also been suggested that dietary restraint is not a reliable predictor of EI (Bellisle, Dalix, Airinei, Hercberg & Péneau, 2009; Klesges, Klem, Epkins & Klesges, 1991). It is, however, very easy to measure and account for eating restraint in studies using a simple questionnaire, such as the three factor eating questionnaire (TFEQ; Stunkard & Messick, 1985) and this is generally regarded as good practice when conducting studies measuring appetite and EI.

1.2.3.2 Methodological issues in measuring appetite and EI

Measuring appetite and food intake is complex (Maraki et al., 2005; Stensel, 2010) and there are several well-documented difficulties that researchers face when doing so. It has been suggested that participants eating behaviours change when they are aware that they are being monitored (Blundell et al., 2010). Recently, it has been shown that differences in foods consumed the evening prior to investigational testing the following morning can affect appetite sensitivity (Chandarana et al., 2009), a factor which has not been consistently controlled for in many previous studies. It has been reported that individuals can eat significantly different amounts of the same *ad libitum* foods on two separate occasions, although standardising diet prior to intervention studies may reduce this effect (Gregersen, 2008). When measuring food intake over a prolonged period it is often more convenient for both the participant and researcher to use a self-report food diary. However, participants notoriously under-report when asked to complete such a diary, and therefore data collected using this method is often thought to have low internal validity and is viewed with caution by most researchers (Livingstone & Black, 2003). This method does, however, possibly provide a more representative observation of an individual's eating habits than when they are asked to choose foods from a limited selection, such as at a buffet provided by the researcher. Measuring EI using a buffet, rather than a homogenous meal, does allow for differences in macronutrient intake to be observed, though it can be challenging to ensure that all the foods provided are rated equally palatable between subjects.

1.2.3.3 Mechanisms of action for the effect of breakfast on appetite and energy intake

It is thought that eating breakfast can help to control appetite, and therefore EI and weight management, by influencing satiety through insulin responses (Blom et al., 2005; Holt & Miller, 1995). Skipping breakfast can lead to disturbances in insulin sensitivity which is known to increase appetite (Farshchi et al., 2005) and an increase in the insulin response to a meal is associated with reduced satiety (Holt & Miller, 1995). It is thought that the main nutritional components of a typical breakfast meal, (i.e. CHO and fibre) may "directly improve glucose metabolism and insulinemic response" (Marangoni et al., 2009, page 167), increasing satiety and reducing EI for the remainder of the day. It has also been suggested that the protein and lipids from milk products, often consumed at breakfast, can influence the secretion of the appetite hormones ghrelin (Foster-Schubert et al., 2008), glucose-dependent insulinotropic peptide (GIP) and glucagon-like peptide 1 (GLP-1) (Blom et al., 2005) and therefore can modify appetite also. A reduction in the fluctuation of blood glucose is also thought to reduce feelings of hunger (Ceriello et al., 2008), which may be achieved through the consumption of a high-fibre breakfast (Liljeberg et al., 1999). Furthermore, consuming breakfast, especially one high in fibre, may improve tolerance to CHO consumed at the next meal (Liljeberg et al., 1999; Pereira et al., 2011). Indeed, in a recent study by Astbury, Taylor and Macdonald (2011), it was confirmed that consuming, compared to omitting breakfast improved the hormonal and metabolic responses to food consumed later in the day.

The literature, in general, does support the theory that acute breakfast consumption, compared to omission, is beneficial for appetite control. Subjective appetite appears to be marginally more sensitive to breakfast manipulations than EI, and differences observed in the former do not always coincide with changes in the latter. Methodological differences between studies such as the populations tested and the types of breakfast assessed will likely have contributed to any ambiguities.

1.3 The effect of exercise on cognition, mood and appetite

A large proportion of the general population exercise regularly for health benefits, which are well documented in the literature (Miles, 2007). These include improved mental health and well-being and enhanced appetite and weight control. This section of the literature review will mainly discuss the effects of acute exercise, as this is more relevant to the scope of this thesis.

1.3.1 Exercise and cognition

The association between regular physical activity and enhanced cognitive function has been documented (Churchill et al., 2002; Etnier, Nowell, Landers & Sibley, 2006; Etnier et al., 1997; Hillman, Erickson & Kramer, 2008) and people often report that their ability to concentrate and think clearly improves after a bout of aerobic exercise (Tomporowski, 2003). The plethora of studies that have examined the effect of acute exercise on mental function over the past 20 years have produced diverse results, with some studies showing no effect of exercise on cognitive function and others reporting improved cognitive performance with exercise. Inconsistencies in data reported in this area of research are usually attributed to wide variations in testing protocols (Dietrich & Audiffren, 2011). However, when the evidence is viewed cohesively, it is generally concluded that acute exercise can lead to small improvements in some, but not all, aspects of cognitive function (for reviews see Tomporowski, 2003; Lambourne & Tomporowski, 2010).

The effect of exercise on cognitive function differs depending on when it is measured; for example, RT, the focus of the majority of studies in this area (Hung, Tsai, Chen, Wang & Chang, 2013) is generally (Davranche, Audiffren & Denjean, 2006; Kashihara & Nakahara, 2005), though not always (Lemmink & Visscher, 2005), enhanced during exercise, regardless of mode of exercise or of task administered. In a between subjects experiment, Lemmink and Visscher (2005) investigated the effect of intermittent exercise (4 x 8 min on a cycle ergometer) or rest on CRT in male football players (N=16), but found no effect of exercise on reaction speed or accuracy. However, Kashihara and Nakahara (2005) reported a positive effect of 10 min of exercise (at lactate threshold), compared to rest, on a 20 min CRT task in males. Accuracy was unaffected by the intervention, but RT was quicker for the first 8 min of the task following exercise compared to rest. Davranche, Audiffren and Denjean (2006) selected a sample of participants (N=11, 4 females) who had experience in decision-making sports. They were required to cycle (at 90% of their ventilatory threshold power) or rest whilst completing a CRT task, where four symbols were presented on a screen and the participant was required to respond with the correct corresponding movement (flexing or stretching of the left or right wrist) when a symbol appeared. During exercise, compared to rest, RT reduced without an associated decline in accuracy. However, these effects on RT do not seem to be present post-exercise (Audiffren, Tomporowski & Zagrodnik, 2009; Brisswalter & Arcelin, 1997).

Declines in executive function during exercise have been reported (Audiffren, Tomporowski & Zagrodnik., 2009; Davranche & McMorris, 2009). Audiffren, Tomporowski and Zagrodnik (2009) reported an improvement in performance on a random number generation task when performed by 18 participants (9 females) during exercise (35 min cycling at 90% ventilatory threshold), but that this effect disappeared immediately when exercise ceased. Davranche and McMorris (2009) reported a reduction in RT, but a deterioration of response inhibition during exercise (21 min cycling at lactate threshold power) when participants (N=10, 4 females) completed the Simon Task (responding correctly to the colour of a presented circle, but ignoring its location on the screen). However, effects on executive function are not generally seen post-exercise, although this finding is not consistent (Hung et al., 2013). The data on decisional tasks is also varied; this may be due to methodological differences in mode of exercise and task used (Audiffren et al., 2009; Tomporowski, 2003), which may disguise what is already thought to be a very small effect (Etnier et al., 2006; Etnier et al., 1997). However, as previously discussed, simple decisional tasks such as CRT have been found to improve with exercise (Davranche, Audiffren & Denjean, 2006; Kashihara & Nakahara, 2005). Working memory tasks have been shown to be significantly affected by acute, moderate intensity exercise, with effects seen during or after exercise (for meta-analysis see McMorris, Sproule, Turner & Hale, 2011). Individuals exercising for cognitive and mood benefits, which is the population of interest in the current thesis, are likely to desire positive effects on these parameters post-exercise. Therefore, the main focus of the remainder of this section of the review will be on post-exercise cognitive function.

Numerous laboratory studies have investigated the relationship between exercise and cognitive function post-exercise; for example, Hogervorst et al. (1996) reported that a 60 min bout of strenuous cycling [75–85% of maximal oxygen uptake ($\dot{V}O_2$ max)] improved SRT and Stroop performance in male athletes (N=15) but had no effect on CRT or on a tapping task when measured immediately after exercise (Hogervorst, Riedel, Jeukendrup & Jolles, 1996). Decreases in RT have also been reported in a mixed gender sample following a 30 min moderate intensity treadmill run (60-70% $\dot{V}O_2$ max) compared to rest or a bout of resistance exercise, with a more pronounced effect seen in the task involving working memory (Pontifex, Hillman, Fernhall, Thompson & Valentini, 2009). Sibley et al. (2006) reported a small improvement in Stroop performance following 20 min of self-paced treadmill exercise in a mixed gender sample. Although their use of self-paced rather than intensity-controlled exercise could be questioned, the sample number in this study was high compared to that normally used in exercise studies (N=76, 39 male). However, caffeine was only restricted 2 h prior to testing and the authors make no mention of pre-testing dietary control (similarly, neither do Hogervorst et al., 1996 or Pontifex et al., 2009), factors which could potentially influence exercise and cognitive performance (Jeacocke & Burke, 2010; Nehlig, 2010). Water intake is another factor which should be closely monitored and controlled during exercise trials in light of research investigating the influence of hydration status on cognitive function (Lieberman, 2007; Cian et al., 2000); however, many studies do not specify whether or not this factor has been controlled for.

The size of the effect of exercise on cognitive function is thought to be moderated by several factors such as exercise duration and intensity and the type of cognitive assessment used (Brisswalter, Collardeau & Arcelin, 2002; Chang, Labban, Gapin & Etnier, 2012), exercise mode (Lambourne & Tomporowski, 2010), gender (Al-Nimer & Al-Kurashy, 2007) and participant fitness status (Brisswalter & Arcelin, 1997).

1.3.1.1 Exercise duration, intensity and mode

It is generally considered that submaximal exercise ≤ 60 min in duration is most beneficial for cognitive performance; longer periods of exercise (> 60 min) that can cause dehydration (Cian et al., 2000) and a fall in blood glucose (Romijn et al., 1993) may in fact compromise information processing and memory functions (Cian et al., 2000; Tomporowski, 2003). Some early studies reported a positive cognitive effect of very short duration exercise; for example, Aks and colleagues (1998) found that performance on a visual search task was improved following a 10 min bout of cycling in a mixed gender sample; however, in a review by Tomporowski (2003) it was concluded that exercise bouts >20 min in duration were most beneficial for cognitive enhancement.

In addition, the effect of exercise on cognition is thought to differ depending on exercise intensity. High-intensity exercise can be detrimental for cognitive performance due to increased levels of fatigue (Moore, Romine, O'Connor & Tomporowski, 2012; Tomporowski, 2003). In two studies by Kamijo et al. (2004), they used electroencephalography (EEG) to assess arousal level and P300 (a brain response to a cognitive event) to measure information processing in the CNS in 12 male participants after cycling at three different intensities controlled using the rate of perceived exertion scale (RPE; Borg,1973): low (RPE 7–9), medium (RPE 12-14) and high-intensity (to volitional exhaustion, RPE 19-20). They reported that arousal and information processing were reduced after high-intensity cycling and reached an optimum level following medium-intensity exercise, suggesting an inverted-U relationship. The authors concluded that attentional resources allocated to task performance decrease after high-intensity exercise and increase after moderate-intensity exercise (Kamijo et al., 2004). Surprisingly, some previous studies have not included a provisional test of maximal aerobic capacity to ensure all participants were working at similar intensities during the exercise intervention; poor control of this moderator may of course have added to inconsistencies found within the literature (Lambourne & Tomporowski, 2010), although recent studies do tend to monitor this factor more tightly.

Exercise mode has also been identified as a significant moderator in the relationship between exercise and cognition; whilst cycling appears to augment cognitive function both during and after exercise, treadmill exercise appears only somewhat beneficial post-exercise (Lambourne & Tomporowski, 2010). This could be due to the allocation of more physiological and psychological resources when running, which is weight-bearing, than when cycling, which is not. The use of the cycle ergometer in exercise studies is predominant; however, it may be useful to base the chosen mode of exercise on that which is most commonly used by the population of interest, so results have greater real-world application. It would also be advisable to ensure that the chosen exercise mode is one with which the selected participants are familiar; the most consistent effect of exercise on mood is seen when regular exercisers undertake exercise mode which is familiar (Salmon, 2001), and this same concept may arguable apply to cognitive function also. Post-exercise cognitive function may also depend on whether the exercise bout was resistance or endurance based. Pontifex et al. (2009) reported a decrease in RT following a 30 min moderate intensity treadmill run (60-70% $\dot{V}O_2$ max) but not following a rest period or a bout of resistance exercise (Pontifex, Hillman, Fernhall, Thompson & Valentini, 2009).

1.3.1.2 Participant characteristics

The fitness level of the participants studied has previously been suggested as an important moderator in the exercise/cognition relationship. Participants with a higher level of fitness were thought to be able to divert more attention to cognitive tasks during exercise than less fit participants, who may find the task of physically controlling their movements more demanding (Brisswalter & Arcelin, 1997). However, in a later meta-analysis this suggestion was not supported (Etnier et al., 2006). It seems sensible, however, to ascertain the fitness levels of participants before they take part in research, if not for exclusion purposes, to ensure they are capable of completing the selected exercise intervention and to allow for the covarying of this factor if desired. There are differences in the physiological response to exercise interventions between males and females (e.g. Deschenes, Hillard, Wilson, Dubina & Eason, 2006). Deschenes et al. (2006) reported that respiratory exchange ratio, plasma lactate, systolic blood pressure and plasma volume shifts were greater in untrained men (N=10) than in untrained women (N=10) during 30 min cycling at 60-65% peak oxygen uptake ($\dot{V}O_2$ peak). Lactate is known to influence cerebral function (Maran, Cranston, Lomas, Amiel & Macdonald,1994), and it is plausible that these differences in the physiological response to exercise, such as this, may play a role in the different cognitive responses to exercise between men and women. Al-Nimer and Al-Kurashy (2007) reported that psychomotor performance was improved following a 6 min bout of cycling (75 watt power at a speed of 30 m min^{-1}) in women (N=7), but not in men (N=7). The use of mixed gender samples in this area of research is common, but unless this is accounted for statistically, it is impossible to determine whether gender differences are influencing the effects seen. In addition, it is generally acknowledged that females are underrepresented in this literature (Lambourne & Tomporowski, 2010).

An obvious difference between men and women is the presence of the female menstrual cycle. Research assessing the variation in exercise metabolism during the different menstrual phases has produced varying results. Some studies have identified no differences between the follicular and the luteal phases (De Bruyn-Prevost, Masset & Sturbois, 1984; Lynch & Nimmo, 1998), whilst others have found that metabolic and hormonal exercise responses do differ between the two phases (Amiel et al., 1991; Hackney, 1999; Hornum, Cooper, Brasel, Bueno & Sietsema, 1997; Lebrun, McKenzie, Prior & Taunton, 1995). Interestingly, this difference appears to be particularly obvious when assessed following CHO depletion (Lavoie, Dionne, Helie & Brisson, 1987). For example, Lavoie and colleagues (1987) observed a significant difference in blood glucose concentration between the cycle phases after 70 and 90 min of exercise. Differences in blood glucose responses to moderate-intensity exercise during the difference phases were also identified in a more recent study, although these were only subtle (Galliven et al., 1997), however, these results do highlight the possible need to control, or account for, the cycle phase in which women are tested.

1.3.1.3 Longevity of the effects of exercise on cognition

It is of course important to consider the longevity of the effect of exercise on cognition and whether improvements seen directly after exercise are sustained or quickly dissipate; however, relatively few studies have thoroughly examined how cognitive performance changes over time following exercise cessation (Lambourne & Tomporowski, 2010). It has been hypothesised, based on the theory of exercise-induced arousal (discussed in section 1.3.1.4), that cognitive performance would likely decline as the time from the end of the exercise bout increased, but in a recent meta-analysis this was not substantiated (Lambourne & Tomporowski, 2010). Audiffren et al. (2009) reported that the positive effects seen on CRT during a 40 min bout of cycling in a mixed gender sample disappeared almost immediately when exercise ceased (Audiffren et al., 2009), results which echoed data from earlier studies (Brisswalter & Arcelin, 1997; Collardeau, Brisswalter, Vercruyssen, Audiffren & Goubault, 2001). Conversely, improvements in response execution and inhibition (measured using a stop-signal task) have been reported to remain for at least 52 min after exercise cessation following 30 min low-intensity cycling (40% of maximal aerobic power) in a mixed gender sample (N=10) (Joyce, Graydon, McMorris & Davranche, 2009). A decrease in RT on a task measuring working memory has been observed in a mixed gender sample 30 min following a 30 min moderate-intensity run (Pontifex et al., 2009) and Hung et al. (2013) reported improvements in executive function (planning efficiency on the Tower of London task) up to 60 min after the cessation of a 30 min bout of moderate-intensity cycling in a mixed gender sample also (Hung et al., 2013). These results cannot yet be generalised to other facets of cognitive function, modes of exercise or specific populations. It would be interesting to examine the effects of a different mode of exercise, such as running, on different aspects of cognitive function for several hours after exercise ceases in single gender samples to enhance knowledge in this area.

1.3.1.4 Mechanisms of action of the effect of exercise on cognition

Several mechanisms have been suggested to explain changes in cognitive function following exercise, including: exercise-induced arousal (Audiffren et al., 2009; Lambourne & Tomporowski, 2010; Tomporowski, 2003), changes in plasma catecholamines (Chmura, Nazar & Kaciuba-Uscilko, 1994; Cooper, Breese, Grant & Howard, 1973) and synthesis of Brain Derived Neurotrophic Factor (BDNF; Ferris, Williams & Shen, 2007; Griffin et al., 2011; Winter et al., 2007). Detailed biological descriptions of these mechanisms are out of the scope of the current literature review, but each will be explained succinctly.

The theory of exercise-induced arousal has been studied extensively over the last 4 decades and does have some support (for reviews see Lambourne & Tomporowski, 2010; Tomporowski, 2003). The first theory to explain the effect of exercise on cognitive function was presented by Davey (1973) who suggested that exercise was a stressor and therefore as intensity rose, so would arousal (a state of mental and physical alertness), with moderate-intensity exercise being optimal for cognitive function. Similarly, later theories such as that advocated by Sanders (1983) were also based on an inverted-U effect, but additionally suggested that low arousal may be as good as moderate arousal for cognitive performance if sufficient resources were available; this is an impossibility at higher exercise intensities due to "neural noise", the unsystematic, inherent, electrical oscillations found in neural networks (Sanders, 1983). Indeed, it has been suggested that acute exercise affects systems in the brain that change how resources are allocated to cognitive task performance (Audiffren et al., 2009). Following moderate-intensity exercise of 20 min or more it was theorized that arousal would remain high during metabolic recovery and would augment cognitive function for a short period after exercise, and indeed some studies have supported this idea. In Lambourne and Tomporowski's recent comprehensive review (2010), they concluded that an increase in arousal after steady-state, or indeed fatiguing, exercise leads to improvements in speed-orientated and memory-related cognitive processes. Coles and Tomporowski (2008) suggested that the maintenance of free-recall memory performance they observed following 40 min cycling was likely caused by exercise-induced arousal augmenting the storing of information in long-term memory. Indeed, exploratory evidence has suggested that the state of arousal caused by anaerobic exercise may influence long-term memory and learning (Winter et al., 2007).

Closely linked to the hypothesis of exercise-induced arousal is the catecholamine hypothesis (Cooper et al., 1973). Catecholamines are a group of neurotransmitters secreted by cells in the brain, the most abundant of which are adrenaline, noradrenaline and dopamine. Exercising leads to the release of catecholamines to activate or inhibit neurons, facilitating the arousal of the CNS (Chmura et al., 1994), connecting this and the aforementioned exercise induced arousal theory. Peripheral catecholamine concentrations have been found to increase following exercise (Kraemer et al., 1999; Musso, Gianrossi, Pende, Vergassola & Lotti, 1990) although evidence for this is not conclusive (Bracken, Linnane & Brooks, 2005). It has been suggested that exercise-induced increases in plasma catecholamine concentrations may indicate brain increases of noradrenalin and dopamine, which in turn could be responsible for the changes in cognitive performance seen during and after exercise (Chmura et al., 1994; Cooper et al., 1973; McMorris et al., 1999; Winter et al., 2007). Results from studies examining this have been somewhat unclear; Chmura et al. (1994) reported an inverted-U effect for CRT performance, which was faster at rest and whilst exercising at a high intensity, coinciding with lower plasma adrenalin and noradrenalin levels. Improvements on a soccer-specific decision making test (McMorris et al., 1999) and in P300 inactivity (Grego et al., 2004) were reported to occur together with a rise in adrenalin levels during exercise. However, in another study, McMorris and colleagues, found no such effect during a soccer-skill test (McMorris, Sproule, Draper & Child, 2000) and later reported that it is likely catecholamines do not directly affect cognitive function during exercise but that there was some relationship between these two factors (McMorris, Collard, Corbett, Dicks & Swain, 2008; McMorris, et al., 2003). Other authors suggest that brain catecholamines are somewhat responsible for changes in procedural and simple decisional tasks during exercise (Dietrich & Audiffren, 2011). Winter et al. (2007) reported faster vocabulary learning and larger increases in catecholamine concentrations in male participants (N=27) following sprinting, compared to jogging or resting. They also found that dopamine and adrenalin levels related to improved intermediate novel vocabulary retention. However, the longevity of these effects is currently unclear; it has been suggested that the effect of exercise on motor output coincides with the release of brain catecholamines (Audiffren, Tomporowski & Zagrodnik, 2008), suggesting that once exercise ceases, these effects will dissipate.

Another theory which might explain the exercise-cognition relationship is the release of BDNF, a protein which acts on certain neurons in the CNS, supporting their survival and growth; this is known as synaptic plasticity (Vaynman & Gomez-Pinilla, 2005). In the brain, BDNF is active in the hippocampus, cortex and basal forebrain, areas which greatly influence memory and learning (Tyler, Alonso, Bramham & Pozzo-Miller, 2002) and sufficient BDNF levels are thought to be vital for cognitive function (Tsai, Cheng, Yu, Chen & Hong, 2003). Although testing for BDNF levels in human brains is too invasive, BDNF can cross the blood-brain barrier both ways (Pan, Banks, Fasold, Bluth & Kastin, 1998) and therefore plasma/serum and brain BDNF levels correlate strongly. Increased BDNF levels in the blood during (Rasmussen et al., 2009) and following (Ferriset al., 2007; Gold et al., 2003; Griffin et al., 2011; Rasmussen et al., 2009; Winter et al., 2007) exercise have been reported leading to the theory that this mechanism may be responsible for exercise-induced cognitive enhancement. In rats, changes in BDNF levels in the brain continue after exercise has ceased (Berchtold, Castello & Cotman, 2010) and Ferris et al. (2007) reported exercise-induced increases in serum BDNF in both males and females following a 30 min bout of cycling. They found this relationship to be dependent on exercise intensity, but did not find that BDNF levels correlated with performance on the Stroop task, possibly due to the relatively low number of participants tested (N=15). Winter et al. tested 27 male participants and reported that vocabulary learning was faster and BDNF levels higher after intense, compared to moderate, intensity running (Winter et al., 2007). Similarly, Griffin and colleagues (2011) reported increased BDNF levels in male participants following acute high-intensity cycling; this increase was accompanied by an improvement in performance on a face-name matching task, known to recruit the hippocampus, but no change was observed in Stroop task performance, which does not (Griffin et al., 2011). Interestingly, BDNF can also influence body weight and energy homeostasis (Noble, Billington, Kotz & Wang, 2011; Wisse & Schwartz, 2003) and BDNF concentrations are thought to be different in women than in men (Lommatzsch et al., 2005).

To summarise, the literature suggests that exercise can enhance some aspects of cognitive function, although the evidence is not entirely clear and this effect appears to be moderated by a number factors. Evidence for the mood-enhancing effect of exercise however, is more robust and will now be explored.

1.3.2 Exercise and Mood

Regular physical activity is strongly associated with enhanced psychological well-being and improved mood states (e.g. Penedo & Dahn, 2005) and can also reduce anxiety and depression (Conn, 2010; Petruzzello, Landers, Hatfield, Kubitz & Salazar, 1991; Smits et al., 2008; Strohle, 2009) and stress (Hamer, Endrighi & Poole, 2012). Numerous reviews (Berger & Motl, 2000; Ekkekakis & Petruzzello, 1999; Reed & Ones, 2006; Scully, Kremer, & Meade, 1998; Yeung, 1996) and intervention studies (Gauvin, Rejeski & Norris, 1996; Head, Kendall, Ferner & Eagles, 1996; Lluch, Hubert et al., 2000; Maraki et al., 2005; Maroulakis & Zervas, 1993; McGowan, Pierce & Jordan, 1991; Steinberg, et al., 1997; Steptoe, Kearsley & Walters, 1993) over the last two decades have also shown that acute bouts of exercise, in particular cardiovascular exercise (for review see Yeung, 1996), can improve mood.

In 1993, Steptoe et al. reported that immediately following exercise, mental vigour and exhilaration were significantly higher in men who cycled (at either 50 or 70% $\dot{V}O_2$ max) for 20 min, with the enhanced feeling of exhilaration reported 30 min post-exercise also (Steptoe et al., 1993); however, the between-subjects study design used in this study is generally not considered ideal practice. Similarly, in 2000, Lluch et al. reported a significant decrease in lethargy and a tendency towards reduced tension (when measured using VAS) following 40 min cycling (70% $\dot{V}O_2$ max), compared to rest, in female regular exercisers (N=11), although contentment and irritability were unaffected.

1.3.2.1 Exercise mode

Although, as previously stated, the use of the cycle ergometer remains predominant in exercise research, the effects of running and jogging on mood have also been considered. Head et al. (1996) reported reductions in tension and depression (measured using the POMS) in a mixed gender sample (N=20, 10 females), after 1 h treadmill walking at 50% $\dot{V}O_2$ max. Hoffman and Hoffman (2008) reported higher vigour and reduced fatigue (measured using the POMS) after a 30 min treadmill run in a mixed gender sample (N=16, 8 female), although intensity in this study was controlled using rate of perceived exertion (RPE) rather than a physiological measure. There was no familiarisation session prior to the test session, or comparison to a rest condition (Hoffman & Hoffman, 2008). A 30 min bout of moderate-intensity (60% $\dot{V}O_2$ max) exercise on a treadmill or stepper machine has reportedly led to a decrease in negative, and an increase in positive, mood state (measured using the Spielberger State Anxiety Inventory) in male cohort (Cox, Thomas & Davis, 2001), although again, these exercise interventions were not compared to a resting control condition.

Aerobics classes are a popular form of exercise for females; positive affect has been found to increase (measured using the Positive and Negative Affect Schedule) following a 1 h aerobics class in a female sample (N= 12) who did not exercise regularly (Maraki et al., 2005). Improved positive mood following an aerobic workout or aerobic dance class compared to a rest condition in a larger (N=64) mixed gender sample has also been reported (Steinberg, Skyes, Moss, Lowery & Le Boutillier, 1997). It should be noted that it is more of a challenge to closely monitor and control exercise intensity during these types of exercise sessions. Gauvin et al. (1996) conducted an observational study of women undertaking a physical activity program, which comprised at least 20 min of a vigorous-intensity activity of the participant's choice**.** They reported that acute physical activity of this intensity improved affect and revitalization (Gauvin et al., 1996). Being observational in nature, many aspects of this study were unregulated; however, it is promising to see that the effects of exercise on mood can be seen in both a laboratory and in a field setting. Indeed, Rocheleau and colleagues (2004) highlighted the possibility that exercise experiments conducted in a laboratory setting may lack external validity due to the vastly different environment in which exercise takes place compared to the real world, and that this may interfere with the mechanisms that lead to post-exercise mood changes. It was suggested that it may be important to test this relationship in a more natural environment to improve the external validity of data (Rocheleau, Webster, Bryan & Frazier, 2004).

The above evidence suggests that improvements in mood are seen after several different modes of exercise, however not all forms of exercise appear to elicit these positive effects. In an early study by McGowan et al. (1991) they used the POMS questionnaire to assess the effect of a single bout of exercise on mood. It was reported that 75 min of running or weight lifting reduced overall mood disturbance, tension, depression, anger and confusion, but these effects were not seen following a karate class (McGowan et al., 1991). They speculated that the lack of effect seen following the karate class was due to it being of lower intensity, although exercise intensity was not measured in this study (McGowan et al., 1991). It could also be suggested that as karate is a contact sport, which involves duelling with a partner, this may have a very different effect on mood than less confrontational sports such as running and weight lifting.

1.3.2.2 Exercise intensity and duration

There is evidence to suggest that low-moderate intensity exercise of less than 10 min can enhance mood states; Thayer *et al.* (1993) reported increases in perceived energy and decreases in tension following a 5 min walk, undertaken in a naturalistic setting, in two small, mixed gender samples (N=16 & 18). Results from more recent studies have shown positive mood changes following 10 min of exercise (Anderson & Brice, 2011; Ekkekakis, Hall, VanLanduyt & Petruzzello, 2000; Hansen, Stevens & Coast, 2001). Ekkekakis et al. (2000) assessed the mood of 56 young healthy adults (28 female) after a 10 min walk or rest using the Feeling Scale (Hardy & Rejeski, 1989), the Felt arousal scale (Svebak & Murgatroyd, 1985), the Self-Assessment Manikin (Lang, 1980), the Affect Grid (Russell, Weiss, & Mendelsohn, 1989), the Positive and Negative Affect Schedule (Watson, Clark & Tellegen, 1988), the Activation–Deactivation Adjective Checklist (Thayer, 1986) and a state anxiety scale. The walk took place outside, in good weather conditions. Pleasant affect was higher following the walk, when compared to a resting control group. Hansen, Stevens and Coast (2001) used the POMS to assess the effect of 10, 20 and 30 min cycling (60% of the participant's estimated $\dot{V}O_2$ max) or resting in 21 young, healthy females. Positive mood effects (improvements in vigour, fatigue and total mood) were seen after 10 min cycling and less confusion after 20 min cycling. Increasing exercise duration to 30 min only resulted in minor additional improvements in mood state. Recently, Anderson and Brice (2011) reported a 10 min bout of jogging outside (twice the pace of normal walking speed) enhanced mood (as measured using the incredibly short POMS) in both genders (N=20) when compared to an resting control group (N=20). However, it should be noted that these studies used self-pacing or $\dot{V}O_2$ max estimation, rather than a more robust control of exercise intensity. It is also important to consider that the effects of exercise may differ depending where the exercise takes place; outside or indoors. Exercising outdoors exposes participant to many uncontrollable external factors, but may more closely reflect their usual exercise environment.

It has also been reported that the mood response of active and inactive males (N=48) did not differ between cycling at 50 or 70% $\dot{V}O_2$ max (Steptoe, Kearsley and Walters, 1993), but in a later study, Rocheleau, Wester, Bryan and Frazier (2004) reported that an increase in the duration and/or intensity of both resistance and cardiovascular exercise did result in a greater improvement in mood in both males (N=71) and females (N=64). Methodological differences may explain these conflicting results. It is generally thought that moderate-intensity exercise may be most favourable for mood benefits (Zervas, Ekkekakis, Emmanuel, Psychoudaki & Kakkos, 1993) and that very high-intensity exercise may negatively affect mood; however, Pronk, Crause and Rohack (1995) reported decreased tension and increased self-esteem (measured using the POMS) in women (N=22) following a maximal exertion walking test, so this may not be the case. Indeed, mood enhancement (perceived physical state, perceived psychological strain and calmness as measured using the MoodMeter® questionnaire) after running at a high (80–85% $\dot{V}O_2$ peak) but not low (50–

55% $\dot{V}O_2$ peak) or preferred intensity has been reported in 24 regular runners (9 female) (Schneider et al., 2009).

1.3.2.3 Participant characteristics

There are several factors to consider when assessing the effect of exercise on mood. These include perceived exercise enjoyment (Berger & Motl, 2000; Plante et al., 2007) and the participant's expectancy of a particular exercise event (Anderson & Brice, 2011). Those who are used to undertaking exercise of a particular mode and intensity may be more likely to report positive mood effects following a similar exercise bout based on their previous experiences. Indeed, it has been reported that higher negative affect was seen in a group who exercised on a cycle ergometer, compared to a group who were given a choice of exercise mode, suggesting exercise preference may moderate this relationship (Daley & Maynard, 2003). In addition, the most constant effect of exercise on mood is seen when regular exercisers undertake exercise at an intensity level and mode which is familiar (Salmon, 2001). To successfully test exercise interventions and mood, it may be advisable to control for these preferences when selecting participants (Anderson & Brice, 2011).

The extent to which exercise induces positive mood changes varies significantly between individuals (Dietrich & McDaniel, 2004) and not all populations show positive changes in mood post-exercise; Lofrano-Prado and colleagues (2012) reported negative changes in mood (an increase in anxiety and fatigue, and a decrease in vigour) following low and high-intensity exercise (10% below and above ventilatory threshold respectively) in obese males (N=8). A greater positive mood effect (an increase in vigour and decrease in fatigue and measured using the POMS) following acute exercise has been reported in regular exercisers compared with non-regular exercisers (Hoffman & Hoffman, 2008), although an earlier study by Steptoe et al. (1993, described in section 1.3.2.2) found no difference in post-exercise mental vigour and exhilaration between inactive men and sportsmen (Steptoe et al, 1993). In untrained participants, it has been suggested that any increase in positive mood seen after exercise ceases is simply due to a 'sense of relief' that the exercise session is over (Wininger, 2007). Fitness status has been suggested as a mediator for cognitive function following exercise, but it appears that this only moderates the relationship between exercise and affect at high intensities (Ekkekakis and Petruzzello, 1999).

The effects of exercise on mood may of course be moderated by gender and this has been noted in the literature. Rocheleau et al. (2004) reported that exercise led to lower negative mood in women compared to men. They suggested that this may be due to the fact that in general, women report higher levels of depression and anxiety (e.g. Merns, 1995) and therefore may experience additional mood benefits after exercise compared to men (Yeung, 1996). Gauvin et al. (1996) reported that the greatest improvements in post-exercise mood were seen in women who reported feeling worst before exercise and in a recent cross-sectional study it was reported that exercise improves more aspects of mood in women than in men and that the largest benefits are seen at different intensities for each gender; high for men and moderate for women (Asztalos, De Bourdeaudhuij & Cardon, 2010). Women tend to report mood enhancement as a reason for exercising more so than men (Furnham, Badmin & Sneade, 2002; Tiggemann & Williamson, 2000), therefore this population may be more likely to desire the maximum possible mood-enhancing effects from exercise. Whilst it is commonly thought that mood in females is influenced by menstrual cycle phase, this theory has recently come into question (Romans, Clarkson, Einstein, Petrovic & Stewart, 2012), therefore this factor may not be as important to control for in this type of research as previously believed.

It has been suggested that low adherence to regular exercise may be due to the delay in seeing some of the benefits (e.g. weight loss and disease prevention; Rocheleau et al., 2004). A lack of immediate reward in these areas may reduce motivation; however, as discussed, improvements in mood can be seen immediately following an acute exercise session and therefore more focus on this benefit as the main goal of exercise may help to improve adherence.

Research has focused on identifying the optimum duration and intensity for maximum mood benefits and how this relationship may be moderated by other factors such as age and gender (Rocheleau et al., 2004). However, little research has considered if nutritional status prior to exercise may also influence this relationship, and this is a main focus of the studies presented in this thesis.

1.3.2.4 Longevity of acute effects

Post-exercise mood tends to be measured immediately post-exercise or a short while after exercise cessation. It has been found that improvements in positive mental state (Redd & Ones, 2006) and exhilaration (Steptoe et al., 1993) can be seen up to 30 min after a bout of acute exercise, and increases in well-being and decreases in fatigue and psychological distress have been reported 60 min after exercise cessation (Cox, Thomas & Davis, 2001). A decrease in stress and increase in positive mood has been observed 2 h after treadmill walking or running in a mixed gender sample (Hopkins, Davis, VanTieghem, Whalen & Bucci, 2012). Even more encouragingly, it has been found that improvements in mood state seen in females following an exercise class had not fully dissipated 24 h later (Maroulakis & Zervas, 1993). However, there does appear to be a lack of data from studies in this area which have monitored mood changes following exercise >1 h post-exercise. This may be due to the difficulty in controlling the continual increase over time of other factors, such as food intake and daily activities, which could influence mood state.

1.3.2.5 Mechanisms of action of the effect of exercise on mood

Despite a plethora of research attempting to uncover the mechanisms behind the mood-enhancing effect of exercise, there is no clear answer as yet. During exercise, several changes occur in the body which could contribute to the observed mood changes; these include a rise in core temperature, alterations in central neural activity (Hall, Ekkekakis & Petruzzello, 2007) and the secretion of hormones and neurotransmitters (Dubnov & Berry, 2013). It has also been suggested that the observed mood changes may occur due to distraction from everyday worries (Raglin & Morgan, 1985). Indeed, it is very likely that the mood-enhancing effect of exercise occurs via several mechanisms.

The distraction hypothesis suggests that a break from negative thoughts and everyday stress may moderate the exercise-mood relationship (Craft, 2005; Morgan, 1985). Although studies investigating this theory have generally found that the anxiety and tension-reducing effect of exercise is only equal to that of a period of relaxation (Berger, Friedmann & Eaton, 1988; Felts &

Vaccaro, 1988), it is generally accepted that exercise has a greater ability to improve positive mood states (Saklofske, Blomme & Kelly, 1992). Somewhat in line with this is the reticular-activating hypofrontality (RAH) model. During exercise, the higher-order functions of the prefrontal cortex are thought to disengage, which may keep unsupportive emotional processes from compromising motor function (Dietrich & Audiffren, 2011). Human imaging studies show increased pre-frontal cortex activity following exercise also, which correlated with feelings of calmness and tiredness (Hall et al., 2007). However, further research is needed to examine whether these changes persist, and are responsible for, mood changes in the post-exercise recovery period (Schneider, et al., 2009).

A theory which has received considerable attention and support in the literature in the past is the endorphin hypothesis, which attributes the positive post-exercise mood changes to the elevated presence of endorphins in the CNS (Boecker et al., 2008; Steinberg & Sykes, 1985; Thorén, Floras, Hoffmann & Seals, 1990). It has been shown that endogenous opioids, such as endorphins, are released in the brain after prolonged exercise and that this increase coincides with increased feelings of euphoria (Boecker et al., 2008). However, it is also known that endorphin molecules do not freely cross the blood-brain barrier, and therefore may not be responsible for the increase in mood during and after exercise (Dearman & Francis, 1983), although an increase in body temperature during exercise may increase permeability of the blood-brain barrier (Watson et al., 2005). Indeed, the thermogenic hypothesis suggests that an increase in body temperature may cause the immediate mood enhancing effects following exercise (Raglin & Morgan, 1985), although studies testing this hypothesis have not supported this theory (see Yeung, 1996).

Endorphins are also thought to interact with neurotransmitters, such as dopamine, to improve mood (Dishman & O'Connor, 2009). In line with this is the monoamine hypothesis (Pierce, Kuppart & Harry, 1979), which suggests that exercise results in an increase in the availability of brain neurotransmitters (dopamine, serotonin and noradrenaline), the levels of which are reportedly lower in depressed individuals (Daley, 2008). Exercise has been found to lead to an increase in dopamine release, which affects emotional responses (Meeusen, Piacentini & De Meirleir, 2001) and serotonin production which regulates mood (Kubitz & Mott, 1996).

It has been more recently suggested that anandamide, which is a cannabinoid neurotransmitter linked to emotional processes, may be responsible for the observed mood changes. In a study by Sparling and colleagues, they reported significantly higher levels of plasma anandamide after running or cycling compared to resting (Sparling, Giuffrida, Piomelli, Rosskopf & Dietrich, 2003). This neurotransmitter does freely cross the blood-brain barrier and is therefore more likely responsible for the mood effects seen than endorphins (Dietrich & McDaniel, 2004).

In summary, exercise does indeed appear to have the potential to produce improvements in mood, in particular reducing tension and fatigue and increasing vigour, although this effect is moderated by several influences. A factor closely linked to mood is appetite control and this too appears sensitive to exercise interventions: this is discussed in the following sections.

1.3.3 Exercise, Appetite and Energy Intake

As previously stated, exercise is often used as a method of weight control, particularly in females (Silliman et al., 2004). Exercise leads to an increase in energy expenditure (EE), creating an energy deficit and subsequent weight loss if energy is not replaced (Donnelly, et al., 2009; Donnelly, et al., 2003; Jakicic, 2009). Extensive research in previous years has looked at the possible effect of exercise on appetite; if exercise stimulates appetite and subsequent EI, any weight-loss effects of exercise may be lost. Inducing a negative energy balance by reducing food intake has been shown to subsequently increase hunger and EI (Green, Rogers, Elliman & Gatenby, 1994; Hubert, King & Blundell, 1998, described in section 1.2.3) and a common belief is that the energy expended as a result of exercise has the same effect on these parameters; a small number of studies have provided evidence which partially supports this theory (Martins, Morgan, Bloom & Robertson, 2007; Pomerleau, Imbeault, Parker & Doucet, 2004). Martins, Morgan, Bloom and Robertson (2007) assessed the effect of exercise (cycling for 60 min at 65% HR max) on subjective appetite and EI in 12 healthy participants (6 female). Hunger was reduced transiently during exercise. Exercise increased EI at an *ad libitum* lunch 1 h post-exercise, but overall EI was reduced when EE during exercise was considered. Pomerleau, Imbeault, Parker and Doucet (2004) assessed EI and subjective appetite in 13 moderately active women who took part in three conditions; no exercise, low-intensity and high-intensity exercise (walking on a treadmill at 40 and 70% peak oxygen uptake respectively; both generating an EE of 350 kcal). The high-intensity exercise session, compared to no exercise, led to a higher EI at lunch. However, relative EI was lower following exercise, compared to no exercise. Subjective appetite was not significantly affected by the interventions.

Others studies, however, report contradictory results (Broom, Stensel, Bishop, Burns & Miyashita, 2007; Farah, Brunstrom & Gill, 2012; Jokisch, Coletta & Raynor, 2012). Broom, Stensel, Bishop, Burns and Miyashita (2007) reported that exercise (running at 72% $\dot{V}O_2$ max for 60 min) suppressed hunger (assessed using a 16 point scale) 3 h post-exercise compared to rest (N=9, all males). Participants were required to fast the evening prior to testing and record dietary intake the day prior to the first test session, which was replicated the day prior to the second test session, both good practices to implement in this area of research. Farah, Brunstrom and Gill (2012) assessed the effect of exercise (60 min walking on a treadmill at an intensity of ~6 METs) or resting on subjective appetite in 27 participants (13 female). Exercise reduced hunger ratings and lowered prospective ideal proportion size. Whilst the authors did attempt to control exercise intensity, using a more robust method (such as $\dot{V}O_2$ max or HR max) would have been desirable. Jokisch, Coletta and Raynor (2012) measured EI in active (N=10) and inactive (N=10) males following 45 min cycling (at 65–75% of age-predicted HR max) or reading. The inactive participants ate significantly less when provided with an *ad libitum* meal 60 min post-exercise, rather than post-rest. However, the active participants showed superior overall acute energy compensation.

Furthermore, numerous studies have failed to show any relationship between exercise and subjective appetite or EI (Hubert et al., 1998; Imbeault, Saint-Pierre, Almeras & Tremblay, 1997 ; King, Miyashita, Wasse & Stensel, 2010; King, Lluch, Stubbs & Blundell, 1997; Lluch, King & Blundell, 2000). Imbeault, Saint-Pierre, Almeras and Tremblay (1997) assessed EI in young, healthy males (N=11) after exercising at a low (35% $\dot{V}O_2$ max) or high (70% $\dot{V}O_2$ max) intensity, or resting. Neither subjective appetite or EI differed following exercise compared to rest, but relative EI was lower following high-intensity exercise compared to the other two conditions. King, Lluch, Stubbs & Blundell (1997) reported no increase in hunger or EI (measured using self-report food diaries) following a high-intensity exercise session (50 min running at 70% HR max) in young healthy males (N=8). Physical activity was restricted in the two days prior to testing sessions, which goes beyond the normal 24 h restriction period that is normally used in studies. King, Miyashita, Wasse and Stensel (2010) assessed the effect of a longer duration period of running (90 min) at a similar exercise intensity as King et al. (1997). Appetite was suppressed during exercise, compared to rest, but this effect was not seen post-exercise. In the 24 h post-exercise period, there was also no compensatory increase in EI (as measured using *ad libitum* buffet meals). Whilst the authors specify that participants were required to fast for 10 h prior to testing, there did not appear to be any control over pre-testing day diet in this, or in the previous study by King et al. (1997).

A number of studies have reported that exercise-induced appetite suppression (often referred to as exercise-induced anorexia) appears to be brief does not affect overall EI compared to resting, although exercise can increase the time before food is desired (King & Blundell, 1995; King, Burley & Blundell, 1994). In two studies, King et al. (1994) examined the effects of low or high-intensity exercise (N=11 males), or long or short-duration exercise (N=12 males) on subjective appetite and EI when compared to a rest condition. High-intensity exercise suppressed hunger during exercise and increased the time until eating occurred post-exercise (referred to as "food resistance" by the authors). Only the long-duration, high-intensity exercise led to a significant negative energy balance post-exercise. King and Blundell (1995) reported similar effects; a delay in the onset of eating in response to high intensity (70% $\dot{V}O_2$ max) cycling or running compared to rest in healthy male subjects (N=24). Additionally, even when appetite sensations following exercise are augmented, this does not always appear to lead to an increase in EI; previously, Maraki et al. (2005) reported that a 1 h aerobics class increased appetite sensations in females (N=11) who did not exercise regularly, but post-exercise EI did not differ between the exercise and rest conditions. Recent literature suggests that any increase in EI post-exercise appears to be only partial in relation to energy expended during exercise (King et al., 2010; Martins et al., 2007; Stensel, 2010). Indeed, EI following the undertaking of a longer term physical activity programme does increase, but only to compensate for about 30 % of the energy used in activity (Blundell, Stubbs, Hughes, Whybrow & King, 2003). There may of course be an effect of exercise on subsequent subjective appetite and EI, but not one which is robust enough to override everyday habitual behaviours and influence EI (Stubbs, 1998); differences in the strength of these habits may explain why some individuals appear to compensate for the energy expended during exercise and others do not (Blundell et al., 2003).

As previously discussed in 2.1.3, there are several difficulties in measuring EI, such as a change in participants eating behaviours when they are aware they are being monitored (Blundell et al., 2010) and under-reporting when EI is measured in a free-living environment (Livingstone & Black, 2003). Studies have usually only assessed EI for a few hours post-exercise, although some have looked at this parameter over a longer time period. For example, King et al. (2010) assessed EI over a 22.5 h period following a 90 min treadmill run, but no significant change was seen. Recently, Hagobian et al. suggested that in order to look at the effects of exercise on energy balance, participants "should be studied in both energy-deficient (EI not raised to match expenditure) and energy-balanced (EI raised to match the new higher EE) conditions" (Hagobian et al., 2009, page 233).

1.3.3.1 Participant characteristics

Measuring appetite and food intake is complex; both can be affected by many variables such as age, gender, body composition, participant fitness levels, level of dietary restraint and individual differences, all of which may manipulate the balance between psychological and physical control of appetite and food intake, making it difficult to generalise research findings (Maraki et al., 2005; Stensel, 2010). For example, previous data suggested that regular physical activity may improve the accuracy of satiety signalling systems (Long, Hart & Morgan, 2002). Somewhat conversely, active individuals have also been shown to not decrease their EI when they are forced to rest, rather than exercise, despite the reduction in EE, undesirably leading to a positive energy balance (Blundell et al., 2003). Even though conflicting, this evidence suggests that the habitual activity level of participants is a factor which should be controlled for in this area of research.

Another factor thought to influence the effect of exercise on appetite responses and therefore EI and overall balance is eating restraint. Overall, it appears that exercise may result in a larger negative energy balance in restrained compared with unrestrained eaters (Lluch et al., 2000), controlling appetite in these individuals, rather than disinhibiting it (King, 1999). However, the role this behavioural factor plays in the exercise-energy balance relationship appears complex (Martins, Morgan & Truby, 2008).

1.3.3.2 Gender

Gender-differences in the appetite response to exercise have been investigated. In general, it appears that whilst exercise does not appear to substantially affect subjective appetite and subsequent EI in men, the opposite is often observed in women (Imbeault et al., 1997; Kawano et al., 2012; Pomerleau et al., 2004), who may also report an increase in the palatability of foods following exercise (King & Blundell, 1995; King, Snell, Smith & Blundell, 1996). King et al. (1996) reported that intense exercise (70% $\dot{V}O_2$ max) led to an increase in the palatability of foods consumed at a post-exercise buffet in young unrestrained females (N=13), but their sample did not report the hunger suppression during exercise, commonly seen in men. This could lead to the reduction, or even the eradication, of any exercised-induced energy deficit and could explain why exercise seems less effective for weight loss for this gender (Donnelly et al., 2003). However, more recent data suggests that subjective appetite and EI following exercise does not differ between the sexes (Hagobian et al., 2012) and that if the same target EE is met, this can result in similar weight loss for both men and women (Caudwell et al., 2012). Hagobian et al. (2012) assessed the effect of cycling (70% $\dot{V}O_2$ peak until 30 % of total daily EE was expended) or 60 min resting in 11 men and 10 women. They reported no differences in subjective appetite or EI, when measured using an *ad libitum* buffet 40 min post-exercise. Indeed, whilst previous data showing differing hormonal responses to exercise in men and women appear to support the idea that exercise may stimulate appetite in women (Hagobian et al., 2009; Hickey et al., 1997), the data from the same study by Hagobian. et al (2012) has challenged this theory. Data for gender differences in *ad libitum* EI and brain activity following exercise remains inconclusive (for review see Hagobian & Evero, 2013) and further research is required to substantiate any gender theories (Stensel, 2010). As previously mentioned (see section 1.2.3.1), appetite may also be influenced by menstrual cycle phase in females (Dye and Blundell, 1997).

1.3.3.3 Exercise Intensity and Mode

Generally the literature shows that exercise intensity has a prominent influence on subsequent appetite and EI. High-intensity exercise (> 60% $\dot{V}O_2$ max) reduces appetite during and following exercise, but only for a short while (Broom et al., 2007; King & Blundell, 1995; King et al., 1994; Martins et al., 2007). However, high-intensity exercise has also been shown to increase appetite in obese males (Lofrano-Prado et al., 2012; study as described in section 1.3.2.3).

The most popular modes of exercise used in this area of research are walking or running on a motorized treadmill or cycling on a stationary bike. Whilst it could be suggested that appetite responses to a bout of exercise may depend on the mode used, this may not always be the case; King and Blundell (1995) reported no difference in EI response to high-intensity (70% $\dot{V}O_2$ max) cycling or running in male subjects (N=24) in a repeated measures design. However, in a recent study by Kawano et al. (2013) the effects of rope skipping and cycling (both 3 x 10 min with a similar EE) on subjective appetite in 15 healthy male participants were compared to a resting control condition. More prominent hunger suppression was seen following the rope skipping compared to cycling, suggesting a difference between weight-bearing and non-weight bearing exercises. In addition, higher concentrations of the appetite-supressing hormone peptide YY (PYY; discussed in section 1.3.3.3) have been found following aerobic (60 min running) compared to weight-training (90 min free weight lifting) exercise in 11 young, healthy males (Broom, Batterham, King & Stensel, 2009).

1.3.3.4 Mechanisms of action of the effect of exercise on appetite and energy intake

Several factors, physiological and environmental, contribute to eating behaviour. Energy and macronutrient intake is determined by the magnitude and frequency of eating occasions and food choices (Blundell, 1991; Blundell, Green & Burley, 1994). It has been suggested that exercise has the potential to regulate appetite through "improving the sensitivity of the physiological satiety signalling system, by adjusting macronutrient preferences or food choices and by altering the hedonic response to food" (Blundell et al., 2003, page 651). Several mechanisms may contribute to these effects; whilst the focus of the current thesis is on the non-metabolic effects of exercise and appetite, these are explained briefly below to give a more complete depiction of this research area.

The neurotransmitter serotonin, the concentration of which increases during exercise, has appetite-suppressing properties (Halford & Blundell, 2000), and may explain the temporary reduction in appetite seen during, and a short time after, exercise. In addition, several hormones are thought to be involved in appetite regulation. These hormones signal satiation, the process which leads to eating cessation, and satiety, the process which reduces hunger, increases fullness and prevents further eating (Blundell et al., 2010). Long-term energy balance regulation is controlled by two hormones, insulin (released from the pancreas) and leptin (released from adipose tissue), which signal satiety (Stensel, 2010). Exercise, whether it leads to an energy deficit, or a deficit which is immediately replaced post exercise, has been shown to reduce later postprandial insulinaemia (Burton, Malkova, Caslake & Gill, 2007) which suggests an improvement in insulin sensitivity.

Ghrelin, an episodic hormone, responds to food intake and, in its acylated form, is thought to play a prominent role in the stimulation of appetite and EI. A reduction in acylated ghrelin during (King et al., 2010) and following (Broom et al., 2009; Broom et al., 2007) acute moderate-intensity exercise has been previously reported. This effect appears to last up to 1 h post-exercise, although it is not consistently accompanied by a reduction in subjective hunger, bringing to question ghrelin's role in the development of exercise-induced anorexia. Other satiety hormones, namely peptide YY (PYY) and GLP-1 have also been studied in relation to exercise. In particular, PYY is thought to have strong appetite-supressing properties, and augmented levels of this hormone have been reported following acute exercise (Broom et al., 2007; Martins et al., 2007).

It should be noted that the response of these hormones to exercise differs between men and women (Hagobian & Braun, 2010). Previous studies have noted increases in acylated ghrelin, lower insulin concentrations (Hagobian et al., 2009) and lower leptin levels (Hickey et al., 1997) in women, but not in men, in response to exercise training; this may provide a reason as to why appetite is often seen to be stimulated by exercise in women, but not men.

In addition, neural responses in the brain in areas associated with reduced food pleasure, consumption and motivation to eat have been shown to be reduced following exercise, which likely also contributes to the paradigm of post-exercise appetite suppression (Evero, Hackett, Clark, Phelan & Hagobian, 2012). These homeostatic appetite-regulating mechanisms may also be influenced, and indeed be dominated, by hedonistic drives; reward pathways that relate to the pleasure of palatable foods (Blundell et al., 2010). Indeed, female restrained eaters have reported increased pleasure from a range of foods after exercise (Lluch, King & Blundell, 1998).

To conclude, exercise, in particularly that of a high-intensity, does appear to create a transient suppression of subjective appetite, but this does not appear to coincide with a reduction in EI, at least in a male population. Less research has been conducted looking at the effect of nutritional status prior to exercise on appetite, and indeed on cognitive function and mood. This interaction is the main focus of this thesis and will be discussed further in the subsequent sections.

1.4 Breakfast and Exercise Interaction

As outlined in the previous sections of this literature review, both breakfast and exercise can affect cognitive performance, mood and appetite. Given the apparent importance of breakfast consumption for wellbeing and the additional health benefits of exercise, it is attractive to speculate that combining these two practices would be advantageous for the aforementioned parameters; this concept is the focus of the current thesis. In exercise intervention studies participants tend to perform exercise following an over-night fast. This practice has been shown to increase fat oxidation during exercise (Backhouse, Williams, Stevenson & Nute, 2007; Enevoldsen, Simonsen, Macdonald, & Bülow, 2004; Gonzalez, Veasey, Rumbold & Stevenson, 2013); however, fasting prior to morning exercise is contradictory of research which suggests that breakfast consumption is important for health (Barton et al., 2005; Pereira et al., 2011; Smith, 1998).

In a recent survey by Reeves et al. they asked individuals (N=699) who regularly engaged in moderate-intensity physical activity how they felt breakfast influenced their energy levels. Only 23 % agreed they preferred not to have breakfast before exercise, whereas at least 40 % of the sample agreed that they had more energy on days that they ate breakfast, that eating breakfast led to increased physical activity, and that they felt they must eat breakfast before they engaged in exercise (Reeves et al., 2013).

If exercise is undertaken in the morning, breakfast is a likely source of pre-exercise nutrition but little is known about how pre-exercise nutrition affects post-exercise mental performance, mood and appetite; specifically, the relationship between breakfast consumption and exercise has not been explored in depth. Although there are nutritional guidelines available for athletes to follow with regards to exercise performance, for example, consuming CHO following an overnight fast and 2-4 h before exercise (Hargreaves et al., 2004), for those exercising recreationally rather than for competition or performance enhancement, these guidelines may not be applicable.

It is known that CHO and/or protein administration before or during exercise can improve cognition (Ali & Williams, 2009; Collardeau et al., 2001; Lieberman et al., 2002), increase feelings of vigour (Lieberman et al., 2002) and pleasure (Backhouse, Bishop, Biddle & Williams, 2005) and attenuate fatigue (Welsh, Mark, Burke, & Williams, 2002) and confusion (Lieberman et al., 2002), although few studies have looked at the effect of consuming a typical meal before exercise. However, this evidence does suggest a link between nutritional status and exercise on cognition and subjective physical state.

Exercise can transiently suppress hunger in a fasted state (Broom, et al., 2007; King et al., 2010) and fed state (Martins et al., 2007). Martins et al. (2007) reported that breakfast consumption prior to a 60 min bout of cycling, compared to rest, suppressed hunger and led to a lower relative EI at an *ad libitum* lunch in 12 healthy participants (6 female). Even if an exercise-induced increase in appetite is observed, it may in fact correspond with an increase in the satiating effect of food consumed post-exercise. This has been seen when exercise training is undertaken in a fasted (Martins, Kulseng, King, Holst & Blundell, 2010) and a fed state (Cheng, Bushnell, Cannon & Kern, 2009; King, et al., 2009). Cheng, Bushnell, Cannon and Kern (2009) reported that 50 min cycling (60% $\dot{V}O_2$ max) performed 2 h after, rather than prior to, a high fat breakfast prolonged the appetite suppressing effect of the meal in moderately active men (N=12). However, neither Martins et al. (2007) nor Cheng et al. (2009) compared the post-exercise effects of pre-exercise breakfast consumption to breakfast omission. Further evidence is needed to validate the efficacy of this approach (Stensel, 2010), but these results taken in tandem with those showing the effects of breakfast consumption on appetite control (as described in section 1.3.3), suggest it is possible that breakfast consumption and exercise may interact to benefit appetite control and EI, improving any weight loss benefits the exercise period provided.

Two previous laboratory studies have looked at the interaction between exercise and consuming a low or high-energy breakfast post-exercise in female samples. In 1998, Hubert et al. conducted a study investigating the differences between consuming a high or low-energy breakfast after exercise (cycling for 40 min at 70% $\dot{V}O_2$ max) or rest in healthy females (N=11). Following consumption of a low-energy breakfast, hunger and food cravings were increased during the morning and EI increased at lunch compared to the high-energy breakfast; however, exercising prior to breakfast consumption did not alter these effects. In 2000, Lluch and colleagues studied the effect of a low (64 kcal, 15g CHO) or high-energy (500 kcal, 93g CHO) breakfast after rest or a period of cycling (~40 min at 70% $\dot{V}O_2$ max) in 11 young healthy females. Exercise, compared to rest, prior to consuming the high-energy meal reduced post-meal fullness ratings, but had the opposite effect when a low-energy meal was consumed. Separately, exercise and breakfast affected ratings of tension and lethargy, with exercise and a high-energy breakfast both reducing these variables compared to their opposing conditions. Lower contentment and increased irritability were reported following the low-energy breakfast, but this was attenuated if exercise, rather than rest, was undertaken before breakfast. It was concluded that the condition that led to the largest energy deficit was not associated with the poorest mental states (Lluch et al., 2000). It would have been interesting if these studies had included a fasted condition and if the effect of breakfast prior to, rather than after, exercise had been measured. In addition, an alternative mode of exercise, such as running, may produce different results to those reported previously (Stensel, 2010).

The timing of breakfast consumption may also moderate this relationship; although it has been shown that breakfast improves post-prandial metabolism, whether consumed before or after a bout of exercise (Fauzi & Farah, 2011), it is often stated that breakfast should be consumed before the start of daily activities (Timlin & Pereira, 2007). This, taken with data that show improved physical performance and cognitive performance when CHO is consumed prior to exercise, suggests it is plausible that breakfast and exercise may interact to affect these parameters if breakfast is consumed prior to morning exercise. There has been an attempt to investigate this in previous studies with varying results (Hill et al., 2011; Paul et al., 1996; Vermorel et al., 2003).

Vermorel et al. (2003) investigated the effect of the size of breakfast consumed by school children on a day that they had a morning physical education (PE) lesson. The results from this study highlighted the need for children to consume a substantial breakfast on days when they take part in PE in the morning to improve attention and memory. The same theories may apply to morning adult exercisers who exercise in a fasted state.

In a study by Paul et al. (1996) they omitted or administered a cereal breakfast (providing 645 and 582 kJ/m^2 for males and females respectively) to 12 participants (6 men) before a 90 min cycle (60% $\dot{V}O_2$ max). EI (measured at an *ad libitum* lunch) and cognitive performance were recorded in this study although there was no difference between eating breakfast and fasting on these parameters. Fatigue during the recovery period and perceived hunger and desire to eat were found to be higher in the fasted than non-fasted trials. However, this study did not compare the effects of exercise to those of resting following the same nutritional interventions. More recently, there was no difference identified in the mood state (energy, tiredness, tension and calmness) of male (N=15) and female (N=22) swimmers assessed in a field setting, who either consumed CHO (10 fluid ounces of strawberry gelatin, 45 g CHO, 200 kcal) or a placebo (10 fluid ounces of sugar-free strawberry gelatin, 4 g CHO, 25 kcal) before a 90 min morning training session (Hill et al., 2011).

Deighton and colleagues assessed the effect of a 60 min treadmill run (70% $\dot{V}O_2$ max) when performed before or after breakfast in 12 healthy, young males. The breakfast consisted of toasted white bread with jam, a banana and orange juice and provided 30 % of the estimated energy needs of each participant. They reported that exercise performed after breakfast had a greater appetite-suppressing effect than when performed in a fasted state, although *ad libitum* EI did not differ between conditions, meaning both interventions led to a negative energy balance (Deighton, Zahra & Stensel, 2012). However, these results could have been influenced by the vastly different time periods between exercise termination and the *ad libitum* meals between the treatment conditions, although this is acknowledged by the authors. Currently, however, these results cannot be generalised to a female population, and it would be interesting to investigate this relationship using a different type of breakfast meal, such as a cereal-based breakfast, which is also commonly consumed in the UK (Reeves et al., 2013).

The results so far do not appear to support the theory that breakfast consumption prior to exercise is beneficial for appetite, cognition and mood. However, study results may vary depending on time of CHO/meal administration, the macronutrient composition of the meal given, the test population characteristics, the behavioural tests used and the energy status of the subject (Lieberman, 2002). The two adult intervention studies identified that have assessed the effect of breakfast prior to exercise have used mixed gender samples. Given that gender differences have been observed in the effects of exercise on appetite (Hagobian & Braun, 2010; Hagobian et al., 2009; Hickey et al., 1997), cognition (Al-Nimer & Al-Kurashy, 2007) and mood (Rocheleau et al., 2004; Asztalos, De Bourdeaudhuij & Cardon, 2010), it is necessary to assess this relationship in single gender samples. It is generally acknowledged that females are underrepresented in exercise literature (Lambourne & Tomporowski, 2010) and for this reason the majority of studies in this thesis have focused on female samples. In addition, assessing this relationship using a mode of exercise different to that of cycling or swimming may also add to data in this area of research.

1.4.1 Mechanisms of action for the interactive effect of breakfast and exercise on cognition, mood and appetite

There have been several mechanisms suggested that may explain the link between exercise and nutritional status and the subsequent effect on cognition, mood and appetite. As previously discussed (see section 1.2.1.6), it is well documented that the brain requires a continuous supply of glucose to function efficiently and that hypoglycaemic conditions can negatively affect brain function (Gold et al., 1995; McCrimmon, Deary, Huntly, MacLeod & Frier, 1996). During aerobic exercise, peripheral glucose requirements and utilization of glucose by the brain increases (Ide, Horn & Secher, 1999). This can deplete CHO stores fairly rapidly, lowering blood glucose concentration and possibly causing hypoglycaemic conditions during prolonged exercise (Romijn et al., 1993; Walters, 2002), resulting in reduced brain function. The brain is very metabolically active and cerebral blood flow studies have shown that exercise increases its metabolic requirements in certain regions (Ide et al., 1999); CHO in particular may reduce the effects of energy depletion in the brain by attenuating the synthesis of certain metabolites and neurotransmitters (Lieberman, et al., 2002). Immediately post-exercise, Backhouse and colleagues

(2005) observed a higher concentration of plasma glucose when CHO, compared to placebo, had been consumed during a moderate intensity 2h cycle, which corresponded with increased feelings of pleasure in males.

An increase in peripheral tryptophan and a consequent increase in brain serotonin are thought to cause tiredness and central fatigue during exercise (Blomstrand, Hassmén, Ekblom & Newsholme, 1991; Davis & Bailey, 1997). However, when CHO is administered during exercise there is no observed increase in plasma tryptophan, which could attenuate these feelings (Davis et al., 1992; Lieberman et al., 2002). Tryptophan levels are also heavily influenced by protein intake; levels of tryptophan have also been altered in humans through the administration of branched-chain amino acids (BCAAs) which are found naturally in food sources high in protein. During prolonged heavy exercise BCAA supplementation results in a decline in perceived exertion and mental fatigue during exercise and an enhancement in cognitive performance following exercise (for review see Blomstrand, 2001). In theory, if a breakfast consisting of CHO and protein is consumed prior to exercise, this same mechanism may prevent fatigue not only during, but also in the post-exercise recovery period. Paul et al. (1996) attributed the higher fatigue reported during the recovery period following a 90 min cycle to a higher tryptophan-LNAA ratio observed in fasted, rather than fed, subjects. As serotonin is known to increase satiety ratings, this may also explain why the same authors report no differences in EI between the conditions, despite higher hunger ratings in the fasted condition (Paul et al., 1996).

Exercise, whether it leads to an energy deficit, or a deficit that is immediately replenished post-exercise, has been shown to reduce later post-prandial insulinaemia (Burton-Freeman & Keim, 2008) and insulin resistance (for review see Borghouts & Keizer, 2000). An increase in insulin resistance, and therefore a decrease in glucose tolerance, is associated with poorer short-term cognitive function (selective attention; Nilsson, Radeborg, & Bjorck, 2012, described in section 1.2.1.5) and appetite regulation (Flint et al., 2007) and a greater likelihood of depressive disorders (Petrlová, Rosolova, Hess, Podlipný & Šimon, 2004). As breakfast consumption compared to omission, is also beneficial for insulin sensitivity (Farshchi et al., 2005; Pereira et al., 2011), it is plausible that consuming breakfast prior to exercise may elicit positive effects on cognition, mood and appetite via this mechanism.

Another mechanism that may moderate the relationship between breakfast and exercise is BDNF concentration. This growth factor can influence body weight and energy homeostasis (Noble et al., 2011; Wisse & Schwartz, 2003) and a sufficient concentration of BDNF are thought to be vital for cognitive function (Tsai, et al., 2003). In addition, BDNF concentration is reportedly lower in depressed individuals (Lee & Kim, 2010). Increased BDNF in the blood following exercise have been reported (Ferris et al., 2007; Gold et al., 2003; Griffin et al., 2011; Rasmussen et al., 2009; Winter et al., 2007) leading to the theory that this mechanism may be responsible for the cognitive benefits seen after exercise. Although limited research has been conducted thus far, BDNF also appears to be sensitive to chronic (Sánchez-Villegas et al., 2011) and acute (Karczewska-Kupczewska et al., 2012) dietary changes in humans. Sachez-Villegas and colleagues (2011) reported an increase, although non-significant, in plasma BDNF following a three year Mediterranean diet and Karczewska-Kupczewska et al. (2012) found the consumption of a high-fat meal decreased plasma BDNF in male subjects. Interestingly, serum BDNF levels are positively correlated with insulin sensitivity in women (Karczewska-Kupczewska et al., 2011). If this mechanism does partially moderate the interaction between nutritional status and exercise on cognitive function, mood and appetite, there may be differences between the genders as BDNF levels are thought to be different in men and women (Lommatzsch et al., 2005).

1.5 The interaction between cognition, mood and appetite

It is not uncommon to see either cognition and mood, appetite and mood or appetite and cognition assessed together following the same intervention. Studies investigating weight loss strategies often look at appetite concurrently with mood or cognitive function. In particular, mood and appetite appear to be closely linked, with changes in either parameter also influencing cognitive function. For example, following breakfast consumption a positive correlation between alertness and fullness has been reported (Holt et al., 1999). Over-eating, often caused by a psychological increase in appetite rather than the desire to suppress actual physical feelings of hunger, can lead to poorer mood and worse cognitive performance (Smith, Ralph & McNeill, 1991). In a study by Fischer, Colombani & Wenk in 2004, they found negative correlations between hunger and desire to eat ratings and feelings of energy, liveliness, calmness, relaxation and central RT in 15 male participants following consumption of creams varying in macronutrient content.

Hill and colleagues (1991) saw that female cravers (N=206) reported higher boredom and anxiety during the day and poor mood tended to be present before cravings occurred (Hill, Weaver & Blundell, 1991). In support, Christensen and Pettijohn (2001) administered the Cravings Questionnaire, POMS, Beck Depression Inventory and the Vitality Inventory to a large sample of university students (N=251, 138 female) and found that poorer mood led to sweet CHO cravings in those classed as CHO cravers. Nearly 90% of females, but only 53% of males, were classified as CHO cravers in this study, suggesting that the relationship between mood and food cravings would likely be stronger in a female population. Poorer cognitive performance and mood have also been reported in restrained and dieting women (Green et al., 1995; Green, Rogers, Elliman & Gatenby, 1994). It has been suggested that cognitive performance is worsened during dieting not only because of a possible lack of adequate nutrients but also from the anxiety and stress created by forcing and sustaining dietary restraint (Green et al., 1994); skipping a meal such as breakfast, may exert a similar effect. It is important that the palatability of foods used in *ad libitum* study meals is high across participants, as this has a large influence over eating cessation (Blundell & Rogers, 1991). If a food is deemed more palatable, this can increase feelings of satiety following consumption and increase mood through an increase in endorphins; both of which may positively influence cognitive performance (Dye & Blundell, 2002).

Cognitive performance and mood are frequently measured in the same study; it has been suggested that mood may influence cognitive performance (Chepenik, Cornew & Farah, 2007), possibly by controlling motivation (Hoyland et al., 2008); however, perhaps unexpectedly, a more positive mood has been associated with a poorer working memory performance (as measured using a running memory span task), but not with poorer response inhibition (as measured using Stroop) when assessed in a large sample of students (N=180, 92 females) (Martin & Kerns, 2011). Conversely, a recent report showed that changes in cognition following exercise do not correlate with mood, suggesting that separate neural systems may facilitate the effects on these parameters (Hopkins et al., 2012). However, studies incorporating measures of appetite and mood as well as cognitive function are somewhat lacking in the literature (Hoyland et al., 2009). As exercise promotes mood enhancement and an improvement in mood is associated with better appetite control, there may well be a mediating relationship between these parameters (Hoyland et al., 2008); further research assessing these factors after exercise, particularly in a female population, seems warranted.

1.6 Aims and Objectives

The primary aim of this thesis is to examine the effects of consuming breakfast prior to morning exercise on post-exercise cognition, mood and appetite. In addition, a second aim of this thesis is to gather information on the dietary and exercise practices of a habitually active female population.

It is intended that information from the current PhD will provide nutritional guidance for recreational exercisers, in particular active females, whose reason for exercising may be for mental health benefits and appetite control, rather than physical performance enhancement. Also, it is anticipated that the collection of information on the habitual behaviours of active females may inform and guide future research examining this particular population.

Chapter 2: The effect of breakfast consumption and exercise on appetite, cognitive performance and mood later in the day in active males

2.1 Introduction

Previous research has explored the effects of pre-exercise nutrition on physical performance, creating a set of guidelines for athletes and the active population to follow. For example, it is recommended that CHO is consumed 2-3 h prior to exercise to improve endurance capacity (American Dietetic Association, 2009). However, achieving optimal physical performance is often not the sole motivation for exercise. Performance is a multi-dimensional paradigm, which also encompasses aspects of cognition and mood. An acute bout of sub-maximal exercise has been shown to improve some facets of cognitive performance, such as RT (Etnier et al., 1997) and decision making (Adam, Teeken, Ypelaar, Verstappen & Paas, 1997; McMorris & Graydon, 1996), as well as mood (Scully, Kremer, Meade, Graham & Dudgeon, 1998), an effect often thought to be caused by increased arousal during the recovery period (Lambourne & Tomporowski, 2010). Many members of the general population exercise regularly for these additional health benefits. It has been found that consuming CHO during exercise can enhance these cognitive (Ali & Williams, 2009; Collardeau et al., 2001) and mood (Lieberman et al., 2002) effects demonstrating an interaction between nutritional state and exercise.

The timing of exercise likely influences pre-exercise nutritional intake. When exercise is undertaken in the morning, it is perhaps more common to remain fasted due to lack of time. Some individuals may choose to exercise in a fasted state due to the associated increase in fat oxidation (Backhouse et al., 2007; Gonzalez et al., 2013), as weight loss is also a common goal of exercise. Exercise can transiently suppress hunger (Broom et al., 2007; King et al., 2010; Martins et al., 2007) and an increase in EI post-exercise appears to be only partial in relation to energy expended during exercise (King et al., 2010; Martins et al., 2007; Stensel, 2010), advocating this practice for weight loss. However, if breakfast is omitted prior to exercise, research which states that breakfast consumption is important for health and wellbeing is contradicted (Barton et al., 2005; Pereira et al., 2011; Smith, 1998). In a recent survey (N=699), nearly half of the active individuals asked agreed that they had more energy on days when they ate breakfast and that they felt they must eat breakfast before they engaged in exercise (Reeves et al., 2013). The positive health benefits of consuming breakfast include mood enhancement (Kral et al., 2012) and improvement in some aspects of cognitive performance, in particular, memory (for review see Hoyland, Dye & Lawton, 2009). Consuming breakfast can also reduce overall appetite and EI for the rest of the day, an observation supported by previous trials (Astbury et al., 2011; Farshchi et al., 2005; Hubert et al., 1998). Although the acute mood-enhancing effects of breakfast do tend to diminish after a few hours (Smith et al., 1999), consuming a mid-morning snack has been shown to improve declining mood following a large breakfast (Benton et al., 2001). Even if guidelines for exercise recovery are followed and energy is replaced immediately following exercise (for example, by consuming chocolate milk; Karp et al., 2006; Thomas, Morris & Stevenson, 2009), omitting breakfast and inducing a further energy deficit through exercise following an overnight fast may detrimentally affect cognition, mood and appetite later in the day.

Exercising in a post-prandial state has been shown to reduce appetite (Cheng et al., 2009; Deighton et al., 2012; Martins et al., 2007). However, breakfast omission was not compared directly with breakfast consumption in these trials. Paul et al. (1996) previously reported no difference in post-recovery EI following consumption or omission of a cereal breakfast prior to cycling, despite increases in hunger reported when breakfast was omitted. However, this study did not compare the effects of exercise to those of resting following the same nutritional interventions. In addition, an alternative mode of exercise, such as running, may produce different results to those reported previously (Stensel, 2010). Many earlier studies have not assessed the satiety response to food within 1 h post-exercise (Martins et al., 2007; Paul et al., 1996); beyond this time point, the effects of exercise on appetite may have disappeared (King et al., 1994).

Trials which have investigated the effect of consuming or omitting breakfast prior to exercise on cognitive performance have produced diverse results (Hill et al., 2011; Paul et al., 1996; Vermorel et al., 2003). Vermorel et al. (2003) suggested that when adolescents have a morning physical education lesson they require a substantial breakfast for cognitive benefits later in the day. There was no difference identified in the mood state of swimmers who either consumed or omitted CHO before a morning training session (Hill et al., 2011) although Paul et al. (1996) reported an increase in mental fatigue during the recovery period following a 90 min cycle if breakfast was omitted rather than consumed beforehand, but found no effect on cognition. It has been suggested that further research on nutritional status and appetite regulation is required in active individuals (La Bounty, Campbell & Wilson, 2011) and that studies examining the potential interactive effects of both meal consumption and exercise (Cheng et al., 2009) and studies assessing cognition, mood and appetite in tandem (Hoyland et al., 2009) are required. The importance of comparing the interaction between meal omission or consumption and exercise or rest within subjects rather than making assumptions based on results from different studies, has also been highlighted (Hubert et al., 1998). Therefore the purpose of this study was to assess the effect of breakfast consumption and breakfast omission prior to rest or exercise, followed by a post-exercise chocolate milk drink on appetite, cognitive performance and mood responses. It was hypothesized that consuming breakfast prior to exercise may elicit the most beneficial effects with regards to appetite control, cognitive performance and mood following a morning run.

2.2 Methods

This study received ethical approval from the School of Life Sciences Ethics Committee at Northumbria University. Participants were recruited from Northumbria University and the local area through email and poster advertising.

2.2.1 Screening

Participants were required to attend an initial screening session where they were asked to read an information sheet (Appendix A) detailing the nature of the study, the requirements and the inclusion/exclusion criteria before completing an informed consent form.

Participants also completed a general health screen questionnaire (Appendix B), a physical activity questionnaire (IPAQ; Craig et al., 2003) and the TFEQ to measure dietary restraint (Stunkard & Messick, 1985).

2.2.1.1 General inclusion criteria

Individuals were eligible to take part in this study if they:

- were aged 18-35 years
- were a non-smoker

- were in good health
- were free from social drugs, medication and herbal and dietary supplements
- had no history of, or current, head trauma, learning difficulties, attention deficit hyperactivity disorder (ADHD), dyslexia, migraines or gastric problems
- had a good standard of English, equivalent to that of a native English speaker
- were not a high consumer of caffeine (<600 mg per day)
- were recreationally active
- had a healthy body mass index (BMI; >18 and <25 kg/m^2)
- had a blood pressure of ≤140/90 mmHg

2.2.1.2 Study specific inclusion criteria

All participants were male, unrestrained eaters (TFEQ score of <11) and were able to run for 1 h continuously at a moderate speed.

2.2.1.3 Anthropometry and blood pressure

Anthropometric and blood pressure measures were taken at screening. Height was measured to the nearest 0.1 cm using a portable stadiometer (Seca Ltd, Birmingham, UK) and body mass was measured to the nearest 0.1 kg using a digital scale (Seca Ltd, Birmingham, UK). Participants removed footwear and heavy clothing for these assessments. Participants' BMI was calculated as weight in kilograms divided by the square of their height in metres. Blood pressure was assessed using a Boso-medicus prestige blood pressure monitor (Bosch + Sohn, Germany).

2.2.2 Cognitive task and VAS training

Cognitive tasks and VAS were administered using the Computerised Mental Performance Assessment System (COMPASS, Northumbria University), a programme used to present standard psychometric tests. COMPASS has been used in several previous nutritional intervention studies and has been shown to be sensitive to cognitive enhancement following supplementation of a variety of substances (e.g. Jackson, Deary, Reay, Scholey & Kennedy, 2012; Kennedy et al., 2010; Kennedy et al., 2011; Wightman, Haskell, Forster, Veasey & Kennedy, 2012). Presentation of tasks and mood scales was via a laptop computer. All responses were recorded via a button response box (comprising buttons for Yes/No, Left/Right, Blue/Green/Yellow/Red and a central RT button). Participants were required to wear ear defenders throughout the cognitive tasks to minimise noise distraction. The battery of cognitive tasks was repeated three times during the training session to decrease the chance of learning effects during main trials.

2.2.2.1 Cognitive Tasks

The cognitive tasks chosen had previously shown sensitivity to either exercise and/or breakfast interventions.

Simple Reaction Time (SRT; ~90 sec)

An arrow pointing upwards appeared in the centre of the computer screen at irregular intervals (between 1 and 2.5 sec). The participant was instructed to press the centre button on the response pad when the arrow appeared, responding as quickly as possible. The task was scored for overall RT.

Stroop task (~2 min)

Words describing one of four colours (‘RED’, ‘YELLOW’, ‘GREEN’, ‘BLUE’) were presented in different coloured fonts in the centre of the computer screen. The participant pressed one of four coloured response buttons in order to identify the font colour (e.g. if the word

‘GREEN’ was presented in a blue font, the correct response would be to respond with the blue button). The presented words were either ‘congruent’ (word and font are the same colour) or ‘incongruent’ (word and font are different colours) and were presented in a random order. In total, 120 words were presented. The task was scored for RT and accuracy of responses to ‘congruent’ and ‘incongruent’ words.

Four Choice Reaction Time (FCRT; ~90 sec)

Four direction arrow keys were displayed on the computer screen. The arrows ‘lit up’ at irregular intervals (between 1 and 3.5 sec), one at a time. Participants were instructed to use the index finger of their dominant hand to press the corresponding button on the response pad (left/right/up/down) when an arrow became lit, responding as quickly and as accurately as possible. In total, 32 stimuli were presented. The task was scored for RT and accuracy of responses.

NBack (~2 min)

A series of single letters appeared on the screen, presented one at a time. If the letter that appeared was also presented three letters previously in the series (a “target” letter), participants were asked to press the ‘YES’ button on the response pad and if the letter that appeared was not presented three letters previously in the series (a “non-target” letter), to press the ‘NO’ button on the response pad, responding as quickly and accurately as possible to every letter presented. In total, 36 stimuli were presented, encompassing 12 target pairs. The task was scored for RT and accuracy.

Rapid Visual Information Processing task (RVIP; 5 min)

A series of single digit numbers between 1 and 9 appeared on the screen continuously at a rate of 100 per min. Participants were required to use the index finger of their dominant hand to press the centre button on the response box, reacting as quickly and accurately as possible, when they identified three odd or even digits presented in succession. Eight correct target strings were presented each minute. The task was scored for percentage of target strings correctly detected, average RT for correct detections and number of false alarms (incorrect responses).

Mental Fatigue and Task Difficulty VAS

Two single visual analogue scales measuring mental fatigue and task difficulty were completed at the end of each set of tasks. Each scale was labelled “not at all” (left end of scale) and “extremely” (right end of scale).

2.2.2.2 Mood and Physical State VAS (MPS VAS)

A set of mood and physical state visual analogue scales (taken from Rogers, Martin, Smith, Heatherley, & Smit, 2003) were completed before each set of cognitive tasks measuring subjective ratings of mood and physical state (“relaxed,” “alert,” “jittery,” “tired,” “tense,” “headache,” “overall mood”). Participants were asked to click on a 100mm line on the computer screen to grade their current subjective status for each state. Each scale was labelled “not at all” (left end of scale) and “extremely” (right end of scale), except for “overall mood” which was labelled “very bad” and “very good”. During exercise trials, participants also completed a single VAS immediately following the exercise session rating to what extent they enjoyed the run. All VAS scales were scored as mm along the line towards ‘extremely’.

2.2.2.3 Appetite VAS

Subjective appetite ratings were recorded before each set of cognitive tasks using VAS (a valid and sensitive method of measuring appetite; Hill, Rogers & Blundell, 1995; Stensel, 2010). These were presented on paper. Participants were asked to draw a vertical line on a 100 mm line to grade their current subjective status for feelings of “hunger,” “fullness,” “satisfaction,” “desire to eat,” “thirstiness,”). Each scale was labelled “not at all” (or similar, left end of scale) and "extremely" (or similar, right end of scale). Participants could not refer to their previous ratings when completing the VAS. All VAS scales were scored as mm along the line towards 'extremely'.

2.2.3 Exercise Tests

2.2.3.1 Indirect calorimetry

In both exercise tests, oxygen uptake ($\dot{V}O_2$) was measured using indirect calorimetry. Expired gas samples were collected using an online gas analysis system (Metalyzer 3B, Cortex) calibrated using gases of known concentrations and a 3*l* syringe.

2.2.3.2 Preliminary Exercise Test

A preliminary exercise test was used to establish the relationship between $\dot{V}O_2$ and running speed on a flat treadmill using a 16 min test. The test began at a low-moderate speed (between 7-8.5 $km{\cdot}h^{-1}$). Every 4 min, the speed of the treadmill was increased by 1 $km{\cdot}h^{-1}$ until 16 min had elapsed. $\dot{V}O_2$ was recorded for the final 60 sec of each stage.

2.2.3.3 Maximal Exercise Test

Participants were allowed 5-10 min recovery after the preliminary test (section 2.2.3.2) before undertaking a maximal exercise test to establish their $\dot{V}O_2$ max. An incremental treadmill test was utilized (Williams, Nute, Broadbank & Vinall, 1990) whereby the speed of the treadmill remained constant (typically 9-11 $km{\cdot}h^{-1}$) but the gradient of the treadmill was increased by $1\%{\cdot}min^{-1}$ to exhaustion. Verbal encouragement was given towards the latter stages of the test to ensure that subjects worked to exhaustion. A respiratory exchange ratio of $\geq$1.15 was used as a marker to ascertain that $\dot{V}O_2$ max had been reached.

2.2.3.4 Calculating the exercise intervention duration

The results of the previously described exercise tests were used to establish the running speed equivalent to 60% of each participant's $\dot{V}O_2$ max. The duration of exercise needed at this intensity to expend 2.9 MJ was then calculated for each individual. This resulted in varying degrees of a positive or negative energy balance in each condition, with the smallest of these, an energy deficit in the B E (Breakfast and Exercise) condition, still considered meaningful in appetite research (Hill, 2009). The within subjects design with matched EE during exercise should have eradicated any significant effects that varying exercise durations may have had on the results.

2.2.4 Pre-testing guidelines

Differences in foods consumed the evening prior to investigational testing can affect appetite sensitivity (Chandarana et al., 2009) and cognitive performance (Lamport et al., 2011) the following morning. Therefore, on the day preceding the first trial, participants were required to keep a record of their food intake and physical activity which was replicated the day preceding subsequent trials. This data was collected using a standard food diary (Appendix C) on which the participant recorded the timing of food consumption, whether it was consumed home or away, the brand and cooking methods, the amount served and any leftovers. Detailed instructions were provided with each food diary and participants were trained on the level of detail required at screening. If necessary, participants were provided with a digital food scale for the duration of the study. On returning food diaries to the laboratory, the food diaries were checked and any ambiguities were discussed and rectified. In the 24 h period prior to each main trial, participants abstained from alcohol and vigorous physical activity and did not consume anything but water for 12 h prior to the start of each main trial.

2.2.5 Participants

Twelve, healthy, active men were screened and successfully completed the study. Their mean ± standard deviation (SD) age, height, body mass (BM), Body Mass Index (BMI) and $\dot{V}O_2$ max were 23.2 ± 2.4 y, 177.6 ± 7.0 cm, 77.2 ± 5.3 kg, 24.5 ± 2.0 kg/m^2 and 50.7 ± 1.2 mL · kg^{-1} · min^{-1}, respectively.

2.2.6 Experimental Protocol (Figure 2.1)

Each participant completed four trials, in a randomised, cross-over design, consisting no breakfast and rest (NB NE), breakfast and rest (B NE), no breakfast and exercise (NB E) or breakfast and exercise (B E). The first trial was undertaken between 48 h and 14 days of the initial screening visit. Trials were separated by ≥ 48 h and all trials were performed under similar laboratory conditions. Trials began at 0730 h (±15 min). After confirming compliance to the study restrictions, a baseline completion of the cognitive tasks and mood scales was then undertaken, before participants were administered the test breakfast or remained fasted. Participants then rested for 2 h, following guidelines which state CHO should be consumed 2 h prior to exercise for performance benefits (American Dietetic Association, 2009) and to allow for full digestion of breakfast before exercise was undertaken. During this period subjective appetite was measured at 30 min intervals and cognitive performance and mood at 60 and 120 min. In between these periods, participants were allowed to read, write or watch a DVD. In the exercise trials (NB E and B E), participants then completed a treadmill run at 60 % of their $\dot{V}O_2$ max, until 2.9 MJ had been expended. HR and rate of perceived exertion (RPE) were measured at 10 min intervals throughout. RPE was measured using the Borg scale (see Borg, 1973). This scale ranged from six (no exertion) to 20 (maximal exertion). Appetite was measured at the mid-way point. Exercise intensity was maintained throughout this period via an online gas analysis system (described in section 2.2.3.1). On rest days (NB NE and B NE), participants rested for the equivalent amount of time. Cognitive performance and mood were reassessed before participants were administered a test drink, as previously used to assess appetite response post-breakfast (Astbury et al., 2011). The drink was also typical to that commonly consumed to aid physical recovery post-exercise (Thomas, Morris & Stevenson, 2009). Participants were then required to rest for 90 min. This duration reflects that used in a previous study assessing the effect of a post-breakfast drink on appetite sensations

(Astbury et al., 2011) and also ensured that lunch was consumed at an appropriate time. Cognitive performance and mood were assessed again at 30 min post-drink (to assess these factors when metabolic responses to the drink may have been occurring) and immediately prior to, and post, lunch (to assess the effect of lunch). The *ad libitum* lunch was consumed 90 min post-drink, and participants were asked to consume enough food to feel satisfied to a normal level. After lunch, they completed the cognitive battery and mood scales for a final time and were then free to leave the laboratory. Heart rate was monitored throughout each trial using telemetry (Polar T31 transmitter, Polar Electro Oy, HQ, Professorintie 5, FIN-90440 Kempele, Finland). Water intake was recorded during each first rest trial and first exercise trial and was approximately matched in the subsequent rest and exercise trials to control hydration status which can influence cognitive function and mood (Armstrong et al., 2012).

2.2.7 Treatments/Test meals (detailed in Table 2.1)

During the breakfast trials, participants were provided with a breakfast consisting 72 g of syrup flavour oats (Oats So Simple Golden Syrup, Quaker Oats Ltd, Reading, UK) with 360 ml of semi-skimmed milk (Tesco, Dundee, UK) cooked in a microwave on full power (800 W) for 2 min as per the manufactures instructions. This breakfast, believed to be a popular healthy breakfast choice in the general population (Reeves et al., 2013), provided 444 kcal (1.9 MJ; 17 % protein, 60 % CHO, 23 % fat), providing approximately 18 % of a typical males energy needs, just under that recommended for breakfast (Timlin & Pereira, 2007). Participants were given a maximum of 15 min to consume the breakfast. The post-exercise/rest snack comprising 250 ml chocolate milk (Yazoo, Campina Ltd, West Sussex, UK) which provided 175 kcal (0.7 MJ; 18 % protein, 63 % CHO, 19 % fat) was administered. This was served at room temperature and participants were instructed to finish the drink within 5 min. Participant’s confirmed verbally that the drink was well liked. Previous data supports the consumption of chocolate milk as a successful post-exercise recovery aid for physical performance (Karp et al., 2006; Thomas et al., 2009). Chocolate milk has also been used to assess the satiety response following a breakfast intervention (Astbury et al., 2011), and is therefore an applicable post-exercise snack when assessing the interactive effect of breakfast and exercise on satiety.

The *ad libitum* lunch consisted of pasta shapes (penne; Tesco Stores Ltd, Herts, UK) cooked in the microwave for 13 min in unsalted water and then homogenised with tomato sauce (Bolognese pasta sauce, Tesco), grated cheese (Tesco) and olive oil (Tesco). Meals were prepared on the morning of each trial, refrigerated and then re-heated in the microwave for 2 min 30 s when required. Each portion provided 815 kcal (3.4 MJ; 14 % protein, 49 % CHO, 37 % fat), representing approximately 30 % of a typical males energy needs (Scientific Advisory Committee on Nutrition, 2011) and was served in bowl which was weighed prior to and after consumption to the nearest g (HF-1200g scale; A&D Company Limited, Japan) to assess intake.

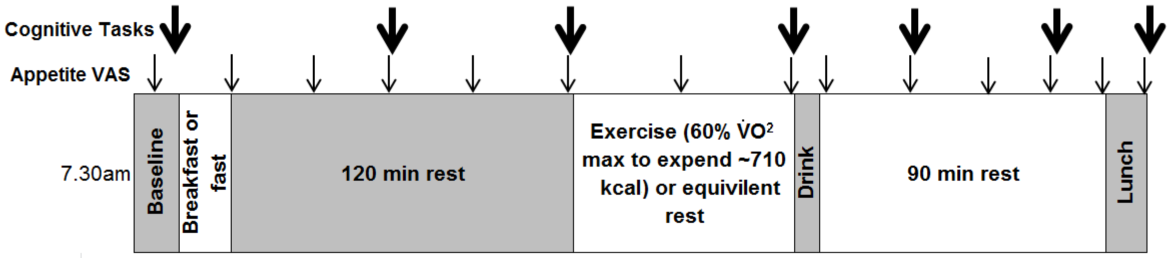

Figure 2.1 Study 1 Schematic

Table 2.1. Nutritional content of study foods

	kJ/Kcal	Carbohydrate (g)	Protein (g)	Fat (g)	Fibre (g)
Breakfast					
72g Syrup flavour porridge oats	1129/271	48	6	5	6
360ml Semi-skimmed milk	752/180	17	13	7	0
Total	2560/451	65	19	12	6
Snack					
250ml Chocolate milk	713/175	25	8	4	2
Lunch					
125g Penne Pasta	1863/444	90	15	2	1
250g Bolognase pasta sauce	440/110	15	2	4	6
15g Oilve Oil	555/135	0	0	15	0
40g Cheddar Cheese	686/249	Trace	10	14	0
Total	3544/938	105	27	35	7

2.2.8 Statistical Analysis

A power calculation revealed that a sample size of 12 would provide statistical power above 80% with an alpha level of .05 (G*Power; Faul, Erdfelder, Lang & Buchner, 2007). Before the main statistical analysis, paired sample *t* tests were used to compare pre-dose baseline data to assess for differences in performance across the study days. Outcomes for each individual task (SRT, Stroop, FCRT, NBack, RVIP, mental fatigue VAS, difficulty VAS and MPS VAS and appetite VAS) were analysed as 'change from baseline' (CFB).

Data were split into three distinct parts for analysis: post-breakfast (assessing the effects of breakfast consumption vs. breakfast omission only) using a two-way repeated measures analysis of variance (AVOVA), breakfast (NB = 0, B = 1) x repetition; during and/or immediately post-exercise/rest (to assess the immediate interaction between the breakfast and exercise interventions) using a three-way repeated measures ANOVA [repetition × breakfast (NB = 0, B = 1) × exercise (NE = 0, E = 1)] and post-drink (to assess the appetite and cognitive responses to the test drink) using a three-way repeated measures ANOVA [repetition × breakfast (NB = 0, B = 1) × exercise (NE = 0, E = 1)]. Appetite VAS were analysed as time-averaged area under the curve (AUC; calculated using the trapezoidal method) using a *t* test post-breakfast and a two-way repeated measures AVOVA [breakfast (NB = 0, B = 1) × exercise (NE = 0, E = 1)] for during/post -exercise and post-drink. Post-lunch appetite VAS AUC was also analysed separately using a *t* test. Analysing appetite VAS as AUC is thought to be a more reliable method than using absolute scores at single time points (Blundell, et al., 2010; Flint, et al., 2006). All analyses were conducted using Minitab 16 (Minitab Ltd, Coventry, UK) and allowed the easy identification of any main effects of breakfast (irrespective of exercise) and of exercise (irrespective of breakfast). Planned comparisons (using *t* tests calculated with the Mean Squares Error) were then employed to show where the significance lay in significant interactions or strong trends shown by the ANOVA, which were corrected for multiple comparisons using the Bonferroni correction. An alpha level of .05 was used for all statistical tests. Effect sizes for significant results are reported using Cohen's D (*d*). A small, medium and large effect size was indicated with a *d* value of $\geq$ 0.10, 0.30 and 0.50 respectively.

2.3 Results

There were no significant differences between mean baseline scores for any of the treatment conditions or outcome measures. Significant main effects of breakfast and exercise and interactions for COMPASS tasks, mood and physical state VAS and Appetite VAS are reported below. Due to a data capture error only 11 participants were included in the NBack and Stroop analysis and 9 in the RVIP analysis. No significant results were found for NBack incorrect RT, correct target responses and correct non-target responses and Stroop task congruent correct responses and RT and incongruent correct responses and RT and therefore this data is not presented.

2.3.1 Post-breakfast analysis

Cognitive performance and mood

No effects on cognitive performance (Table 2.2) or mood (Table 2.3) were observed during the 2 h post-breakfast period

Appetite VAS

Main effects of breakfast were observed for ratings of satisfaction [$F(1,11) = 68.60$, $p < .0001$, $d = 3.33$] and fullness [$F(1,11) = 81.70$, $p < .0001$, $d = 3.49$] which were higher and desire to eat [$F(1,11)=66.48$, $p<.0001$, $d = 2.00$] and hunger [$F(1,11) = 86.28$, $p < .0001$, $d = 2.02$] which were lower, when breakfast was consumed compared to omitted (Table 2.4).

2.3.2 During-Post Exercise/Rest Analysis

Cognitive performance and mood

No cognitive performance (Table 2.2) or mood (Table 2.3) variable effects were observed immediately following the exercise or rest period.

Table 2.2

Baseline and change from baseline scores for each cognitive measure for each treatment condition

Measure	Treatment	Baseline score	Post-breakfast		Post-exercise/rest	Post-drink		
			60 min	120 min		30 min	75 min	Post Lunch
Simple Reaction Time (ms)	NB NE	294.1 ± 16.2	-20.9 ± 16.4	-8.6 ± 15.3	-6.8 ± 16.4	-2.7 ± 17.2	11.1 ± 31.8	5.0 ± 13.7
	B NE	268.7 ± 0.6	6.7 ± 0.9	6.7 ± 0.6	22.3 ± 1.0	13.6 ± 1.1	17.4 ± 1.0	4.2 ± 0.9
	NB E	285.9 ± 13.3	-5.5 ± 16.5	3.4 ± 12.4	0.6 ± 9.5	4.9 ± 7.1	6.4 ± 9.4	7.2 ± 11.1
	B E	294.3 ± 17.0	4.8 ± 31.2	-0.1 ± 17.7	-28.9 ± 19.7	-10.1 ± 16.5	-16.0 ± 19.7	-25.0 ± 19.4
Stroop accuracy (%)[a]	NB NE	71.8 ± 1.0	0.9 ± 0.8	1.0 ± 0.9	1.0 ± 0.7	0.7 ± 0.9	1.2 ± 0.8	1.8 ± 0.7
	B NE	72.3 ± 1.1	-0.1 ± 0.8	-1.4 ± 2.3	0.9 ± 1.0	-0.9 ± 0.8	-0.1 ± 0.9	-0.1 ± 1.4
	NB E	72.8 ± 1.2	-1.0 ± 0.9	-0.4 ± 0.7	1.4 ± 0.9	0.9 ± 0.7	-1.5 ± 1.1	-0.3 ± 0.8
	B E	71.6 ± 1.2	0.1 ± 0.9	0.5 ± 0.7	2.5 ± 1.0	1.1 ± 0.8	-0.1 ± 1.1	0.5 ± 1.1
Stroop RT (ms)[a]	NB NE	631.2 ± 29.1	-10.0 ± 16.0	-8.3 ± 16.7	-9.8 ± 14.4	-18.8 ± 18.6	-21.6 ± 14.7	-36.3 ± 16.8
	B NE	612.4 ± 26.9	-7.9 ± 12.4	-7.7 ± 21.8	8.4 ± 17.9	14.9 ± 19.3	20.1 ± 17.7	22.7 ± 28.4
	NB E	612.4 ± 26.5	25.3 ± 13.3	-1.9 ± 11.6	-24.2 ± 10.5	-15.4 ± 14.2	26.3 ± 14.9	18.5 ± 15.7
	B E	630.4 ± 28.0	12.3 ± 21.7	-0.8 ± 21.5	-30.1 ± 16.4	-4.1 ± 13.4	4.1 ± 26.9	-5.5 ± 13.9
Four Choice Reaction Time Accuracy (%)	NB NE	97.9 ± 0.8	0.3 ± 0.9	0.5 ± 0.5	0.5 ± 0.6	-0.8 ± 1.0	0.8 ± 0.9	1.0 ± 0.9
	B NE	98.4 ± 0.9	-0.8 ± 0.8	0.0 ± 1.2	-0.3 ± 0.9	-0.3 ± 0.8	-0.5 ± 0.9	-0.5 ± 1.0
	NB E	96.9 ± 1.7	1.0 ± 1.6	2.3 ± 1.6	0.8 ± 0.8	2.1 ± 1.5	1.6 ± 1.1	1.8 ± 1.2
	B E	98.7 ± 0.8	-0.3 ± 0.6	-0.3 ± 1.1	0.8 ± 0.6	0.0 ± 1.0	-2.1 ± 0.7	0.8 ± 0.9
Four Choice Reaction Time (ms)	NB NE	476.7 ± 22.1	-4.8 ± 7.3	-12.8 ± 11.8	4.9 ± 15.5	-2.7 ± 13.1	8.0 ± 18.9	-4.3 ± 12.6
	B NE	454.3 ± 22.3	23.5 ± 12.9	3.3 ± 11.9	8.6 ± 14.4	33.9 ± 21.0	41.5 ± 10.5	3.6 ± 13.8
	NB E	485.7 ± 24.7	-2.0 ± 16.0	-20.3 ± 15.0	-28.6 ± 15.4	-19.4 ± 15.8	-15.3 ± 19.6	-27.5 ± 13.5
	B E	483.4 ± 33.6	-1.2 ± 20.9	-3.7 ± 31.6	-21.8 ± 27.6	-2.9 ± 22.8	5.8 ± 28.3	-8.7 ± 23.3

Table 2.2 continued.

NBack accuracy (%)[a]	NB NE	93.9 ± 1.9	-96.0 ± 2.0	-151.4 ± 1.9	-125.1 ± 2.4	-138.1 ± 1.2	-146.4 ± 1.7	-203.0 ± 1.8
	B NE	93.4 ± 1.7	-27.9 ± 2.0	-127.5 ± 2.6	-115.6 ± 1.7	-132.7 ± 1.9	-162.2 ± 2.2	-87.5 ± 1.9
	NB E	93.4 ± 2.0	-150.7 ± 2.0	-123.0 ± 1.9	-187.5 ± 1.8	-190.8 ± 2.0	-313.7 ± 2.4	-238.7 ± 2.2
	B E	93.4 ± 1.4	-84.8 ± 1.6	-173.3 ± 1.9	-254.7 ± 1.8	-276.7 ± 1.4	-261.6 ± 1.3	-315.6 ± 2.1
NBack RT (ms)[a]	NB NE	1134.4 ± 94.4	-0.5 ± 61.5	-0.5 ± 58.8	-0.5 ± 70.0	0.2 ± 59.6	-1.0 ± 88.1	1.5 ± 76.9
	B NE	1073.5 ± 147.3	0.8 ± 47.3	0.5 ± 72.2	-0.3 ± 58.0	-1.0 ± 91.4	-1.3 ± 75.3	-0.3 ± 77.0
	NB E	1226.6 ± 155.4	0.8 ± 75.4	-0.5 ± 37.6	1.8 ± 58.5	-0.8 ± 124.8	-2.3 ± 136.1	0.3 ± 125.9
	B E	1276.5 ± 208.4	1.8 ± 51.5	-0.8 ± 71.9	-0.3 ± 71.3	0.8 ± 120.1	-1.0 ± 134.1	-1.0 ± 129.0
RVIP accuracy (%)[b]	NB NE	53.9 ± 3.7	-4.4 ± 4.6	-5.3 ± 4.5	-6.1 ± 6.3	-8.3 ± 5.1	-4.7 ± 4.9	-2.2 ± 5.1
	B NE	59.4 ± 4.4	0.8 ± 4.6	1.9 ± 4.3	-4.2 ± 3.5	-3.9 ± 3.6	-5.3 ± 3.2	-6.4 ± 2.5
	NB E	56.7 ± 5.4	-0.6 ± 4.8	-5.0 ± 5.3	-1.1 ± 6.8	-3.3 ± 7.7	-3.1 ± 6.5	-3.9 ± 4.4
	B E	59.4 ± 5.4	-6.9 ± 3.0	-8.3 ± 3.4	-2.2 ± 4.2	-4.4 ± 5.1	-7.8 ± 4.5	-4.4 ± 6.6
RVIP reaction time (ms)[b]	NB NE	498.1 ± 18.2	6.2 ± 12.0	5.7 ± 14.0	-7.9 ± 14.0	2.8 ± 13.9	-21.7 ± 10.1	-75.5 ± 54.2
	B NE	474.4 ± 14.5	29.2 ± 17.6	39.9 ± 20.2	29.4 ± 20.9	25.1 ± 13.2	37.6 ± 21.4	14.7 ± 12.0
	NB E	481.2 ± 17.2	-2.6 ± 14.1	10.9 ± 6.9	-13.8 ± 9.0	8.5 ± 15.2	15.3 ± 8.6	14.5 ± 20.1
	B E	486.1 ± 21.6	3.9 ± 8.2	16.8 ± 13.3	1.5 ± 16.9	7.8 ± 15.4	2.6 ± 12.9	-5.2 ± 13.9
RVIP false alarms (number)[b]	NB NE	3.6 ± 1.2	-1.1 ± 1.1	-1.1 ± 1.2	-0.7 ± 1.1	1.7 ± 1.7	-0.4 ± 1.6	-0.9 ± 1.3
	B NE	2.3 ± 0.5	0.0 ± 0.7	1.0 ± 1.4	0.6 ± 0.7	1.0 ± 0.7	0.2 ± 0.9	0.6 ± 1.0
	NB E	3.0 ± 1.1	0.2 ± 1.4	-0.2 ± 1.0	0.1 ± 1.8	0.6 ± 1.9	1.8 ± 2.8	-0.2 ± 1.3
	B E	3.1 ± 1.3	0.1 ± 0.7	2.2 ± 0.6	1.2 ± 1.2	0.6 ± 0.9	2.4 ± 2.4	1.6 ± 1.6

Means ± SEM are presented, N=12, [a] N=11, [b] N=9

Table 2.3

Baseline and change from baseline (CFB) scores for each mood measure for each treatment condition

Measure	Treatment	Baseline score	Post-breakfast CFB		Post-exercise/rest	Post-drink CFB		
			60 min	120 min		30 min	75 min	Post Lunch
Post-Cognitive VAS Mental Fatigue	NB NE	51.3 ± 5.0	-1.5 ± 2.7	1.1 ± 3.6	8.1 ± 5.6	6.6 ± 5.1	10.9 ± 5.9	7.1 ± 4.6
	B NE	49.3 ± 5.0	7.3 ± 2.8	7.8 ± 2.7	5.3 ± 4.4	12.9 ± 4.0	15.3 ± 4.6	6.8 ± 4.7
	NB E	44.8 ± 4.8	6.5 ± 2.3	12.3 ± 2.8	12.7 ± 3.9	18.8 ± 4.2	24.2 ± 4.7	15.4 ± 5.2
	B E	50.3 ± 5.3	-1.7 ± 3.5	5.9 ± 3.5	6.7 ± 3.8	8.5 ± 5.3	10.2 ± 4.4	6.4 ± 4.2
Difficulty	NB NE	49.3 ± 4.5	-1.8 ± 2.1	0.2 ± 3.5	6.8 ± 4.4	7.8 ± 4.3	8.0 ± 4.3	3.3 ± 3.0
	B NE	49.6 ± 3.2	2.8 ± 2.7	5.5 ± 3.0	2.3 ± 2.3	3.2 ± 3.7	6.4 ± 3.0	0.8 ± 4.3
	NB E	47.7 ± 3.6	0.5 ± 3.1	8.6 ± 1.5	7.4 ± 3.7	11.2 ± 4.1	13.4 ± 5.2	9.1 ± 2.9
	B E	48.4 ± 3.7	1.5 ± 2.4	2.6 ± 3.4	6.9 ± 3.3	4.1 ± 4.2	9.3 ± 2.8	7.1 ± 2.4
MPSVAS Relaxed	NB NE	39.8 ± 3.6	8.6 ± 2.7	11.5 ± 3.2	5.3 ± 3.5	5.8 ± 3.8	6.3 ± 5.1	12.3 ± 5.3
	B NE	42.3 ± 4.1	6.4 ± 4.9	3.8 ± 5.9	9.8 ± 5.7	7.1 ± 5.9	7.0 ± 7.9	19.3 ± 4.3
	NB E	40.3 ± 4.1	2.8 ± 3.3	8.1 ± 5.0	11.6 ± 5.6	5.0 ± 5.3	6.7 ± 5.0	15.0 ± 6.8
	B E	38.4 ± 3.8	10.3 ± 4.1	9.8 ± 4.0	12.1 ± 4.3	8.8 ± 5.9	5.4 ± 6.3	13.9 ± 3.7
Alert	NB NE	21.9 ± 6.8	-6.3 ± 4.5	-10.4 ± 5.6	-9.3 ± 6.3	-11.1 ± 6.5	-8.3 ± 7.9	-13.4 ± 6.0
	B NE	17.2 ± 4.4	-4.4 ± 3.0	-4.4 ± 3.5	-5.4 ± 3.5	-3.9 ± 3.8	-2.7 ± 5.1	-6.8 ± 4.0
	NB E	15.1 ± 3.7	-2.4 ± 2.0	-3.5 ± 2.1	-2.7 ± 2.9	-3.4 ± 3.5	0.6 ± 2.8	-4.7 ± 3.6
	B E	26.1 ± 6.6	-11.1 ± 5.6	-11.3 ± 4.7	-7.3 ± 6.3	-9.0 ± 4.8	-11.1 ± 6.0	-12.2 ± 5.8
Jittery	NB NE	49.8 ± 5.0	11.9 ± 7.5	13.6 ± 6.6	10.8 ± 7.2	11.8 ± 7.9	10.6 ± 7.5	15.6 ± 6.3
	B NE	60.8 ± 2.8	2.4 ± 4.5	2.0 ± 4.3	0.5 ± 5.1	-2.3 ± 5.9	-2.2 ± 6.0	4.9 ± 4.5
	NB E	63.2 ± 3.4	3.3 ± 2.0	-3.2 ± 3.3	-7.9 ± 4.6	-3.8 ± 3.6	-6.8 ± 4.4	3.9 ± 3.2
	B E	60.9 ± 3.8	6.2 ± 4.6	4.5 ± 4.4	-1.8 ± 5.9	5.8 ± 5.8	0.5 ± 5.6	5.7 ± 2.7

Table 2.3 continued.

Tired	NB NE	54.8 ± 4.3	-7.5 ± 3.9	-12.4 ± 3.5	-10.6 ± 4.2	-8.6 ± 6.6	-8.8 ± 7.2	-20.8 ± 4.9
	B NE	56.4 ± 5.1	-12.3 ± 4.8	-13.4 ± 6.1	-17.6 ± 5.4	-16.3 ± 7.2	-9.0 ± 7.5	-25.8 ± 6.0
	NB E	57.3 ± 5.7	-11.4 ± 6.3	-15.3 ± 4.7	-11.1 ± 9.3	-10.7 ± 8.7	-8.3 ± 7.7	-16.7 ± 7.3
	B E	58.5 ± 5.9	-9.3 ± 3.1	-12.1 ± 4.1	-9.3 ± 5.7	-6.9 ± 7.5	-6.6 ± 8.1	-13.8 ± 4.1
Tense	NB NE	29.8 ± 4.0	-5.6 ± 3.5	-6.0 ± 3.9	-5.3 ± 4.5	-9.0 ± 5.5	-6.9 ± 5.5	-12.2 ± 4.9
	B NE	20.2 ± 3.1	4.6 ± 6.6	-1.4 ± 3.7	3.3 ± 4.0	2.1 ± 4.1	4.7 ± 5.9	1.8 ± 5.1
	NB E	24.3 ± 3.6	-3.8 ± 2.7	0.7 ± 2.9	3.3 ± 4.8	2.7 ± 4.7	8.4 ± 5.0	2.0 ± 3.2
	B E	32.3 ± 4.5	-5.3 ± 2.9	-7.8 ± 3.1	-5.8 ± 6.6	-2.1 ± 4.9	-3.6 ± 5.3	-9.5 ± 2.5
Headache	NB NE	38.3 ± 3.9	1.8 ± 3.9	2.8 ± 5.0	4.5 ± 5.4	7.7 ± 6.9	12.8 ± 6.5	6.0 ± 5.5
	B NE	40.8 ± 4.8	1.4 ± 2.7	3.0 ± 4.3	2.8 ± 5.7	7.8 ± 5.9	11.7 ± 6.1	-0.5 ± 6.2
	NB E	35.4 ± 4.8	5.3 ± 2.6	2.5 ± 2.9	9.0 ± 5.8	15.3 ± 6.4	17.7 ± 6.3	11.9 ± 5.6
	B E	42.2 ± 4.9	-4.5 ± 2.8	0.1 ± 3.0	-0.5 ± 4.0	6.2 ± 4.6	8.8 ± 4.4	0.7 ± 3.6
Overall Mood	NB NE	85.3 ± 3.4	-0.7 ± 5.7	0.3 ± 5.7	-3.8 ± 2.7	3.9 ± 4.0	0.3 ± 6.1	6.8 ± 3.3
	B NE	81.3 ± 7.8	1.3 ± 1.2	6.4 ± 8.2	6.0 ± 8.7	3.1 ± 9.6	-3.1 ± 11.0	3.3 ± 10.7
	NB E	88.3 ± 2.4	-0.8 ± 3.5	1.8 ± 2.5	5.0 ± 2.4	-5.6 ± 4.3	-7.2 ± 4.4	2.8 ± 2.2
	B E	76.1 ± 5.8	7.0 ± 3.3	8.6 ± 3.6	8.6 ± 4.2	1.3 ± 3.7	9.4 ± 3.4	10.8 ± 3.5
Mental Fatigue	NB NE	56.5 ± 3.4	1.0 ± 3.1	1.0 ± 3.6	1.5 ± 3.0	-2.9 ± 3.7	-0.1 ± 4.1	6.3 ± 2.7
	B NE	58.7 ± 2.9	-0.3 ± 1.6	1.9 ± 2.4	-0.2 ± 3.9	-1.5 ± 3.8	-1.9 ± 4.4	6.8 ± 3.4
	NB E	54.7 ± 4.4	2.4 ± 2.5	3.1 ± 3.2	2.1 ± 3.5	-1.1 ± 3.9	-1.4 ± 3.3	11.3 ± 4.0
	B E	53.3 ± 4.1	4.9 ± 3.3	5.3 ± 4.0	7.3 ± 3.1	3.0 ± 4.3	6.3 ± 5.0	12.4 ± 4.7

Means ± SEM are presented

Table 2.4
Time-averaged AUC values for subjective appetite measures following breakfast (B) or no breakfast (NB)

Measure	Condition	AUC (mm)				
		Baseline	Post-breakfast AUC (mm)	Pre-post exercise/rest	Post-exercise /rest recovery period	Post-lunch
Hunger	B	56 ± 4	32 * ± 3	45 * ± 3	55 * ± 3	35 * ± 1
	NB	54 ± 4	62 ± 3	63 ± 4	64 ± 2	39 ± 1
Desire to eat	B	65 ± 4	39 * ± 4	52 * ± 3	60 * ± 3	37 * ± 2
	NB	60 ± 4	69 ± 3	69 ± 3	71 ± 2	42 ± 1
Fullness	B	31 ± 3	64 * ± 3	48 * ± 3	39 * ± 3	60 * ± 1
	NB	31 ± 3	23 ± 2	23 ± 2	28 ± 3	55 ± 1
Satisfaction	B	31 ± 3	63 * ± 3	48 * ± 2	39 * ± 2	61 * ± 2
	NB	38 ± 3	25 ± 2	23 ± 2	27 ± 2	55 ± 1

Mean values ± SEM are presented
* Mean value was significantly different from NB (p <.05)

Appetite VAS

A trend for a breakfast x exercise interaction was observed for hunger pre-post exercise/rest [F(1,11) = 3.86, p =.075]. Comparisons revealed that hunger was suppressed during exercise more so than the same breakfast condition at rest (NBE < NBNE (d = 0.75) and BE<BNE (d = 0.50), both p <.001). Also, breakfast supressed hunger during both exercise and rest more so than no breakfast (BE<NBE (d = 0.85) and BNE<NBNE (d = 1.53), both p <.001; Figure 2.2, Table 2.5).

There were main effects of breakfast for all appetite measures (Table 2.4). Participants were significantly more full [F(1,11) = 62.29, p <.001, d = 2.04] and satisfied [F(1,11) = 81.86, p <.001, d = 2.27] and were less hungry [F(1,11) = 36.06, p <.001, d = 1.10] and desired less to eat [F(1,11) = 32.91, p <.001, d = 1.20] when breakfast was consumed, irrespective of exercise/rest. Exercise also reduced hunger [F(1,11)=13.88, p=.003, d = 0.56] and increased satisfaction [F(1,11) = 6.87, p =.024, d = 0.31] and fullness [F(1,11) = 5.94, p = .033, d = 0.35] compared to rest, irrespective of breakfast.

Table 2.5
Time-averaged AUC values for subjective appetite measures following breakfast (B) or no breakfast (NB) and exercise (E) or rest (NE)

Measure	Condition	AUC (mm) Baseline	Pre-post exercise	Post-exercise recovery period	Post-lunch
Hunger	NB NE	58 ± 6	70 *† ± 4	65 ± 4	38 ± 2
	B NE	55 ± 6	49 ± 3	73 ± 3	43 ± 2
	NB E	54 ± 6	57 ± 2	29 ± 4	54 ± 2
	B E	53 ± 6	42 *† ± 4	26 ± 2	54 ± 2
Desire to eat	NB NE	66 ± 5	49 ± 4	54 ± 4	34 ± 2
	B NE	64 ± 5	52 ± 3	59 ± 4	36 ± 2
	NB E	65 ± 5	46 ± 3	39 ± 4	60 ± 2
	B E	57 ± 6	47 ± 4	39 ± 2	59 ± 2
Fullness	NB NE	26 ± 4	57 ± 6	64 ± 3	41 ± 2
	B NE	29 ± 5	66 ± 3	69 ± 4	40 ± 2
	NB E	37 ± 5	27 ± 3	27 ± 4	55 ± 2
	B E	33 ± 4	27 ± 3	28 ± 4	56 ± 2
Satisfaction	NB NE	29 ± 5	42 ± 4	56 ± 4	37 ± 2
	B NE	38 ± 5	52 ± 5	62 ± 4	37 ± 2
	NB E	34 ± 4	50 ± 4	39 ± 4	60 ± 2
	B E	38 ± 5	49 ± 4	39 ± 3	64 ± 3

Mean values ± SEM are presented
* Mean value was significantly different from B NE (p <.05)
† Mean value was significantly different from NB E (p <.05)

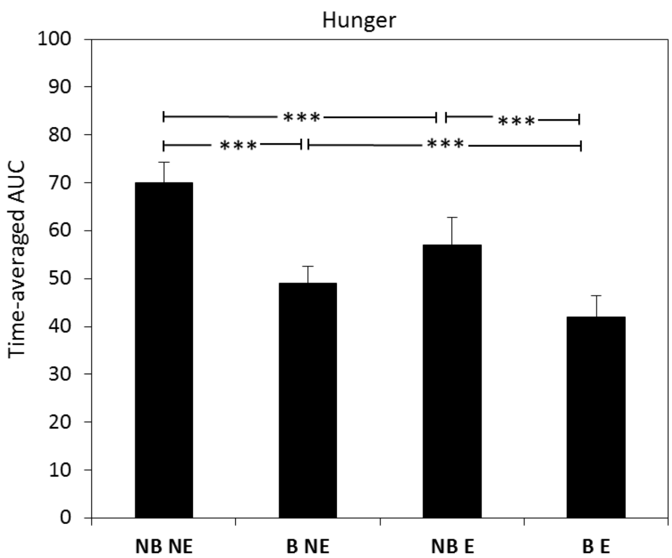

Figure 2.2 Effects of breakfast consumption or omission (B or NB) on ratings of hunger during exercise and rest (E or NE) in active males. Values are time-averaged AUC ± SEM, N=12, ***p < .001.

2.3.3 Post-drink Analysis

Cognitive Performance (Table 2.2)

No effects were observed for the SRT or NBack tasks.

FCRT

No interactions between breakfast and exercise were observed for this task. A main effect of breakfast on FCRT correct responses was observed [F (1, 11) = 5.04, p = .046, d = 0.44] with less correct responses given when breakfast was consumed compared to omitted (irrespective of exercise).

Stroop

A significant exercise x breakfast interaction was observed for Stroop task accuracy [F (1, 10)=7.84, p = .019]. Comparisons revealed poorer accuracy in the B NE condition compared to the B E condition (p = .001, d = 1.15) the NB E condition (p = .013, d = .42) and the NB NE condition (p < .001, d = .60; Figure 2.3a).

RVIP

A significant exercise x breakfast interaction was observed for the RVIP task [F(1,10) = 10.74, p=.011, d = 0.99]. Comparisons revealed a quicker RT for correct detections in the NB NE condition than in the B NE condition (p = .009; Figure 2.3b).

Mental fatigue and task difficulty ratings (Table 2.3)

A significant breakfast x exercise interaction was seen [F (1, 11) = 11.89, p = .005] with significantly higher mental fatigue ratings reported in the NB E condition compared to the NB NE (p = .021, d = 0.68) and B E condition (p = .017, d = 1.49; Figure 2.3c). No significant effects were observed for task difficulty

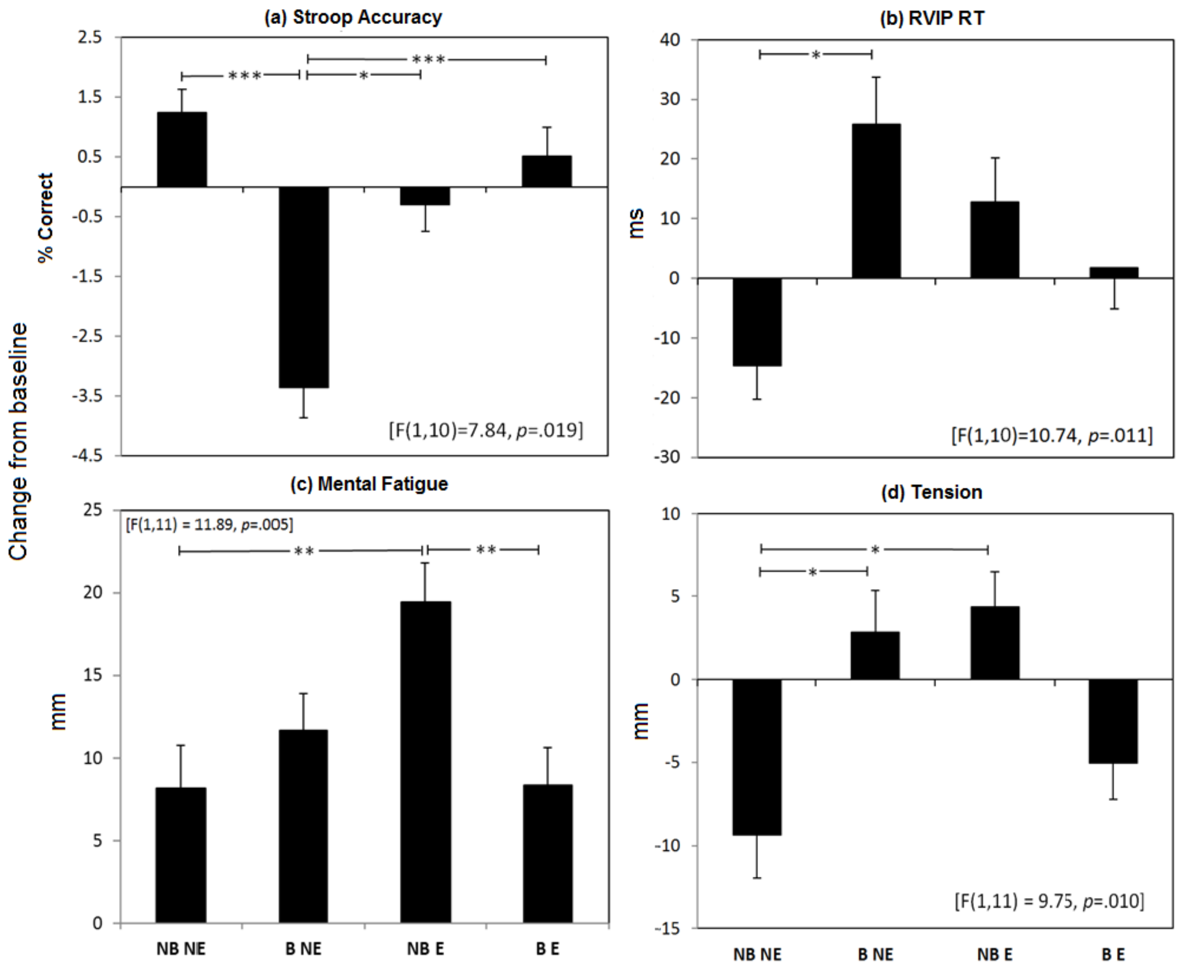

Figure 2.3 The effects of prior breakfast consumption or omission (B or NB) and exercise or rest (E or NE) on (a) Stroop task accuracy (N=11), (b) Rapid Visual Information Processing task RT (N=9), (c) mental fatigue (N=12) and (d) tension (N=12) following a mixed-macronutrient drink in active males. Values are change from baseline ± SEM, (*p <.05; **p <.01; *** p <.001)

MPS VAS

No significant effects of breakfast or exercise on ratings of relaxation, alertness, jitteriness, tiredness, headache or overall mood were observed (Table 2.3).

Tension ratings

A breakfast x exercise interaction was found for ratings of tension [F (1, 11) = 9.75, p = .010]. Tension was significantly higher in the B NE (p = .017, d = 0.70) and NB E (p = .006, d = 0.83) conditions compared to the NB NE condition (Figure 2.3d; Table 2.3).

Appetite VAS

Main effects of breakfast were found for all appetite measures post-drink. Participants were significantly more full [F(1,11) = 10.42, p = .008, d = -0.86] and satisfied [F(1,11) = 18.13, p =.001, d = 1.25] and less hungry [F(1,11) = 20.09, p =.001, d = 0.70] and desired less to eat [F(1,11) = 14.14, p =.003, d = 0.79] when breakfast was consumed, irrespective of exercise/rest (Figure 2.4, Table 2.4). These same effects of breakfast were observed post lunch also (p <.05), however, a main effect of exercise was also observed post-lunch whereby hunger was higher if exercise was undertaken, irrespective of breakfast consumption [F(1,11) = 5.48, p =.039, d = 0.43].

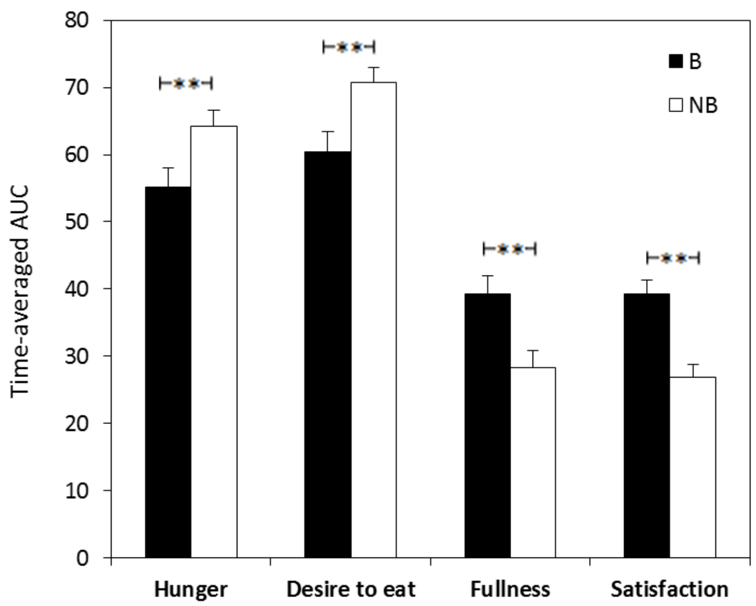

Figure 2.4 Effects of breakfast consumption (B) or omission (NB) on ratings of hunger, desire to eat, fullness and satisfaction over a 1.5 h period following a mid-morning mixed-macronutrient drink in active males. Values are time-averaged area under the curve (AUC) ± SEM, N=12, $^{**}p$ <.01.

EI and energy balance

There were no significant differences between conditions observed for EI at the *ad libitum* lunch. However, main effects of breakfast [F (1, 11) = 68.73, p < .001, d = 0.87] and exercise [F (1, 11) = 153.53, p < .001, d = 1.91] were observed for subsequent energy balance. The consumption of breakfast (irrespective of exercise) and resting rather than exercising (irrespective of breakfast) both led to a significantly higher energy balance at the end of the test session (p <.05, Figure 2.5).

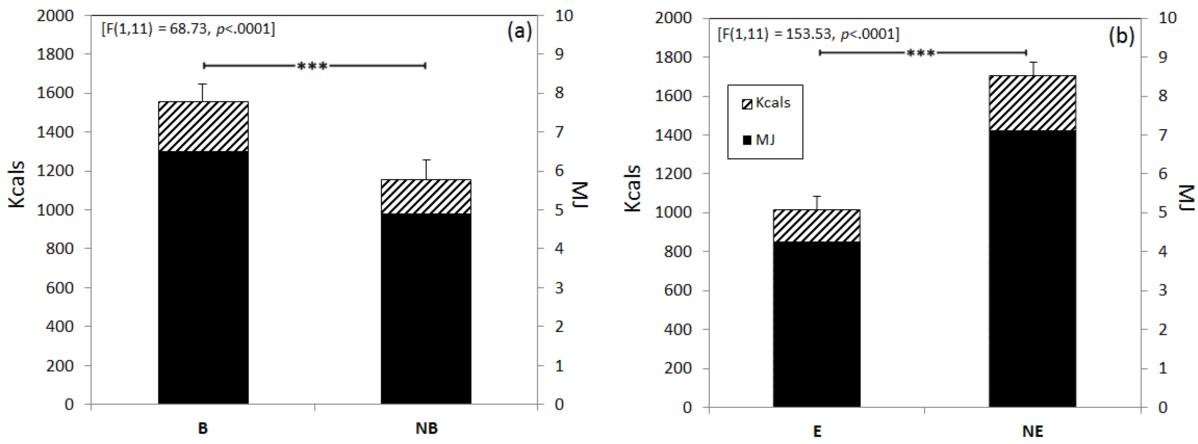

Figure 2.5 Energy balance (kcal and MJ) following an *ad libitum* lunch consumed after (a) breakfast consumption or omission (B or NB) and (b) exercise or rest (E or NE) in active males. Values are absolute ± SEM, N=12

HR, RPE and exercise enjoyment VAS

There were no significant differences observed for RPE or enjoyment VAS ratings during the exercise trials. Due to a large amount of missing data points, data for HR was not analysed.

2.4 Discussion

This study investigated the effects of breakfast consumption or omission prior to exercise or rest on appetite, cognitive performance and mood in healthy, habitually active males. The results suggest that breakfast consumption and exercise interact to influence hunger and some aspects of cognitive performance and mood.

Following the post-exercise drink, mental fatigue ratings were significantly higher when breakfast was omitted, compared to consumed, prior to exercise. An increase in tension was also observed when exercise, compared to rest, was undertaken in a fasted state. Paul et al. (1996) previously reported lower ratings of post-exercise fatigue following breakfast consumption, rather than omission, prior to cycling. The authors suggested that the protein in the breakfast likely attenuated an exercise-induced rise in brain serotonin, a neurotransmitter known to have a sedative effect (Sobczak et al., 2003) and to increase fatigue sensitivity (Newsholme, Acworth & Blomstrand, 1987). In addition, brain requirements for fuel (i.e. glucose) may be high during the post-exercise recovery period (Ide, Horn, & Secher, 1999); if fuel availability is poor, this could be detrimental for mood (Benton, Slater & Donohoe, 2001). Consuming a high-CHO meal prior to exercise may reduce this effect by increasing pre-exercise glycogen stores (Hargreaves, Hawley & Jeukendrup, 2004). These results suggest that consuming, rather than omitting, breakfast before exercise is somewhat beneficial for post-exercise mental state, supporting the original hypothesis. It has been previously reported that breakfast consumption or omission prior to swimming does not alter mood (energy, tiredness, tension and calmness; Hill et al., 2011), however, as discussed, breakfast omission prior to cycling increased fatigue (Paul et al., 1996). These results, taken in tandem with those from the current study suggest that exercise mode may influence how pre-exercise nutritional state alters post-exercise mood.

Following the test drink, an improvement in RVIP RT was observed when breakfast was omitted, compared to consumed, prior to rest; in addition, FCRT accuracy was also enhanced following breakfast omission, irrespective of exercise. A high-CHO meal can reduce alertness (Benton, 2002; Cunliffe et al., 1997) and RT is often reported to decrease with increased feelings of hunger (Fischer, Colombani & Wenk, 2004), such as those reported in the fasted conditions in the current study. Michaud, Musse, Nicolas & Mejean et al. (1991) also previously reported an impairment in concentration following a high-caloric breakfast in children and adolescents. However, the same authors reported improved episodic memory following the same condition, a cognitive trait previously shown to be positively influenced by breakfast consumption (e.g. Benton & Parker, 1998). The RVIP and NBack tasks both measure working memory and we also saw no positive influence of breakfast on either. Breakfast also decreased FCRT and Stroop accuracy in the current study, suggesting a negative impact on decision making and response inhibition. The higher tension ratings reported when breakfast was consumed prior to rest could also explain these results given the recognised relationship between mood and cognitive performance (Chepenik et al., 2007). However, the negative effect of breakfast consumption on RVIP RT and Stroop accuracy appeared to be alleviated by exercise in this sample. The literature does suggest that exercise is stimulating (Lambourne & Tomporowski, 2010) and an increase in arousal post-exercise can decrease RT (Etnier et al., 1997) and facilitate the speed of decision making (Adam et al., 1997; McMorris & Graydon, 1996). The current results do not support the hypothesis that breakfast prior to exercise may enhance post-exercise cognitive performance, and similarly, Paul et al. (1996) also reported no effect of breakfast consumption prior to cycling on cognitive performance, despite both studies reporting higher fatigue following fasted exercise. However, they do suggest that in habitually active males, exercise can reverse any negative effect of consuming a large breakfast on cognitive performance.

Predictably, breakfast consumption reduced subjective appetite compared to breakfast omission in the post-prandial period prior to the exercise or rest intervention, a result which supports that of many previous studies (Delargy, 1995; Hubert, 1998; Ruxton & Kirk, 1997; Astbury, 2011). The suppression of hunger initiated by breakfast consumption, compared to omission, remained strong during both the exercise and rest interventions. Both consuming breakfast prior to rest (Astbury et al., 2011) and exercise in the post-prandial period (Cheng et al., 2009; Deighton, 2012) have been shown to increase satiety. Recently, Deighton and colleagues (2012) reported that a 60 min treadmill run performed after breakfast had a greater appetite-suppressing effect than that performed in a fasted state in males. However, they did not assess the effects of both breakfast consumption and omission prior to a rest condition. In the current study, hunger suppression was augmented during exercise compared to during rest, in both breakfast conditions. This is in agreement with previous findings (Martins, 2007).

Cheng et al. (2009) reported that consuming a high-fat meal 2 h before, rather than immediately after, a 50 min bout of cycling prolonged the satiating effect of the meal in moderately active men (Cheng et al., 2009). The authors did suggest that these effects could be assessed following consumption of a high-CHO meal, however, although the CHO-rich breakfast administered prior to exercise in the current study transiently suppressed hunger during exercise and rest, it did not interact with exercise to influence the satiating effect of food consumed post-exercise. Paul et al. (1996) also reported lower hunger ratings during a post-exercise recovery period when breakfast was consumed, compared to omitted, prior to cycling, although neither study assessed satiety by administering food soon after the cessation of exercise as in the current study.

Although the current results do provide some support for the study hypothesis that appetite responses to exercise can be influenced by pre-exercise nutritional state, this interaction between breakfast and exercise was short-lived and disappeared after consumption of the test drink; in fact, attenuation in hunger suppression was seen immediately post-lunch if exercise, rather than rest, was undertaken. This somewhat contradicts earlier data which suggest that the satiating effect of food consumed post-exercise is increased when exercise is undertaken in both a fasted (Martins, Kulseng, King, Holst & Blundell, 2010) or a fed state (King et al., 2009). It is possible that this effect may have disappeared over the 90 min time period between exercise cessation and lunch as these effects are typically seen for a short period after exercise only (King et al., 1994), though exercise also did not affect the satiating effect of the post-exercise drink which was consumed <20 min post-exercise. On the other hand, breakfast consumption, irrespective of exercise, remained favourable for all appetite measures during the exercise/rest intervention, following consumption of the test drink, in agreement with Astbury et al. (2011), as well as immediately post-lunch. This supports previous data suggesting that although both meal consumption and exercise can increase satiety, food ingestion is a more robust method of achieving this effect (Hubert et al., 1998).

Regardless of the extent to which the different conditions created an energy deficit or positive energy balance, this did not alter EI at the *ad libitum* lunch. The resulting effect was a significantly higher relative end energy balance in the B NE condition, which may have weight gain implications. Indeed, it has been proposed that if habitually active individuals are required to rest when they would normally exercise, food intake is not adjusted accordingly, leading to a positive energy balance (J. Blundell, Stubbs, Hughes, Whybrow & King, 2003). Previously, Paul et al. reported no difference in post-recovery EI, despite an increase in hunger observed after undertaking cycling in a fasted compared to fed state (Paul, et al., 1996). However, Astbury et al. (2011) reported that breakfast consumption increased the satiety response to a drink consumed later in the morning and a decreased EI at lunch. Although we too saw that breakfast positively influenced subjective appetite, it did not alter EI.

Post-drink, positive appetite sensations following breakfast consumption prior to exercise coincided with lower mental fatigue and tension ratings. Mood and appetite are closely linked, for example, following breakfast consumption a positive correlation between alertness and fullness has been reported (Holt, 1999) and Fischer, Colombani & Wenk (2004) found negative correlations between hunger and desire to eat ratings and feelings of energy, liveliness, calmness and relaxation.

It is important to note that whilst the majority of participants in this study were habitual breakfast consumers, four participants (25%) did not consume breakfast often enough to be classed as habitual consumers (consuming breakfast at least four times per week). Although there is some evidence to suggest that long-term breakfast habits may influence responses to acute breakfast consumption (Halsey et al., 2012; Pereira et al., 2011), given that consuming breakfast prior to exercise was not a completely novel situation for any of the participants, it is unlikely this would have significantly influenced the results. Another caveat in the current study was that tolerance to the nutritional interventions was not measured. Although participants confirmed verbally that the test drink and pasta lunch were well liked, some participants did not find the test breakfast pleasant to eat. Information on the habitual morning exercise routine of this sample would have also been beneficial when assessing the effect of the chosen interventions. Finally, it should be noted that some of the effects of breakfast and exercise only occurred in the presence of the chocolate milk drink. It could certainly be speculated that additional or differing effects would have been seen had the chocolate milk drink been omitted from the study.

In conclusion, the results suggest that in habitually active males, a poorer pre-exercise nutritional state can negatively influence mood state post-exercise. Also, consuming breakfast can negatively influence cognitive performance, an effect reversed by undertaking exercise. Exercise can transiently reduce hunger, more so when undertaken following breakfast omission, but breakfast consumption has a more comprehensive and prolonged appetite suppressing effect. Lower subjective appetite occurs concurrently with an improvement in mood. Currently, this data only extends to young, healthy males; conducting a similar study using a female population, who are generally under-represented in the literature, would add to knowledge in this research area.

Chapter 3: The exercise and nutritional practices of habitually active women

3.1 Introduction

The importance of breakfast consumption for cognitive, mood and appetite benefits has already been highlighted in this thesis (Barton et al., 2005; Pereira et al., 2011; Smith, 1998; also see Chapter 1). However, breakfast is a commonly skipped meal for women (Ozdogan et al., 2010; Silliman et al., 2004), who are more likely to use this practice for weight control than men (Dundes, 2008). Data from Chapter 2 demonstrated that breakfast omission prior to exercise may be detrimental for post-exercise mood and appetite control in active men. To date, no studies have assessed the effect of breakfast prior to exercise on these parameters in a recreationally active female population. It has been suggested that women are more sensitive to changes in mood than men (Hagobian et al., 2009; Spring, Maller, Wurtman, Digman & Cozolino, 1982), and therefore may be more susceptible to any negative effects of omitting breakfast, particularly prior to exercise. Women have previously reported that an exercise class undertaken in the morning required more effort than at other times of the day (Maraki et al., 2005) and less frequent breakfast consumption in adolescent girls is associated with lower morning physical activity levels (Corder et al., 2011). These findings highlight the potential need for adequate nutritional intake before morning exercise in these populations. In addition, exercise mode and intensity can also alter the effect of exercise on appetite (Bellisle, 1999; Pomerleau, et al., 2004), cognitive performance (Tomporowski, 2003) and mood (Terry, 2004; Yeung, 1996). These results emphasize the need for information describing the common practices of a population in order to design intervention studies which are acceptably representative of that population's typical routine.

Accordingly, the purpose of the current survey was to gather information on the current dietary and exercise practices of an active female population in order to accurately investigate the effect of nutritional practices, in particular breakfast habits, prior to exercise on cognition, mood and appetite in this population. Acquiring a clear picture of the exercise and dietary routines active women are currently following and the reasons behind them, and also gaining an understanding of how breakfast and pre-exercise dietary habits might alter their perception of the effects of exercise and breakfast on appetite, cognition and mood, will aid intervention study design in the future.

3.2 Methods

This study received ethical approval from Northumbria University's Faculty of Health and Life Sciences Ethics Committee. All participants provided written informed consent before taking part.

3.2.1 Participants

A convenience sample was recruited, providing a "snapshot" of the population of interest. Participants were recruited through internal university email, face-to-face by staff members at a local fitness club in Newcastle upon Tyne and via a link posted on a social network site. In total, 319 participants gave informed consent to take part in the survey. The final sample consisted of 201 participants. One hundred and eighteen participants were withdrawn either because they did not fulfil the exercise criteria specified for participation or did not answer sufficient questions to be included in the final sample. Before taking part in the survey, participants were asked to confirm that they met the general inclusion criteria specified in section 2.2.1.1 and also fulfilled the following criteria: they were female, aged 18-45, habitually active (defined as "being physically active* for at least 30 min a day, at least 3 days per week for at least the previous 12 months", *not including periods of walking unless they considered walking as an exercise session in its own right and not a means of commuting). Whilst previous studies have classified habitual activity as participating in exercise regularly for at least 2 (O'Donovan et al., 2005) or even 5 (Gilliat-Wimberly, Manore, Woolf, Swan & Carroll, 2001) years, a period of just 6 months has also been used to categorize this group (Stein, Rivera & Pivarnik, 2003), therefore it was considered that 12 months regular exercise participation was sufficient to class participants as habitually active for this study. This did include active commuting if they ran or cycled to work and considered this to be a main part of their exercise routine. Potential participants were advised that they should not take part in the survey if they took part in competitive sporting events more than twice a year for which they trained or if they considered themselves to be an athlete. This was to ensure that the sample consisted of recreationally active females who were not following a specific training and nutritional plan for competition preparation.

3.2.3 Experimental Protocol

Prior to being administered, the survey was piloted. Eighteen students at Northumbria University gave written informed consent and completed the survey, giving both verbal and written feedback on it's content and clarity, which was then used to create the final version. The pilot data was not included in the final analysis. The data for the final study was collected either via paper form (see Appendix D) or using an online survey tool. Online surveys have been found to produce comparable mean scores and reliability coefficients compared with data collected using a paper version of the same survey (Miller et al., 2002). No incentive was offered for taking part in the survey, therefore it was not a concern that individual's would complete the survey multiple times.

The survey consisted of 6 sections: Demographic information (six questions); Dietary Habits, Appetite and Mood (sixteen Likert Scales with response options as follows: Strongly Agree, Agree, Neither Agree nor Disagree, Disagree and Strongly Disagree); General Exercise Habits (four questions) and Morning Exercise; Mid-Day Exercise and Evening Exercise (each fourteen questions). Participants were required to fill out the first three sections and any of the remaining sections for which they fulfilled the criteria; exercising regularly (at least once a week) at the specified time of day (Morning, 06.00-11.00 h; Mid-day, 11.00-17.00 h or Evening, 17.00-23.00 h). This was implemented using adaptive questioning when the survey was completed online. In total, the survey took approximately 15 min to complete. The options "flexibility" and "fitness" given for possible reasons for exercising were taken from the "Personal Incentives to exercise Questionnaire" (PIEQ (Duda & Tappe, 1989); and the options "Weight control", "Health reasons", "To improve body tone", "To improve mood" and "Enjoyment" from the "Reasons to exercise inventory" (Silberstein, Striegel-Moore, Timko & Rodin, 1988).

3.2.4 Statistical Analysis

Data were analysed using SPSS version 19 (SPSS, Inc., Chicago, IL, USA). The data is presented in tables with absolute values (frequencies) and percentage values. Means and SD were calculated where appropriate. Chi-square (χ^2) statistics (or Likelihood ratios (Λ) where expected values were small) were used to examine differences in frequencies of responses to questions relating to dietary and exercise habits between groups, reported with the odds ratio (OR) and 95% confidence intervals (CI). These statistical tests were deemed sufficient to assess if the number of participants that agreed or disagreed with a particular statement differed between groups. Group comparisons were made between regular breakfast consumers (eating breakfast at least 4 times per week) and non-regular breakfast consumers. Separate analysis for questions relating to the perceived effect of exercise on cognition, mood and appetite was also conducted for regular morning exercisers who ate before an exercise session and those who did not. The relationship between breakfast frequency and BMI was also compared using χ^2 (using underweight, normal and overweight as BMI categories). Group differences in age, BMI, marital status and exercise frequency were assessed using independent *t* tests or χ^2 depending on the type of variable. No significant differences between groups for these variables were found (p >.05), and therefore no adjustments were necessary for further χ^2 analysis. No question in the survey was compulsory; therefore, the number of participants included for each analysis (N) is shown for questions that were not answered by the whole sample.

3.3 Results

The participants who took part in the survey were aged 18-45 years with a mean age of 24.7 ± 6 years (N=194) and a mean BMI of 22.8 ± 3.3 kg/m^2 (range 16.2 – 37.2 kg/m^2; N=197). The majority of the sample were single (70.6 %), 16.4 % were living with a partner and 12.9 % were married.

3.3.1 Breakfast Habits

The majority of the sample were classed as regular breakfast consumers (83.6 %), eating breakfast at least 4 days per week (Table 3.1). The most frequently consumed foods at breakfast were cereals (28.4 %) and bread products (23.1 %; Table 3.1). No association was found between breakfast frequency and BMI (χ^2 (2) = .880, p > .05).

Table 3.1
Frequency of breakfast consumption and types of foods consumed regularly at breakfast for a sample of habitually active women (N=201)
Frequencies and percentages reported (rounding errors in the sum of some percentages).

	Frequency	%
Breakfast Frequency (N=201)		
Everyday	132	65.7
5-6 times per week	19	9.5
4-5 times per week	17	8.5
2-3 times per week	17	8.5
once per week or less	16	8
Regular (≥ 4 times per week)	168	83.6
Non-Regular (<4 times per week)	33	16.4
Breakfast Types		
Cereal	114	28.4
Bread products (Bread, toast, muffins, crumpets, sandwiches)	93	23.1
Eggs	42	10.4
Fruit	39	9.7
Porridge	39	9.7
Yoghurt	26	6.5
Other (Fish, rice, salad, protein drink, soup, cheese, nuts, beans)	23	5.7
Sweets foods	7	1.7
Meat	7	1.7
Smoothie	7	1.7
Cereal Bar	5	1.2

3.3.2 Exercise Routine

Data on exercise routine (frequency, time of day and duration) is summarised in Table 3.2. Weight control was the most common reason for exercising (45.0 %), followed by fitness (22.5 %) and enjoyment (13.5 %). The most popular physical activity was running (61.7 %; Table 3.3). Of those who listed weight control as their main reason for exercise, 83.3 % were also regular breakfast consumers.

Table 3.2.
Exercise routine and main reasons for exercising in a sample of habitually active women (N=201 unless otherwise indicated).
Frequencies and percentages reported.

	*Frequency	%
Sessions per week		
5+	60	29.9
3 - 4	141	70.1
Time of day		
Morning: 6 - 11am (N=196)	109	55.9
Mid-day: 11 - 5pm (N=170)	92	45.8
Evening : 5 - 11pm (N=184)	126	62.7
No. of regular exercise times		
One	64	31.8
Two or more	137	68.2
Main reason for exercise (N=200)		
Weight control	90	45
Fitness	45	22.5
Enjoyment	27	13.5
To improve body tone	18	9
Health	10	5
To improve mood	4	2
Other	4	2
Social	2	1
Flexibility/agility	0	0

*The number of participants who reported exercising at the specified time of day

3.3.3 Dietary Routine

Data on the timing of food consumption in relation to exercise is summarised in Table 3.4. As several participants specified “routine” or “habit” as a reason for their choice, this was included as an additional category. Regular morning exercisers tended to eat breakfast or a snack within 2 h either side of the start of their exercise session (98.7 %). The main reason given for eating before a morning exercise session was to have more energy (42.3 %), whilst the main reasons for not eating before a morning exercise session were to make exercise feel more comfortable (52.8 %) and lack of time (33.3 %, Table 3.5).

Regular breakfast consumers were 11.2 (95% CI - 2.92) times more likely to eat before a morning exercise session than non-regular breakfast consumers (χ^2 (1) = 16.73, p<.0001). The majority of regular breakfast consumers who exercised in the morning consumed breakfast before their exercise session, rather than after (76% *vs.* 24% respectively).

Table 3.3
Regular modes of exercise (undertaken ≥twice per month) in a sample of habitually active women (N=201)
Frequencies (N participants) and percentages reported

Exercise Mode	**Frequency**	**%**
Running (alone and clu	48	38.1
Cross-trainer	27	21.4
Cycling (stationary bik	26	20.6
Weight training	25	19.8
Cycle (outside)	15	11.9
Aerobics (taught class	15	11.9
Other	15	11.9
Step machine	13	10.3
Rowing	12	9.5
Aerobics (home DVD)	11	8.7
Swimming	10	7.9
Power Walking	9	7.1
Dance/Zumba	7	5.6
Pilates	6	4.8
Netball	3	2.4
Spinning	2	1.6
Horse Riding	2	1.6
Bootcamp	2	1.6
Body Combat	2	1.6
Boxing	1	0.8
Raquet Sports	1	0.8
Yoga	1	0.8
Kettlebells	0	0
Pole Dancing	0	0

Table 3.4

Times of meal or snack consumption before and after an exercise session in a sample of habitually active women

Frequencies and percentages reported (rounding errors in the sum of some percentages

	Number in			< 30min		< 1 h		1-2 h		2-3 h		3-4 h		4-5 h		5+ h	
	sample	Yes	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%
Eat before morning exercise	109	71	65.1	20	28.2	30	42.3	20	28.2	1	1.4	0	0	0	0	0	0
After morning exercise	107	66	60.6	30	45.5	25	37.9	10	15.2	1	15.2	0	0	0	0	0	0
Before mid-day exercise	94	75	79.8	15	20	26	34.7	24	32	5	6.7	4	4.3	1	1.3	0	0
After mid-day exercise	94	55	58.5	26	47.3	16	29.1	11	20	1	1.8	1	1.8	0	0	0	0
Before evening exercise	126	107	84.9	9	8.4	30	28	33	30.8	15	14	7	6.5	6	5.6	7	6.5
After evening exercise	126	95	75.4	16	16.8	49	51.6	27	28.4	2	2.1	1	1.1	0	0	0	0

Table 3.5.
Reasons for eating or not eating before a morning exercise session (between 06.00-11.00 hours) in a sample of habitually active women.
Frequencies and percentages reported.

	Morning session		Mid-day session		Evening Session	
Number in group	71		75		94	
	Freq.	%	Freq.	%	Freq.	%
Eat before session						
I feel I have more energy	30	42.3	41	54.7	48	51.1
I feel like I am burning more calories	2	2.8	2	2.7	4	4.3
I feel like I perform better	3	14.1	6	8.0	12	12.8
It makes exercise feel more comfortable	4	29.6	16	21.3	17	18.1
Routine/habit	3	4.2	8	10.7	4	4.3
Other	5	7.0	2	2.7	9	9.6
Number in group	36		1		15	
Do not eat before session						
I don't have time	12	33.3	0	0.0	5	33.3
I feel like I have more energy	1	2.8	0	0.0	1	6.7
I feel like I am burning more calories	2	5.6	0	0.0	1	6.7
I feel like I perform better	1	2.8	1	100.0	7	46.7
It makes exercise feel more comfortable	19	52.8	0	0.0	0	0.0
Routine/habit	1	2.8	0	0.0	0	0.0
Other	0	0.0	0	0.0	1	6.7
Number in group	63		55		94	
Eat after session						
I feel hungry	36	57.1	40	72.7	63	67.0
I feel I should replace the calories I have expended	13	20.6	2	3.6	8	8.5
To recover more quickly	10	15.9	5	9.1	12	12.8
Other	1	1.6	3	5.5	4	4.3
As a reward for exercising	0	0.0	3	5.5	3	3.2
Routine/habit	3	4.8	2	3.6	4	4.3
Number in group	42		36		25	
Do not eat after session						
I don't feel hungry	14	33.3	22	61.1	14	56.0
I don't want to replace the calories I have expended	12	28.6	7	19.4	6	24.0
I don't have time	9	8.3	4	11.1	4	16.0
Other	7	16.7	2	5.6	1	16.0
Routine/habit	0	0.0	1	2.8	0	0.0

3.3.4 Appetite, Mood and Cognition

Likert scales assessing the perceived effect of exercise and breakfast on appetite, mood and cognition were analysed as a whole sample before data was split for further comparative analysis; regular *vs*. non-regular breakfast consumers (as previously defined) and morning exercisers who ate before exercise *vs*. those who did not (only for questions relating to exercise). For group comparisons, the "neither agree nor disagree" response category was omitted from the analysis. It is appropriate to have > 5 in each category for χ^2 analysis between groups, and to ensure this the remaining four responses were collapsed into two groups to form; "Agreed" and "Disagreed". Table 3.6 shows a summary of Likert scale responses for the sample as a whole and for the specified groups.

The majority of the sample agreed that their mood was better after exercising (96.5%), that exercising made them feel more alert (89.5%), less tired (76.0%) and improved their ability to perform well at work/when studying/when doing their daily tasks (79.0%) and their concentration (85.0%; Table 3.6). Response to the latter was dependant on breakfast habits (Λ (2) = 9.58, p = .003) with regular breakfast consumers 10.7 (95% CI 2.4) times more likely to agree with this statement than those who did not consume breakfast regularly. Compared to non-regular breakfast consumers, regular breakfast consumers were more likely to agree that when they skipped breakfast their mood (χ^2 (2) = 41.16, p < .0001) and concentration (χ^2 (2) = 51.6, p < .000) were worse (13.8 (95% CI 5.5) and 20.1 (95% CI 7.6) times more likely respectively) and that their appetite increased for the rest of the day (χ^2 (2) = 15.9, p <.0001; 5.6 (95% CI 2.3) times more likely). Compared to when they had not exercised, nearly half of the sample (49.3%) agreed that they felt hungrier in the 4 h following an exercise session, with 81.0% of those individuals also agreeing that they felt they ate more in the 4 h following an exercise session. Responses to these questions were not affected by regular breakfast habits or by nutritional routine prior to morning exercise (p >.05).

Table 3.6
Responses to questions referring to mood, cognition and appetite in relation to nutritional routine and exercise in habitually active women. Data shown is for the sample as a whole, regular (≥4 times per week) and non-regular (<4 times per week) breakfast consumers and those who eat or do not eat before a morning exercise session (where appropriate)
Frequencies and percentages, Chi-squared or Likelihood Ratio, *p* -values and Odds ratio (95% confidence intervals)

Question		*n*	Strongly Agree* Freq.	Strongly Agree* %	Agree* Freq.	Agree* %	Neither Agree nor Disagree Freq.	Neither Agree nor Disagree %	Disagree* Freq.	Disagree* %	Strongly* Disagree Freq.	Strongly* Disagree %	χ^2	*P*	OR (95% CI)†
I find my mood is better after exercising	Whole sample	201	118	58.7	76	37.8	6	3	0	0.0	1	0.5			
	Regular	164			163	99.4			1	0.6			0.19	1.000	
	Non-regular	31			31	100.0			0	0.0					
	Eat	76			75	98.7			1	1.3			0.47	1.000	
	Do not eat	35			35	100.0			0	0.0					
I feel exercising improves my concentration	Whole sample	200	58	29	112	56.0	22	11	7	3.5	1	0.5			
	Regular	150			147	98.0			3	2.0			Λ 9.58	.003	10.65 (2.38-47.61)
	Non-regular	28			23	82.1			5	17.9					
	Eat	66			64	97.0			2	3.0			Λ 0.54	.595	
	Do not eat	32			30	93.8			2	6.3					
I feel exercising makes me feel more alert	Whole sample	201	77	38.3	103	51.2	14	7	7	3.5	0	0			
	Regular	156			152	97.4			4	2.6			3.63	.091	
	Non-regular	31			28	90.3			3	9.7					
	Eat	68			64	94.1			4	5.9			0.42	.662	
	Do not eat	34			33	97.1			1	2.9					
I feel exercising makes me feel less tired	Whole sample	200	53	26.5	99	49.5	22	11	25	12.5	1	0.5			
	Regular	148			130	87.8			18	12.2			4.21	.050	
	Non-regular	30			22	73.3			8	26.7					
	Eat	63			56	88.9			7	11.1			Λ .315	.746	
	Do not eat	33			28	84.8			5	15.2					

Table 3.6 continued

Question		n	Strongly Agree		Agree*		Neither Agree nor Disagree		Disagree*		Strongly Disagree				
			Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%	χ^2	P	OR (95% CI)†
I feel exercising improves my ability to perform well at work/when studying/in doing my daily tasks	Whole sample	201	55	27.5	103	51.5	37	18.5	5	2.5	0	0			
	Regular	143			140	97.9			3	2.1			Λ 2.56	.114	
	Non-regular	20			18	90.0			2	10.0					
	Eat	66			64	97.0			2	3.0			Λ 1.52	.566	
	Do not eat	30			30	100.0			0	0.0					
I feel my mood is worse if I skip meals	Whole sample	201	60	29.9	82	40.8	34	16.9	22	10.9	3	1.5			
	Regular	141			126	89.4			15	10.6			13.35	.001	5.25 (2.02-13.64)
	Non-regular	26			16	61.5			10	38.5					
If I skip breakfast, my mood is much worse	Whole sample	201	61	30.3	66	32.8	33	16.4	34	16.9	7	3.5			
	Regular	138			118	85.5			20	14.5			41.16	<.0001	13.77 (5.52-34.32)
	Non-regular	30			9	30.0			21	70.0					
If I skip breakfast, my concentration is much worse	Whole sample	199	64	32.2	75	37.7	31	15.6	24	12.1	5	2.5			
	Regular	137			127	92.7			10	7.3			51.60	<.0001	20.11 (7.64-52.93)
	Non-regular	31			12	38.7			19	61.3					
If I skip breakfast, my appetite increases for the rest of the day	Whole sample	196	56	28.6	42	21.4	38	19.4	47	24.0	13	6.6			
	Regular	129			89	69.0			40	31.0			15.92	<.0001	5.56 (2.26-13.69)
	Non-regular	28			8	28.6			20	71.4					

Table 3.6 continued

Question		n	Strongly Agree Freq.	Strongly Agree %	Agree* Freq.	Agree* %	Neither Agree nor Disagree Freq.	Neither Agree nor Disagree %	Disagree* Freq.	Disagree* %	Strongly Disagree Freq.	Strongly Disagree %	χ^2	P	OR (95% CI)†
I feel hungrier in the 4 hours following an exercise session compared to if I have not exercised	Whole sample	201	20	10	79	39.3	46	22.9	50	24.9	6	3			
	Regular	126			83	65.9			43	34.1			1.17	.291	
	Non-regular	29			16	55.2			13	44.8					
	Eat	57			42	73.7			15	26.3			0.80	.450	
	Do not eat	28			18	64.3			10	35.7					
I feel I eat more in the 4 hours following an exercise session compared to if I haven't exercised	Whole sample	200	15	7.5	61	30.5	38	19	76	38.0	10	5			
	Regular	131			63	48.1			68	51.9			0.38	.556	
	Non-regular	31			13	41.9			18	58.1					
	Eat	56			29	51.8			27	48.2			0.015	1.000	
	Do not eat	32			17	53.1			15	46.9					
I feel hungrier during rest days which follow an exercise day	Whole sample	201	10	5	65	32.3	73	36.3	48	23.9	5	2.5			
	Regular	107			64	59.8			43	40.2			0.40	.630	
	Non-regular	21			11	52.4			10	47.6					
	Eat	49			32	65.3			17	34.7			1.01	.780	
	Do not eat	18			11	61.1			7	38.9					

* Groups collapsed for chi-squared ($\chi2$) analysis between regular and non-regular breakfast consumers and those who eat before a morning exercise session and those who do not

†p value significant at .05 level (two-sided)

‡ OR (odds ratio) and 95% confidence interval for differences between "agree" and "disagree" responses

Λ Likelihood ratio used instead of $\chi2$

Rounding errors in the sums of some percentages

3.4 Discussion

This survey investigated the dietary and exercise behaviours of a sample of habitually active women and assessed how their breakfast habits altered their perception of the effects of exercise and breakfast on appetite, cognition and mood. The results show that breakfast consumption frequency alters the perceived effect of exercise on concentration in this sample. In addition, skipping breakfast is not perceived as detrimental for concentration, mood or appetite if omitted habitually.

In support of previous research, the majority of the population in the survey agreed that exercise improved their mood (Maroulakis & Zervas, 1993; McGowan et al., 1991), concentration (Tomporowski, 2003) and made them feel less tired (Lluch et al., 2000; Maroulakis & Zervas, 1993). Non-regular breakfast consumers were less likely to agree that exercise improved their concentration, though remaining fasted prior to morning exercise did not affect how the sample perceived exercise impacted their concentration, or indeed any other parameter measured in relation to the effect of exercise. This perhaps suggests that it is overall breakfast frequency, which is known to positively contribute to an individual's general nutritional state (Timlin & Pereira, 2007), that is important for maximising the benefits of exercise, rather than the timing of breakfast consumption in relation to exercise. However, non-regular breakfast consumers were significantly more likely to undertake morning exercise in a fasted state than regular breakfast consumers, who tended to consume breakfast before a morning exercise session, rather than after which suggests this habit may in fact influence post-exercise concentration. If so, this could be due to improved brain fuel availability; it is established that CHO supplementation before and during exercise can improve post-exercise cognitive performance (Ali & Williams, 2009; Collardeau et al., 2001).

Recently Reeves et al. (2013) reported that nearly half of the active participants they surveyed (N=699) agreed that they had more energy on days that they ate breakfast and that they felt they must eat breakfast before they engaged in exercise. However, intervention studies looking at consuming or omitting breakfast prior to exercise have produced varied results. Consuming breakfast before a morning physical education lesson was found to be beneficial for children's cognitive performance before lunch (Vermorel, et al., 2003), however, previously it was found that breakfast consumption or omission prior to cycling (Paul et al., 1996) and swimming (Hill et al.,

2011) had no effect on cognitive performance in mixed gender adult samples. This does suggest a likely influence of exercise mode in this relationship (Bellisle, 1999); the most common modes of exercise in the current survey were running and using a cross-trainer and these should perhaps be considered as the most applicable exercise modes when studying the current population. Although this data showed that non-regular breakfast consumers did generally report eating after morning exercise if they did not do so before, it may be that pre- exercise nutrition is important for post-exercise cognitive benefits in the current population, although this should be explored further in a well-controlled intervention study.

In addition, it should certainly be considered that those who reported not eating before a morning exercise session cited “To make exercise feel more comfortable (i.e. prevent sickness or stitches)” as the main reason for this, followed by “I don’t have time”, reasons similar to those previously cited by college swimmers who did not eat before a morning training session (Hill et al., 2011). Therefore, to successfully encourage this group to eat before exercise, it is likely that breakfast would need to be very light and quick to consume. Whether this type of breakfast intervention would be sufficient to elicit the potential improvements in cognitive performance, mood and appetite post-exercise is a concept worth further exploration. The types of foods consumed most regularly at breakfast by the sample in the current study were cereals and bread products, well known healthy breakfast choices, which could form the basis of future intervention test meals for this population.

Although it has been reported that omitting breakfast can negatively affect mood (Benton et al., 2001; Kral et al., 2012), appetite (Farshchi et al., 2005; Pereira et al., 2011) and cognitive function (Benton & Parker, 1998; Wesnes et al., 2003), data in this area is certainly controversial (Hoyland et al., 2009; Yeung, 1996). In general, the perceived negative effects of skipping breakfast and fasting prior to morning exercise on the appetite, mood and cognition in the current sample appeared minimal if this practice was part of their typical routine. Habits such as these likely remain as part of an individual’s routine because they feel they are advantageous for them, or at least not detrimental. Differences in the effect of breakfast consumption and omission between habitual and non-habitual breakfast consumers have been highlighted previously (Halsey et al., 2012; Kral et al., 2012), which, taken with the current findings, does raise issues for future interventions focussing the interaction between breakfast and exercise. It may not be sufficient to only account for breakfast consumption frequency; the normal exercise habits and nutritional routine prior to exercise of an individual and the reasons behind these practices should perhaps also be acknowledged. The alteration of an individual's routine with regards to nutritional habits and exercise is likely to have a profound effect on study findings, particularly when using subjective measures. Indeed, a decline in mood state has been observed following consumption of a breakfast which deviated in composition from that which an individual would usually consume (Lloyd et al., 1996), and when breakfast is omitted when it would normal be consumed (Kral et al., 2012). As the findings of the current survey suggest, not all seemingly disadvantageous habits such as skipping breakfast have perceived negative consequences for individuals who undertake them, at least in this sample of habitually active women. Nonetheless, arguably without manipulating these behaviours, it would remain unclear as to whether greater positive outcomes could be achieved if their routine was changed; therefore, the aforementioned caveats should be well controlled for in this case.

Whilst the majority of the sample reported feeling hungrier in the 4 h post-exercise, this was not dependent on breakfast frequency, despite previous data which show that consuming breakfast regularly can improve appetite control (Pereira et al., 2011). Interestingly, most of the participants who reported feeling hungrier following exercise also reported that they felt they ate more in the 4 h following an exercise session compared to if they had not exercised. Intervention studies generally show that although acute exercise can increase subjective appetite following exercise, EI does not increase (Hubert et al., 1998; King, Tremblay & Blundell, 1997). Although this may be due to an increase in the satiating effect of food following exercise (King et al., 2009), it has also been previously suggested that this occurrence may be a reflection of feeding in an unfamiliar environment (Bellisle, 1999), suggesting future scope for field studies in this area. An increase in appetite sensations, whether or not it leads to an increase in EI, can have a negative impact on cognitive performance (Green, Rogers & Elliman, 2000) and mood (Hill et al., 1991) in women; therefore controlling appetite has implications beyond those of weight regulation in this population.

Although women are more likely to skip breakfast as a method of weight control than men (Dundes, 2008), exercising in a fasted state did not appear to be used as a weight loss strategy in the current sample; most of the individuals who listed weight loss as a main reason for exercise were regular breakfast consumers, the majority of whom ate breakfast before they exercised. Interestingly, although an inverse association between breakfast skipping and BMI has previously been identified (Barton et al., 2005; Keski-Rahkonen, Kaprio, Rissanen, Virkkunen & Rose, 2003), no relationship between BMI and frequency of breakfast consumption was found in the current survey. Breakfast skipping may not greatly influence BMI regulation in habitually active individuals, although self-reported height and weight data is often underreported, as previously found in a sample of college women (Jacobson & DeBock, 2001).

A limitation of the current study is the low number of non-regular breakfast consumers. Although this seems to be a common occurrence in breakfast frequency studies (Corder et al., 2011), it must be considered when interpreting this data. In addition, an error with data capture meant no information on normal exercise intensity was collected, a variable which can affect cognitive performance (Tomporowski, 2003), mood (Terry, 2004; Yeung, 1996) and also appetite (Pomerleau et al., 2004). It should also be considered that conclusions drawn from a convenience sample such as used in the current study are somewhat limited; they do, however, provide information from which future hypotheses can be developed.

The results from this survey show that although non-regular breakfast consumers are not as likely to report that this practice has adverse effects on their mood, cognition and appetite as those who regularly consume breakfast, they are less likely to agree that exercise improves their concentration. Future research could assess whether or not regular or acute breakfast consumption can enhance the positive effects of exercise, particularly exercise undertaken in the morning. Moreover, as lack of time and avoiding discomfort during exercise were the main reasons cited for exercising in a fasted state, consideration should be given to the most appropriate type and size of breakfast to recommend for this population to consume pre-exercise. To conclude, regular breakfast consumption may enhance the effect of exercise on concentration, but further studies are required.

Chapter 4: The effect of the dietary and exercise practices of female habitual morning exercisers on cognition, mood and appetite on days of exercise and days of rest

4.1 Introduction

Habitually active females tend to exercise for weight loss/control (Silliman et al., 2004), mood benefits or simply for enjoyment (see Chapter 3). Beneficial pre-exercise nutritional practices for those who exercise for reasons such as these, rather than to improve physical performance have not been well established. It appears that the majority of active females do not choose to fast before undertaking exercise in the morning, but those that do follow this practice cite a lack of time or to avoid discomfort during exercise as reasons for doing so (see Chapter 3). Skipping breakfast prior to morning exercise conflicts with evidence which supports the importance of breakfast consumption for health (Barton et al., 2005; Pereira et al., 2011; Smith, 1998). Everyday breakfast consumption is associated with mood enhancement (Kral et al., 2012) and lower levels of stress and poor mental health (Smith, 1998; Smith et al., 1999). Regular breakfast consumption can also help to regulate appetite (Pereira et al., 2011; Schlundt et al., 1992), EI (Farshchi et al., 2005) and BMI (Barton et al., 2005). Women have previously reported that an exercise class undertaken in the morning required more effort than at other times of the day (Maraki et al., 2005) and less frequent breakfast consumption in adolescent girls is associated with lower morning physical activity levels (Corder et al., 2011), findings which emphasize the potential need for adequate nutritional intake before morning exercise in these populations.

Previous studies have looked at the effect of pre-exercise nutrition on cognitive performance (Hill et al., 2011; Paul et al., 1996; Vermorel et al., 2003) and appetite (Gonzalez et al., 2013; Paul et al., 1996) during and immediately after exercise. Eating breakfast before a morning physical education lesson has been found to benefit children's cognitive performance before lunch (Vermorel et al., 2003). In active adult males, breakfast consumption, compared to omission, prior to exercise followed by a post-exercise chocolate drink reduced mental fatigue and decreased subjective appetite post-exercise (see Chapter 2 and Gonzalez et al., 2013). Conversely, other studies have shown no effect of breakfast consumption prior to exercise on cognitive performance or mood (Hill et al., 2011; Paul et al., 1996).

To date, no studies have assessed the effect of breakfast prior to exercise on these parameters in a recreationally active female population. It has been suggested that women are more sensitive to changes in mood and appetite than men (Hagobian et al., 2009; Spring et al., 1982), and therefore may be more susceptible to any negative effects of omitting breakfast, particularly prior to exercise. To assess the suitability of testing this hypothesis in a randomized controlled trial, the current study preliminarily investigated whether consuming breakfast prior to morning exercise affects cognitive performance, mood, appetite and EI for the remainder of the day in a field setting. To address the previously highlighted issues of lack of time to eat or not eating breakfast to avoid discomfort during exercise (see Chapter 3), this study focussed on identifying whether breakfast affects these parameters in a dose response manner. In addition, in Chapter 3, we reported that the majority of the habitually active female sample we surveyed agreed that exercise improved their mood and made them feel more alert and less tired. Nearly half of the sample also agreed that they felt that their appetite increased after exercise, suggesting that their mood and dietary behaviours may differ on days of exercise and days of rest; the current study also aimed to assess possible variances in these parameters between these two conditions.

4.2 Methods

4.2.1 Screening and training

Ethical approval for the study protocol was granted by the Ethics Committee of the Faculty of Health and Life Sciences at Northumbria University. Prior to participation, volunteers gave written informed consent. All participants confirmed that they met the general inclusion criteria specified in section 2.2.1.1. Specific criteria for inclusion in this study were that participants were female and habitually active, which was defined as exercising for at least 30 min, 3 times per week. The period of habitual physical activity specified in Chapter 2 was reconsidered and changed to 6 months for this study to increase the number of participants eligible to take part in the study and to reflect that used in a previous study investigating a female population (Stein et al., 2003). Participants also confirmed that they exercised in the morning at least once per week. Participants completed a screening session (as previously reported in section 2.2.1) and anthropometric and blood pressure measures were taken (section 2.2.1.3). This session also comprised the collection of demographic information and training and familiarisation with the mobile phone cognitive tasks (detailed in section 4.2.2) and experimental procedures. Participants were also fully briefed on how to correctly complete a food diary (as detailed in 2.2.4) and were provided with a set of electronic kitchen scales for the duration of the study where necessary.

4.2.2 Cognitive tasks and mood and appetite VAS: Mobile Phone

Cognition, mood and appetite assessment were undertaken via a Java™-enabled mobile telephone (Nokia 6300, Keilalahdentie, Finland) using software designed by Brian Tiplady (http://www.penscreen.com). This is a sensitive method of administering cognitive tasks and mood VAS, which has been previously tested in a free-living situation (Thomson, Nimmo, Tiplady & Glen, 2009; Tiplady, Oshinowo, Thomson & Drummond, 2009). All VAS scales were scored as percentage along the line towards ‘extremely’. The set of tasks took approximately 10 min to complete. During the training sessions, participants completed the set of cognitive tasks 3 times to decrease the chance of learning effects during main trials.

With the exception of the SRT task, which may have been too easy to be sensitive to the interventions, and the Stroop task, which is not available for use on the mobile phone, similar tasks were chosen as in Chapter 2. This was for continuity throughout this thesis and also because a different population, assessed in a different setting, was used in the current study.

4.2.2.3 Cognitive Tasks

Arrow Reaction Time (ART; ~90 sec)

An arrow pointing left or right appeared in the centre of the mobile phone screen at irregular intervals (between 1 and 2.5 sec). The participant was instructed to press a key to identify the direction of the arrow (4 for “LEFT”, 6 for “RIGHT”), responding as quickly and as accurately as possible. The task was scored for overall RT and accuracy.

NBack (~2 min)

A series of single letters appeared on the screen, presented one at a time. Participants were instructed to press a key to identify if the letter that appeared was presented 2 letters previously in the series (4 for "YES", 6 for "NO"), responding as quickly and accurately as possible to every letter presented. The task was scored for RT and accuracy, both overall and to correct and incorrect and target and non-target responses separately.

Rapid visual information processing task (RVIP; 5 min)

A series of single digit numbers between 1 and 9 appeared on the screen continuously at a rate of 100 per min-1 for 5 min. Participants were required to use the index finger of their dominant hand to press the 4 button on the keypad, reacting as quickly and accurately as possible, when they identified three odd or even digits presented in succession. Eight correct target strings were presented each minute. The task was scored for percentage of target strings correctly detected, average RT for correct detections and number of false alarms (incorrect responses).

Mental Fatigue and Task Difficulty VAS

Two single VAS measuring mental fatigue and task difficulty were completed at the end of each battery of tasks. Each scale was labelled "not at all" (left end of scale) and "extremely" (right end of scale).

4.2.2.4 MPS VAS and Appetite VAS

VAS, as described in sections 2.2.2.2 and 2.2.2.3, were used to assess mood and physical state and appetite on the mobile phone. Participants were asked to move a cross left or right, using the 4 or 6 buttons on the keypad, on a 25 mm line on the mobile phone screen to grade their current subjective status for each state. A paper version of these VAS (using 100 mm lines) was also used to assess these factors immediately following exercise.

4.2.3 Pre-testing guidelines

Pre-testing guidelines were followed as described in section 2.2.4.

4.2.4 Participants

Forty five, healthy, active females completed the study. Their mean ± SD age, height, body mass (BM), BMI and TFEQ restraint score were 21.4 ± 3.3 y, 168.6 ± 0.07 cm, 62.4 ± 7.8 kg, 21.8 ± 2.8 kg/m^2 and 9.1 ± 4.9 respectively. Fourteen participants were restrained eaters, scoring >11 on the TFEQ.

4.2.5 Experimental protocol

Each participant completed two study days, exercise and rest, in a randomised, cross-over design. The first trial was undertaken between 48 h and 14 days of the initial screening visit. Study days were separated by ≥ 48 hours and took place away from the laboratory in the participants own environment. On each study day participants completed the mobile phone cognitive tasks upon waking (baseline), at 1130 h, 1500 h and 2000 h. Participants were asked to find a quiet place to complete the tasks. On the exercise study day, they would also undertake a morning exercise session (between the hours of 0600 and 1100) which was of typical mode and intensity for them. Details of this exercise session (time, type, duration, intensity) were recorded in a log immediately after (Appendix E). At this time point they were also asked to complete the paper and pencil MPS, appetite and exercise intensity VAS. On the rest study day, participants were asked to not participate in any structured, strenuous activity. From breakfast the day proceeding until breakfast the day after each study day, participants were required to keep a record of their food intake and physical activity (see Appendix C). Food diaries were analysed using Microdiet (Downlee Systems Ltd, UK).

4.2.6 Statistical Analysis

A power calculation carried out a priori indicated that a total sample size of 42 would provide statistical power to detect large effects (0.5 for Pearson's *r* and 0.6 for one-way ANOVA; in accordance with Cohen, 1988) above 95% with an alpha level of .05 (G*Power; Faul, Erdfelder, Lang, & Buchner, 2007).

Scores for each individual task (Appetite VAS, Mood and Physical State VAS (MPS VAS), ART, NBack, RVIP, mental fatigue VAS and task difficulty VAS) were analysed as CFB using SPSS 19 (SPSS, Inc., Chicago, IL, USA). Given the field nature of the data collection, it was deemed appropriate to average scores across the 3 post-exercise/rest time points to give overall exercise day and rest day score for each variable rather than analysing these data at individual time-points. A paired samples *t*-test was used to assess differences in these scores between the exercise and rest study days. Partial correlations were conducted to assess the effect of the size of breakfast consumed prior to exercise on post-exercise scores. Ratings for exercise intensity (mm) were multiplied by exercise duration (min) to give each individual an overall exercise workload score which was controlled for in the partial correlation analysis of the exercise day data. An alpha level of .05 was used for all statistical tests.

4.3 Results

The average waking time on exercise days was 0755 h (range: 0615-9.45 h) and on rest days was 0825 h (range: 0700-1100 h). The average time to start exercising was 0900 h (range: 0645-1015 h) and the average exercise session duration was 62 ± 22 min (range: 25-135 min). The average exercise workload score was 443 ± 220. The average pre-exercise breakfast size was 234 ± 152 kcal (range: 18-743 kcal). Significant results or strong trends are reported below.

4.3.1 Exercise vs. Rest Analysis (Table 4.1)

Forty two participants were included in the exercise vs. rest day analysis. Three were excluded due to non-compliance to the study protocol. There were no significant differences between exercise and rest day mean baseline scores for any of the outcome measures. No significant effects for the cognitive tasks, Appetite VAS or overall EI outcome variables were found between the rest and exercise study days. In keeping with the purpose of this study, significant correlations between appetite measures and between cognitive task outcomes or between mood measures will be highlighted in Table 4.2, but not discussed.

Table 4.1 Mean change scores for mood and physical state VAS, cognitive task performance, appetite VAS and energy intake on days of exercise or rest in habitually active women (N=42)

Measure	Exercise	Rest	t	*p*
Mood and Physical State VAS(%)				
Tension	-5.6 ± 3.1	-9.9 ± 3.2	-0.987	.330
Fatigue	-6.1 ± 3.0	-2.7 ± 2.6	1.057	.297
Relaxed	3.1 ± 3.0	3.6 ± 2.5	0.115	.909
Tired	-7.1 ± 3.3	-10.1 ± 3.5	-0.693	.492
Jittery	-8.3 ± 3.2	-11.0 ± 3.4	-0.746	.460
Thirsty	19.7 ± 3.3	21.0 ± 3.9	0.28	.781
Headache	-9.4 ± 3.0	-17.6 ± 3.1	-1.999	.052
Alert	-1.7 ± 2.3	-1.5 ± 2.4	0.083	.934
Mood	11.3 ± 2.4	18.4 ± 3.3	1.94	.059
Cognitive Tasks				
ART (ms)	-37.1 ± 12.3	-18.9 ± 7.6	1.115	.271
ART Correct (%)	-38.1 ± 12.0	-22.2 ± 7.4	0.973	.360
ART Errors	3.4 ± 4.4	5.4 ± 3.3	0.361	.720
NBack Correct Target	-0.9 ± 0.6	-0.2 ± 0.6	1.206	.350
NBack Correct Target RT (ms)	-130.1 ± 46.4	-129.5 ± 32.2	0.013	.990
NBack Incorrect Target	1.3 ± 0.5	0.5 ± 0.6	-1.339	.188
NBack Correct Non-target	0.5 ± 1.1	1.8 ± 0.7	1.356	.183
NBack Correct Non-target RT (ms)	-172.7 ± 48.0	-158.6 ± 31.3	0.304	.762
NBack Incorrect Non-target	0.2 ± 0.5	-0.3 ± 0.3	-1.178	.246
NBack Correct (%)	-1.4 ± 0.7	-0.1 ± 0.7	1.687	.099
NBack Average RT (ms)	-144.0 ± 27.5	-96.9 ± 27.2	1.388	.173
RVIP Correct (%)	1.4 ± 0.8	2.8 ± 0.6	1.479	.147
RVIP Average Correct RT (ms)	-22.8 ± 6.5	-34.5 ± 7.4	-1.267	.212
RVIP Errors	-0.1 ± 0.7	0.3 ± 0.5	0.543	.590
Mental Fatigue (%)	-1.1 ± 2.6	0.3 ± 2.9	0.397	.693
Difficulty (%)	-0.8 ± 1.2	-2.8 ± 2.9	-0.678	.502
Appetite VAS(%)				
Hunger	-10.7 ± 3.0	-12.0 ± 3.4	-0.309	.759
Desire to eat	3.1 ± 3.0	3.6 ± 2.5	0.115	.909
Fullness	-6.3 ± 3.0	-2.1 ± 2.9	1.384	.740
Satisfaction	16.5 ± 2.8	16.0 ± 3.4	-0.171	.650
Energy Intake (kcal)	1626.9 ± 92.2	1621.3 ± 97.6	-0.062	.951

Mean values ± SEM are presented

MPS VAS

Trends towards participants reporting a smaller reduction of headache on the exercise day compared to rest day (p = .052) but better mood on the rest day compared to exercise day (p = .059) were identified.

4.3.2 Breakfast Prior to Exercise Analysis

There were no significant correlations between pre-exercise EI and any of the exercise day baseline scores. There were no significant correlations between any of the post-exercise cognitive task outcomes or the appetite VAS scores and the amount of breakfast consumed prior to exercise (all p >.05).

MPS VAS

Mental fatigue

EI intake at breakfast prior to exercise was significantly related to post-exercise mental fatigue ($r(43) = .307$; $p = .043$). A higher EI was associated with lower mental fatigue (Figure. 4.1).

Alert

EI at breakfast prior to exercise was significantly related to post-exercise alertness ($r(43) = .315$; $p = .037$). A higher EI was associated with higher alertness (Figure 4.1).

Mood

EI at breakfast prior to exercise was significantly related to overall mood post-exercise ($r(43) = .372$; $p = .013$). A higher EI was associated with better overall mood (Figure 4.1).

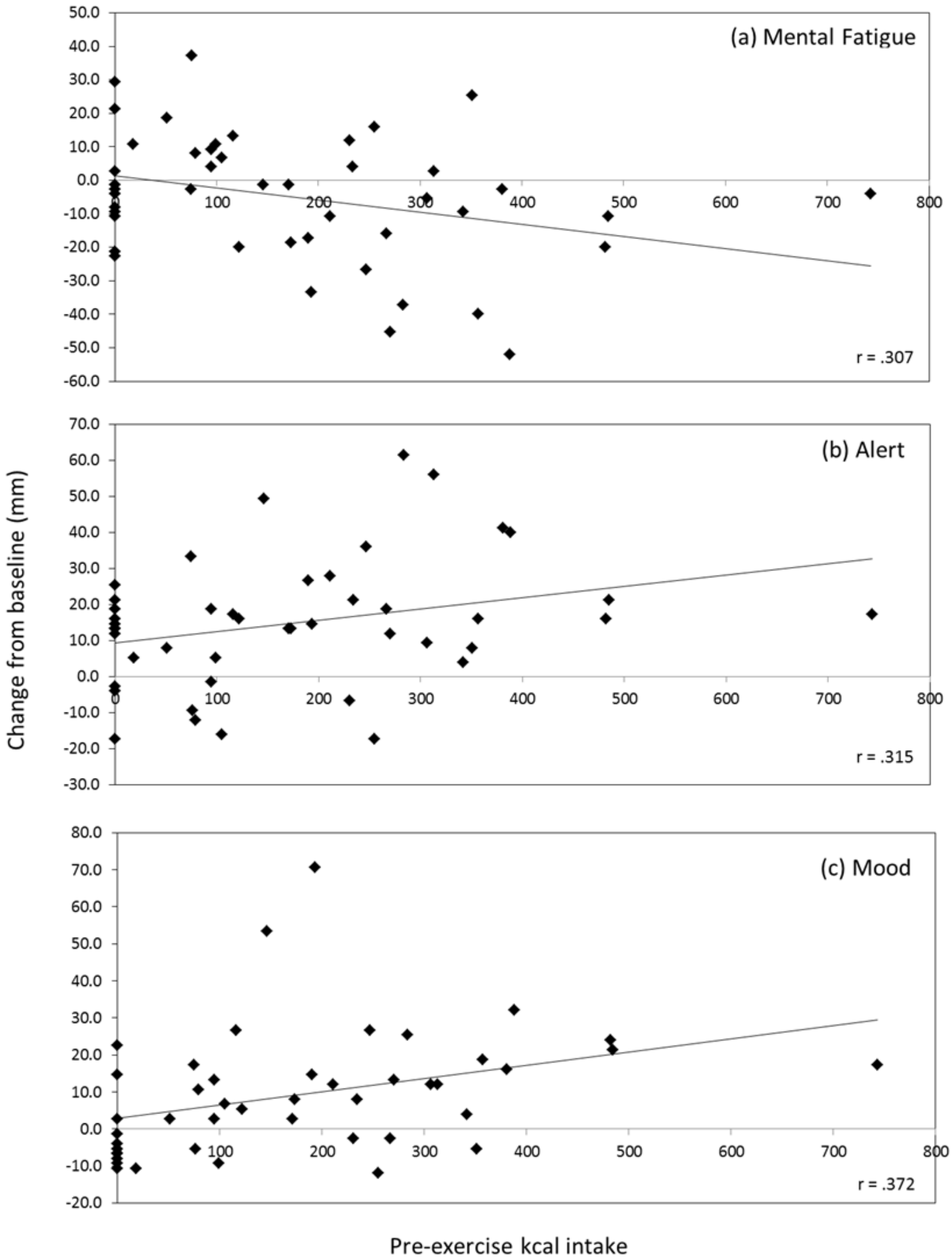

Figure 4.1 The effects of breakfast size (kcal) prior to morning exercise on (a) mental fatigue, (b) alertness and (c) mood, in habitually active females (N=45). Values are CFB.

Tired

There was also a trend towards less tiredness when EI (kcal) was higher before exercise ($r(43) = .270$; $p = .076$).

Thirsty

EI at breakfast prior to exercise was significantly related to thirstiness. A higher EI was associated with lower thirstiness ($r(43) = -.333$; $p = .027$).

Energy intake

Pre or post-exercise EI did not correlate significantly with TFEQ restraint scores. EI at breakfast prior to exercise was significantly related to post-exercise EI ($r(43) = .421$; $p = .004$). A higher breakfast EI was associated with a higher post-exercise EI (Figure. 4.2).

EI, mood and cognition

Post-exercise EI was associated with lower fatigue ($r(43) = 0.378$; $p = .011$) and jitteriness ($r(43) = .306$; $p = .04$,), higher feelings of relaxation ($r(43) = .325$; $p = .032$) and alertness ($r(43) = .307$; $p = .043$) and less headache ($r(43) = .326$; $p = .031$), with a trend towards better mood also ($r(43) = .253$; $p = .098$). RVIP RT ($r(43) = .327$; $p = .03$) and overall ART ($r(43) = .352$; $p = .019$) were significantly slower (with a trend towards slower NBack correct target RT also; $r(43) = .295$; $p = .052$) when post-exercise EI was higher. Conversely, a quicker correct ART was associated with higher post-exercise EI ($r(43) = .347$; $p = .021$).

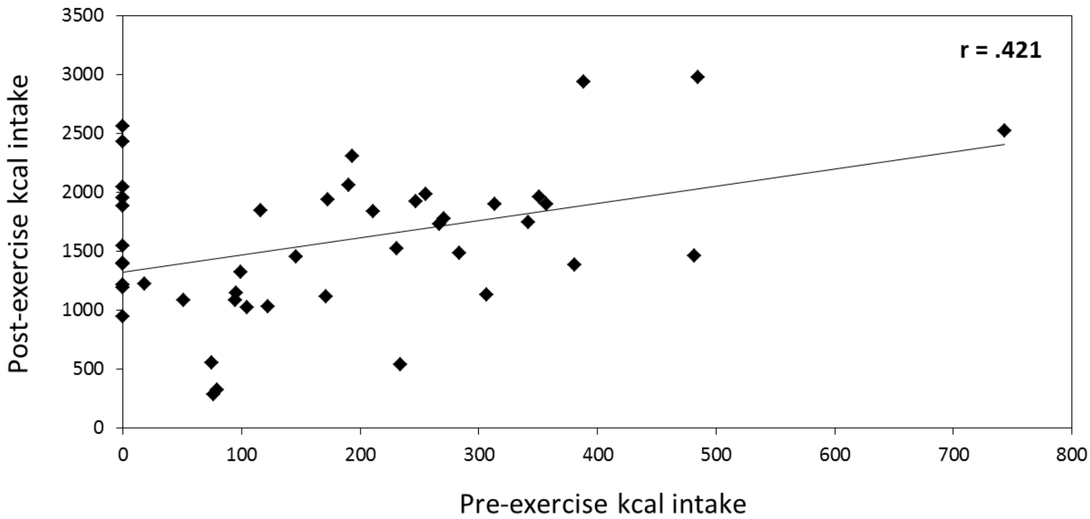

Figure 4.2 The effects of breakfast size (kcal) prior to morning exercise on energy intake post-exercise, in habitually active females (N=42)

Post-exercise subjective appetite, mood and cognition

Higher hunger was associated with having more of a headache ($r(43) = .313$; $p = .038$) and feeling less alert ($r(43) = .313$; $p = .038$). Fullness also positively correlated with relaxation ($r(43) = .357$; $p = .017$), alertness ($r(43) = .432$; $p = .003$) and mood ($r(43) = .341$; $p = .023$), with a trend towards less headache ($r(43) = .252$; $p = .099$). In addition, there were trends towards associations between higher hunger and quicker overall ($r(43) = .264$; $p = .083$) and correct ($r(43) = .269$; $p = .077$) ART. There was a trend towards higher feelings of fullness correlating with a higher percentage of correct answers on the NBack task also ($r(43) = .270$; $p = .076$). A higher desire to eat ($r(43) = .370$; $p = .013$), higher hunger [$r(43) = .0290$; $p = .057$, (trend only)] and lower feelings of satisfaction [$r(43) = .264$; $p = .070$ (trend only)] positively correlated with task difficultly ratings. A higher rating of thirstiness was also associated with lower alertness ($r(43) = -.342$; $p = .023$).

Post-exercise mood and cognition

Higher alertness was associated with significantly more correct target responses on the NBack task ($r(43) = 351$; $p = .020$), with trends towards less incorrect NBack target responses ($r(43) = .285$; $p = .061$), quicker RT for correct non-target responses ($r(43) = .278$; $p = 068$,) and lower overall NBack RT ($r(43) = .277$; $p = .069$). A higher mood was also significantly associated with higher accuracy (% correct) on the NBack task ($r(43) = .311$; $p = .040$). Higher fatigue and ratings of tiredness (trend only) were associated with a lower percentage correct on the NBack task ($r(43) = 331$; $p = .028$ and $r(43) = .288$; $p = .058$ respectively), with the former also associated with more NBack incorrect non-target responses ($r(43) = .310$; $p = .040$). However, higher relaxation was also significantly associated with slower NBack correct non-target RT responses ($r(43) = .321$; $p = .033$), with a trend towards fewer correct non target responses ($r(43) = .285$; $p = .061$) and a slower overall RT ($r(43) = .290$; $p = .057$) in this task also. Higher tension and jitteriness were significantly associated with more ART errors ($r(43) = .364$; $p = .015$), with higher jitteriness associated with higher RVIP errors also ($r(43) = .313$; $p = .039$). An increase in task difficulty ratings was associated with fewer NBack correct target responses ($r(43) = -.320$; $p = .034$) and RVIP correct responses ($r(43) = -.327$; $p = .030$) and a higher RVIP average correct RT ($r(43) = .332$; $p = .028$).

Table 4.2

Correlations between variables (energy intake, mood and appetite VAS and cognitive function) post-exercise in an habitually active female sample (N=45; *p<.05)

Measure		1	2	3	4	5	6	7	8
1. Pre-exercise energy intake	r	1.000							
	p	.							
2. Energy Intake	r	0.421	1.000						
	p	0.004 *	.						
3. Tension	r	-0.059	-0.186	1.000					
	p	0.703	0.226	.					
4. Hunger	r	-0.153	-0.152	0.033	1.000				
	p	0.321	0.324	0.830	.				
5. Fatigued	r	-0.307	-0.378	0.466	-0.003	1.000			
	p	0.043 *	0.011 *	0.001 *	0.982	.			
6. Relaxed	r	0.152	0.325	-0.362	-0.086	-0.253	1.000		
	p	0.323	0.032 *	0.016 *	0.579	0.097	.		
7. Eat	r	0.078	0.103	-0.205	0.694	-0.124	0.088	1.000	
	p	0.614	0.505	0.182	0.000 *	0.422	0.571	.	
8. Tired	r	-0.270	-0.119	0.333	0.053	0.550	0.064	-0.108	1.000
	p	0.076	0.440	0.027 *	0.733	0.000 *	0.679	0.485	.
9. Jittery	r	0.017	-0.306	0.481	0.003	0.460	-0.253	0.043	0.080
	p	0.914	0.043 *	0.001 *	0.985	0.002 *	0.097	0.781	0.604
10. Full	r	0.101	0.272	-0.161	-0.649	-0.043	0.357	-0.624	-0.055
	p	0.514	0.074	0.295	0.000 *	0.782	0.017 *	0.000 *	0.722
11. Thirsty	r	-0.333	-0.200	0.135	0.324	0.209	0.133	0.083	0.297
	p	0.027 *	0.193	0.384	0.032 *	0.173	0.388	0.591	0.050
12. Headache	r	-0.136	-0.326	0.210	0.313	0.184	-0.200	0.023	-0.082
	p	0.380	0.031 *	0.172	0.038 *	0.231	0.193	0.884	0.598
13. Alert	r	0.315	0.307	-0.197	-0.313	-0.395	0.201	-0.132	-0.630
	p	0.037 *	0.043 *	0.199	0.038 *	0.008 *	0.191	0.391	0.000
14. Satisfied	r	-0.102	0.113	-0.067	-0.619	0.054	0.199	-0.746	0.032
	p	0.511	0.466	0.664	0.000 *	0.729	0.195	0.000 *	0.836
15. Overall mood	r	0.372	0.253	-0.458	-0.167	-0.513	0.590	-0.039	-0.384
	p	0.013 *	0.098	0.002 *	0.277	0.000 *	0.000 *	0.802	0.010
16. ART	r	0.048	0.352	-0.052	-0.264	-0.110	-0.096	-0.037	-0.149
	p	0.756	0.019 *	0.739	0.083	0.477	0.536	0.814	0.335
17. ART Correct	r	0.000	0.347	-0.143	-0.269	-0.138	-0.071	-0.051	-0.145
	p	0.998	0.021 *	0.353	0.077	0.373	0.645	0.744	0.348
18. ART Errors	r	0.207	0.071	0.364	0.052	0.040	-0.085	0.026	-0.054
	p	0.178	0.647	0.015 *	0.738	0.796	0.581	0.864	0.730
19. NBack Correct Target	r	0.089	-0.011	0.021	-0.106	-0.011	-0.077	-0.096	-0.197
	p	0.563	0.942	0.892	0.495	0.941	0.619	0.533	0.199
20. NBack Correct Target RT	r	0.091	0.295	0.022	0.045	-0.020	0.210	-0.070	0.173
	p	0.557	0.052	0.890	0.772	0.896	0.171	0.652	0.263
21. NBack Incorrect Target	r	-0.177	-0.074	0.001	0.011	0.223	-0.091	0.027	0.214
	p	0.251	0.635	0.993	0.946	0.145	0.557	0.861	0.164
22. NBack Correct Non-target	r	-0.052	-0.204	0.019	-0.187	0.060	-0.285	-0.062	-0.145
	p	0.737	0.184	0.903	0.224	0.700	0.061	0.689	0.348
23. NBack Correct Non-target RT	r	0.123	0.146	-0.037	-0.028	-0.191	0.321	-0.105	0.056
	p	0.425	0.344	0.810	0.859	0.214	0.033 *	0.499	0.717
24. NBack Incorrect Non-target	r	-0.168	-0.082	0.098	0.138	0.310	-0.110	0.072	0.210
	p	0.277	0.597	0.528	0.372	0.040 *	0.477	0.642	0.171
25. NBack Correct	r	0.222	0.075	-0.059	-0.108	-0.331	0.094	-0.064	-0.288
	p	0.148	0.628	0.702	0.487	0.028 *	0.544	0.679	0.058
26. NBack Average RT	r	0.116	0.237	-0.009	0.009	-0.116	0.288	-0.095	0.123
	p	0.453	0.121	0.954	0.955	0.454	0.058	0.541	0.428
27. RVIP Correct	r	-0.001	0.038	0.203	0.003	0.015	-0.098	-0.070	0.029
	p	0.995	0.806	0.187	0.985	0.923	0.528	0.649	0.854
28. RVIP Average Correct RT	r	0.057	0.327	-0.020	0.031	-0.128	0.216	0.149	0.105
	p	0.713	0.030 *	0.900	0.843	0.408	0.159	0.333	0.496
29. RVIP Errors	r	0.072	0.016	0.125	0.075	0.218	-0.097	0.011	0.105
	p	0.642	0.920	0.419	0.628	0.156	0.532	0.944	0.496
30. MenFatE	r	-0.134	-0.102	0.086	0.044	0.156	-0.313	0.080	0.052
	p	0.386	0.508	0.577	0.778	0.311	0.039 *	0.606	0.739
31. DifficultyE	r	0.051	0.176	-0.113	0.290	-0.105	0.021	0.370	0.046
	p	0.744	0.252	0.464	0.057	0.497	0.891	0.013 *	0.765

Table 4.2 continued

Measure		9	10	11	12	13	14	15	16
9. Jittery	r	1.000							
	p	.							
10. Full	r	-0.220	1.000						
	p	0.151	.						
11. Thirsty	r	-0.126	-0.153	1.000					
	p	0.417	0.321	.					
12. Headache	r	0.222	-0.252	0.239	1.000				
	p	0.148	0.099	0.117	.				
13. Alert	r	-0.020	0.432	-0.342	-0.076	1.000			
	p	0.899	0.003 *	0.023 *	0.623	.			
14. Satisfied	r	-0.245	0.809	-0.072	-0.106	0.256	1.000		
	p	0.110	0.000 *	0.640	0.493	0.094	.		
15. Overall mood	r	-0.315	0.341	-0.153	-0.144	0.506	0.180	1.000	
	p	0.037 *	0.023 *	0.321	0.352	0.000 *	0.242	.	
16. ART	r	0.010	0.215	-0.277	-0.213	0.068	0.091	-0.201	1.000
	p	0.950	0.160	0.068	0.165	0.663	0.559	0.190	.
17. ART Correct	r	-0.105	0.205	-0.257	-0.236	0.058	0.106	-0.198	0.966
	p	0.496	0.183	0.092	0.123	0.707	0.492	0.198	0.000
18. ART Errors	r	0.443	0.033	-0.080	0.073	0.121	-0.067	0.000	0.169
	p	0.003 *	0.832	0.605	0.637	0.433	0.665	0.999	0.274
19. NBack Correct	r	-0.139	0.217	-0.015	0.019	0.351	0.064	0.192	0.057
Target	*p*	0.366	0.156	0.921	0.900	0.020 *	0.679	0.213	0.714
20. NBack Correct	r	-0.197	0.121	-0.027	-0.012	-0.234	0.178	-0.128	0.336
Target RT	*p*	0.199	0.433	0.862	0.937	0.127	0.248	0.409	0.026
21. NBack Incorrect	r	0.278	-0.194	0.054	0.115	-0.285	-0.030	-0.217	-0.049
Target	*p*	0.068	0.206	0.728	0.457	0.061	0.848	0.158	0.753
22. NBack Correct	r	0.085	0.124	-0.064	-0.009	0.205	-0.010	0.006	0.023
Non-target	*p*	0.583	0.422	0.680	0.954	0.182	0.948	0.967	0.883
23. NBack Correct	r	-0.156	0.137	-0.059	-0.097	-0.278	0.216	0.116	0.068
Non-target RT	*p*	0.311	0.376	0.702	0.529	0.068	0.160	0.452	0.659
24. NBack Incorrect	r	0.124	-0.226	0.279	0.046	-0.056	-0.181	-0.265	-0.062
Non-target	*p*	0.423	0.141	0.067	0.765	0.717	0.240	0.082	0.689
25. NBack Correct	r	-0.248	0.270	-0.215	-0.097	0.249	0.119	0.311	0.074
	p	0.105	0.076	0.162	0.533	0.104	0.440	0.040 *	0.631
26. NBack Average	r	-0.191	0.140	-0.047	-0.060	-0.277	0.213	-0.004	0.216
RT	*p*	0.215	0.366	0.762	0.699	0.069	0.165	0.979	0.159
27. RVIP Correct	r	-0.082	0.057	0.245	0.119	0.057	0.096	-0.086	-0.155
	p	0.596	0.714	0.109	0.440	0.715	0.534	0.577	0.314
28. RVIP Average	r	0.067	0.028	-0.140	-0.050	-0.117	-0.100	-0.038	0.384
Correct RT	*p*	0.667	0.855	0.366	0.748	0.448	0.517	0.806	0.010
29. RVIP Errors	r	0.313	-0.152	0.103	0.157	-0.129	-0.146	-0.069	0.129
	p	0.039 *	0.325	0.505	0.309	0.404	0.346	0.654	0.405
30. MenFatE	r	0.188	-0.234	-0.070	-0.122	-0.221	-0.143	-0.306	-0.089
	p	0.222	0.126	0.653	0.432	0.149	0.353	0.043 *	0.566
31. DifficultyE	r	0.038	-0.236	0.066	-0.202	-0.288	-0.275	-0.172	0.087
	p	0.805	0.123	0.672	0.189	0.058	0.070	0.264	0.573

Table 4.2 continued

Measure		17	18	19	20	21	22	23	24
17. ART Correct	r	1.000							
	p	.							
18. ART Errors	r	-0.081	1.000						
	p	0.603	.						
19. NBack Correct Target	r	0.071	0.012	1.000					
	p	0.648	0.939	.					
20. NBack Correct Target RT	r	0.327	0.004	-0.223	1.000				
	p	0.030 *	0.979	0.145	.				
21. NBack Incorrect Target	r	-0.073	0.014	-0.779	-0.109	1.000			
	p	0.638	0.928	0.000 *	0.482	.			
22. NBack Correct Non-target	r	-0.006	0.100	0.549	-0.616	-0.156	1.000		
	p	0.971	0.520	0.000 *	0.000 *	0.311	.		
23. NBack Correct Non-target RT	r	0.073	-0.077	-0.326	0.712	-0.079	-0.572	1.000	
	p	0.636	0.618	0.031 *	0.000 *	0.609	0.000 *	.	
24. NBack Incorrect Non-target	r	-0.019	-0.142	-0.003	-0.111	0.169	-0.206	-0.430	1.000
	p	0.901	0.359	0.982	0.474	0.274	0.181	0.004 *	.
25. NBack Correct	r	0.062	0.087	0.585	0.070	-0.784	0.336	0.246	-0.734
	p	0.691	0.573	0.000 *	0.650	0.000 *	0.026 *	0.107	0.000
26. NBack Average RT	r	0.214	-0.040	-0.298	0.923	-0.101	-0.642	0.928	-0.295
	p	0.163	0.795	0.050	0.000 *	0.513	0.000 *	0.000 *	0.052
27. RVIP Correct	r	-0.113	-0.109	0.256	-0.005	-0.111	0.000	0.006	0.174
	p	0.465	0.480	0.094	0.975	0.472	1.000	0.968	0.258
28. RVIP Average Correct RT	r	0.362	0.054	0.067	0.303	-0.049	-0.188	0.271	-0.071
	p	0.016 *	0.729	0.664	0.045 *	0.754	0.222	0.075	0.649
29. RVIP Errors	r	0.097	0.132	0.119	-0.117	0.113	0.016	-0.320	0.226
	p	0.532	0.393	0.444	0.451	0.465	0.917	0.034 *	0.141
30. MenFatE	r	-0.048	-0.199	-0.170	-0.189	0.189	-0.010	-0.103	0.184
	p	0.755	0.196	0.271	0.219	0.218	0.947	0.504	0.232
31. DifficultyE	r	0.107	-0.072	-0.320	-0.033	0.233	-0.158	0.052	0.002
	p	0.490	0.642	0.034 *	0.833	0.127	0.306	0.739	0.991

Table 4.2 continued

Measure		25	26	27	28	29	30	31
25. NBack Correct	r	1.000						
	p *	.						
26. NBack Average RT	r	0.173	1.000					
	p	0.263	.					
27. RVIP Correct	r	-0.030	0.001	1.000				
	p	0.847	0.996	.				
28. RVIP Average Correct RT	r	0.059	0.310	-0.079	1.000			
	p	0.703	0.040 *	0.611	.			
29. RVIP Errors	r	-0.201	-0.238	-0.148	0.316	1.000		
	p	0.192	0.120	0.337	0.037 *	.		
30. MenFatE	r	-0.245	-0.157	-0.214	0.050	0.101	1.000	
	p	0.109	0.308	0.163	0.747	0.513	.	
31. DifficultyE	r	-0.182	0.011	-0.327	0.332	0.138	0.573	1.000
	p	0.236	0.944	0.030 *	0.028 *	0.372	0.000 *	.

Abbreviations: RT, reaction time; ART, arrow reaction time; RVIP, rapid visual information processing task; MenFatE, mental fatigue post-exercise; DifficultyE, task difficulty post-exercise

4.4 Discussion

This study investigated the effect of dietary and exercise practices on cognition, mood and appetite on days of exercise and days of rest in healthy, habitually active females. The results suggest that breakfast size prior to exercise is associated with some aspects of mood and physical state and EI post-exercise, but that cognitive performance, mood, appetite and EI do not differ significantly on days of exercise and rest. They also infer that relationships between mood, cognitive performance and subjective appetite exist post-exercise in this population. The average EI at breakfast of 234 kcal was not dissimilar to that reported in a previous study of 80 young adult females (251 kcal; Benton & Parker, 1998).

An increase in pre-exercise EI was associated with lower mental fatigue, increased alertness and better overall mood. Although it is not possible to infer causal effects in these relationships, the result for fatigue is in agreement with data from previous studies (Paul et al., 1996 and see Chapter 2). In Chapter 2, mental fatigue was reduced in males when breakfast was consumed, compared to omitted, prior to exercise, although overall mood and alertness were unaffected. It is possible that the use of non-regular breakfast consumers in the study discussed in Chapter 2 confounded the effects of breakfast on mood somewhat. In the current study, each participant consumed their usual breakfast and followed their normal diet and exercise routine, possibly eradicating any poor effects on mood due to a forced change in habits. It is of course plausible that these results reflect gender differences; males may be less sensitive to changes in mood than females (Spring et al., 1982); however, Paul et al. (1996) also failed to find changes in mood when breakfast was omitted prior to cycling in a mixed gender sample. The current study did not find any effects of breakfast prior to exercise on post-exercise cognitive function. It is easy to speculate that this is likely due to the free-living setting of the study, with participants completing tasks in an uncontrolled environment and also the capacity of the study to only detect large effects. However, the lack of cognitive effects does support previous findings from the aforementioned laboratory based studies which also failed to find a difference between pre-exercise breakfast consumption or omission, on post-exercise cognition (Paul et al., 1996 & Chapter 2). However, both of these studies did have relatively small sample sizes for cognitive assessment; further investigation of these variables under laboratory conditions in a larger, female-only sample seems appropriate.

An increase in pre-exercise breakfast energy content was associated with higher post-exercise EI. Previous research shows that breakfast consumption is beneficial for appetite control (Pereira et al., 2011; Schlundt et al., 1992) and can reduce subsequent EI (Farshchi et al., 2005). In Chapter 2, breakfast consumption compared to omission was better for subject appetite control, but did not affect EI at lunch. In the current study, there was no association with pre-exercise breakfast EI and subjective appetite, but consuming a larger breakfast prior to exercise was associated with a greater EI over the remainder of the day. Although this may cause concern with regards to weight gain, previous data does show that whilst those who consume breakfast do have a larger overall EI than those who skip breakfast, breakfast consumers have a lower BMI (Cho et al., 2003). It is of course important to consider that data on EI collected via food diaries is often not reliable (Schoeller, 1995), and that these results may simply be a reflection of under-reporting. The effect of pre-exercise breakfast size on EI was not accompanied by changes in subjective appetite. It could be that whilst the mobile phone VAS are sensitive to changes in mood (Palmblad & Tiplady, 2004), they may not be sensitive enough to detect changes in appetite, which can be very subtle. Typically, 100 mm VAS are used to assess subjective appetite via paper and pencil collection, a method thought to be valid (Hill et al., 1995; Stensel, 2010). Measuring appetite with a handheld device presenting VAS of 84 mm has been validated against paper and pencil methods (Gibbons, Caudwell, Finlayson, King & Blundell, 2011), but this was not the case when measuring appetite via a small wrist-watch device which presented VAS of just 39 mm (Rumbold, Dodd-Reynolds & Stevenson, 2013). However, in the current study even when measured immediately after exercise using a more standard 100 mm scale, no effects on subjective appetite were observed.

Mood and appetite appear to be closely linked. Previous studies have shown a positive correlation between alertness and fullness (Holt, 1999) and negative correlations between hunger and desire to eat ratings and feelings of energy, liveliness, calmness and relaxation (Fischer et al., 2004). Recently, it has been suggested that an increase in satiety is associated with a reduction in dysphoric mood (Hetherington et al., 2013). The same relationship was identified post-exercise in the current population; poorer appetite control was associated with poorer ratings on several mood state measures, and additionally on cognitive task difficulty ratings. Hoyland and colleagues (2008) previously suggested that exercise-induced mood enhancement may have a mediating relationship with appetite control and our results support this idea. However, the data from the current study should be viewed with caution given the possible insensitivity of the method used to measure appetite, as previously discussed.

Reaction time reduced in conjunction with increased subjective appetite, a similar result to that previously found by Fischer et al.(2004) and lower post-exercise EI was associated with a decrease in RVIP RT and ART, consistent with literature which suggests RT increases following a high-energy meal compared to remaining fasted (Fischer et al., 2004). It has been suggested that mood may affect cognitive performance by controlling motivation (Hoyland et al., 2008). However, it has also been suggested that changes in cognition following exercise do not correlate with mood (Hopkins et al., 2012). The current study found associations between improved mood and better ART and NBack performance. The latter is a measure of working memory; previously a more positive mood has been associated with a poorer working memory performance (Martin & Kerns, 2011), a finding which our results contradict. It does appear that mood, subjective appetite and cognitive function influence one another to some extent; improvements in mood and/or subjective appetite are likely to be especially beneficial.

In Chapter 3, the majority of the habitually active female sample we asked agreed that exercise improved their mood and made them feel more alert and less tired. Nearly half of the sample also agreed that they felt their appetite increased after exercise, suggesting that their mood and dietary behaviours may differ on days of exercise and days of rest. However, the current data does not support these observations, with no significant differences seen in any of the outcome measures between the exercise or rest study days and only strong trends towards participant's reporting a lesser headache on exercise days, but a better mood on rest days.

The limitations of conducting a field study are obvious. The lack of control over the environment in which the study is completed may indeed lead to confounding results, or the inability to detect subtle effects which may only become apparent in a more controlled environment. However, data collected in a free-living, real-life setting are useful to guide the direction of research and formulate hypotheses. It should also be noted that all but one of the participants were restrained eaters. Partial correlation analysis allows for the inclusion of one covariate only and exercise workload score was considered a more important factor to control for (given its larger variation) than eating restraint when assessing exercise day appetite scores and EI. It has been suggested that dietary restraint is not a reliable predictor of EI (Bellisle et al., 2009; Klesges et al., 1991) and that restraint scores calculated using the TFEQ are not associated with subjective appetite states (Drapeau, et al., 2005), suggesting that this factor may not have influenced these results.

In summary, these results support previous findings in a male cohort, in that breakfast prior to exercise appears beneficial for post-exercise fatigue, mood and tiredness. They also suggest that in a female population, further mood benefits may be obtained if breakfast is consumed prior to exercise, and that this effect may be dose-dependent. Testing this theory using a randomized, controlled trial in this population seems warranted.

Chapter 5: The effect of breakfast size prior to morning exercise on cognition, mood and appetite in female habitual morning exercisers

5.1 Introduction

A variety of health benefits are associated with regular exercise including physical performance, fitness enhancement and improved mood, cognition and weight control. Pre-exercise nutritional guidelines exist for individuals looking to improve their physical performance, but less is known about the effect of pre-exercise nutrition on mood, cognitive performance and appetite later in the day. Breakfast appears beneficial for short-term mood enhancement (Kral et al., 2012; Smith et al., 1999), although the cognitive benefits of this meal appear to be limited to episodic memory (as discussed in detail in section 1.2.1).

Research has shown that exercise undertaken following an overnight fast leads to augmented fat oxidation in males (Backhouse et al., 2007; Gonzalez et al., 2013), which may be preferable if weight loss is a main goal of exercise. However, breakfast is constantly advocated as part of a healthy lifestyle for overall well-being and health (Barton et al., 2005; Pereira et al., 2011; Smith, 1998) and the consequences of skipping this meal prior to inducing a further energy deficit through exercise are not currently clear. Robust breakfast research consistently highlights the importance of breakfast consumption for appetite control for the remainder of the day (Delargy et al., 1995; Hubert et al., 1998; Ruxton & Kirk, 1997). If exercising in a fasted state leads to poorer appetite control, any gains from increased EE during exercise may be lost. In Chapter 2, better appetite control was seen when breakfast was consumed prior to exercise in active males. To extend knowledge in this area further, an active female population were chosen as the population of interest for the current study.

Vermorel et al. (2003) advised that adolescents should consume a substantial breakfast on days they undertake morning physical education to avoid cognitive decline before lunch. Following a 90 min cycle, Paul et al. (1996) reported augmented mental fatigue when breakfast had been omitted beforehand, but found no effect on cognitive performance in a mixed gender sample. Similarly, results from the study conducted in Chapter 2 also showed higher mental fatigue following a treadmill run when breakfast was omitted prior to exercise in active males. However, in a recent study swimmers either consumed or omitted CHO before a morning training session, but no significant effect on post-exercise mood state was found (Hill et al., 2011). No study to date has looked at the interactive effect of breakfast consumption or omission prior to exercise on cognitive performance and mood in a habitually active female sample. In Chapter 4, a possible dose-response effect of breakfast prior to exercise was identified, with a larger breakfast leading to preferable mood states post-exercise in active females. However, in addition to increased fat oxidation, other reasons to skip breakfast before exercise are likely to be lack of time and avoiding discomfort (e.g. stitches) during exercise, as discussed in Chapter 3. Therefore, the aim of this study was to see if a small breakfast, which was quick to eat, could lead to cognitive or mood benefits over no breakfast or consuming a larger breakfast prior to a morning exercise session.

5.2 Methods

5.2.1 Initial screening

Ethical approval for the study protocol was granted by the Ethics Committee of the Faculty of Health and Life Sciences at Northumbria University. Prior to participation, written informed consent was given. Participants completed a screening session (as detailed in section 2.1.2.1) and anthropometric and blood pressure measures were taken (described in section 2.2.1.3). Screening also comprised the collection of demographic information and training and familiarisation with the computer and mobile phone cognitive tasks (described in section 4.2.2) and experimental procedures. The computer cognitive tasks consisted of those described in section 2.2.2.1 (with the exception of the SRT task which was omitted as specified in section 4.2.2**),** the MPS VAS (detailed in section 2.2.2.2) and a computerised version of the appetite VAS listed in section 2.2.2.3. The tasks were repeated 4 times during this session (three times on the computer and once on the mobile phone) to decrease the chance of learning effects on the study days. Participants were also fully briefed on how to correctly complete a food diary (previously reported in section 2.2.4) and were provided with a set of electronic kitchen scales for the duration of the study where necessary. Participants confirmed that they met the general inclusion criteria for the study (as described in section 2.2.1.1). Specific criteria for inclusion in the study were that participants were female, habitually active (exercising for at least 30 min, 3 times a week, for at least the previous 6 months as per Chapter 4 and Stein, et al., 2003), were able to run for 30 min continuously at a moderate speed, regularly exercised in the morning and usually ate breakfast prior to a morning exercise session. All participants also confirmed a liking for all of the food items provided in the study.

5.2.2 Exercise tests

At screening, participants also undertook preliminary and maximal exercise tests as indicated below.

5.2.2.1 Preliminary exercise test

A preliminary exercise test was used to establish the relationship between HR and running speed on a flat treadmill using a 16 min test. The test began at a low-moderate speed (between 7-8.5 km·h^{-1}). Every 4 min, the speed of the treadmill was increased by 1 km·h^{-1} until 16 min had elapsed. Heart rate (HR) was recorded every 5s for the final 60 sec of each stage and was then averaged for this time period.

5.2.2.2 Maximal Exercise Test

Participants were allowed 5-10 min recovery after the preliminary test (section 5.2.2.1) before undertaking a maximal exercise test to establish their maximum HR (HR max). An incremental treadmill test was utilized (Williams, Nute, Broadbank & Vinall, 1990) whereby the speed of the treadmill remained constant (typically 9-11 km·h^{-1}) but the gradient of the treadmill was increased by 1% min^{-1} to exhaustion. Verbal encouragement was given towards the latter stages of the test to ensure that subjects worked to exhaustion. A HR within 10 beats·min^{-1} of age-predicted HR max was deemed as satisfactory.

The running speed equivalent to 65% of each participant's heart rate reserve (HRR) was then determined. HRR is accepted as an accurate method of controlling exercise intensity and is calculated as HR max - resting HR. Previously, 60-70% of HRR has been used to achieve exercise of moderate intensity (Hung et al., 2013).

5.2.3 Pre-testing guidelines

Pre-testing guidelines were followed as described in section 2.2.4, with the addition of the consumption of a standardized meal the evening prior to each study day which was provided by the researcher. This meal consisted of a pack of Uncle Bens grilled Mediterranean vegetable microwave risotto (412 kcal, 78.8 g CHO, 9.6 g protein, 6 g fat) prepared with water as per the manufacturer's instructions and an Ambrosia low-fat custard pot (134kcal, 23.2 g CHO, 4.4 g protein, 2.7 g fat). Participants were required to consume this meal before 20.00 h the evening prior to each study day, and to ensure this was the last food they consumed before each of the test sessions.

5.2.4 Participants

Twenty four young, healthy, habitually active females took part in the study. Their mean ± SD age, height, BM, BMI and TFEQ restraint score were 20.9 ± 2.3 y, 170.0 ± 7.0 cm, 63.0 ± 6.4 kg, 21.9 ± 1.9 kg/m^2 and 8.1 ± 4.4 respectively. Seven participants were restrained eaters, scoring >11 on the TFEQ. Where participants were not using hormonal contraception, they were tested in the same phase of their menstrual cycle.

5.2.5 Procedure/ Experimental protocol (Fig. 5.1)

Each participant completed three trials, in a randomised, cross-over design, where they were administered one of three breakfasts: 40 g cereal + 166ml milk (234 kcal), 20 g cereal + 83 ml milk (117 kcal) or no breakfast. The first trial was undertaken between 48 h and 14 days of the initial screening visit. Trials were separated by ≥ 48 h and all trials were performed under similar laboratory conditions. Trials began at 0815 h (±15 min). After confirming compliance to the study restrictions, participants completed baseline cognitive tasks and mood and appetite VAS before being administered the test breakfast or remaining fasted. After a 45 min rest, participants completed the cognitive and mood tasks and appetite VAS again before undertaking a 30 min treadmill run (at approximately 65% HRR). Heart rate was monitored throughout the exercise period using telemetry (Polar T31 transmitter, Polar Electro Oy, HQ, Professorintie 5, FIN-90440 Kempele, Finland) and RPE (Borg, 1973) measured at 5 min intervals. Participants then completed the cognitive tasks and mood and appetite VAS immediately after, and at 1 and 2 h, post-exercise. They were then administered an *ad libitum* pasta lunch where they were asked to consume enough food to feel satisfied to a normal level. After lunch, they completed the cognitive battery and mood and appetite VAS for a final time and were then free to leave the laboratory. Water intake was recorded during the first trial and was matched in the subsequent trials (as in Chapter 2, section 2.2.6). Participants also completed the cognitive tasks and the mood and appetite VAS via a mobile phone at 1500 and 1900 h and completed a food diary for the rest of the day.

Subjective appetite ratings were recorded before each set of cognitive tasks using VAS (as listed in section 2.2.2.3) via presentation on a computer. Participants were asked to move a cross using the mouse on a 100 mm line to grade their current subjective status. Appetite VAS were also completed at the mid-way point during the exercise session using the pen and paper method (as described in section 2.2.2.3). It has previously been found that measuring appetite using pen and paper produces comparable mean scores and reliability coefficients compared to using the same VAS presented on a computer (Miller et al., 2002).

In addition, participants were also required to rate how much they liked the breakfast and lunch meals (immediately following consumption) and how much they enjoyed the exercise session (rated as soon as possible post-exercise), also via 100 mm VAS presented on a computer.

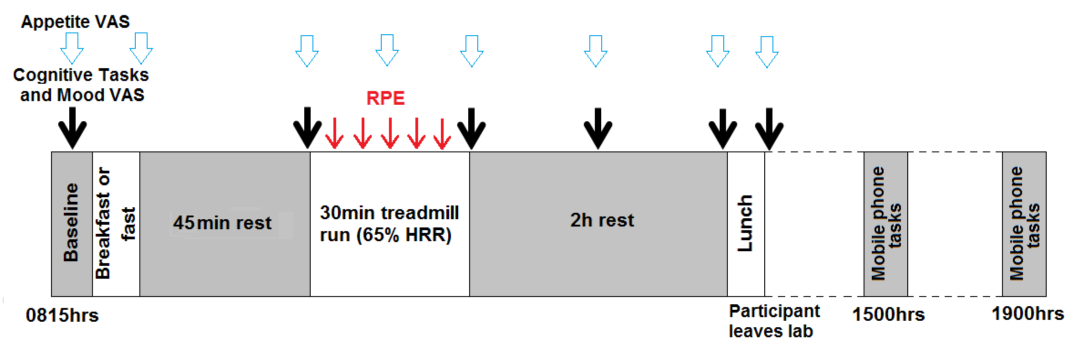

Figure 5.1 Study 4 Schematic

5.2.6 Treatments/Test meals (Table 5.1)

The nutritional content of the breakfast and lunch provided in the study are detailed in Table 5.1. For the two breakfast trials, participants were given a breakfast consisting 40 g or 20 g of Special K breakfast cereal (Kellogg's, UK) with 166 ml and 83 ml of semi-skimmed milk (Sainsburys, UK) respectively. These sizes were selected to provide a smaller and larger breakfast based the standard portion sized given by the manufacturer of 30 g cereal with 125 ml milk. The energy content of the larger of these breakfasts also closely resembled the average energy content consumed at breakfast as reported by a similar population in Chapter 4. Participants were given a maximum of 10 min to consume the breakfast. Each portion of the *ad libitum* lunch was prepared in advance and re-heated in the microwave for 5 min as required. Participants were initially served 400 g of pasta. Approximately every 3-5 min, more pasta was added to the bowl (300 g initially, then 100 g thereafter) until the participant indicated that they were full. Participants were not allowed to completely finish a portion before the bowl was refilled.

It was decided to omit the consumption of a post-exercise drink, as in Chapter 2. This was to ensure the data was derived from definite fasted *vs.* fed conditions.

Table 5.1
Nutritional content of study foods

	kJ/Kcal	Carbohydrate (g)	Protein (g)	Fat (g)	Fibre (g)
Breakfasts					
20g Special K cereal	321/76	15	3	Trace	Trace
83ml Semi-skimmed milk	171/42	4	1.5	1.5	0
Total	492/118	19	4.5	1.5	Trace
40g Special K cereal	642/152	30	6	Trace	Trace
166ml Semi-skimmed milk	342/81	8	3	3	0
Total	984/236	38	9	3	1
Lunch					
125g Penne Pasta	1894/446	91	15	2	3
250g Tomato and Herb pasta sauce	540/128	20	4	3	4
15g Oilve Oil	508/123	0	0	14	0
40g Cheddar Cheese	648/156	Trace	10	13	0
Total per 430g portion	3544/938	111	29	32	7
Total per 100g	824/218	26	7	7	1.5

5.2.6 Statistical Analysis

A power calculation carried out a *priori* indicated that a total sample size of 24 would provide statistical power above 80% with an alpha level of .05 (Faul et al., 2007). Before the main statistical analysis, a one-way ANOVA was used to compare pre-breakfast baseline data to assess for differences in performance across the study days.

Scores for each individual task outcome completed on the computer (MPS VAS, FCRT, Stroop, NBack, RVIP, mental fatigue VAS and task difficulty VAS) were analysed as CFB. All appetite VAS were analysed as time-averaged AUC, calculated using the trapezoidal method.

Data for the breakfast and lunch liking VAS, exercise enjoyment VAS, RPE, EI and the mobile phone tasks were analysed as absolute values. TFEQ scores were used as a covariate in the EI analysis only as it has been previously found that restraint scores calculated using the TFEQ were not associated with subjective appetite sensations (Drapeau, 2005).

Data were split into three parts for analysis: pre-exercise, post-exercise and mobile phone data. A 3 x 4 (breakfast x repetition) repeated-measures ANOVA was used to assess differences in performance and mood during the post-exercise time-points in the laboratory and a 3 x 2 (breakfast x repetition) ANOVA for the mobile phone data analysis. A one-way repeated-measures ANOVA was used when data was collected only at a single time point (for example, pre-exercise).

All analyses were carried out using SPSS 19 (SPSS, Inc., Chicago, IL, USA). To be conservative, planned comparisons (using *t* tests calculated with the Mean Squares Error) were then employed to show where the significance lay in interactions or main effects only with $p < 0.1$ shown by the ANOVA. An alpha level of .05 was used for the planned comparisons. Effect sizes for significant results are reported using Cohen's D (*d*).

5.3 Results

There were no significant differences between mean baseline scores for any of the treatment conditions or outcome measures. Due to a data capture error only 17 participants were included in the Mobile Phone tasks analysis. Significant results or trends are reported below with Means and Standard Error Means (SEM) reported where appropriate.

5.3.1 Pre and during exercise analysis

Pre-exercise

Cognitive Tasks (See Table 5.2)

Stroop

Trends towards a main effect of breakfast were observed for overall Stroop RT [F (2, 23) = 2.68, p = .079] and correct Stroop RT [F (2, 23) = 2.51, p = .092]. Comparisons revealed that these RTs were significantly quicker when the 20 g breakfast was consumed compared to the 40 g breakfast (p =.048, d = 0.57 and p = .047, d = 0.56) respectively) with trends towards significantly quicker RTs compared to the NB condition also (p = .054 and .074 respectively).

A significant main effect of breakfast was observed for Stroop congruent RT [F (2, 23) = 3.25, p = .048] and a trend towards a main effect for Stroop correct congruent RT [F (2, 23) = 2.97, p = .061; Figure 5.2]. Comparisons revealed that these RTs were significantly quicker when the 20 g breakfast was consumed compared to the NB condition (p = .017, d = 0.67 and p = .016, d = 0.65 respectively) with trends towards significantly quicker RTs compared to the 40 g breakfast also (p = .079 and .077 respectively).

NBack

Trends towards a main effect of breakfast were observed for NBack missed sequences [F (2, 23) = 2.53, p = .091] and NBack % correct [F (2, 23) = 2.73, p = .076]. Comparisons revealed there were significantly less missed sequences and more correct responses (increase accuracy) when the 20 g breakfast was consumed compared to NB (p = .046, d = 0.51 and p = .024, d = 0.76) respectively; Figure 5.2). There was also a trend towards less missed sequences compared to consuming the 40 g breakfast also (p = .075).

Table 5.2

Baseline and change from baseline scores for each cognitive measure for each treatment condition

Measure	Condition	COMPASS Tasks (change from baseline)						Mobile Phone Tasks (absolute values)	
		Baseline score	Pre-exercise	Post-exercise	1hr post-exercise	2hrs post-exercise	Post-lunch	1500hrs	1900hrs
Four Choice Reaction Time (ms)	NB	457.3 ± 13.2	25.7 ± 11.4	18.4 ± 11.9	29.9 ± 12.9	32.7 ± 13.4	50.5 ± 18.1	426.8 ± 15.0	428.4 ± 14.2
	20 g	471.6 ± 15.7	3.1 ± 10.1	-10.4 ± 9.7	3.1 ± 10.2	2.6 ± 10.6	13.1 ± 13.7	431.3 ± 14.2	436.5 ± 17.3
	40 g	459.2 ± 12.1	24.4 ± 13.3	-5.9 ± 11.3	4.6 ± 10.7	9.7 ± 10.8	19.6 ± 7.9	423.1 ± 17.8	437.9 ± 24.5
Four Choice Reaction Time Correct RT (ms)	NB	458.21 ± 13.22	24.7 ± 11.3	17.7 ± 11.9	29.6 ± 12.8	32.7 ± 13.5	49.5 ± 18.1	385.4 ± 11.7	375.5 ± 10.4
	20 g	471.53 ± 15.68	3.3 ± 10.1	-10.3 ± 9.8	2.9 ± 10.3	3.3 ± 10.8	13.2 ± 13.8	392.3 ± 12.9	395.3 ± 12.4
	40 g	459.3 ± 12.09	25.1 ± 13.2	-5.8 ± 11.2	5.3 ± 10.6	9.9 ± 10.8	20.0 ± 7.8	390.8 ± 15.5	397.9 ± 21.9
Four Choice Reaction Time Accuracy (%)	NB	98.8 ± 0.4	0.5 ± 0.4	0.8 ± 0.3	0.4 ± 0.3	0.3 ± 0.6	0.5 ± 0.4	385.4 ± 11.7	375.5 ± 10.4
	20 g	99.6 ± 0.2	0.1 ± 0.3	0.1 ± 0.3	-0.5 ± 0.4	-0.5 ± 0.4	-0.3 ± 0.5	392.3 ± 12.9	395.3 ± 12.4
	40 g	99.9 ± 0.1	-1.0 ± 0.4	-0.7 ± 0.3	-0.8 ± 0.4	-0.5 ± 0.4	-0.4 ± 0.3	390.8 ± 15.5	397.9 ± 21.9
Stroop accuracy (%)	NB	97.8 ± 0.3	-0.3 ± 0.4	0.0 ± 0.3	-1.1 ± 0.4	-1.3 ± 0.5	-0.9 ± 0.5		
	20 g	97.0 ± 0.5	0.2 ± 0.4	-0.3 ± 0.6	-0.3 ± 0.4	0.3 ± 0.5	-0.1 ± 0.4		
	40 g	97.5 ± 0.3	0.0 ± 0.4	-0.2 ± 0.4	-0.8 ± 0.3	-0.5 ± 0.4	-0.3 ± 0.4		
Stroop Overall RT (ms)	NB	621.9 ± 11.5	-0.3 ± 8.3	-18.7 ± 6.4	-1.0 ± 8.8	-17.0 ± 9.2	-5.9 ± 12.6		
	20 g	631.4 ± 17.1	-25.3 * ± 10.7	-29.9 ± 8.2	-22.2 ± 10.8	-29.0 ± 11.6	-20.7 ± 9.8		
	40 g	620.6 ± 14.0	0.3 ± 7.6	-14.0 ± 8.8	-12.1 ± 6.8	-16.3 ± 9.4	-6.5 ± 10.8		
Stroop Correct RT (ms)	NB	622.82 ± 11.66	-1.5 ± 7.8	-18.6 ± 6.6	-2.0 ± 8.3	-16.6 ± 9.3	-6.5 ± 12.6		
	20 g	631.63 ± 17.18	-24.7 * ± 11.0	-29.9 ± 8.3	-21.9 ± 10.8	-28.1 ± 11.8	-19.7 ± 9.7		
	40 g	620.49 ± 14.16	1.1 ± 7.8	-13.5 ± 8.6	-12.1 ± 7.1	-15.2 ± 9.6	-5.3 ± 10.7		
Stroop Congruent Correct (%)	NB	97.782 ± 0.653	0.5 ± 0.7	-0.3 ± 0.8	-0.3 ± 0.8	-1.1 ± 0.8	0.2 ± 0.7		
	20 g	97.41 ± 0.612	0.1 ± 0.8	-0.5 ± 0.8	-0.1 ± 0.5	0.1 ± 0.6	0.1 ± 0.6		
	40 g	97.452 ± 0.542	-0.4 ± 0.7	-0.5 ± 0.7	-0.5 ± 0.7	-0.1 ± 0.8	-0.4 ± 0.8		

Table 5.2 continued

Stroop Incongruent correct (%)	NB	97.735 ± 0.37	-0.7 ± 0.7	0.1 ± 0.4	-1.4 ± 0.6	-1.3 ± 0.6	-1.5 ± 0.7		
	20 g	96.766 ± 0.6	0.4 ± 0.5	-0.2 ± 0.8	-0.3 ± 0.7	0.4 ± 0.6	-0.2 ± 0.5		
	40 g	97.467 ± 0.427	0.3 ± 0.6	0.0 ± 0.7	-0.9 ± 0.5	-0.6 ± 0.7	-0.2 ± 0.6		
Stroop Congruent RT (ms)	NB	590.49 ± 11.25	18.1 † ± 10.3	-13.5 ± 8.4	10.2 ± 11.3	2.3 ± 12.9	-5.6 ± 12.7		
	20 g	609.28 ± 16.37	-19.9 ± 13.2	-33.3 ± 10.1	-24.2 ± 9.5	-22.4 ± 12.6	-26.1 ± 12.5		
	40 g	591.97 ± 10.3	7.8 ± 7.9	-2.5 ± 12.3	-7.0 ± 7.1	-1.9 ± 8.0	-5.3 ± 12.7		
Stroop Incongruent RT (ms)	NB	636.91 ± 12.99	-10.1 ± 9.8	-21.6 ± 7.5	-6.1 ± 10.1	-25.2 ± 8.3	-5.7 ± 13.5		
	20 g	643.01 ± 18.07	-28.5 ± 11.2	-28.2 ± 9.1	-21.8 ± 12.4	-32.6 ± 12.2	-19.4 ± 10.2		
	40 g	634.34 ± 16.16	-3.0 ± 9.3	-17.5 ± 9.1	-15.6 ± 8.3	-23.6 ± 11.2	-7.2 ± 11.2		
Stroop Correct Congruent RT (ms)	NB	591.24 ± 11.35	18.3 † ± 10.5	-13.4 ± 8.7	10.2 ± 10.8	3.8 ± 13.2	-6.0 ± 12.4		
	20 g	610.04 ± 16.74	-20.0 ± 14.1	-32.6 ± 10.7	-24.7 ± 9.9	-21.1 ± 12.9	-24.9 ± 13.1		
	40 g	592.88 ± 10.4	7.8 ± 8.2	-2.8 ± 12.4	-6.7 ± 7.5	-1.4 ± 8.1	-4.8 ± 13.0		
Stroop Correct Incongruent RT (ms)	NB	637.72 ± 13.23	-11.7 ± 9.2	-21.4 ± 7.6	-7.3 ± 9.7	-25.1 ± 8.3	-5.6 ± 13.9		
	20 g	643.11 ± 18.12	-27.8 ± 11.3	-28.7 ± 9.2	-21.0 ± 12.3	-32.0 ± 12.3	-18.3 ± 10.0		
	40 g	633.65 ± 16.39	-1.8 ± 9.5	-16.5 ± 9.1	-15.5 ± 8.8	-22.1 ± 11.6	-5.8 ± 11.2		
NBack accuracy (%)	NB	91.1 ± 1.6	-1.7 † ± 1.2	-0.9 ± 1.5	-1.0 ± 1.5	1.3 ± 1.2	-2.8 ± 1.4	89.7 * ± 1.1	88.9 ± 1.6
	20 g	87.7 ± 1.8	3.2 ± 1.5	1.4 ± 1.6	1.3 ± 1.7	2.8 ± 1.7	2.1 ± 2.0	89.6 * ± 1.4	87.3 ± 1.5
	40 g	88.3 ± 1.8	0.5 ± 2.1	0.9 ± 1.9	2.4 ± 1.8	2.3 ± 1.6	3.4 ± 1.8	87.7 ± 1.6	89.1 ± 1.3
NBack RT (ms)	NB	741.6 ± 38.5	-10.7 ± 19.4	-60.5 ± 20.4	-61.3 ± 21.8	-77.6 ± 24.1	-87.2 ± 28.6	831.3 ± 62.3	792.0 ± 56.2
	20 g	724.2 ± 36.5	-20.0 ± 27.0	-54.1 ± 18.2	-41.3 ± 21.2	-82.9 ± 32.6	-71.6 ± 24.4	844.2 ± 59.4	778.0 ± 56.7
	40 g	724.6 ± 35.8	24.1 ± 28.3	-69.5 ± 19.5	-70.2 ± 21.1	-75.6 ± 21.2	-78.1 ± 26.3	832.5 ± 82.6	800.6 ± 76.0
NBack Missed Sequences (number)	NB	0.2 ± 0.1	0.2 † ± 0.2	0.2 ± 0.2	0.2 ± 0.1	0.2 ± 0.1	0.1 ± 0.1		
	20 g	0.8 ± 0.4	-0.6 ± 0.4	-0.6 ± 0.4	-0.3 ± 0.4	-0.8 ± 0.4	-0.7 ± 0.4		
	40 g	0.4 ± 0.2	0.1 ± 0.2	0.0 ± 0.2	-0.2 ± 0.2	0.0 ± 0.2	-0.2 ± 0.1		

Table 5.2 continued.

NBack Correct RT (ms)	NB	730.9 ± 38.8	-6.7 ± 20.3	-63.6 ± 22.6	-53.0 ± 23.2	-60.8 ± 26.3	-83.8 ± 30.2	17.3 ± 1.1	16.6 ± 0.9
	20 g	730.3 ± 37.5	-33.1 ± 23.7	-64.8 ± 20.1	-47.9 ± 19.9	-91.9 ± 31.5	-79.1 ± 25.6	16.2 ± 1.1	14.1 ± 1.2
	40 g	722.0 ± 35.8	25.9 ± 30.0	-68.5 ± 18.9	-65.2 ± 18.5	-77.6 ± 21.4	-74.5 ± 23.3	16.2 ± 1.1	15.5 ± 1.2
NBack Correct Target (%)	NB	82.7 ± 3.5	-2.6 ± 2.9	-3.0 ± 2.9	-3.0 ± 3.6	2.3 ± 2.9	-7.5 ± 4.1	5.6 ± 0.9	6.5 ± 1.1
	20 g	77.9 ± 3.6	1.7 ± 3.5	-0.5 ± 3.4	0.8 ± 3.4	2.6 ± 3.2	-0.7 ± 3.4	5.9 ± 1.0	8.0 ± 1.3
	40 g	76.8 ± 3.8	1.9 ± 3.8	3.5 ± 3.7	3.8 ± 4.1	6.2 ± 3.8	6.5 ± 4.1	6.3 ± 1.0	6.5 ± 1.2
NBack Target RT (ms)	NB	791.1 ± 47.4	-0.7 ± 0.9	0.9 ± 1.0	0.5 ± 1.3	1.6 ± 1.0	0.2 ± 0.8	767.8 ± 55.1	741.6 ± 45.4
	20 g	750.9 ± 51.8	1.8 ± 1.1	0.1 ± 1.2	0.5 ± 1.1	-0.1 ± 1.3	0.9 ± 1.3	816.5 ± 57.4	779.9 ± 62.2
	40 g	747.7 ± 46.6	0.3 ± 1.4	-0.1 ± 1.3	1.4 ± 1.1	0.4 ± 1.2	1.5 ± 1.1	796.1 ± 65.9	773.5 ± 71.9
NBack Correct Non-target (%)	NB	96.0 ± 0.8	-16.4 ± 31.8	-73.5 ± 33.2	-74.7 ± 26.4	-108.6 ± 32.1	-109.5 ± 41.0	76.9 * ± 0.9	76.7 ± 1.0
	20 g	95.6 ± 1.1	-20.4 ± 38.2	-33.1 ± 31.3	-18.8 ± 44.7	-102.0 ± 44.5	-89.0 ± 42.1	77.8 * ± 0.8	77.6 ± 0.9
	40 g	95.4 ± 0.8	69.2 ± 36.4	-62.8 ± 26.6	-70.1 ± 29.1	-48.9 ± 27.3	-81.9 ± 36.5	75.7 ± 1.0	77.9 ± 0.6
NBack Non-target RT (ms)	NB	725.3 ± 39.1	-2.6 ± 24.2	-47.2 ± 24.3	-49.0 ± 24.5	-57.3 ± 27.5	-74.4 ± 26.4	894.8 ± 77.2	842.5 ± 73.2
	20 g	740.2 ± 37.4	-41.2 ± 24.2	-86.3 ± 21.5	-66.0 ± 16.5	-102.8 ± 28.5	-88.5 ± 25.9	871.9 ± 81.6	776.1 ± 60.7
	40 g	728.2 ± 35.8	4.4 ± 30.2	-74.2 ± 20.5	-77.5 ± 22.9	-91.5 ± 21.9	-83.0 ± 25.3	868.9 ± 104.4	827.6 ± 85.9
RVIP accuracy (%)	NB	49.7 ± 4.6	-2.1 ± 2.9	1.5 ± 2.5	-2.8 ± 2.4	-0.4 ± 2.6	-2.6 ± 2.2	19.2 ± 2.5	19.4 ± 2.4
	20 g	52.7 ± 4.3	-4.9 ± 2.1	0.6 ± 2.7	-1.3 ± 2.7	1.5 ± 2.4	-3.0 ± 2.5	19.9 ± 2.2	21.1 ± 2.3
	40 g	53.6 ± 5.1	-1.5 ± 1.8	2.0 ± 2.4	-2.6 ± 1.9	0.7 ± 1.9	-5.3 ± 2.7	20.1 ± 2.4	19.4 ± 2.2
RVIP reaction time (ms)	NB	468.1 ± 23.0	24.5 ± 21.6	15.0 ± 21.2	14.8 ± 22.4	31.1 ± 22.2	12.5 ± 19.4	468.2 ± 14.7	460.6 ± 11.2
	20 g	493.1 ± 10.8	3.8 ± 8.0	-8.7 ± 7.4	0.4 ± 10.8	-3.2 ± 9.3	-2.4 ± 9.0	495.4 ± 12.2	466.2 ± 11.0
	40 g	458.1 ± 22.1	12.4 ± 6.5	26.4 ± 34.1	3.9 ± 8.9	-7.5 ± 6.9	-2.2 ± 8.6	474.5 ± 9.6	474.9 ± 10.8
RVIP false alarms (number)	NB	0.5 ± 0.2	-0.1 ± 0.2	-0.3 ± 0.2	-0.1 ± 0.2	0.3 ± 0.4	0.0 ± 0.2	2.6 * ± 0.7	4.2 † ± 1.4
	20 g	0.8 ± 0.2	0.0 ± 0.3	-0.1 ± 0.2	-0.1 ± 0.2	-0.2 ± 0.2	-0.3 ± 0.3	3.5 ± 0.9	1.7 * ± 0.5
	40 g	0.5 ± 0.2	0.2 ± 0.3	-0.2 ± 0.2	0.0 ± 0.2	-0.2 ± 0.3	0.2 ± 0.2	4.2 ± 1.4	4.5 ± 1.6

Means ± SEM are presented

* Mean value was significantly different from 40 g breakfast

† Mean value was significantly different from 20 g breakfast

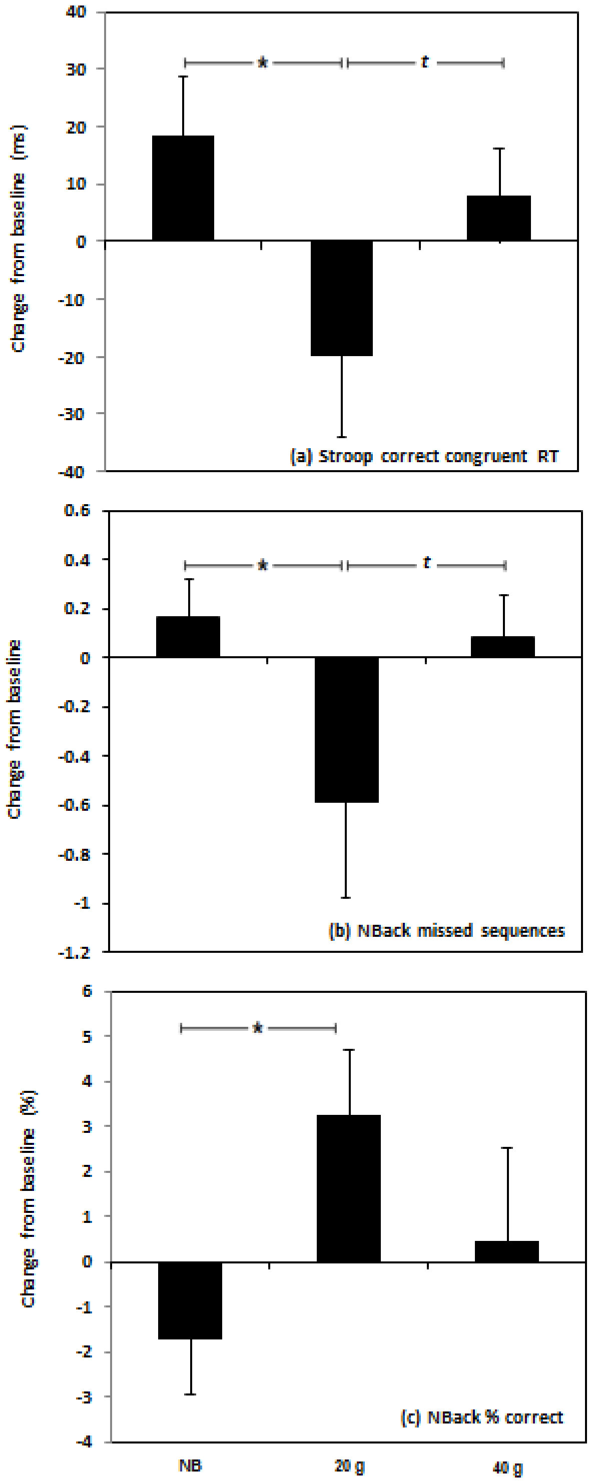

Figure 5.2 The effects of consuming breakfast cereal (20 g or 40 g) or no breakfast (NB) on (a) Stroop correct congruent RT, (b) NBack missed sequences and (c) NBack % correct in habitually active females (N=24). Values are CFB (*t* $p < .08$, $*p < .05$)

Mood and Physical State Visual Analogue Scales (see Table 5.3)

Mental Fatigue

A marginally significant main effect of breakfast condition was observed for mental fatigue ratings [F (2, 23) = 3.15, p = .052]. Comparisons revealed that participants were significantly more mentally fatigued when breakfast was omitted compared to consuming the 40 g breakfast (p =.016, d = 0.70; Figure 5.3).

Relaxed

A trend for a main effect of breakfast condition was observed for relaxed ratings [F (2, 23) = 2.89, p = .066]. Comparisons revealed that participants were significantly less relaxed when breakfast was omitted compared to consuming the 40 g breakfast (p =.023, d = 0.68; Figure 5.3).

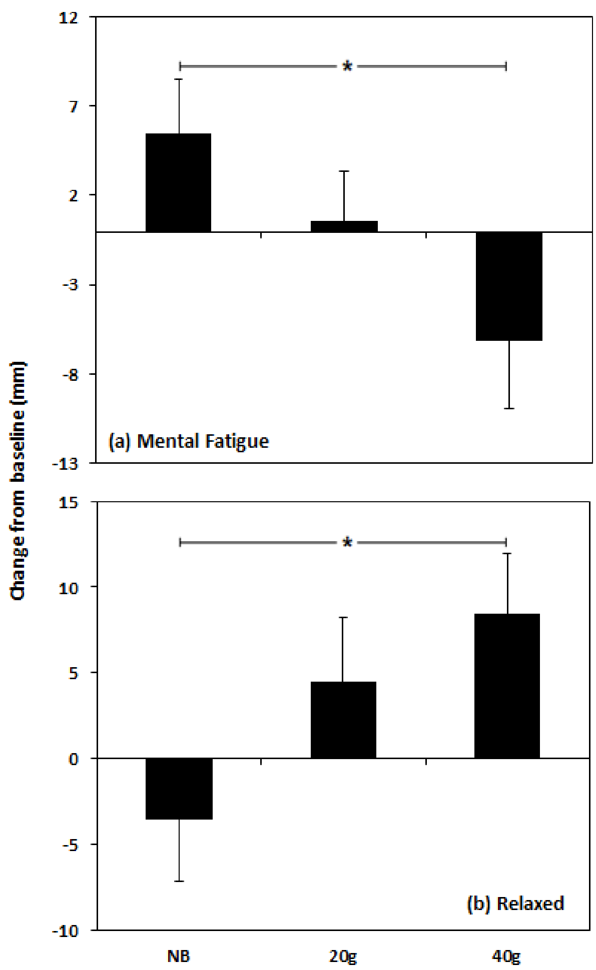

Figure 5.3 The effects of consuming breakfast cereal (20 g or 40 g) or no breakfast (NB) on (a) mental fatigue and (b) relaxation, in habitually active females (N=24). Values are change from baseline (*p <.05)

Table 5.3
Baseline and change from baseline or absolute scores for each mood measure for each treatment condition

Measure	Condition	COMPASS Tasks (change from baseline)						Mobile Phone Tasks (absolute values)	
		Baseline score	Pre-exercise	Post-exercise	1 h post-exercise	2 h post-exercise	Post-lunch	1500 h	1900 h
MPSVAS									
Relaxed	NB	58.5 ± 3.5	-3.5 † ± 3.6	0.7 ± 4.5	1.3 * ± 3.5	-3.9 * ± 3.7	2.2 * ± 2.6	58.1 ± 4.3	55.5 ± 3.9
	20 g	54.2 ± 3.2	4.5 ± 3.8	0.5 ± 3.9	8.5 ± 3.9	4.9 ± 3.5	11.3 ± 3.5	58.4 ± 4.4	52.2 ± 5.3
	40 g	52.6 ± 3.8	8.4 ± 3.6	0.0 ± 3.9	6.3 ± 4.0	9.3 ± 3.5	11.2 ± 3.7	59.1 ± 4.9	56.5 ± 4.4
Alert	NB	41.6 ± 3.4	4.6 ± 3.7	17.0 ± 3.3	10.0 ± 4.4	2.9 ± 4.9	12.8 ± 4.8	50.8 ± 3.8	52.9 ± 4.1
	20 g	44.4 ± 3.1	7.9 ± 3.0	12.9 ± 4.3	6.4 ± 4.5	6.1 ± 5.3	13.8 ± 4.7	52.2 ± 4.0	50.1 ± 3.8
	40 g	44.8 ± 3.0	6.4 ± 3.9	13.0 ± 3.4	6.9 ± 3.6	10.9 ± 3.7	14.0 ± 3.9	54.8 ± 3.7	53.9 ± 2.9
Jittery	NB	24.8 ± 3.3	-0.6 ± 2.3	4.0 ± 3.5	2.4 ± 3.4	2.8 ± 2.3	-0.9 ± 2.1	26.4 ± 3.0	31.1 ± 5.6
	20 g	25.0 ± 3.0	-0.9 ± 3.0	6.9 ± 4.4	2.6 ± 3.9	2.7 ± 4.5	1.1 ± 3.3	32.9 ± 5.1	28.0 ± 4.1
	40 g	25.0 ± 3.2	0.1 ± 2.4	3.5 ± 4.0	2.3 ± 3.5	5.9 ± 3.8	0.8 ± 3.7	28.0 ± 4.4	30.6 ± 4.7
Tired	NB	48.5 ± 4.2	2.0 ± 3.1	-3.5 ± 4.3	-6.8 ± 4.9	2.4 ± 4.1	-2.8 ± 4.5	52.0 ± 4.4	52.2 ± 4.4
	20 g	54.0 ± 3.2	-4.3 ± 3.3	-5.0 ± 2.8	-6.3 ± 3.9	-3.4 ± 4.0	-13.7 ± 4.9	45.6 ± 4.2	55.5 ± 4.3
	40 g	55.6 ± 3.1	-2.8 ± 2.7	-5.4 ± 3.4	-6.3 ± 4.1	-7.3 ± 4.4	-9.7 ± 5.3	51.1 ± 4.5	49.9 ± 4.6
Tense	NB	27.7 ± 3.3	1.7 ± 3.3	3.1 ± 3.2	-1.5 ± 2.9	1.4 ± 3.3	-2.8 ± 2.8	31.8 ± 3.6	28.2 *† ± 3.1
	20 g	28.4 ± 3.5	0.2 ± 2.1	-2.1 ± 3.4	-0.8 ± 2.9	3.5 ± 3.5	-3.8 ± 3.1	30.4 ± 3.8	37.2 ± 4.7
	40 g	30.1 ± 3.2	-1.6 ± 2.7	-2.8 ± 2.7	-2.8 ± 3.9	-2.3 ± 3.4	-2.4 ± 3.4	28.9 ± 3.3	33.4 ± 3.5

Table 5.3 continued.

Headache	NB	20.3 ± 3.7	1.7 ± 3.2	3.6 ± 3.3	0.5 ± 3.6	4.2 ± 4.5	-1.7 ± 3.6	26.1 ± 4.0	19.3 ± 3.7
	20 g	18.3 ± 3.4	-0.1 ± 2.1	-1.0 ± 2.8	-0.1 ± 3.2	-1.2 ± 3.4	-7.3 ± 2.6	17.2 ± 2.7	19.8 ± 3.6
	40 g	18.5 ± 3.2	-1.0 ± 1.4	-3.8 ± 3.0	-0.4 ± 2.5	-4.4 ± 2.7	-6.5 ± 2.4	22.1 ± 4.2	22.6 ± 3.3
Overall Mood	NB	56.7 ± 3.5	-2.3 ± 2.3	4.0 ± 2.1	0.3 ± 2.3	-4.5 ± 2.6	10.6 ± 2.1	58.6 * ± 3.6	63.1 ± 3.7
	20 g	57.5 ± 2.7	3.3 ± 2.1	9.0 ± 2.1	3.7 ± 2.3	1.2 ± 3.0	12.0 ± 3.2	63.5 ± 3.3	58.8 ± 3.2
	40 g	56.3 ± 3.2	4.0 ± 2.3	7.0 ± 2.4	6.6 ± 2.9	2.7 ± 3.7	12.3 ± 3.4	64.9 ± 3.3	61.9 ± 3.3
Mental Fatigue	NB	33.3 ± 3.6	5.5 * ± 3.1	0.1 ± 4.1	4.8 ± 4.0	7.9 ± 3.7	0.3 ± 4.2	42.1 ± 4.6	39.3 ± 4.6
	20 g	36.8 ± 3.3	0.6 ± 2.8	0.5 ± 3.4	0.6 ± 4.7	4.1 ± 5.6	-4.4 ± 5.2	39.5 ± 4.5	45.4 ± 4.3
	40 g	38.9 ± 4.4	-6.2 ± 3.7	-3.9 ± 3.5	-2.7 ± 4.4	-3.9 ± 4.8	-7.8 ± 5.1	40.2 ± 4.6	38.1 ± 4.7
Post-Cognitive VAS									
Mental Fatigue	NB	44.8 ± 3.3	5.3 ± 2.9	4.0 ± 3.5	8.4 ± 3.2	10.3 ± 3.6	13.1 ± 3.1	47.8 ± 4.9	48.7 ± 4.9
	20 g	48.5 ± 3.3	1.4 ± 1.9	3.1 ± 3.8	4.9 ± 3.8	0.7 ± 5.2	2.4 ± 4.6	60.9 ± 4.2	62.8 ± 3.4
	40 g	49.2 ± 3.0	-3.0 ± 3.6	1.0 ± 3.1	-0.2 ± 3.6	-2.2 ± 3.8	-1.0 ± 3.7	50.6 ± 4.8	60.2 ± 4.0
Difficulty	NB	42.3 ± 3.5	3.3 ± 2.2	4.5 ± 3.1	6.1 ± 3.1	7.4 ± 3.4	7.3 ± 3.0	51.8 ± 4.1	48.7 ± 3.7
	20 g	44.4 ± 3.9	2.0 ± 2.9	-1.0 ± 3.4	0.9 ± 4.2	2.3 ± 4.2	1.0 ± 4.0	56.7 ± 4.8	52.2 ± 3.7
	40 g	43.0 ± 3.1	-1.5 ± 2.4	-3.4 ± 3.5	-3.7 ± 3.5	-4.4 ± 3.4	-4.3 ± 4.8	48.9 ± 3.6	49.4 ± 3.6

Means ± SEM are presented
* Mean value was significantly different from 40 g breakfast (p <.05)
† Mean value was significantly different from 20 g breakfast (p <.05)

Appetite VAS (See Table 5.4)

Pre-exercise

Significant main effects of breakfast were observed for post-breakfast hunger [F (2, 23) = 15.18, $p < .0001$], desire to eat [F (2, 23) = 18.46, $p < .0001$], fullness [F (2, 23) = 22.35, $p <.0001$] and satisfaction [F (2, 23) = 18.66, $p < .0001$].

When they had consumed NB compared to the 20 g and 40 g breakfasts participants reported feeling more hungry ($p < .001$, $d = 0.92$ and $p <.0001$, $d = 01.61$ respectively) and desired to eat more ($p = .01$, $d = 0.78$ and $p <.0001$, $d = 1.78$ respectively) and felt less full ($p <.0001$, $d = 1.17$ and $p <.0001$, $d = 1.76$ respectively) and satisfied ($p <.0001$, $d = 1.19$ and p <.0001, $d = 1.45$ respectively).

They also reported feeling that they desired to eat less ($p <.01$, d = 1.11), with trends towards feeling less hungry ($p = 0.061$) and fuller ($p = 0.064$) after consuming the 40 g compared to 20 g breakfast.

During exercise

Significant main effects of breakfast were observed for pre-post exercise hunger [F (2, 23) = 23.88, $p < .0001$], desire to eat [F (2, 23) = 23.11, $p < .0001$], fullness [F (2, 23) = 43.09, $p <.0001$] and satisfaction [F (2, 23) = 39.91, $p < .0001$].

When they had consumed NB compared to the 20 g and 40 g breakfasts participants reported feeling more hungry ($p <.0001$, $d = 1.11$ and $p <.0001$, d = 1.86 respectively; Figure 5.4) and desired to eat more ($p <.0001$, $d = 1.12$ and $p <.0001$, $d = 1.60$ respectively) and felt less full ($p <.0001$, $d = 1.63$ and $p <.0001$, $d = 2.09$ respectively) and satisfied ($p <.0001$, $d = 1.67$ and $p <.0001$, $d = 1.79$ respectively).

They also reported feeling that they were significantly less hungry ($p = .025$, $d = 0.68$; Figure 5.4) and felt they could eat less ($p = .020$, $d = 0.59$) after consuming the 40 g compared to 20 g breakfast.

Table 5.4
Time-averaged AUC values for subjective appetite measures following no breakfast (NB) or a 20 g or 40 g breakfast before, during and after exercise

Measure	Condition	AUC (mm)				AUC (%)
		Baseline	Post-breakfast	Pre-post exercise	Post-exercise recovery period	Afternoon/ Evening
Hunger	NB	61 ± 3	17 *† ± 3	17 *† ± 3	59 *† ± 3	24 ± 3
	20 g	61 ± 4	15 ± 3	15 * ± 3	54 * ± 2	24 ± 3
	40 g	59 ± 3	10 ± 2	12 ± 2	50 ± 2	24 ± 3
Desire to eat	NB	61 ± 3	13 *† ± 3	14 *† ± 3	61 *† ± 3	27 ± 2
	20 g	64 ± 2	11 * ± 2	14 * ± 3	58 * ± 1	29 ± 3
	40 g	58 ± 3	10 ± 2	14 ± 3	53 ± 2	27 ± 3
Fullness	NB	30 ± 3	16 *† ± 3	13 *† ± 3	32 *† ± 2	37 ± 4
	20 g	31 ± 4	13 ± 3	16 ± 3	36 * ± 2	39 ± 3
	40 g	30 ± 3	11 ± 2	14 ± 3	41 ± 2	39 ± 4
Satisfaction	NB	39 ± 3	16 *† ± 3	11 *† ± 2	36 *† ± 3	37 ± 3
	20 g	38 ± 4	14 ± 3	13 ± 3	43 * ± 2	38 ± 3
	40 g	35 ± 2	11 ± 2	14 ± 3	48 ± 2	38 ± 4

Mean values ± SEM are presented
* Mean value was significantly different from 40 g breakfast (p <.05)
† Mean value was significantly different from 20 g breakfast (p <.05)

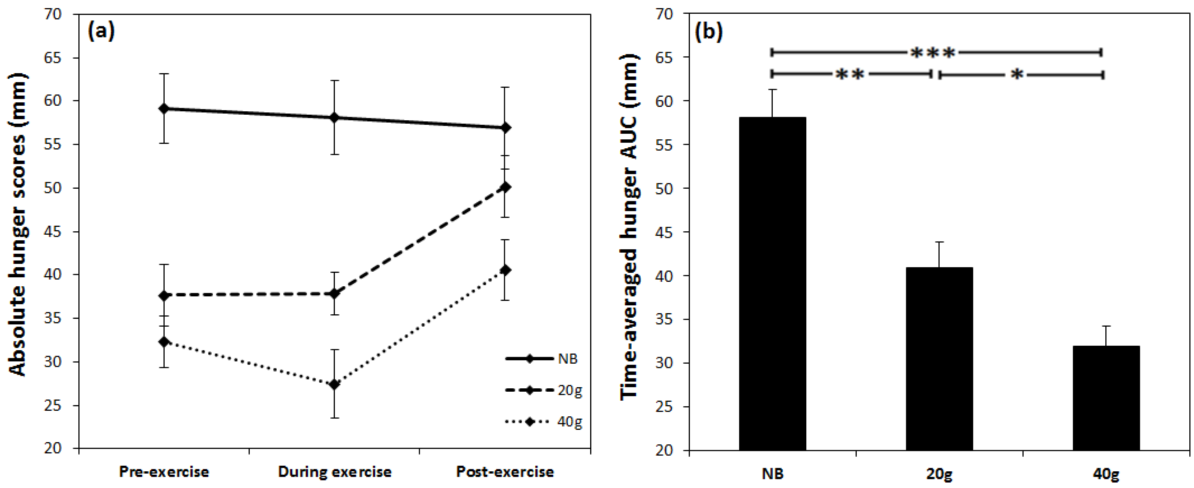

Figure 5.4 The effects of consuming breakfast cereal (20 g or 40 g) or no breakfast (NB) prior to exercise on pre-, during and post-exercise hunger in habitually active females (N=24). Values are (a) absolute and (b) time-averaged AUC (**p <.01, ***p <.001)

5.3.2 Post-exercise analysis

Computer Tasks

Cognitive Tasks

No significant results were found for computer cognitive task performance between the different treatment conditions post-exercise.

Mood and Physical State VAS

Relaxed

A significant breakfast x repetition interaction was observed for relaxed scores [F (2, 23)=2.51, p = .025]. Comparisons revealed that at 1 and 2 h post-exercise and post-lunch participants were significantly less relaxed in the NB condition compared to the 20 g breakfast condition (p = .01, d = 0.40, p <.01, d = 0.50 and p <.01, d = 0.60 respectively) and 40 g breakfast condition (p = .084 (trend only), p <.001, d = 0.75 and p <.01, d = 0.57 respectively; Figure 5.5).

Initial analysis revealed a marginally significant main effect for lower mental fatigue in both breakfast conditions post-exercise [F (2, 23)=3.18, p = .051], but effects were lost with further analysis. No other significant differences were observed between conditions for the Mood and Physical State Visual Analogue Scales. There were also no significant differences observed between conditions for RPE during exercise or exercise enjoyment (Table 5.5).

Appetite VAS

Significant main effects of breakfast were observed for post-exercise hunger [F (2, 23) = 6.60, p = .003], desire to eat [F (2, 23) = 6.49, p = .003], fullness [F (2, 23) = 6.20, p = .004] and satisfaction [F (2, 23) = 16.41, p < .0001; Figure 5.6].

Comparisons revealed when no breakfast was consumed compared to the 20 g and 40 g breakfasts participants reported feeling more hungry (p = .064, d = 0.43 and p <.01, d = 01.78

respectively) and desired to eat more (40 g only, p <.01, d = 0.79 respectively) and felt less full (p = .084, d = 0.45 and p <.01, d = 0.83 respectively) and satisfied (p <.01, d = 0.58 and p <.0001, d = 0.97 respectively).

They also reported feeling that they felt they could eat significantly less (p = .044, d = 0.64) and were significantly more satisfied (p = .025, d = 0.43; Figure 7.6) and were less hungry (p = .090, d = 0.48) and felt fuller (p = .086, d = 0.45) after consuming the 40 g compared to 20 g breakfast.

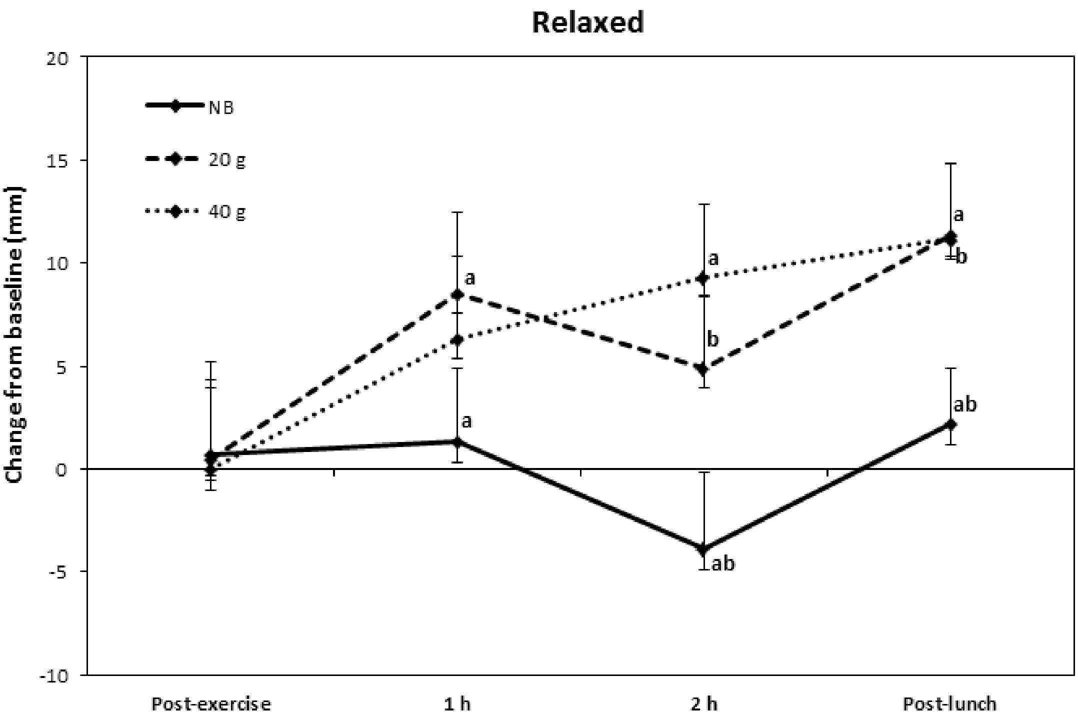

Figure 5.5 The effects of consuming breakfast cereal (20 g or 40 g) or no breakfast (NB) prior to exercise on feelings of relaxation immediately, 1 and 2 h post-exercise and post-lunch, in habitually active females (N=24). Values are change from baseline. Points which share a letter are significantly different from one another (*p <.05)

Energy Intake

There was no effect of TFEQ restraint score on EI. There was no significant difference between the conditions for EI during the *ad libitum* lunch, post-lunch or net EI (Table 5.5).

Table 5.5
Rate of percieved exertion during exericise, exercise enjoyment, meal liking and energy intake (lunch, post-lunch and net) mean values (N=24)

Measure	Condition	Mean value		
RPE	NB	10.8	±	0.3
	20 g	10.7	±	0.3
	40 g	10.6	±	0.3
Exercise Enjoyment (mm)	NB	53.8	±	2.3
	20 g	54.6	±	3.1
	40 g	58.7	±	2.1
Breakfast Liking (mm)	NB	19.4*†	±	2.7
	20 g	68.9	±	3.0
	40 g	67.9	±	3.5
Lunch Liking (mm)	NB	74.5	±	3.0
	20 g	76.5	±	2.2
	40 g	75.8	±	2.4
Lunch Energy Intake (kcal)	NB	763.2	±	37.2
	20 g	786.2	±	37.1
	40 g	778.7	±	38.8
Post-lunch Energy Intake (kcal; N=22)	NB	1000.8	±	76.9
	20 g	1055.9	±	105.6
	40 g	1067.5	±	114.5
Net Energy Intake (kcal; N=22)	NB	1780.14	±	80.59
	20 g	1957.21	±	114.64
	40 g	2088.57	±	132.30

Means ± SEM are presented
* Mean value was significantly different from 40 g breakfast (p <.05)
† Mean value was significantly different from 20 g breakfast (p <.05)

Meal liking

A significant main effect of breakfast was observed for the "breakfast liking" VAS [F (2, 23) = 106.83, p <.0001]. Comparisons revealed that participants liked the 20 g and 40 g breakfast significantly more than no breakfast (p <.0001, d = 3.62 and p <.0001, d = 3.20 respectively), although both the 20 g and 40 g breakfast were liked equally as much (Table 5.5). There were no significant differences between conditions for the "lunch liking" VAS (Table 5.5).

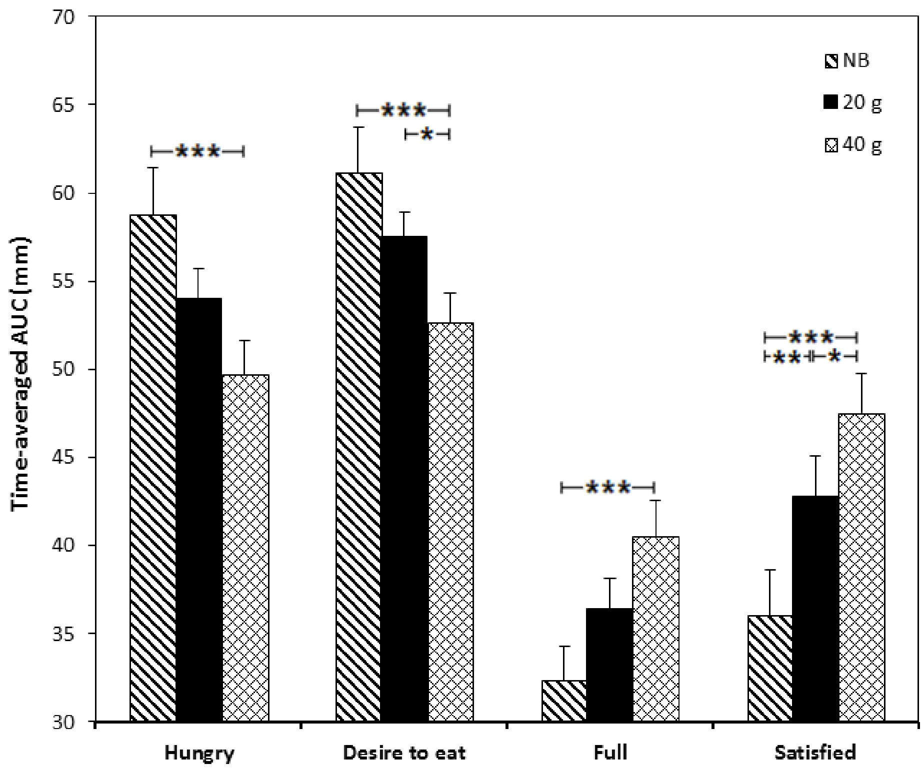

Figure 5.6 The effects of consuming breakfast cereal (20 g or 40 g) or no breakfast (NB) prior to exercise on hunger, desire to eat, fullness and satisfaction over a 3 h post-exercise period , in habitually active females (N=24). Values are time-averaged AUC (*p <.05, **p <.01, ***p <.001)

Mobile Phone Tasks

Cognitive Tasks (Table 5.2)

NBack

A significant breakfast x repetition interaction was observed for correct non-target responses [F (2, 16) = 3.85, p = .032] and trends for a breakfast x repetition interaction observed for incorrect non-target responses [F (2, 16) = 2.96, p = .066] and percentage of correct responses [F (2, 16) = 3.05, p = .062]. Comparisons revealed that at 1500 h performance on these parameters was worse following consumption of the 40 g breakfast compared to the 20 g breakfast (p <.01, d = 0.56, p = .006, d = 0.41 and p = .044, d = 0.32 respectively) and NB condition (p = .044, d = 0.31, p = .010, d = 0.38 and p = .029, d =0.38 respectively; Figure 5.7). However, at 1900 h, there were strong trends towards less correct non-target responses in the NB condition compared to the 40 g breakfast condition (p =.055) and less correct responses in the 20 g breakfast condition compared to the 40 g breakfast condition (p =.054).

RVIP

A significant breakfast x repetition interaction was observed for RVIP false alarms [F (2, 16) = 4.86, p = .014]. Comparisons revealed that at 1500 h participants made significantly less false alarms in the NB condition compared to the 40 g breakfast condition (p =.019, d = 0.37). However, at 1900 h there were significantly less false alarm responses in the 20 g breakfast condition compared to the NB (p <.01, d = 0.58) and 40 g breakfast (p <.0001, d = 0.58) conditions (Figure 5.8).

Mood and Physical State VAS (Table 5.3)

Mental Fatigue

A significant main effect of breakfast condition was observed for mental fatigue ratings 5-9 hours post-exercise [F (2, 16) = 4.38, p = .021]. Comparisons revealed that participants were significantly less mentally fatigued in the NB condition compared to the 20 g breakfast condition (p = .018, d = 0.62; Figure 5.9).

Tension

A significant breakfast x repetition interaction was observed for tension scores [F (2, 16) = 3.38, p = .046]. Comparisons revealed that at 1900 h participants were significantly less tense in the NB condition compared to the 20 g (p <.01, d = 0.55) and 40 g (p = .045, d = 0.38) breakfast conditions (Figure 5.10).

Mood

A trend for a breakfast x repetition interaction was observed for overall mood scores [F (2, 16) = 2.71, p = .081]. Comparisons revealed that at 1500 h participants reported lower mood scores in the NB condition compared to the 20 g (p =.057 (trend only) and 40 g (p = .016, d = 0.44) breakfast conditions (Figure 5.10).

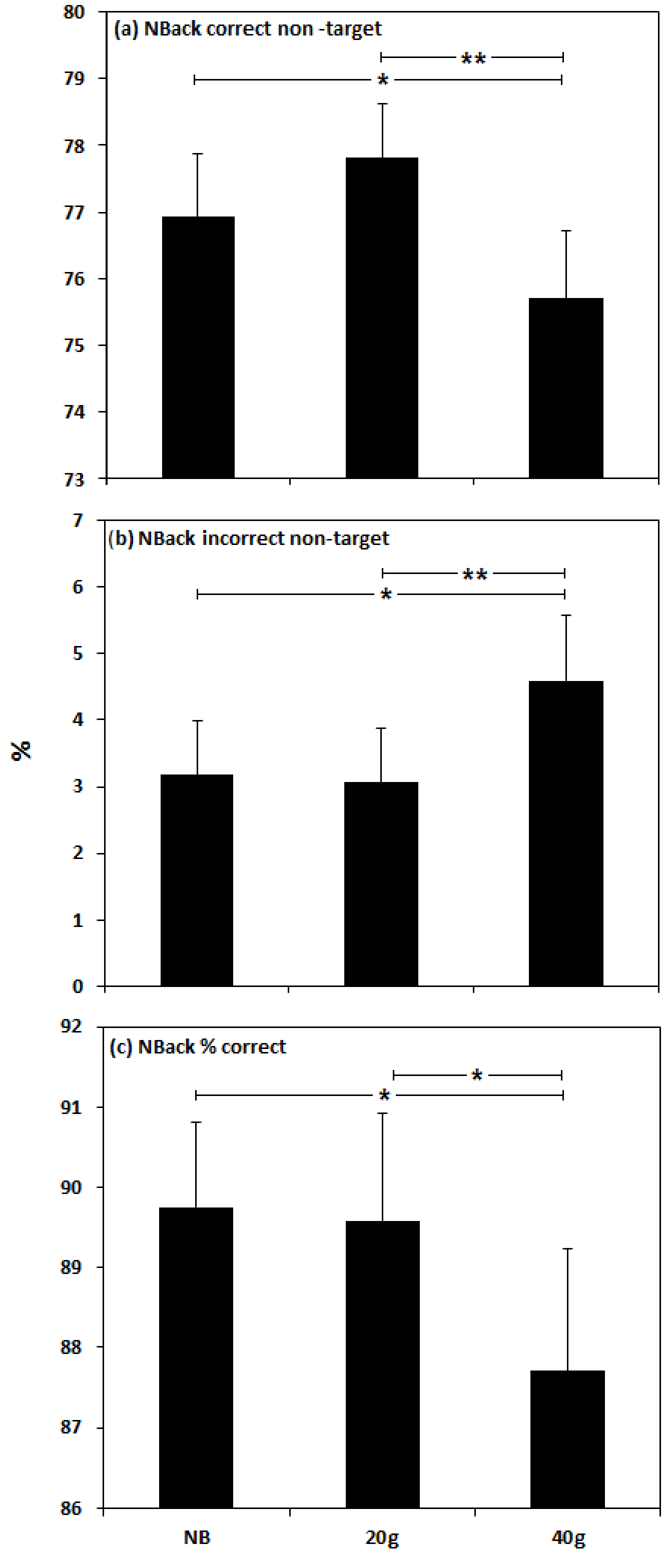

Figure 5.7 The effects of consuming breakfast cereal (20 g or 40 g) or no breakfast (NB) prior to exercise on (a) NBack correct non-target responses (b) NBack incorrect non-target responses (c) NBack % correct at 5 h (1500 h) post-exercise, in habitually active females (N=17) (**p* <.05, ***p* <.01)

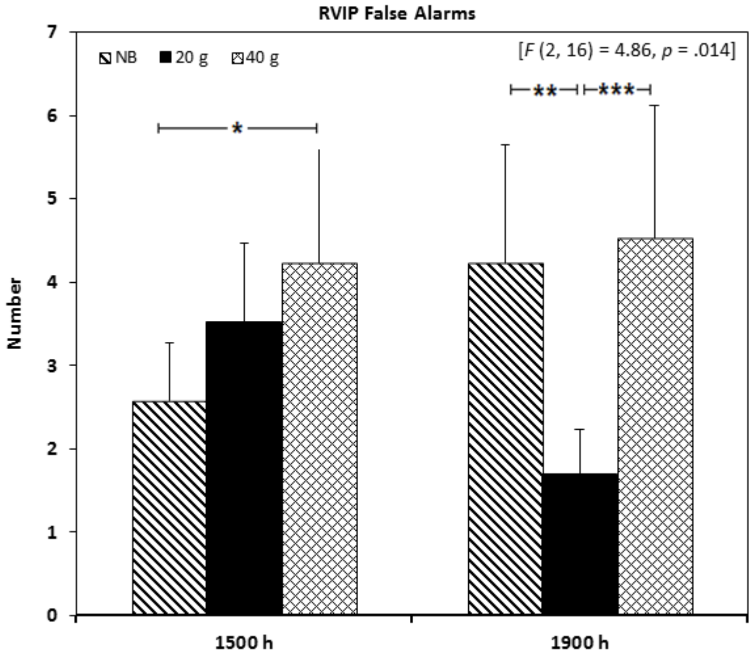

Figure 5.8 The effects of consuming breakfast cereal (20 g or 40 g) or no breakfast (NB) prior to exercise on RVIP false alarms at 5 h (1500 h) and 9 h (1900 h) post-exercise, in habitually active females (N =17) (*p <.05, **p <.01, ***p <.001)

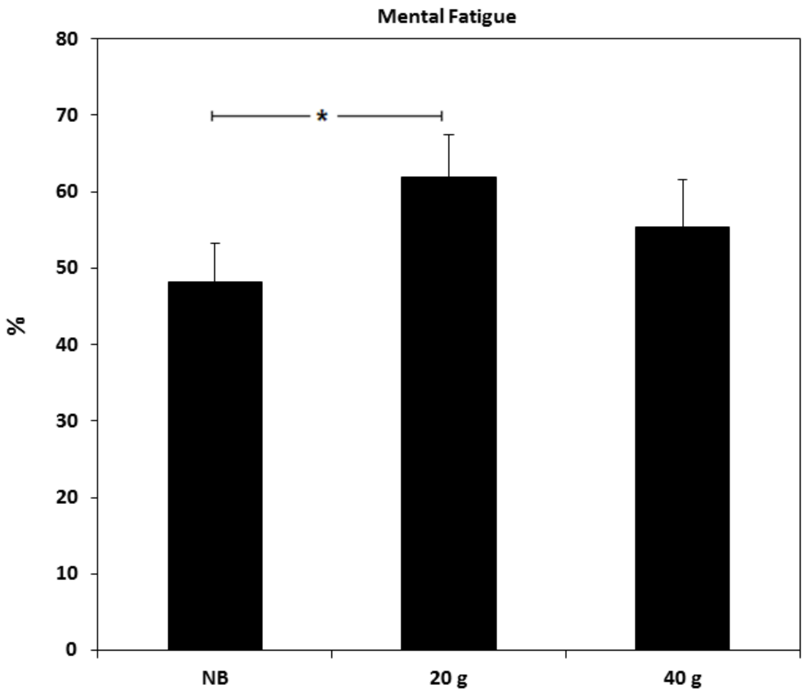

Figure 5.9 The effects of consuming breakfast cereal (20 g or 40 g) or no breakfast (NB) prior to exercise on ratings of mental fatigue 5-9 h post-exercise, in habitually active females (N=17) (*p <.05)

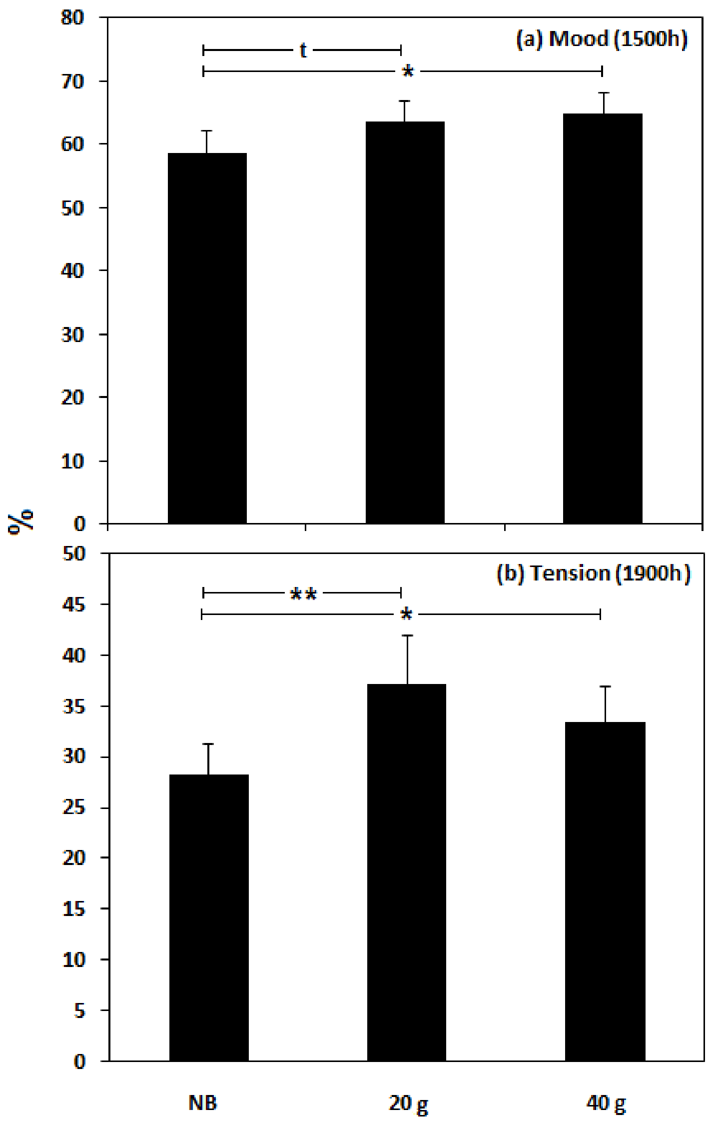

Figure 5.10. The effects of consuming breakfast cereal (20 g or 40 g) or no breakfast (NB) prior to exercise on ratings of (a) mood 5 h post-exercise (1500 h) and (b) tension 9 h post-exercise (1900 h), in habitually active females (N=17) (*t* p <.06,**p* <.05, ***p* <.01).

Appetite VAS (Table 5.4)

There were no significant differences observed between conditions for subjective appetite between 1500 and 1900 h.

5.4 Discussion

This study aimed to assess the effect of the consumption of two different sized breakfasts and breakfast omission prior to exercise on cognitive performance, mood and appetite. The results suggest that breakfast consumption compared to breakfast omission prior to exercise is favourable for appetite control and for some mood benefits in the hours following exercise, but consuming a smaller breakfast may prevent mid-afternoon cognitive detriments.

Breakfast omission, compared to consuming the larger breakfast increased mental fatigue and decreased relaxation prior to exercise. Participants also reported feeling more relaxed at 1 and 2 h post-exercise and immediately following lunch when they had consumed, compared to omitted, breakfast. However, despite seeing better Stroop and NBack performances following the 20 g breakfast prior to exercise, no effects of breakfast on cognition were found during the post-exercise period up until lunch. At 1500 h, poorer overall mood was reported when breakfast was omitted compared to consumed. Worse performance on the NBack and RVIP tasks were also observed at this time point when the larger breakfast was consumed compared to the smaller breakfast or NB and at 1900 h, fewer RVIP errors were seen following consumption of the smaller breakfast, with a trend towards better NBack performance when the larger breakfast was consumed compared to the other conditions. However, at 1900 h, tension was lower when breakfast had been omitted compared to consumed and from 1500 h onwards, lower mental fatigue was reported in the NB condition compared to the smaller breakfast condition.

Perceived physical exertion during the exercise period was not affected by prior breakfast consumption in the current study, or previously when breakfast was omitted prior to exercise in active males (Chapter 2) or in a mixed gender sample (Paul et al., 1996). However, these past studies did report higher mental fatigue in the post-exercise recovery period when breakfast had been omitted, whereas we saw no significant effects of breakfast on mental fatigue at this time; initial analysis did reveal a strong trend for lower mental fatigue in both breakfast conditions post-exercise, but effects were lost with further analysis. Both CHO and exercise can increase levels of brain serotonin, a mood modulator which can increase sensitivity to fatigue (Newsholme, Acworth & Blomstrand, 1987). Paul et al. suggested that the protein in the breakfasts they administered diminished this serotonin increase during exercise. It is plausible that the smaller amount of protein present in the breakfasts in the current study (4.5 and 9.0 g), compared to those administered by Paul et al. (approx. 14.0 - 19.0 g) and in Chapter 2 (19g) was not sufficient to significantly decrease exercise-induced brain serotonin synthesis, therefore making differences in post-exercise fatigue less discernible between conditions. However, we did see that from mid-afternoon, mental fatigue was reportedly higher following consumption of the smaller breakfast compared to breakfast omission. It could be speculated that this negative effect of breakfast consumption on mental fatigue later in the day would also have been observed in previous studies had it too been measured at this time.

Previous research does suggest that even a very small breakfast is beneficial for short-term mood (Smith & Stamatakis, 2010). This is an effect demonstrated in the current study also with participants reporting feeling more relaxed in the hours following exercise and better overall mood mid-afternoon when either the small or larger breakfast was consumed. This could be attributed to the fact that consuming, rather than omitting, breakfast more closely reflected the usual routine of this sample; some evidence suggests that habitual breakfast habits may influence mood responses to acute breakfast consumption (Le Noury et al., 2002; Lloyd et al., 1996). The positive effect of breakfast consumption on mood mid-afternoon was not seen later in the evening, when in fact tension was higher with consumption of the smaller breakfast compared to breakfast omission. Mental fatigue was also higher from mid-afternoon onwards when the smaller breakfast was consumed compared to NB, results which appear to discredit the hypothesis that breakfast consumption compared to omission is beneficial for mood. However, post-lunch onwards participants were free to consume their own diet and follow their usual daily routine. Collection of detailed information on these factors was attempted, but very few participants provided enough information to warrant further analysis of this data, in particular not specifying the time of food consumption or physical activity. Differences in these factors may have greatly influenced subjective mood, likely masking the subtle positive effects of breakfast seen in the controlled laboratory conditions.

No effects of breakfast on cognition were seen in the post-exercise recovery period. This is consistent with results from Paul et al. (1996) who also found no effect on cognition of breakfast prior to cycling. Breakfast prior to exercise appeared negative for cognitive performance but not until mid-afternoon, when NBack and RVIP performance were both poorer when the larger breakfast had been consumed prior to exercise. Both these tasks are measures of working memory, a facet of cognitive function which has not shown previous sensitivity to breakfast interventions but these data perhaps suggest that this domain of cognition is negatively affected by prior breakfast consumption. However, these results did appear to reverse in the evening. It is interesting that detriments in cognitive performance in the large breakfast condition were not detected in the initial post-exercise period as observed in Chapter 2. This could be due to differences in the type and energy content of the breakfasts administered in the two studies. An unexpected result was that cognitive differences were observed between conditions on tasks completed on the mobile phone tasks but not on those completed in the laboratory. It is plausible to suggest a delayed effect of breakfast on cognitive performance, or of course a second-meal effect, whereby the effects of breakfast on cognitive performance only became apparent after the next meal had been consumed. In addition, the NBack task completed on the mobile phone was a slightly easier version; it may be that this task is more sensitive to cognitive changes caused by differences in EI.

Consuming, compared to omitting, breakfast led to favourable subjective appetite ratings at every time point following breakfast up until immediately after lunch. Slightly weaker effects were seen after exercise, with the greatest differences observed between the NB and 40 g breakfast conditions. These results are consistent with a plethora of literature suggesting appetite control is improved following breakfast consumption compared to omission (Delargy et al., 1995; Hubert et al., 1998; Ruxton & Kirk, 1997). A positive effect of breakfast on appetite responses following a second feeding has been noted in a previous study, when all participants received the same amount of food as a mid-morning snack following prior breakfast consumption or omission (Astbury et al., 2011). However, in the current study, we did not see not see any effects of breakfast on appetite beyond immediately post-lunch; there may be several reasons for this. In the current study, after the post-lunch measurement of appetite was taken, it was not recorded again until approx. 2 h post lunch. It could be that by this point, the second-meal effects of breakfast on appetite had disappeared. In addition, although the mobile phone VAS have been validated for use for appetite measurement, it may be a less sensitive measure than using larger VAS on a computer screen. Participants had also resumed their normal diet at this point, and although no significant difference in post-lunch EI was reported, it is certainly likely that dietary factors will have influenced EI and subjective appetite, especially given the well-known complications in gathering accurate food-intake information using food diaries (Shibuya, Tanaka, Kuboyama & Ogaki, 2004).

Despite the fact that consuming breakfast was beneficial for subjective appetite, the lack of difference in EI at lunch or post-lunch suggests the NB condition would be considered most favourable if a reduction in overall energy balance was the required outcome (NB, 1511 kcal; 20 g breakfast, 1618 kcal and 40 g breakfast, 1735 kcal). However, the improved appetite profile seen following breakfast consumption coincided with an improvement in at least one facet of mood at most time points throughout the study day; we reported a similar effect in Chapter 2 in male subjects when superior appetite control occurred concurrently with lower mental fatigue ratings.

It is thought that this is the first controlled intervention study to demonstrate that breakfast consumption prior to exercise can influence both mood and cognitive performance later in the day in an active female sample. Vermorel et al. (2003) has suggested that when adolescents have a morning physical education lesson they require a substantial breakfast for cognitive benefits later in the day (Vermorel, Bitar, Vernet, Verdier & Coudert, 2003) and in the previous field study described in Chapter 4 using an active female population, a possible dose-response effect of breakfast size prior to exercise was observed, with a larger breakfast prior to exercise leading to preferable mood states (better overall mood and alertness and lower fatigue). Indeed, in the current study both breakfasts did produce favourable mood responses up to 5 h post-exercise compared to omitting breakfast, the larger breakfast slightly more so. However, the larger breakfast led to cognitive decline mid-afternoon, an effect not seen with the smaller breakfast. Nabb and Benton (2006) have previously reported that performance on memory tests was better following consumption of low caloric meals which led to minor increases in blood glucose (Nabb & Benton, 2006). The positive effects on mood were not long lasting, but, cognitive performance in the evening still appeared to benefit marginally from consumption of the smaller breakfast.

A limitation of the current study is the uncontrolled nature of the mobile phone tasks data collection and it is possible that a variety of factors may have influenced task performance at these times and as such, these results should be viewed with caution. However, this novel method is considered suitable for data collection of this nature (Palmblad & Tiplady, 2004) and the "free-living" data it provides is lacking in the literature. Another facet of the current study which may contradict with previous research is the use of such small meals for breakfast. It has been suggested that breakfast should be "…of an energy level between 20 and 35% of total daily energy needs" (Timlin & Pereira, 2007; page 268). The breakfasts in the current study provided only approximately 5 and 10 % of the energy needs of a typical adult female. However, in the previous field study (Chapter 4) we found that the average breakfast for this population contained just 234 kcal, not dissimilar in value to that reported in a previous study of 80 young adult females (251 kcal; Benton and Parker, 1998), so the larger of the breakfasts administered in the current study may perhaps reflect that typically consumed by the population of interest.

It should certainly be noted that research on the importance of eating a substantial breakfast regularly for other health benefits is fairly conclusive, and results from the current study which show benefits of a smaller breakfast may not be applicable to the majority. However, if post-exercise mood and appetite benefits can be gained from eating a very small, quick breakfast of not much more than 100 kcal, those who skip breakfast prior to exercise due to lack of time or to avoid discomfort during exercise may be able to incorporate a breakfast such as this into their morning exercise routine successfully. Testing of this theory in a controlled trial using this particular population would be a logical next step in this area of research. It would also be interesting to see if these effects of pre-exercise nutrition are the same if a post-exercise snack is consumed also, which may be a more realistic practice in an active population than fasting until lunch.

Chapter 6: General discussion

A plethora of research has examined the effects of consuming breakfast or undertaking an acute bout of exercise on cognition, mood and appetite. Data suggest that breakfast consumption can enhance memory (for review see Hoyland et al., 2009) and mood state (e.g. Pasman et al., 2003; Smith, 2003) and is highly advocated for greater appetite (e.g. Hubert et al., 1998) and weight (e.g. Cho et al., 2003) control. Some facets of cognitive function are improved following acute, submaximal exercise (for review see Chang et al., 2012) and the mood-enhancing effects of exercise are well documented (for review see Reed & Ones, 2006). Whilst the effects of acute exercise on appetite and EI are not yet entirely conclusive, it is generally agreed that an acute bout of exercise can suppress appetite transiently, but does not significantly affect EI (King et al., 2010; Stensel, 2010). However, limited studies to date have examined the effect of consuming breakfast, a likely source of nutrition before morning exercise, prior to exercise on cognitive function, mood and appetite post-exercise. Extensive research has aided the development of pre-exercise guidelines for athletes wishing to improve their physical performance, but these strategies may not apply if cognitive and mood enhancement or appetite control are the main reasons for an individual's participation in exercise. Subsequently, the studies presented within this thesis intended to investigate the effects of consuming breakfast prior to morning exercise on post-exercise cognition, mood and appetite. A second aim of this thesis was to gather information on the dietary and exercise practices of a habitually active female population, a generally under-represented group in exercise research, and to apply this information to subsequent studies in order to improve the relevance of the data. The purpose of this chapter is to discuss, summarise and reflect upon the findings from the experimental studies conducted, as reviewed below.

This thesis began by looking at the effect of breakfast prior to exercise in an active male population (Chapter 2). Breakfast consumption prior to exercise appeared beneficial to reduce post-exercise mental fatigue and tension and reduced appetite when consumed before exercise or rest, but did not influence EI. Exercise also reversed post-breakfast cognitive impairment, but breakfast and exercise did not interact to affect appetite, EI or cognitive performance.

In Chapter 3, a survey was designed to collect data on the dietary and exercise habits of an active female population. Habitually active women were less likely to consume food before they exercised in the morning compared to at others times of the day. They tended to agree that their mood, alertness, tiredness, concentration and ability to perform well at work/when studying/when doing their daily tasks improved after exercise. Nearly half of the sample reported an observed increase in appetite and EI following exercise compared to when they rested. Those who regularly skipped breakfast were less likely to consider that this habit negatively affected their mood or appetite. However, they were more likely to omit breakfast before exercising in the morning and less likely to report that exercise improved their concentration, suggesting that breakfast consumption, regular or acute, may modulate post-exercise attentiveness. The main reasons given for fasting before exercise were to avoid discomfort during exercise and lack of time, which brought to question the type of breakfast which may be suitable for this population to consume prior to exercise.

To develop these observations, in Chapter 4 the effect of breakfast prior to morning exercise on cognitive performance, mood and appetite in a habitually active female sample in a field setting was examined. This study utilised a mobile phone as the method of data collection, a fairly novel technique which allows validated VAS and cognitive tasks to be completed in the participants own surroundings. This study revealed significant correlations between appetite and mood, appetite and cognition and mood and cognition, further advocating the testing of these parameters collectively. More interestingly, a higher EI at breakfast prior to morning exercise was associated with lower mental fatigue and higher alertness and overall mood post-exercise, providing a rationale for testing the dose-response of breakfast EI prior to exercise in a more closely controlled laboratory environment.

Therefore, in Chapter 5, the effect of consuming no breakfast and two breakfasts differing in energy content prior to morning exercise on cognitive function, mood and appetite in an active female sample was examined. Breakfast size and exercise interacted to affect mood and cognitive performance, but not appetite and EI. Consuming either breakfast also led to higher feelings of relaxation in the initial post-exercise period and better mood mid-afternoon. Mid-afternoon cognitive detriments were reported following the higher-energy breakfast compared to no breakfast, an effect not seen with the lower-energy breakfast. In agreement with previous literature and the results from Chapter 2, breakfast consumption compared to omission was beneficial for subjective appetite, but did not affect EI.

6.1 Appetite and Energy Intake

Over recent decades there has been a rise in obesity in the general population (Timlin & Pereira, 2007). A large percentage of the sample of active women who completed the survey in Chapter 3 specified weight control as their main motivation to exercise. Therefore, from a relevance perspective, perhaps one of the more applicable aspects of the current programme of studies was the effect of breakfast and exercise on appetite control and EI. Consuming breakfast prior to exercise led to lower reported subjective appetite when compared to breakfast omission in both in both active men (Chapter 2) and women (Chapter 5). However, it had no influence on EI when measured using a controlled *ad libitum* lunch in both Chapters, or overall energy balance (Chapter 2) or net EI (Chapter 5). There was also no effect of EI prior to morning exercise on post-exercise appetite or EI when measured in women in a field environment (Chapter 4). Whilst these results do mirror the exercise and EI literature (e.g. Maraki et al., 2005), they do not support previous breakfast research which states that consuming, compared to omitting breakfast, can reduce EI (Astbury et al., 2011; Farshchi et al., 2005). It is known that exercise enhances EE compared to resting and can be an effective method to aid weight loss if this energy is not replaced (Donnelly et al., 2003; Donnelly et al., 2009; Jakicic, 2009). It has been shown that exercising in a fasted state increases fat oxidation in both men (Enevoldsen et al., 2004; Gonzalez et al., 2013) and women (Backhouse et al., 2007) compared to exercise after a meal has been consumed. At the beginning of this programme of studies, it was speculated that if this practice led to an increase in appetite post-exercise, EI may increase subsequently, eradicating any weight-loss benefits; however, the results from the current thesis do not support this hypothesis. If weight loss is the main reason that an individual chooses to exercise, it appears that they should favour fasted morning exercise over consuming breakfast prior to exercise to maximise exercise–induced fat loss. Nonetheless, it is of course important to recognise the numerous noted benefits of consuming breakfast regularly for several aspects of health, both physical (Cho et al., 2003; Pollitt & Mathews, 1998; Rampersaud et al., 2005) and mental (Hoyland et al., 2009). If an increase in EE and fat oxidation by omitting breakfast prior to exercise is accompanied by a diminution in other areas of health this practice may not be as beneficial as it appears; further research is needed examining the longer-term effects of skipping breakfast before exercise is undertaken to assess this. It important also to consider that not consuming breakfast prior to exercise and skipping breakfast may actually be two different scenarios. If breakfast is omitted before exercise, but consumed after exercise, the benefits of EE and fat loss may be maintained alongside the additional appetite and mood benefits of breakfast consumption. However, when we consider that breakfast has previously been defined as a meal "eaten before or at the start of daily activities" (Timlin & Pereira, 2007; page 6) it could be questioned as to whether a meal consumed after morning exercise is indeed "breakfast", and if consuming it post, rather than pre-exercise would alter its effect on cognition, mood or appetite. It has been shown that breakfast improves post-prandial metabolism whether consumed before or after a bout of exercise (Fauzi & Farah, 2011), but the effect on cognitive function, mood and appetite would be an interesting concept to explore further in future studies. It may also be attractive to investigate whether participants perspective of whether a meal is "breakfast" or not has any influence on these factors.

When measured in a free-living setting, a larger breakfast consumed prior to exercise was associated with a higher EI post-exercise, when exercise intensity was controlled for. This too appears to contradict previous research which has shown that consuming compared to omitting breakfast reduces subsequent EI, also when measured in a free living environment (Farshchi et al., 2005). However, it is quite possibly reflective of the fact that those with a larger appetite generally would tend to consume more at every meal than those with a lower appetite. Even though EI was higher when a larger breakfast was consumed, when we look at net EI, few participants exceeded the recommended daily EI for a women of approx. 2000 kcal (Scientific Advisory Committee on Nutrition, 2011); even when they did, in this group this is perhaps unlikely that this would cause weight gain issues due to the active lifestyle these women lead. It should also be noted a higher EI post-exercise was associated with a number of positive outcomes; lower fatigue and jitteriness and higher relaxation and alertness. Despite reporting (via the survey conducted in Chapter 3) a perceived increase in hunger and EI post-exercise, compared to rest, this was not observed in active women when measured in a field setting (Chapter 4). A similar result was also found in Chapter 2, when active males reported lower subjective appetite after breakfast, but there were no notable differences between the exercise and rest interventions. It was speculated that BDNF may play a role in post-exercise appetite control; BDNF levels increase during exercise (e.g. Rasmussen, et al., 2009) and this growth factor can influence body weight and energy homeostasis (Noble et al., 2011; Wisse & Schwartz, 2003). A sufficient concentration of BDNF is thought to be vital for cognitive function (Tsai et al., 2003) and is lower in depressed individuals (Lee & Kim, 2010). However, as there were no differences in EI, cognitive function or mood between the rest and exercise conditions seen in Chapters 2 and 4, it is perhaps questionable as to whether BDNF levels differed considerably between the two conditions, or indeed whether changes in this protein alone are enough to significantly alter these factors.

Despite seeing no effects on EI, the robust effect that consuming breakfast had on subjective appetite sensations in both Chapters 2 and 5 should not be ignored. Evidently, this effect of breakfast on appetite was not entirely consistent; in Chapter 2, fasted exercise temporarily decreased appetite ratings, an effect not seen when breakfast was consumed beforehand, with a similar, although non-significant, effect seen in Chapter 5 also. It has been reported previously that this "exercise-induced anorexia" does not seem as prominent in females as in males (King et al., 1996) and this may explain why the data did not reach significance in Chapter 5. Serotonin can suppress appetite (Halford & Blundell, 2000), though it is unlikely that the breakfast administered in the laboratory trials in this thesis would have caused a significant rise in serotonin; whilst a very high-CHO meal can lead to an increase in this neurotransmitter, the presence of just 5% protein is enough to diminish this effect (Benton, 2002). In contrast to when resting, consuming CHO during exercise attenuates a rise in plasma tryptophan (Davis et al., 1992; Lieberman et al., 2002). However, exercising does increase serotonin levels (Kubitz & Mott, 1996) and it is plausible that the protein and CHO consumed in the breakfast trials decreased this rise, leading to augmented subjective appetite sensations in the fasted trials. This theory is substantiated further by the decrease in mental fatigue reported in the initial post-exercise period in this same study when breakfast was consumed prior to exercise, as this effect can also be explained by a lesser presence of serotonin, which can increase sensitivity to fatigue (Newsholme et al., 1987). Also, skipping breakfast can lead to disturbances in insulin sensitivity which is known to increase appetite (Farshchi et al., 2005). Although insulin was not measured, it is plausible that exercise reversed this effect temporarily, as exercise has been shown to improve insulin sensitivity (Borghouts & Keizer, 2000).

However, this exercise-induced appetite suppression in the fasted trials was transient, and overall consuming breakfast was beneficial for subjective appetite control at nearly all time points in both Chapters 2 and 5. It is thought that the main nutritional components of a typical breakfast meal (i.e. CHO and fibre) may lead to preferential glucose metabolism and insulinemic response (Blom et al., 2005; Liljeberg et al., 1999), which can reduce feelings of hunger (Ceriello et al., 2008). Research has also shown that the action of insulin likely plays a much more prominent role in appetite regulation than glucose (Lavin et al., 1996); an increased insulin response to a meal (lower insulin sensitivity) is associated with reduced satiety (Holt & Miller, 1995).

Interestingly, serum BDNF levels are positively correlated with insulin sensitivity in women (Karczewska-Kupczewska et al., 2011) and it is possible that this mechanism may have played a role in reducing appetite following the breakfast prior to exercise interventions in Chapter 5 of this thesis. As previously discussed, changes in BDNF following exercise, compared to rest, may not lead to a significant difference in EI between these conditions, but as serum BDNF is increased following exercise (Ferris et al., 2007; Gold et al., 2003; Griffin et al., 2011; Rasmussen et al., 2009; Winter et al., 2007), this could have interacted with, and augmented, the acute improvement in insulin sensitivity following breakfast consumption; BDNF levels have also been found to negatively correlate with appetite, although this has only been reported in an older adult sample (Stanek et al., 2008).

Although reduced subjective appetite did not affect EI in Chapters 2 and 5, it should be recognised that this improvement in appetite control may well have other benefits. In particular, there is a recognized reciprocal link between mood and subjective appetite; poorer mood can trigger cravings and overeating (Hill et al., 1991) and feelings of hunger are related to poorer mood (Fischer et al., 2004; Holt, 1999). If appetite control and mood enhancement are main goals of exercise, the results from this thesis would suggest that consuming breakfast prior to exercise be the recommended practice as appetite control was superior following breakfast consumption accompanied by decreased mental fatigue (Chapter 2) and increased relaxation and overall mood (Chapter 5).

It is interesting to deliberate the effect that habitual dietary practices, beyond those of breakfast consumption, may have had on EI in the studies in this thesis, and indeed on EI measured in previous research. Omitting a meal may not produce a large enough change in subjective appetite sensations to override strong everyday habitual food practices, such as consuming a meal of a certain size at a particular time point in the day, or consuming a meal provided in its entirety so as to avoid wasting food. This concept has been proposed when considering the effect of exercise alone on EI (Stubbs, 1998) and has been suggested as a reason why some individuals appear to compensate for the energy expended during exercise and others do not (Blundell et al., 2003).

6.2 Mood

The positive differences in mood following breakfast consumption prior to exercise are perhaps some of the most encouraging findings from this thesis. Previous research has found that skipping breakfast is associated with higher levels of fatigue (Tanaka, Mizuno, Fukuda, Shigihara & Watanabe, 2008). The reduction in post-exercise mental fatigue when breakfast was consumed in Chapter 2 is in agreement with an earlier study by Paul et al. (1996) and, as previously discussed, could be attributed to the presence of sufficient protein in the breakfast meal which diminished an exercise-induced rise in tryptophan, and therefore in brain serotonin (Paul et al., 1996). Serotonin can increase fatigue sensitivity (Newsholme et al., 1987) and induce feelings of drowsiness thought to be caused by an associated increase in melatonin (Richardson, 2004; Silber & Schmitt, 2010; Vanecek, 1998). As previously mentioned, consuming CHO during exercise also attenuates a rise in plasma tryptophan (Davis et al., 1992; Lieberman et al., 2002) and therefore consuming a combination of both protein and CHO prior to exercise may be particularly beneficial to moderate post-exercise mental fatigue. Without the presence of either protein or CHO in the NB conditions, the exercise period likely led to increased serotonin during and post-exercise which stimulated feelings of mental fatigue. If the presence of less serotonin is the mechanism responsible for this effect, it is perhaps not surprising that the effects on mood in Chapter 2 were limited to mental fatigue; it is a higher concentration of serotonin which is usually associated with improved mood states (Smith & Stamatakis, 2010; Wurtman & Wurtman, 1986) and as consuming breakfast may have resulted in a decrease in serotonin, this may explain why no other mood effects were identified.

It is interesting that the same effect on mental fatigue during the initial post-exercise recovery period was not seen in the active female sample in Chapter 5, especially if it is considered that females appear to be particularly sensitive to changes in mood caused by serotonin manipulation (Booij et al., 2002). This may of course suggest that serotonin is not the main influencing factor on mental fatigue in these studies. Both breakfasts administered in Chapter 5 contained a smaller amount of protein (4.5 and 9.0 g), that given in Chapter 2 (19 g) and in the study by Paul et al. (1996; approx. 14.0 - 19.0 g) and this lesser quantity may not have been sufficient to significantly decrease exercise-induced brain serotonin synthesis, therefore making differences in post-exercise fatigue between conditions less obvious. In addition, these breakfasts each contained ~18% protein, much higher than the 5% thought to be required to diminish serotonin production (Benton, 2002), again bringing to question the role of this neurotransmitter as a mechanism for the mood effects observed. Later in this discussion, it is proposed that changes in serotonin are also unlikely to have caused the difference observed in cognitive performance in Chapter 2; however, despite this it is still plausible that this component could have influenced mood, as it has been seen that the effects of serotonin on mood and cognitive function can occur independently of one another (Mendelsohn et al., 2009).

The positive effect of exercise on post-exercise relaxation seen in Chapter 5, but not Chapter 2, could possibly reflect the fact that all participants in Chapter 5 were recruited based on the confirmation that they regularly undertook running in the morning; this level of familiarity to the exercise intervention was not confirmed in the sample tested in Chapter 2 and it has been suggested that the effect of exercise on mood is moderated by how conversant the mode of exercise is (Salmon, 2001).

Brain requirements for fuel (i.e. glucose) may be high during the post-exercise recovery period (Ide et al., 1999); if fuel availability is poor, this could be detrimental for mood (Benton & Parker, 1998; Pollitt & Matthews, 1998). Foster et al. (2007) found higher blood glucose accompanied increases in alertness and contentment when breakfast was consumed rather than omitted. Consuming a meal containing CHO prior to exercise may contribute to post-exercise mood state by increasing pre, and therefore post, exercise glycogen stores (Hargreaves et al., 2004); there was some evidence for this found in both Chapters 2 and 5. The observed increased feelings of relaxation when breakfast was consumed, rather than omitted, in Chapter 5 do support previous breakfast research where breakfast was associated with feeling more relaxed (Benton &

Brock, 2010) and calmer (Smith et al., 1999). It is quite possible that this effect was simply due to the fact that consuming, rather than omitting breakfast was the usual practice for the sample of women tested. It has been suggested that habitual breakfast behaviours may influence mood changes in response to acute breakfast consumption (Lloyd et al., 1996).

These improvements in mood do appear to somewhat coincide with lower subjective appetite. It is likely that the appetite-supressing effect of consuming breakfast prior to exercise contributed to the improved mood seen post-exercise; therefore, if mood enhancement is the required post-exercise outcome, this practice should be encouraged. It is of course important not to exaggerate this effect; in the laboratory-based studies (Chapters 2 and 5) during the immediate post-exercise recovery period both men and women only reported an improvement in one mood state of the many that were measured. However, this appetite-mood relationship was also observed in the field study in Chapter 4; post-exercise, higher hunger was associated with having more of a headache and feeling less alert, whilst higher fullness was associated with feeling more relaxed, alert and having a better overall mood, although, surprisingly, there were no direct correlations between breakfast size and any of the post-exercise subjective appetite measures. Still, it appears that whilst changes in subjective appetite may not significantly alter EI, better appetite control appears to contribute to a superior mood state to some extent.

6.3 Cognitive Function

The effects of breakfast and exercise on cognitive function observed in this programme of studies were not entirely clear. This may not be surprising given that the literature documenting the effect of breakfast alone on cognitive function is generally quite disordered. The positive effect of breakfast on memory in a healthy adult population, in particular episodic memory, has been frequently reported (e.g. Benton & Parker, 1998) and can be viewed with some confidence, whilst data on other cognitive domains is inconclusive. As the RVIP and NBack tasks are both measures of working memory, it is perhaps not surprising that there was no positive influence of breakfast on either task in Chapter 2. In fact, following the test drink, an improvement in RVIP RT was observed when breakfast was omitted, compared to consumed, prior to rest. Breakfast also decreased FCRT and Stroop accuracy in this study, suggesting a negative impact on decision making and response inhibition. It could be suggested that an increase in serotonin may have caused this impairment in performance, as it has been previously shown that reducing serotonin levels via BCAA supplementation during exercise (Blomstrand, 2001) and via a low CHO/high protein breakfast (Fischer et al., 2002) subsequently improved cognitive performance. However, there are a couple of considerations which suggest that serotonin may not be the mechanism responsible for the cognitive detriments seen in this study. Firstly, a change in serotonin is thought to affect episodic memory only, and not working memory, response inhibition or decision making (Mendelsohn et al., 2009). Serotonin is just one of multiple neurotransmitters which stimulate the pre-frontal cortex, a brain region responsible for attention, working memory and executive functions, and manipulation of serotonin alone may not compromise its function (Robbins, 2005). Also, as previously stated, it is unlikely that the breakfast provided would have led to a significant change in serotonin levels as it contained > 5% protein (Benton, 2002). Instead, it is more probable that the exercise intervention would have caused a stimulation of serotonin production (Kubitz & Mott, 1996), but as previously discussed (section 6.2), the consumption of breakfast prior to exercise attenuated this effect (Davis et al., 1992; Lieberman et al., 2002). Therefore, serotonin concentration may have been highest in the NB E condition in Chapter 2, but was probably relatively unchanged in the other conditions. When it is considered that attentional processes, although normally unaffected by serotonin, have been shown to improve when serotonin is depleted (Mendelsohn et al., 2009) and associatively, memory impairments have also been found following tryptophan loading, which increased serotonin (Sobczak et al., 2003), the effects in Chapter 2 are in fact the opposite of what would be expected if serotonin was responsible for changes in cognitive function in this case. Another possible mechanism for these effects may be cortisol. Raised blood glucose concentrations, such as were likely in the breakfast conditions, can augment cortisol secretion during challenging cognitive tasks, leading to impaired cognitive performance (Gibson, 2007; Buchanan, Tranel & Adolphs, 2006).

In Chapter 4, breakfast consumption prior to exercise did not affect post-exercise cognitive task performance. This could be because cognition was measured in a field setting, but there were effects observed when this same method was used in Chapter 5. In this chapter, a detrimental effect of the larger breakfast on mid-afternoon NBack and RVIP performance, again the two tasks which measure working memory, were identified. However, these negative effects were not apparent when a smaller breakfast was consumed suggesting that this may be a preferable practice; this is discussed further later. These results somewhat mirror those found by Nabb and Benton (1996), who reported that memory score negatively correlated with the caloric content of the breakfast administered, although Michaud et al. (1991) previously reported improved episodic memory following a high caloric breakfast.

As mentioned, overall the results from this thesis do not suggest that breakfast has an entirely positive effect on cognitive function, in particular on working memory. A recent article by Zilberter and Zilberter (2013) suggests that the belief that consuming breakfast is beneficial for cognitive function may be incorrect. They agree that a stable blood glucose profile appears to contribute positively to cognitive function, but highlight the fact that the most stable post-prandial profile is seen following a high-fat, rather than high-CHO, breakfast (Fischer, 2001). They suggest that the metabolic response seen following consumption of a high-fat breakfast more closely mimics the effects of skipping breakfast, and imply that this practice may in fact produce the same neuroprotective effects as those seen when following a ketogenic (low-CHO) or intermittent fasting diet. Of course, when considering whether or not consuming breakfast is beneficial, it must be considered in context. The authors do mention that the persistent hunger often associated with following these types of diet is often difficult to manage (Stote et al., 2007); naturally, this can lead to detriments in mood (Fischer, et al., 2004) and potentially diminish cognitive function due to the distraction of hunger sensations. Even though fasting may lead to a more stable metabolic response acutely, there is evidence that insulin sensitivity and glucose responses are improved when the next meal after breakfast is consumed both acutely (e.g. Astbury et al., 2011) and regularly (Pereira et al., 2011). It is interesting to reconsider whether consuming breakfast may indeed be the best practice with regards to improving cognitive function. However, the long term health benefits of breakfast consumption are well documented (Pasman, Blokdijk, Bertina, Hopman & Hendriks, 2003; Smith, 1998, 1999; Smith, 2003; Benton & Brock, 2010; Odegaard et al., 2013), and even though breakfast may not have a consistent, robust, positive effect on cognition acutely, its beneficial role for general health and wellbeing is clear and should not be disregarded.

Interestingly, the negative effect of breakfast consumption on RVIP RT and Stroop accuracy did appear to be alleviated by exercise in the active male sample in Chapter 2. The literature does suggest that exercise is stimulating (Lambourne & Tomporowski, 2010) and an increase in arousal post-exercise can improve RT responses (Etnier et al., 1997) and decision making speed (Adam et al., 1997; McMorris & Graydon, 1996). Whilst data from this thesis do not support the hypothesis that breakfast prior to exercise can enhance post-exercise cognitive performance, they do suggest that in habitually active males, exercise can reverse any negative cognitive consequence of breakfast consumption.

Cognitive performance and mood are frequently measured together within the same study. It has been suggested that cognitive function may be moderated by mood state (Chepenik et al., 2007), although this has been recently challenged (Hopkins et al., 2012). Still, a possible mechanism responsible for the cognitive detriments following breakfast may be the increased feelings of tension associated with consuming breakfast prior to rest, given the documented relationship between mood and cognitive performance. However, tension was not higher when breakfast was consumed prior to exercise, possibly due to increased pre-frontal cortex activity following exercise, which correlates with feelings of calmness (Hall et al., 2007). Findings from the field study (Chapter 4) also provide some support for the cognition/mood mediation theory. Feeling more tense and jittery was associated with more ART errors and NBack task performance appeared particularly sensitive to changes in mood; higher fatigue was associated with a decline in performance, whilst a better mood and higher alertness coincided with an improvement in performance on this task. Contradictory, when the same mobile phone field-setting methodology was used in Chapter 5 there was an increase in mood mid-afternoon when breakfast was consumed, but a decrease in cognitive performance at the same time point, the opposite of what would be expected. However, there was little evidence of this relationship when cognitive performance and mood were measured in a laboratory environment. Feeling more relaxed and less mentally fatigued did not appear to coincide with enhanced cognitive performance; a recent reported showed that changes in cognition following exercise do not correlate with mood, suggesting that separate neural systems may facilitate the effects on these parameters (Hopkins et al., 2012), but it is difficult to ascertain whether or not this may be correct from the evidence presented in this thesis.

Poorer appetite control post-exercise (a higher desire to eat and lower satisfaction) positively correlated with task difficultly ratings in the field study (Chapter 4). However, despite a higher post-exercise EI being associated with higher alertness and lower fatigue, this was also associated with slower RVIP RT and ART. Indeed, RT is one aspect of cognition which is often shown to improve when hunger is higher through lower EI (Fischer, et al., 2004; Hopkins et al., 2012).

6.4 Breakfast size

Whilst we see some fairly clear differences between breakfast consumption and omission prior to exercise on post-exercise appetite and mood, results from Chapter 5 did not support the idea that there is a dose response effect of breakfast size. It is possible that this may reflect a small difference between the energy content of the breakfasts administered; there were more significant differences in mood, cognitive function and appetite between the no breakfast and larger breakfast condition, than the smaller breakfast condition, suggesting that this difference of at least 236 kcal may be required to detect variances. As discussed, although mid-afternoon cognitive detriments were reported following the higher-energy breakfast compared to no breakfast, this effect was not seen with the lower-energy breakfast. The results from the survey in Chapter 3 showed that habitually active women were less likely to consume food before they exercised in the morning compared to others times of the day. This survey also revealed that those who were more likely to omit breakfast before exercising in the morning were also less likely to report that exercise improved their concentration, suggesting that breakfast consumption, regular or acute, may modulate post-exercise attentiveness. The main reasons given for fasting before exercise were to avoid discomfort during exercise and lack of time; and the results from Chapter 5 do suggest that a small breakfast which is quick to eat has very similar mood and appetite benefits to a larger breakfast, but may avoid cognitive decline mid-afternoon. This type of breakfast, cereal-based and not much more than 100 kcal may be a suitable breakfast to recommend to this population if appetite control and mood enhancement are the main reasons they choose to exercise. However, a 100 kcal breakfast provides much less than the recommended 20-35% of daily energy needs (Timlin & Pereira, 2007). Therefore, further to the suggestion that future research could focus on establishing if the effects of breakfast differ depending on whether it is consumed before or after exercise, it would also be interesting to see if splitting breakfast between the two time points, perhaps consuming 100 kcal before, and 300 kcal after, exercise may be a beneficial practice.

6.5 Summary

To summarise, it would appear that those exercising to maximise weight loss should perhaps undertake morning exercise in a fasted state, leading to enhanced EE and fat oxidation with no significant effect on subsequent EI. However, if appetite control and mood benefits are the main reason for exercising, the results suggest that consuming breakfast prior to exercise should be encouraged, as the superior appetite control associated with this practice appears to concur with improved mood states post-exercise. However, the results from this thesis do not indicate which practice, consuming or omitting breakfast, is preferential for post-exercise cognitive benefits, nor do they clearly suggest a mechanism which may be responsible for any of the noted effects.

The results from this thesis also suggest that consuming a small cereal based breakfast of around 100 kcal before exercise has comparable positive mood and appetite effects to those associated with consumption of a larger breakfast. Some active women avoid consuming breakfast prior to morning exercise to avoid discomfort during exercise and due to lack of time. However, if mood and appetite improvement is an individual's motivation to exercise, consuming a small breakfast prior to exercise, rather than remaining fasted, should possibly be encouraged.

6.6 Limitations and future directions

Whilst the studies conducted for this PhD thesis do enhance knowledge in this area of research, it is important to recognise their limitations. An obvious caveat is the use of food diaries to measure EI when participants were outside of the laboratory environment. Whilst this is certainly not an uncommon practice for these type of research studies, the limitations of this method mean that data cannot be viewed with complete confidence. Participants notoriously under-report when asked to complete a food diary, decreasing the internal validity of the data (Livingstone & Black, 2003). Studies which monitor EI in a controlled setting over a prolonged period of time require more resources, but should be attempted in future studies in this area. Nonetheless, the use of food diaries may provide a more representative observation of an individual's eating habits than when they are asked to choose foods from a limited selection, such as at a buffet provided by the researcher. However, it is possible that had a buffet been administered in Chapters 2 and 5 which contained several different foods, instead of only a homogenous pasta meal, differences in the types of foods chosen may have been observed as exercise has been shown to alter food choice (King, 1999). A further caveat in Chapter 2 was that tolerance to the nutritional interventions was not measured; food palatability influences eating cessation (Blundell & Rogers, 1991) and satiety (Dye & Blundell, 2002). However, this issue was addressed in Chapter 5.

There may have also been alternative methods in which to administer the breakfast treatments in Chapters 2 and 5. Breakfast amount could have selected as a % of daily energy requirements based on body weight, as used previously (Astbury, Taylor & Macdonald, 2011). To control for any effects of habitual meal size, participants could have been allowed to self-select breakfast quantity at the primary study visit, with an identical breakfast served to each individual on subsequent visits as there may be negative consequences of consuming an unfamiliar-sized meal (Rogers and Lloyd, 1994).

It should also be acknowledged that there is some evidence to suggest that long-term breakfast habits may influence responses to acute breakfast consumption (Halsey et al., 2012; Pereira et al., 2011). However, consuming breakfast prior to exercise was not a completely novel situation for any of the participants in Chapter 2, and therefore it is suspected that it would not have significantly influenced the results. The survey revealed that those who regularly skipped breakfast were less likely to consider that this habit negatively affected their mood or appetite. The positive effects of breakfast on mood seen in Chapter 5 may be because the sample were all habitual breakfast consumers; disturbing their usual routine by withholding breakfast may have led to lower feelings of relaxation. It would have been desirable to test, and compare, both habitual and non-habitual consumers in each intervention study, and this method should be considered for future examination.

The mechanisms mentioned as possible causes for the effects seen in Chapters 2 and 5 are of course speculative; no actual physiological measures of serotonin, glucose, insulin, cortisol or BDNF were taken. With the limited amount of research conducted in this area thus far, particularly in habitually active women, it seemed appropriate to first begin to build a better picture of the habits of this population and preliminarily test to see whether consuming breakfast prior to exercise did in fact affect mood, cognitive function and appetite. Investigations into possible mechanisms are of course important, and would certainly be recommended as a future direction for this topic of research. Studies allowing for direct comparisons between habitual and non-habitual breakfast consumers, different types of breakfast and exercise interventions and even between males and females would all continue to develop understanding in this area of research.

It should be recognised that there are difficulties in general when conducting research which predominantly measures subjective feelings and states. Mood is a complex paradigm, and is influenced by a plethora of both internal and external factors. Whilst it is possible to control the environment in which mood is measured, we can never be entirely certain that any changes in mood seen are due to the small nutritional interventions that are administered, and not due to other external influences. There is also likely to be individual differences in how mood states are interpreted, which creates some ambiguity that the procedures actually measure what they intend to, and we can certainly question if a single VAS can really accurately measure a mood state. With regards to the strength of such data, it could be argued that even if significant effects are found for individual mood states, individuals may be unlikely to notice such minor changes in their mood in their day to day life. Although some cognitive and mood differences between conditions were seen in the evening in Chapter 5, it is of course highly likely that at this point in time we are no longer seeing the effects of breakfast size, but the effects of an accumulation of many different nutritional, behavioural and emotional factors which have occurred once the participant has left the laboratory environment. Differences in whether the evening meal was consumed before or after completing the mobile phone cognitive tasks may explain the enhanced cognitive task performance seen in the larger breakfast condition compared to the other conditions. In a field study, it is difficult to judge the appropriate level of control to impose on the participants; too much could result in the study no longer reflecting a “free-living” environment, but perhaps in this case regulating the timing of meal consumption in relation to completing the tasks would have been useful.

The cognitive tasks selected to use in this thesis have been tested and validated, and do, to the best of our knowledge, measure the aspect of cognition they are intended to. However, it should be recognised that we can never be entirely confident that this is the case. Another, perhaps more pertinent issue when measuring cognitive function is the ability, or lack of ability, of the tasks to reflect cognitive behaviours which occur in a real-life environment.

Individuals also have a tendency to alter their normal behaviour so it fits what they believe is expected of them. As previously discussed, this is particularly apparent when using food diaries to measure EI (Livingstone & Black, 2003). However, it is also likely that individuals will under eat when presented with an *ad libitum* meal which they can see is being monitored and measured by the researcher (Blundell et al., 2010). This effect may be particularly evident in females as previous research has shown that this gender are aware that food consumption can influence the development of personal impressions in a social situation (Mori, Chaiken & Pliner, 1987). Participants may also be more likely to want to be seen to be eating the "right" foods, and as such may not report consuming any foods they deem to be unhealthy (Johansson, Wikman, Ahren Hallmans & Johansson, 2001) and for this reason may change their diet for the duration it is being monitored. As with mood, there are also likely to be individual differences in the way that appetite sensations are perceived, creating difficulties in measuring this factor. Whilst as researchers we do our best to disguise any study outcomes we may be expecting to find, it is often difficult to control people's expectations of what the study is measuring especially as it is often an ethical requirement to provided background information about the research area to participants before they consent to take part. This is particularly true of the nature of the studies presented in this thesis; it was not possible to blind the treatments and this of course should be acknowledged as quite a major issue, hence the strong favouring of double-blind studies where possible in research in general. To address this problem somewhat, treatments given in Chapters 2 and 5 could have been single-blinded and this would certainly be recommended for consideration in future studies in this area. Additional thought should also be given to the information participants are provided with prior to starting the study, perhaps to deceive participants into thinking that there is an alternative motive behind conducting the study.

A reoccurring issue in this, and indeed many, areas of research is the use of samples consisting of university students, mainly through recruitment convenience. Many past breakfast studies have focussed on school children due to the importance of maximising academic performance and it has been suggested that breakfast consumption may increase alertness and motivation to concentrate and learn (Hoyland et al., 2008). However, it could certainly be argued that an increase in academic performance would also be beneficial and entirely relevant to university students also, advocating their use in breakfast/cognition research studies.

Despite these limitations and factors which could not be controlled, it should of course be recognized that the studies in this thesis produced some significant and positive results, reflecting that the studies were well executed and controlled. In any area of research, particularly that which is conducted in humans, all we can do is to recognise the caveats and interpret data based on what it is possible to control.

In conclusion, data from this thesis suggest that whether or not breakfast should be consumed prior to exercise is dependent on the main reason for undertaking exercise. The interactive effect of breakfast and exercise was present, but fairly limited. Consuming even a small breakfast prior to exercise can positively influence mood and appetite, but the effect of breakfast on post-exercise cognitive function remains unclear. Further research is needed to ascertain the most appropriate type of breakfast to consume prior to exercise to maximise appetite, mood and cognitive benefits in recreationally active populations.

References

Abercrombie, H. C., Kalin, N. H., Thurow, M. E., Rosenkranz, M. A. & Davidson, R. J. (2003). Cortisol variation in humans affects memory for emotionally laden and neutral information. *Behavioral Neuroscience, 117*, 505.

Adam, J. J., Teeken, J. C., Ypelaar, P. J. C., Verstappen, F. T. J. & Paas, F. G. W. (1997). Exercise-induced arousal and information processing. *International Journal of Sport Psychology, 28*, 217-226.

Adolphus, K., Lawton, C. L., & Dye, L. (2013). The effects of breakfast on behavior and academic performance in children and adolescents. *Frontiers in human neuroscience*, *7*.

Akitsuki, Y., Nakawaga, S., Sugiura, M. & Kawashima, R. (2011). Nutritional Quality of Breakfast Affects Cognitive Function: An fMRI Study. *Neuroscience & Medicine, 2*, 192-197.

Aks, D. J. O. A. (1998). Influence of exercise on visual search: Implications for mediating cognitive mechanisms. *Perceptual and Motor Skills, 87*, 771-783.

Al-Nimer, M. S. M. & Al-Kurashy, H. M. K. (2007). Gender Differences in Psychomotor Performance After Six Minutes Cycling Exercise. *J. Med. Sci, 7*, 1345–1349.

Ali, A. & Williams, C. (2009). Carbohydrate ingestion and soccer skill performance during prolonged intermittent exercise. *Journal of Sports Sciences, 27*, 1499 - 1508.

American Dietetic Association (2009). Position of the American Dietetic Association, Dietitians of Canada, and the American College of Sports Medicine: Nutrition and Athletic Performance. *Journal of the American Dietetic Association, 109*, 509-527.

Amiel, S. A., Pottinger, R. C., Archibald, H. R., Chusney, G., Cunnah, D. T. F., Prior, P. F. & Gale, E. A. M. (1991). Effect of Antecedent Glucose Control on Cerebral Function During Hypoglycemia. *Diabetes Care, 14*, 109-118.

Anderson, R. J. & Brice, S. (2011). The mood-enhancing benefits of exercise: Memory biases augment the effect. *Psychology of Sport and Exercise, 12*, 79-82.

Arciero, P. J., Goran, M. I. & Poehlman, E. T. (1993). Resting metabolic rate is lower in women than in men. *Journal of Applied Physiology, 75*, 2514-2520.

Armstrong, L. E., Ganio, M. S., Casa, D. J., Lee, E. C., McDermott, B. P., Klau, J. F., Jimenez, L., Le Bellego, L., Chevillotte, E. & Lieberman, H. R. (2012). Mild Dehydration Affects Mood in Healthy Young Women. *The Journal of Nutrition, 142*, 382-388.

Association., A. D. (2013). Diagnosis and classification of diabetes mellitus. *Diabetes Care, 36*, S67-S74.

Astbury, N. M., Taylor, M. A. & Macdonald, I. A. (2011). Breakfast consumption affects appetite, energy intake, and the metabolic and endocrine responses to foods consumed later in the day in male habitual breakfast eaters. *Journal of Nutrition, 141*, 1381-1389.

Asztalos, M., De Bourdeaudhuij, I. & Cardon, G. (2010). The relationship between physical activity and mental health varies across activity intensity levels and dimensions of mental health among women and men. *Public Health Nutrition, 13*, 1207-1214.

Audiffren, M., Tomporowski, P. D. & Zagrodnik, J. (2008). Acute aerobic exercise and information processing: Energizing motor processes during a choice reaction time task. *Acta Psychologica, 129*, 410.

Audiffren, M., Tomporowski, P. D. & Zagrodnik, J. (2009). Acute aerobic exercise and information processing: Modulation of executive control in a Random Number Generation task. *Acta Psychologica, 132*, 85-95.

Backhouse, S. H., Bishop, N. C., Biddle, S. J. H. & Williams, C. (2005). Effect of carbohydrate and prolonged exercise on affect and perceived exertion. *Medicine and Science in Sports and Exercise, 37*, 1768.

Backhouse, S. H., Williams, C., Stevenson, E. & Nute, M. (2007). Effects of the glycemic index of breakfast on metabolic responses to brisk walking in females. *European Journal of Clinical Nutrition, 61*, 590-596.

Barton, B. A., Eldridge, A. L., Thompson, D., Affenito, S. G., Striegel-Moore, R. H., Franko, D. L., Albertson, A. M. & Crockett, S. J. (2005). The Relationship of Breakfast and Cereal Consumption to Nutrient Intake and Body Mass Index: The National Heart, Lung, and Blood Institute Growth and Health Study. *Journal of the American Dietetic Association, 105*, 1383-1389.

Beck, A. T. (1967). *Depression: Clinical, experimental, and theoretical aspects.* New 'York: Hoeber.

Bellisle, F. (1999). Food choice, appetite and physical activity. *Public Health Nutrition, 2*, 357-361.

Bellisle, F., Blundell, J. E., Dye, L., Fantino, M., Fern, E., Fletcher, R. J., Lambed, J., Roberfroid, M., Specter, S., Westenhöfer, J. & Westerterp-Plantenga, M. S. (1998). Functional food science and behaviour and psychological functions. *British Journal of Nutrition, 80*, 173-193.

Bellisle, F., Dalix, A., Airinei, G., Hercberg, S. & Péneau, S. (2009). Influence of dietary restraint and environmental factors on meal size in normal-weight women. A laboratory study. *Appetite, 53*, 309-313.

Benini, L., Castellani, G., Brighenti, F., Heaton, K., Brentegani, M., Casiraghi, M., Sembenini, C., Pellegrini, N., Fioretta, A. & Minniti, G. (1995). Gastric emptying of a solid meal is accelerated by the removal of dietary fibre naturally present in food. *Gut, 36*, 825-830.

Benton, D. (2002). Carbohydrate ingestion, blood glucose and mood. *Neuroscience and Biobehavioral Reviews, 26*, 293-308.

Benton, D. & Brock, H. (2010). Mood and the macro-nutrient composition of breakfast and the mid-day meal. *Appetite, 55*, 436-440.

Benton, D., Owens, D. A. & Parker, P. Y. (1994). Blood glucose memory and attention. *Neuropsychologia, 32*, 595-607.

Benton, D. & Parker, P. Y. (1998). Breakfast, blood glucose, and cognition. *American Journal of Clinical Nutrition, 67*, 772S-778S.

Benton, D., Ruffin, M. P., Lassel, T., Nabb, S., Messaoudi, M., Vinoy, S. & Lang, V. (2003). The delivery rate of dietary carbohydrates affects cognitive performance in both rats and humans. *Psychopharmacology*, *166*(1), 86-90.

Benton, D. & Sargent, J. (1992). Breakfast, blood glucose and memory. *Biological Psychology, 33*, 207-210.

Benton, D., Slater, O. & Donohoe, R. T. (2001). The influence of breakfast and a snack on psychological functioning. *Physiology and Behavior, 74*, 559-571.

Berchtold, N. C., Castello, N. & Cotman, C. W. (2010). Exercise and time-dependent benefits to learning and memory. *Neuroscience, 167*, 588-597.

Berger, B. G., Friedmann, E. & Eaton, M. (1988). Comparison of jogging, the relaxation response, and group interaction for stress reduction. *Journal of Sport and Exercise Psychology, 10*, 431-447.

Berger, B. G. & Motl, R. W. (2000). Exercise and mood: A selective review and synthesis of research employing the profile of mood states. *Journal of Applied Sport Psychology, 12*, 69-92.

Blom, W. A. M., Stafleu, A., de Graaf, C., Kok, F. J., Schaafsma, G. & Hendriks, H. F. J. (2005). Ghrelin response to carbohydrate-enriched breakfast is related to insulin. *The American Journal of Clinical Nutrition, 81*, 367-375.

Blomstrand, E. (2001). Amino acids and central fatigue. *Amino Acids, 20*, 25-34.

Blomstrand, E., Hassmén, P., Ekblom, B. & Newsholme, E. (1991). Administration of branched-chain amino acids during sustained exercise — effects on performance and on plasma concentration of some amino acids. *European Journal of Applied Physiology and Occupational Physiology, 63*, 83-88.

Blundell, J. (1991). Pharmacological approaches to appetite suppression. *Trends in Pharmacological Sciences, 12*, 147-157.

Blundell, J., De Graaf, C., Hulshof, T., Jebb, S., Livingstone, B., Lluch, A., Mela, D., Salah, S., Schuring, E. & Van Der Knaap, H. (2010). Appetite control: methodological aspects of the evaluation of foods. *Obesity Reviews, 11*, 251-270.

Blundell, J. & Rogers, P. (1991). Hunger, hedonics, and the control of satiation and satiety. *Chemical Senses, 4*, 127-148.

Blundell, J., Stubbs, R., Hughes, D., Whybrow, S. & King, N. (2003). Cross talk between physical activity and appetite control: does physical activity stimulate appetite? . *The Proceedings of the Nutrition Society, 62*, 651-661.

Blundell, J. E., Green, S. & Burley, V. (1994). Carbohydrates and human appetite. *The American journal of clinical nutrition, 59*, 728S-734S.

Boecker, H., Sprenger, T., Spilker, M. E., Henriksen, G., Koppenhoefer, M., Wagner, K. J., Valet, M., Berthele, A. & Tolle, T. R. (2008). The Runner's High: Opioidergic Mechanisms in the Human Brain. *Cerebral Cortex, 18*, 2523-2531.

Booij, L., Van der Does, W., Benkelfat, C., Bremner, J. D., Cowen, P. J., Fava, M., Gillin, C., Leyton, M., Moore, P. & Smith, K. A. (2002). Predictors of mood response to acute tryptophan depletion: a reanalysis. *Neuropsychopharmacology, 27*, 852-861.

Borg, G. A. (1973). Perceived exertion: a note on “history” and methods. *Medicine and Science in Sports, 5* 90-93.

Borghouts, L. B. & Keizer, H. A. (2000). Exercise and Insulin Sensitivity: A Review. *International Journal of Sports Medicine, 21*, 1-12.

Bracken, R. M., Linnane, D. M. & Brooks, S. (2005). Alkalosis and the plasma catecholamine response to high-intensity exercise in man. *Medicine and Science in Sports and Exercise, 37*, 227-233.

Brindal, E., Baird, D., Danthiir, V., Wilson, C., Bowen, J., Slater, A., & Noakes, M. (2012). Ingesting breakfast meals of different glycaemic load does not alter cognition and satiety in children. *European Journal of Clinical Nutrition, 66*(10), 1166-117.

Brisswalter, J. & Arcelin, R. (1997). Influence of Physical Exercise on Simple Reaction Time: Effect of Physical Fitness. *Perceptual and Motor Skills, 85,* 1019-1027.

Brisswalter, J., Collardeau, M. & Arcelin, R. (2002). Effects of Acute Physical Exercise Characteristics on Cognitive Performance. *Sports Medicine, 32* 555-566.

Broom, D. R., Batterham, R. L., King, J. A. & Stensel, D. J. (2009). Influence of resistance and aerobic exercise on hunger, circulating levels of acylated ghrelin, and peptide YY in healthy males. *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology, 296*, R29-R35.

Broom, D. R., Stensel, D. J., Bishop, N. C., Burns, S. F. & Miyashita, M. (2007). Exercise-induced suppression of acylated ghrelin in humans. *Journal of Applied Physiology, 102*, 2165-2171.

Buchanan, T. W., Tranel, D. & Adolphs, R. (2006). Impaired memory retrieval correlates with individual differences in cortisol response but not autonomic response. *Learning and Memory, 13*, 382-387.

Buhot, M. C. (1997). Serotonin receptors in cognitive behaviors. *Current Opinion in Neurobiology, 7*, 243-254.

Burton-Freeman, B. M. & Keim, N. L. (2008). Glycemic index, cholecystokinin, satiety and disinhibition: is there an unappreciated paradox for overweight women? *International Journal of Obesity, 32*, 1647-1654.

Burton, F., Malkova, D., Caslake, M. & Gill, J. (2007). Energy replacement attenuates the effects of prior moderate exercise on postprandial metabolism in overweight/obese men. *International Journal of Obesity, 32*, 481-489.

Caudwell, P., Gibbons, C., Hopkins, M., King, N., Finlayson, G. & Blundell, J. (2012). No Sex Difference in Body Fat in Response to Supervised and Measured Exercise. *Medicine and Science in Sports and Exercise*, *45,* 2, 351-358.

Ceriello, A., Esposito, K., Piconi, L., Ihnat, M. A., Thorpe, J. E., Testa, R., Boemi, M. & Giugliano, D. (2008). Oscillating Glucose Is More Deleterious to Endothelial Function and Oxidative Stress Than Mean Glucose in Normal and Type 2 Diabetic Patients. *Diabetes, 57*, 1349-1354.

Chalder T., Berelowitz G., Pawlikowska T., Watts L., Wessely S., Wright D. & Wallace E.P. (1993). Development of a fatigue scale. *Journal of Psychosomatic Research*, *37*(2) , 147-153.

Chandarana, K., Drew, M. E., Emmanuel, J., Karra, E., Gelegen, C., Chan, P., Cron, N. J. & Batterham, R. L. (2009). Subject standardization, acclimatization, and sample processing affect gut hormone levels and appetite in humans. *Gastroenterology, 136*, 2115-2126.

Chang, Y. K., Labban, J. D., Gapin, J. I. & Etnier, J. L. (2012). The effects of acute exercise on cognitive performance: A meta-analysis. *Brain Research, 1453*, 87-101.

Cheng, M. H.-Y., Bushnell, D., Cannon, D. T. & Kern, M. (2009). Appetite regulation via exercise prior or subsequent to high-fat meal consumption. *Appetite, 52*, 193-198.

Chepenik, L. G., Cornew, L. A. & Farah, M. J. (2007). The Influence of Sad Mood on Cognition. *Emotion, 7*, 802-811.

Chmura, J., Nazar, K. & Kaciuba-Uscilko, H. (1994). Choice reaction time during graded exercise in relation to blood lactate and plasma catecholamine thresholds. *International Journal of Sports Medicine, 15*, 172-176.

Cho, S., Dietrich, M., Brown, C. J. P., Clark, C. A. & Block, G. (2003). The Effect of Breakfast Type on Total Daily Energy Intake and Body Mass Index: Results from the Third National Health and Nutrition Examination Survey (NHANES III). *Journal of the American College of Nutrition, 22*, 296-302.

Christensen, L. & Pettijohn, L. (2001). Mood and carbohydrate cravings. *Appetite, 36*, 137-145.

Churchill, J. D., Galvez, R., Colcombe, S., Swain, R. A., Kramer, A. F. & Greenough, W. T. (2002). Exercise, experience and the aging brain. *Neurobiology of Aging, 23*, 941-955.

Cian, C., Koulmann, N., Barraud, P., Raphel, C., Jimenez, C. & Melin, B. (2000). Influences of variations in body hydration on cognitive function: Effect of hyperhydration, heat stress, and exercise-induced dehydration. *Journal of Psychophysiology, 14*, 29.

Cohen, S., Kamarak, T., & Mermelstein, R. (1983).A global measure of perceived stress. *Journal of Health and Social Behaviour, 24, 385-396.*

Coles, K. & Tomporowski, P. D. (2008). Effects of acute exercise on executive processing, short-term and long-term memory. *Journal of Sports Sciences, 26*, 333-344.

Collardeau, M., Brisswalter, J., Vercruyssen, F., Audiffren, M. & Goubault, C. (2001). Single and choice reaction time during prolonged exercise in trained subjects: influence of carbohydrate availability. *European Journal of Applied Physiology, 86*, 150-156.

Conn, V. S. (2010). Depressive Symptom Outcomes of Physical Activity Interventions: Meta-analysis Findings. *Annals of Behavioral Medicine, 39*, 128-138.

Conner, M., Johnson, C., & Grogan, S. (2004). Gender, sexuality, body image and eating behaviours. *Journal of Health Psychology*, *9*(4), 505-515.

Cooper, B. R., Breese, G. R., Grant, L. D. & Howard, J. L. (1973). Effects of 6-hydroxydopamine treatments on active avoidance responding: evidence for involvement of brain dopamine. *Journal of Pharmacology and Experimental Therapeutics, 185*, 358-370.

Corder, K., van Sluijs, E. M. F., Steele, R. M., Stephen, A. M., Dunn, V., Bamber, D., Goodyer, I., Griffin, S. J. & Ekelund, U. (2011). Breakfast consumption and physical activity in British adolescents. *British Journal of Nutrition, 105*, 316-321.

Cox, R. H., Thomas, T. R. & Davis, J. E. (2001). Positive and negative affect associated with an acute bout of aerobic exercise. *J Exerc Physiol, 4*, 13-20.

Craft, L. L. (2005). Exercise and clinical depression: examining two psychological mechanisms. *Psychology of Sport and Exercise, 6*, 151-171.

Craig, C. L., ., Marshall, A. L., Sja-stra-m, M., Bauman, A. E., Booth, M. L., Ainsworth, B. E., Pratt, M., Ekelund, U., Yngve., A., Sallis, J. F. & Oja, O. (2003). International Physical Activity Questionnaire: 12-Country Reliability and Validity. *Medicine and Science in Sports and Exercise, 35*, 1381-1395.

Cunliffe, A., Obeid, O. A. & Powell-Tuck, J. (1997). Post-prandial changes in measures of fatigue: Effect of a mixed or a pure carbohydrate or pure fat meal. *European Journal of Clinical Nutrition, 51*, 831-838.

Daley, A. (2008). Exercise and depression: a review of reviews. *Journal of Clinical Psychology in Medical Settings, 15*, 140-147.

Daley, A. J. & Maynard, I. W. (2003). Preferred exercise mode and affective responses in physically active adults. *Psychology of Sport and Exercise, 4*, 347-356.

Davis, J., Bailey, S., Woods, J., Galiano, F., Hamilton, M. & Bartoli, W. (1992). Effects of carbohydrate feedings on plasma free tryptophan and branched-chain amino acids during prolonged cycling. *European Journal of Applied Physiology and Occupational Physiology, 65*, 513-519.

Davis, J. M. & Bailey, S. P. (1997). Possible mechanisms of central nervous system fatigue during exercise. *Medicine and Science in Sports and Exercise, 29*, 45-57.

Davranche, K., Audiffren, M. & Denjean, A. (2006). A distributional analysis of the effect of physical exercise on a choice reaction time task. *Journal of Sports Sciences, 24*, 323-329.

Davranche, K. & McMorris, T. (2009). Specific effects of acute moderate exercise on cognitive control. *Brain and Cognition, 69*, 565-570.

De Bruyn-Prevost, P., Masset, C. & Sturbois, X. (1984). Physiological response from 18-25 years women to aerobic and anaerobic physical fitness tests at different periods during the menstrual cycle. *Journal of Sports Medicine and Physical Fitness, 24*, 144-148.

de la Hunty, A., Gibson, S. & Ashwell, M. (2013). Does Regular Breakfast Cereal Consumption Help Children and Adolescents Stay Slimmer? A Systematic Review and Meta-Analysis. *Obesity Facts, 6*, 70-85.

de Leon, M. J., McRae, T., Rusinek, H., Convit, A., De Santi, S., Tarshish, C., Golomb, J., Volkow, N., Daisley, K., Orentreich, N. & McEwen, B. (1997). Cortisol Reduces Hippocampal

Glucose Metabolism in Normal Elderly, but Not in Alzheimer's Disease. *Journal of Clinical Endocrinology and Metabolism, 82*, 3251-3259.

Dearman, J. & Francis, K. T. (1983). Plasma levels of catecholamines, cortisol, and beta-endorphins in male athletes after running 26.2, 6, and 2 miles. *The Journal of sports medicine and physical fitness, 23*, 30.

Debons, A. F., Krimsky, I. & From, A. A. (1970). Direct action of insulin on the hypothalamic satiety center. *American Journal of Physiology, 219*, 938-943.

Deighton, K., Zahra, J. C. & Stensel, D. J. (2012). Appetite, energy intake and resting metabolic responses to 60min treadmill running performed in a fasted versus a postprandial state. *Appetite, 58*, 946-954.

Delargy, H. J., Burley, V. J., Osullivan, K. R., Fletcher, R. J. & Blundell, J. E. (1995). Effects of Different Soluble-Insoluable Fibre Ratios at Breakfast on the 24-H Pattern of Dietary-Intake and Satiety *European Journal of Clinical Nutrition, 49*, 754-766.

Deschenes, M. R., Hillard, M. N., Wilson, J. A., Dubina, M. I. & Eason, M. K. (2006). Effects of gender on physiological responses during submaximal exercise and recovery. *Medicine and Science in Sports and Exercise, 38*, 1304-1310.

Dietrich, A. & Audiffren, M. (2011). The reticular-activating hypofrontality (RAH) model of acute exercise. *Neuroscience and Biobehavioral Reviews, 35*, 1305-1325.

Dietrich, A. & McDaniel, W. (2004). Endocannabinoids and exercise. *British Journal of Sports Medicine, 38*, 536-541.

Dishman, R. K. & O'Connor, P. J. (2009). Lessons in exercise neurobiology: The case of endorphins. *Mental Health and Physical Activity, 2*, 4-9.

Donnelly, J., Blair, S., Jakicic, J., Manore, M., Rankin, J. & Smith, B. (2009). American College of Sports Medicine Position Stand. Appropriate physical activity intervention strategies for weight loss and prevention of weight regain for adults. *Medicine and Science in Sports and Exercise, 41*, 459-471.

Donnelly, J. E., Hill, J. O., Jacobsen, D. J., Potteiger, J., Sullivan, D. K., Johnson, S. L., Heelan, K., Hise, M., Fennessey, P. V., Sonko, B., Sharp, T., Jakicic, J. M., Blair, S. N., Tran, Z. V., Mayo, M., Gibson, C. & Washburn, R. A. (2003). Effects of a 16-Month Randomized Controlled Exercise Trial on Body Weight and Composition in Young, Overweight Men and Women: The Midwest Exercise Trial. *Archives of Internal Medicine, 163*, 1343-1350.

Drapeau, V., Blundell, J., Therrien, F., Lawton, C., Richard, D. & Tremblay, A. (2005). Appetite sensations as a marker of overall intake. *British Journal of Nutrition, 93*, 273-280.

Dubnov, G. & Berry, E. M. (2013). Physical Activity and Mood. The Endocrine Connection. In *Endocrinology of Physical Activity and Sport* (pp. 405-415): Springer.

Duda, J. L. & Tappe, M. K. (1989). The Personal Incentives for Exercise Questionnaire: Preliminary Development. *Perceptual and Motor Skills, 68*, 1122-1122.

Dundes, L. (2008). Fleshing out the role of skipping breakfast in weight control. *Supplement to AgroFOOD industry hi-tech, 19*, 26-27.

Dye, L., & Blundell, J. E. (1997). Menstrual cycle and appetite control: implications for weight regulation. *Human reproduction*, *12*(6), 1142-1151.

Dye, L. & Blundell, J. (2002). Functional foods: psychological and behavioural functions. *British Journal of Nutrition, 88*, S187-S211.

Ekkekakis, P., Hall, E. E., VanLanduyt, L. M. & Petruzzello, S. J. (2000). Walking in (affective) circles: Can short walks enhance affect? *Journal of Behavioral Medicine, 23*, 245-275.

Ekkekakis, P. & Petruzzello, S. J. (1999). Acute aerobic exercise and affect. *Sports Medicine, 28*, 337-347.

Enevoldsen, L. H., Simonsen, L., Macdonald, I. A. & Bülow, J. (2004). The combined effects of exercise and food intake on adipose tissue and splanchnic metabolism. *The Journal of Physiology, 561*, 871-882.

Etnier, J. L., Nowell, P. M., Landers, D. M. & Sibley, B. A. (2006). A meta-regression to examine the relationship between aerobic fitness and cognitive performance. *Brain Research Reviews, 52*, 119-130.

Etnier, J. L., Salazar, W., Launders, D. M., Petruzzello, S. J., Han, M. & Nowell, P. (1997). The influence of physical fitness and exercise upon cognitive functioning: a meta-analysis. *Journal of Sport & Exercise Psychology 19*, 249-277.

Evero, N., Hackett, L. C., Clark, R. D., Phelan, S. & Hagobian, T. A. (2012). Aerobic exercise reduces neuronal responses in food reward brain regions. *Journal of Applied Physiology, 112*, 1612-1619.

Farah, N. M. F., Brunstrom, J. M. & Gill, J. M. R. (2012). Using a novel computer-based approach to assess the acute effects of exercise on appetite-related measures. *Appetite, 58*, 196-204.

Farshchi, H. R., Taylor, M. A. & Macdonald, I. A. (2005). Deleterious effects of omitting breakfast on insulin sensitivity and fasting lipid profiles in healthy lean women. *American Journal of Clinical Nutrition, 81*, 388-396.

Faul, F., Erdfelder, E., Lang, A.-G. & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39*, 175-191.

Fauzi, M., & Farah, N. (2011). *Effects of exercise on postprandial metabolism, appetite responses and feeding behaviour.* University of Glasgow.

Felts, W. & Vaccaro, P. (1988). The effect of aerobic exercise on post-exercise state anxiety and psychophysiological arousal as a function of fitness level. *Clin. Kinesiol, 42*, 89-96.

Ferris, L. T., Williams, J. S. & Shen, C.-L. (2007). The effect of acute exercise on serum brain-derived neurotrophic factor levels and cognitive function. *Medicine and Science in Sports and Exercise, 39*, 728.

Fischer, K., Colombani, P., Langhans, W. & Wenk, C. (2001). Cognitive performance and its relationship with postprandial metabolic changes after ingestion of different macronutrients in the morning. *British Journal of Nutrition, 85*, 393-405.

Fischer, K., Colombani, P. C., Langhans, W. & Wenk, C. (2002). Carbohydrate to protein ratio in food and cognitive performance in the morning. *Physiology and Behavior, 75*, 411-423.

Fischer, K., Colombani, P. C. & Wenk, C. (2004). Metabolic and cognitive coefficients in the development of hunger sensations after pure macronutrient ingestion in the morning. *Appetite, 42*, 49-61.

Flint, A., Gregersen, N. T., Gluud, L. L., Moller, B. K., Raben, A., Tetens, I., Verdich, C., Astrup, A., Flint, A. & Gregersen, N. T. (2007). Associations between postprandial insulin and blood glucose responses, appetite sensations and energy intake in normal weight and overweight individuals: a meta-analysis of test meal studies. *British Journal of Nutrition, 98*, 17-25.

Flint, A., MÃ¸ller, B. K., Raben, A., Sloth, B., Pedersen, D., Tetens, I., Holst, J. J. & Astrup, A. (2006). Glycemic and insulinemic responses as determinants of appetite in humans. *The American Journal of Clinical Nutrition, 84*, 1365-1373.

Foster-Schubert, K. E., Overduin, J., Prudom, C. E., Liu, J., Callahan, H. S., Gaylinn, B. D., Thorner, M. O. & Cummings, D. E. (2008). Acyl and Total Ghrelin Are Suppressed Strongly by Ingested Proteins, Weakly by Lipids, and Biphasically by Carbohydrates. *Journal of Clinical Endocrinology and Metabolism, 93*, 1971-1979.

Foster, J., Smith, M., Woodman, M., Zombor, R. & Ashton, J. (2007). Impact of a wholegrain breakfast cereal meal on blood glucose level, mood and affect. *Food Australia, 59*, 593-596.

Fuller, R. W. & Wong, D. T. (1990). Serotonin uptake and serotonin uptake inhibition. *Annals of the New York Academy of Sciences, 600*, 68-80.

Furnham, A., Badmin, N. & Sneade, I. (2002). Body image dissatisfaction: Gender differences in eating attitudes, self-esteem, and reasons for exercise. *The Journal of Psychology: Interdisciplinary and applied, 136*, 581-596.

Galliven, E. A., Singh, A., Michelson, D., Bina, S., Gold, P. W. & Deuster, P. A. (1997). Hormonal and metabolic responses to exercise across time of day and menstrual cycle phase. *Journal of Applied Physiology, 83*, 1822-1831.

Gauvin, L., Rejeski, W. J. & Norris, J. L. (1996). A naturalistic study of the impact of acute physical activity on feeling states and affect in women. *Health Psychology, 15*, 391.

Geer, E. B. & Shen, W. (2009). Gender differences in insulin resistance, body composition, and energy balance. *Gender Medicine, 6, Part 1*, 60-75.

Gibbons, C., Caudwell, P., Finlayson, G., King, N. & Blundell, J. (2011). Validation of a new hand-held electronic data capture method for continuous monitoring of subjective appetite sensations. *International Journal of Behavioral Nutrition and Physical Activity, 8*, 57.

Gibson, E. L. (2007). Carbohydrates and mental function: feeding or impeding the brain? *Nutrition Bulletin, 32*, 71-83.

Gilliat-Wimberly, M., Manore, M. M., Woolf, K., Swan, P. D. & Carroll, S. S. (2001). Effects of Habitual Physical Activity on the Resting Metabolic Rates and Body Compositions of Women Aged 35 to 50 Years. *Journal of the American Dietetic Association, 101*, 1181-1188.

Gilsenan, M. B., de Bruin, E. A., & Dye, L. (2009). The influence of carbohydrate on cognitive performance: a critical evaluation from the perspective of glycaemic load. *British Journal of Nutrition*, *101*(07), 941-949.

Gold, A., MacLeod, K., Thomson, K., Frier, B. & Deary, I. (1995). Cognitive function during insulin-induced hypoglycemia in humans: Short-term cerebral adaptation does not occur. *Psychopharmacology, 119*, 325-333.

Gold, S. M., Schulz, K.-H., Hartmann, S., Mladek, M., Lang, U. E., Hellweg, R., Reer, R., Braumann, K.-M. & Heesen, C. (2003). Basal serum levels and reactivity of nerve growth factor and brain-derived neurotrophic factor to standardized acute exercise in multiple sclerosis and controls. *Journal of Neuroimmunology, 138*, 99-105.

Gonzalez, J. T., Veasey, R. C., Rumbold, P. L. S. & Stevenson, E. J. (2013). Breakfast and exercise contingently affect postprandial metabolism and energy balance in physically active males. *British Journal of Nutrition, FirstView*, 1-12.

Grantham-McGregor, S. (2005). Can the provision of breakfast benefit school performance?. *Food & Nutrition Bulletin*, *26*(2), 144-158.

Green, M. W., Elliman, N. A. & Rogers, P. J. (1995). Lack of effect of short-term fasting on cognitive function. *Journal of Psychiatric Research, 29*, 245-253.

Green, M. W., Elliman, N. A. & Rogers, P. J. (1997). The effects of food deprivation and incentive motivation on blood glucose levels and cognitive function. *Psychopharmacology, 134*, 88-94.

Green, M. W., Rogers, P. J. & Elliman, N. A. (2000). Dietary restraint and addictive behaviors: The generalizability of Tiffany's Cue Reactivity Model. *International Journal of Eating Disorders, 27*, 419-427.

Green, M. W., Rogers, P. J., Elliman, N. A., & Gatenby, S. J. (1994). Impairment of cognitive performance associated with dieting and high levels of dietary restraint. *Physiology and Behavior, 55*, 447-452.

Grego, F., Vallier, J.-M., Collardeau, M., Bermon, S., Ferrari, P., Candito, M., Bayer, P., Magnié, M.-N. & Brisswalter, J. (2004). Effects of long duration exercise on cognitive function, blood glucose, and counterregulatory hormones in male cyclists. *Neuroscience Letters, 364*, 76-80.

Griffin, É. W., Mullally, S., Foley, C., Warmington, S. A., O'Mara, S. M. & Kelly, Á. M. (2011). Aerobic exercise improves hippocampal function and increases BDNF in the serum of young adult males. *Physiology and Behavior, 104*, 934-941.

Hackney, A. (1999). Influence of oestrogen on muscle glycogen utilization during exercise. *Acta Physiologica Scandinavica, 167*, 273-274.

Hagobian, T. A. & Braun, B. (2010). Physical Activity and Hormonal Regulation of Appetite: Sex Differences and Weight Control. *Exercise and Sport Sciences Reviews, 38*, 25-30 10.1097/JES.1090b1013e3181c1095cd1098.

Hagobian, T. A. & Evero, N. (2013). Exercise and Weight Loss: What Is the Evidence of Sex Differences? *Current Obesity Reports, 2*, 86-92.

Hagobian, T. A., Sharoff, C. G., Stephens, B. R., Wade, G. N., Silva, J. E., Chipkin, S. R. & Braun, B. (2009). Effects of exercise on energy-regulating hormones and appetite in men and women. *Am J Phys - Regulatory, Integrative and Comparative Physiology, 296*, R233-R242.

Hagobian, T. A., Yamashiro, M., Hinkel-Lipsker, J., Streder, K., Evero, N. & Hackney, T. (2012). Effects of acute exercise on appetite hormones and *ad libitum* energy intake in men and women. *Applied Physiology, Nutrition, and Metabolism, 38*, 66-72.

Halford, J. C. G. & Blundell, J. E. (2000). Separate systems for serotonin and leptin in appetite control. *Annals of Medicine, 32*, 222-232.

Hall, E. E., Ekkekakis, P. & Petruzzello, S. J. (2007). Regional brain activity and strenuous exercise: Predicting affective responses using EEG asymmetry. *Biological Psychology, 75*, 194-200.

Halsey, L. G., Huber, J. W., Low, T., Ibeawuchi, C., Woodruff, P. & Reeves, S. (2012). Does consuming breakfast influence activity levels? An experiment into the effect of breakfast consumption on eating habits and energy expenditure. *Public Health Nutrition, 15*, 238-245.

Hamer, M., Endrighi, R. & Poole, L. (2012). Physical activity, stress reduction, and mood: insight into immunological mechanisms. In *Psychoneuroimmunology* (pp. 89-102): Springer.

Hansen, C. J., Stevens, L. C. & Coast, J. R. (2001). Exercise duration and mood state: How much is enough to feel better? *Health Psychology, 20*, 267-275.

Hardy, C. & Rejeski, W.Y. (1989). Not what, **but** how one feels: The measurement of affect during exercise. *Journal of Sport and Exercise Psychology, 11*, 304-317.

Hargreaves, M., Hawley, J. A. & Jeukendrup, A. (2004). Pre-exercise carbohydrate and fat ingestion: effects on metabolism and performance. *Journal of Sports Sciences, 22*, 31-38.

Head, A., Kendall, M. J., Ferner, R. & Eagles, C. (1996). Acute effects of beta blockade and exercise on mood and anxiety. *British Journal of Sports Medicine, 30*, 238-242.

Hetherington, M. M., Cunningham, K., Dye, L., Gibson, E. L., Gregersen, N. T., Halford, J. C. G., Lawton, C. L., Lluch, A., Mela, D. J. and Van Trijp, H. C. M. (2013). Potential benefits of satiety to the consumer: scientific considerations. *Nutrition Research Reviews*, *26*, 22-38.

Hickey, M., Houmard, J., Considine, R., Tyndall, G., Midgette, J., Gavigan, K., Weidner, M., McCammon, M., Israel, R. & Caro, J. (1997). Gender-dependent effects of exercise training on serum leptin levels in humans. *American Journal of Physiology-Endocrinology And Metabolism, 272*, E562-E566.

Hill, A. J., Rogers, P. J. & Blundell, J. E. (1995). Techniques for the experimental measurement of human eating behaviour and food intake: a practical guide. *International Journal of Obesity Related Metabolic Disorders, 19*, 361-375.

Hill, A. J., Weaver, C. F. L. & Blundell, J. E. (1991). Food craving, dietary restraint and mood. *Appetite, 17*, 187-197.

Hill, J. O. (2009). Can a small-changes approach help address the obesity epidemic? A report of the Joint Task Force of the American Society for Nutrition, Institute of Food Technologists, and International Food Information Council. *The American Journal of Clinical Nutrition, 89*, 477-484.

Hill, K. M., Whitehead, J. R. & Goodwin, J. K. (2011). Pre-workout carbohydrate supplementation does not affect measures of self-assesed vitality and affect in college swimmers *J Sports Sci Med, 10*, 478-482.

Hillman, C. H., Erickson, K. I. & Kramer, A. F. (2008). Be smart, exercise your heart: exercise effects on brain and cognition. *Nature Reviews. Neuroscience, 9*, 58-65.

Hoffman, M. D. & Hoffman, D. R. (2008). Exercisers Achieve Greater Acute Exercise-Induced Mood Enhancement Than Nonexercisers. *Archives of Physical Medicine and Rehabilitation, 89*, 358-363.

Hogervorst, E., Riedel, W., Jeukendrup, A. & Jolles, J. (1996). Cognitive performance after strenuous physical exercise. *Perceptual and Motor Skills, 83*, 479-488.

Holt, S. H. A., Delargy, H.J., Lawton, C.L. & Blundell, J.E. (1999). The effects of high-carbohydrate vs high-fat breakfasts on feelings of fullness and alertness, and subsequent food intake. *International Journal of Food Sciences and Nutrition, 50*, 13-28.

Holt, S. H. A. & Miller, J. B. (1995). Increased insulin responses to ingested foods are associated with lessened satiety. *Appetite, 24*, 43-54.

Hopkins, D. F. C. & Williams, G. (1997). Insulin receptors are widely distributed in human brain and bind human and porcine insulin with equal affinity. *Diabetic Medicine, 14*, 1044-1050.

Hopkins, M. E., Davis, F. C., VanTieghem, M. R., Whalen, P. J. & Bucci, D. J. (2012). Differential effects of acute and regular physical exercise on cognition and affect. *Neuroscience, 215*, 59-68.

Hornum, M., Cooper, D. M., Brasel, J. A., Bueno, A., & Sietsema, K. E. (1997). Exercise-induced changes in circulating growth factors with cyclic variation in plasma estradiol in women. *Journal of Applied Physiology, 82*, 1946-1951.

Hoyland, A., Dye, L. & Lawton, C. L. (2009). A systematic review of the effect of breakfast on the cognitive performance of children and adolescents. *Nutr Res Rev, 22*, 220-243.

Hoyland, A., Lawton, C. L. & Dye, L. (2008). Acute effects of macronutrient manipulations on cognitive test performance in healthy young adults: A systematic research review. *Neuroscience & Biobehavioral Reviews, 32*, 72-85.

Hubert, P., King, N.A. & Blundell, J. E. (1998). Uncoupling the Effects of Energy Expenditure and Energy Intake: Appetite Response to Short-term Energy Deficit Induced by Meal Omission and Physical Activity. *Appetite, 31*, 9-19.

Hung, T.M., Tsai, C.L., Chen, F.T., Wang, C.C. & Chang, Y.K. (2013). The Immediate and Sustained Effects of Acute Exercise on Planning Aspect of Executive Function. *Psychology of Sport and Exercise*, *14*(5), *728-736.*

Ide, K., Horn, A. & Secher, N. H. (1999). Cerebral metabolic response to submaximal exercise. *Journal of Applied Physiology, 87*, 1604-1608.

Imbeault, P., Saint-Pierre, S., Almeras, N. & Tremblay, A. (1997). Acute effects of exercise on energy intake and feeding behaviour. *British Journal of Nutrition, 77*, 511-521.

Ingwersen, J., Defeyter, M. A., Kennedy, D. O., Wesnes, K. A., & Scholey, A. B. (2007). A low glycaemic index breakfast cereal preferentially prevents children's cognitive performance from declining throughout the morning. *Appetite*, *49*(1), 240-244.

Jackson, P. A., Deary, M. E., Reay, J. L., Scholey, A. B. & Kennedy, D. O. (2012). No effect of 12 weeks' supplementation with 1 g DHA-rich or EPA-rich fish oil on cognitive function or mood in healthy young adults aged 18–35 years. *British Journal of Nutrition, 107*, 232–1243.

Jacobson, B. H. & DeBock, D. H. (2001). Comparison of Body Mass Index by self-reported versus measured height and weight. *Perceptual and Motor Skills, 92*, 128-132.

Jakicic, J. M. (2009). The Effect of Physical Activity on Body Weight. *Obesity, 17*, S34-S38.

Jeacocke, N. A. & Burke, L. M. (2010). Methods to standardize dietary intake before performance testing. *International Journal of Sport Nutrition and Exercise Metabolism, 20*, 87-103.

Jenkins, D. J., Wolever, T. M., Taylor, R. H., Barker, H., Fielden, H., Baldwin, J. M., Bowling, A. C., Newman, H. C., Jenkins, A. L. & Goff, D. V. (1981). Glycemic index of foods: a physiological basis for carbohydrate exchange. *The American Journal of Clinical Nutrition, 34*, 362-366.

Jensen, M. D. (1995). Gender differences in regional fatty acid metabolism before and after meal ingestion. *Journal of Clinical Investigation, 96*, 2297.

Johansson, G., Wikman, A., Ahren, A. M., Hallmans, G., & Johansson, I. (2001). Underreporting of energy intake in repeated 24-hour recalls related to gender, age, weight status, day of interview, educational level, reported food intake, smoking habits and area of living. *Public health nutrition*, *4*(4), 919-928.

Jokisch, E., Coletta, A., & Raynor, H. A. (2012). Acute energy compensation and macronutrient intake following exercise in active and inactive males who are normal weight. *Appetite, 58*, 722-729.

Jonnakuty, C. & Gragnoli, C. (2008). What do we know about serotonin? *Journal of Cellular Physiology, 217*, 301-306.

Joyce, J., Graydon, J., McMorris, T. & Davranche, K. (2009). The time course effect of moderate intensity exercise on response execution and response inhibition. *Brain and Cognition, 71*, 14-19.

Kamijo, K., Nishihira, Y., Hatta, A., Kaneda, T., Wasaka, T., Kida, T. & Kuroiwa, K. (2004). Differential influences of exercise intensity on information processing in the central nervous system. *European Journal of Applied Physiology, 92*, 305-311.

Karczewska-Kupczewska, M., Kowalska, I., Nikołajuk, A., Adamska, A., Zielińska, M., Kamińska, N., Otziomek, E., Górska, M. & Strczkowski, M. (2012). Circulating Brain-Derived Neurotrophic Factor Concentration Is Downregulated by Intralipid/Heparin Infusion or High-Fat Meal in Young Healthy Male Subjects. *Diabetes Care, 35*, 358-362.

Karczewska-Kupczewska, M., Strączkowski, M., Adamska, A., Nikołajuk, A., Otziomek, E., Górska, M. & Kowalska, I. (2011). Decreased serum brain-derived neurotrophic factor concentration in young nonobese subjects with low insulin sensitivity. *Clinical Biochemistry, 44*, 817-820.

Karp, J. R., Johnston, J. D., Tecklenburg, S., Mickleborough, T. D., Fly, A. D. & Stager, J. M. (2006). Chocolate Milk as a Post-Exercise Recovery Aid. *International Journal of Sport Nutrition and Exercise Metabolism, 16*, 78-91.

Kashihara, K. & Nakahara, Y. (2005). Short-term effect of physical exercise at lactate threshold on choice reaction time 1, 2. *Perceptual and Motor Skills, 100*, 275-291.

Kawano, H., Mineta, M., Asaka, M., Miyashita, M., Numao, S., Gando, Y., Ando, T., Sakamoto, S. & Higuchi, M. (2013). Effects of different modes of exercise on appetite and appetite-regulating hormones. *Appetite, 66*, 26-33.

Kawano, H., Motegi, F., Ando, T., Gando, Y., Mineta, M., Numao, S., Miyashita, M., Sakamoto, S. & Higuchi, M. (2012). Appetite after rope skipping may differ between males and females. *Obesity Research & Clinical Practice, 6*, e121-e127.

Kennedy, D., Veasey, R., Watson, A., Dodd, F., Jones, E., Maggini, S. & Haskell, C. (2010). Effects of high-dose B vitamin complex with vitamin C and minerals on subjective mood and performance in healthy males. *Psychopharmacology, 211*, 55-68.

Kennedy, D. O., Dodd, F. L., Robertson, B. C., Okello, E. J., Reay, J. L., Scholey, A. B. & Haskell, C. F. (2011). Monoterpenoid extract of sage (Salvia lavandulaefolia) with cholinesterase inhibiting properties improves cognitive performance and mood in healthy adults. *Journal of Psychopharmacology, 25*, 1088-1100.

Keski-Rahkonen, A., Kaprio, J., Rissanen, A., Virkkunen, M. & Rose, R. J. (2003). Breakfast skipping and health-compromising behaviors in adolescents and adults. *European Journal of Clinical Nutrition, 57*, 842-853.

King, J. A., Miyashita, M., Wasse, L. K. & Stensel, D. J. (2010). Influence of prolonged treadmill running on appetite, energy intake and circulating concentrations of acylated ghrelin. *Appetite, 54*, 492-498.

King, N. & Blundell, J. (1995). High-fat foods overcome the energy expenditure induced by high-intensity cycling or running. *European Journal of Clinical Nutrition, 49*, 114.

King, N. A. (1999). What processes are involved in the appetite response to moderate increases in exercise-induced energy expenditure? *Proceedings of the Nutrition Society, 58*, 107-113.

King, N. A., Burley, V. J. & Blundell, J. E. (1994). Exercise-induced suppression of appetite: effects on food intake and implications for energy balance. *European Journal of Clinical Nutrition, 48*, 715-724.

King, N. A., Caudwell, P. P., Hopkins, M., Stubbs, J. R., Naslund, E. & Blundell, J. E. (2009). Dual-process action of exercise on appetite control: increase in orexigenic drive but improvement in meal-induced satiety. *American Journal of Clinical Nutrition, 90*, 921-927.

King, N. A., Lluch, A., Stubbs, R. J. & Blundell, J. E. (1997). High dose exercise does not increase hunger or energy intake in free living males. *European Journal of Clinical Nutrition, 51*, 478-483.

King, N. A., Snell, L., Smith, R. D. & Blundell, J. E. (1996). Effects of short-term exercise on appetite responses in unrestrained females. *European Journal of Clinical Nutrition, 50*, 663-667.

King, N. A., Tremblay, A. & Blundell, J. E. (1997). Effects of exercise on appetite control: implications for energy balance. *Medicine and Science in Sports and Exercise, 29*, 1076-1089.

Klesges, R. C., Klem, M. L., Epkins, C. C. & Klesges, L. M. (1991). A longitudinal evaluation of dietary restraint and its relationship to changes in body weight. *Addictive Behaviors, 16*, 363-368.

Kraemer, W. J., Häkkinen, K., Newton, R. U., Nindl, B. C., Volek, J. S., McCormick, M., Gotshalk, L. A., Gordon, S. E., Fleck, S. J. & Campbell, W. W. (1999). Effects of heavy-resistance training on hormonal response patterns in younger vs. older men. *Journal of Applied Physiology, 87*, 982-992.

Kral, T. V. E., Heo, M., Whiteford, L. M. & Faith, M. S. (2012). Effects on Cognitive Performance of Eating Compared With Omitting Breakfast in Elementary Schoolchildren. *Journal of Developmental and Behavioral Pediatrics, 33*, 9-16

Kubitz, K. A. & Mott, A. A. (1996). EEG power spectral densities during and after cycle ergometer exercise. *Research Quarterly for Exercise and Sport, 67*, 91-96.

La Bounty, P. M., Campbell, B. I. & Wilson, J. (2011). International Society of Sports Nutrition position stand: meal frequency. *Journal of the International Society of Sports Nutrition, 8*, 4.

Lambourne, K. & Tomporowski, P. (2010). The effect of exercise-induced arousal on cognitive task performance: A meta-regression analysis. *Brain Research, 1341*, 12-24.

Lamport, D. J., Hoyle, E., Lawton, C. L., Mansfield, M. W. & Dye, L. (2011). Evidence for a second meal cognitive effect: glycaemic responses to high and low glycaemic index evening meals are associated with cognition the following morning. *Nutritional Neuroscience, 14*, 66-71.

Lamport, D. J., Lawton, C. L., Mansfield, M. W., & Dye, L. (2009). Impairments in glucose tolerance can have a negative impact on cognitive function: a systematic research review. *Neuroscience & Biobehavioral Reviews*, *33*(3), 394-413.

Lang, P.J. (1980) Behavioral treatment and bio-behavioral assessment: computer applications. J.B. Sidowski, J.H. Johnson, T.A. Williams (Eds.), Technology in mental health care delivery systems, Ablex, Norwood, NJ, 119–137.

Lattimore, P., Walton, J., Bartlett, S., Hackett, A. & Stevenson, L. (2010). Regular consumption of a cereal breakfast. Effects on mood and body image satisfaction in adult non-obese women. *Appetite, 55*, 512-521.

Lavin, J. H., Wittert, G., Sun, W. M., Horowitz, M., Morley, J. E. & Read, N. W. (1996). Appetite regulation by carbohydrate: role of blood glucose and gastrointestinal hormones. *American Journal of Physiology - Endocrinology And Metabolism, 271*, E209-E214.

Lavoie, J. M., Dionne, N., Helie, R. & Brisson, G. R. (1987). Menstrual cycle phase dissociation of blood glucose homeostasis during exercise. *Journal of Applied Physiology, 62*, 1084-1089.

Lawton, C.L., Struthers, L., Hoyland, A., Myrissa, K., & Dye, L. (2011). Effects of increasing dietary fibre on psychological wellbeing. *Ann. Nutr. Metab*, *58*, 266.

Lawton C.L., Walton, J., Hoyland, A.E.F., Howarth, E., Allan, P., Chesters, D., Campbell, C. & Dye, L. (2013). Short term (14 day) consumption of insoluable wheat bran fibre-containing breakfast cereals improves subjective digestive feelings, general wellbeing and bowel function in a dose dependant manner. *Nutrients*, *5*(4), 1436-1455.

Le Noury, J., Lawton, C. & Blundell, J. (2002). Food choice and hedonic responses: difference between overweight and lean high fat phenotypes. *International Journal of Obesity, 26*, S125.

Lebrun, C. M., McKenzie, D. C., Prior, J. C. & Taunton, J. E. (1995). Effects of menstrual cycle phase on athletic performance. *Medicine and Science in Sports and Exercise, 27*, 437-444.

Lee, B.-H. & Kim, Y.-K. (2010). The roles of BDNF in the pathophysiology of major depression and in antidepressant treatment. *Psychiatry investigation, 7*, 231-235.

Leidy, H. J., & Racki, E. M. (2010). The addition of a protein-rich breakfast and its effects on acute appetite control and food intake in 'breakfast-skipping' adolescents. *International Journal of Obesity*, *34*(7), 1125-1133.

Lemmink, K. A. & Visscher, C. (2005). Effect of intermittent exercise on multiple-choice reaction time s of scoccer players 1, 2. *Perceptual and Motor Skills, 100*, 85-95.

Levitsky, D. A. & Pacanowski, C. R. (2013). Effect of skipping breakfast on subsequent energy intake. *Physiology and Behavior, 119*, 9-16.

Lieberman, H. R. (2007). Hydration and Cognition: A Critical Review and Recommendations for Future Research. *Journal of the American College of Nutrition, 26*, 555S-561S.

Lieberman, H. R., Falco, C. M. & Slade, S. S. (2002). Carbohydrate administration during a day of sustained aerobic activity improves vigilance, as assessed by a novel ambulatory monitoring device, and mood. *American Journal of Clinical Nutrition, 76*, 120-127.

Liljeberg, H. G., Åkerberg, A. K. & Björck, I. M. (1999). Effect of the glycemic index and content of indigestible carbohydrates of cereal-based breakfast meals on glucose tolerance at lunch in healthy subjects. *The American journal of clinical nutrition, 69*, 647-655.

Livingstone, M. B. E. & Black, A. E. (2003). Markers of the Validity of Reported Energy Intake. *The Journal of Nutrition, 133*, 895S-920S.

Lloyd, H. M., Green, M. W. & Rogers, P. J. (1994). Mood and cognitive performance effects of isocaloric lunches differing in fat and carbohydrate content. *Physiology and Behavior, 56*, 51-57.

Lloyd, H. M., Rogers, P. J., Hedderley, D. I. & Walker, A. F. (1996). Acute Effects on Mood and Cognitive Performance of Breakfasts Differing in Fat and Carbohydrate Content. *Appetite, 27*, 151-164.

Lluch, A., Hubert, P., King, N. A. & Blundell, J. E. (2000). Selective effects of acute exercise and breakfast interventions on mood and motivation to eat. *Physiology and Behavior, 68*, 515-520.

Lluch, A., King, N. & Blundell, J. (1998). Exercise in dietary restrained women: no effect on energy intake but change in hedonic ratings. *European Journal of Clinical Nutrition, 52*, 300.

Lluch, A., King, N. A. & Blundell, J. E. (2000). No energy compensation at the meal following exercise indietary restrained and unrestrained women. *British Journal of Nutrition, 84*, 219-225.

Lofrano-Prado, M. C., Hill, J. O., Silva, H. J. G., Freitas, C. R. M., Lopes-de-Souza, S., Lins, T. A. & do Prado, W. L. (2012). Acute effects of aerobic exercise on mood and hunger feelings in male obese adolescents: a crossover study. *International Journal of Behavioral Nutrition and Physical Activity, 9*, 1-6.

Lommatzsch, M., Zingler, D., Schuhbaeck, K., Schloetcke, K., Zingler, C., Schuff-Werner, P. & Virchow, J. C. (2005). The impact of age, weight and gender on BDNF levels in human platelets and plasma. *Neurobiology of Aging, 26*, 115-123.

Long, S. J., Hart, K. & Morgan, L. M. (2002). The ability of habitual exercise to influence appetite and food intake in response to high- and low-energy preloads in man. *British Journal of Nutrition, 87*, 517-523.

Lynch, N. & Nimmo, M. (1998). Effects of menstrual cycle phase and oral contraceptive use on intermittent exercise. *European Journal of Applied Physiology and Occupational Physiology, 78*, 565-572.

Macdiarmid, J. I., Cade J.E. & Blundell, J.E. (1996). High and low fat consumers, their macronutrient intake and body mass index: further analysis of the National Diet and Nutrition Survey of British Adults. *European Journal of Clinical Nutrition, 50*, 505-512.

Macht, M. (1996). Effect of high- and low-energy meals on hunger physiological processes and reactions to emotional stress. *Appetite, 26*, 71–88.

Maraki, M., Tsofliou, F., Pitsiladis, Y. P., Malkova, D., Mutrie, N. & Higgins, S. (2005). Acute effects of a single exercise class on appetite, energy intake and mood. Is there a time of day effect? *Appetite, 45*, 272-278.

Maran, A., Cranston, I., Lomas, J., Amiel, S. A., & Macdonald, I. (1994). Protection by lactate of cerebral function during hypoglycaemia. *The Lancet*, *343*(8888), 16-20.

Marangoni, F., Poli, A., Agostoni, C., Di Pietro, P., Cricelli, C., Brignoli, O., Fatati, G., Giovannini, M., Riva, E., Marelli, G., Porrini, M., Rotella, C. M., Mele, G., Iughetti, L. & Paoletti, R. (2009). A consensus document on the role of breakfast in the attainment and maintenance of health and wellness. *Acta Biomed, 80*, 166-171.

Maroulakis, E. & Zervas, Y. (1993). Effects of aeorbic exercise on mood of adult women. *Perceptual and Motor Skills, 76*, 795-801.

Martin, E. A. & Kerns, J. G. (2011). The influence of positive mood on different aspects of cognitive control. *Cognition and Emotion, 25*, 265-279.

Martins, C., Kulseng, B., King, N. A., Holst, J. J. & Blundell, J. E. (2010). The Effects of Exercise-Induced Weight Loss on Appetite-Related Peptides and Motivation to Eat. *Journal of Clinical Endocrinology and Metabolism, 95*, 1609-1616.

Martins, C., Morgan, L. M., Bloom, S. R. & Robertson, M. D. (2007). Effects of exercise on gut peptides, energy intake and appetite. *Journal of Endocrinology, 193*, 251-258.

Martins, C., Morgan, L. & Truby, H. (2008). A review of the effects of exercise on appetite regulation: an obesity perspective. *International Journal of Obesity, 32, 9,* 1337-1347.

McCall, A. L., van Bueren, A. M., Huang, L., Stenbit, A., Celnik, E. & Charron, M. J. (1997). Forebrain endothelium expresses GLUT4, the insulin-responsive glucose transporter. *Brain Research, 744*, 318-326.

McCrimmon, R. J., Deary, I. J., Huntly, B. J. P., MacLeod, K. J. & Frier, B. M. (1996). Visual information processing during controlled hypoglycaemia in humans. *Brain, 119*, 1277-1287.

McGowan, R. W., Pierce, E. F. & Jordan, D. (1991). Mood alterations with a single bout of physical activity. *Perceptual and Motor Skills, 72*, 1203-1209.

McMorris, T., Collard, K., Corbett, J., Dicks, M. & Swain, J. P. (2008). A test of the catecholamines hypothesis for an acute exercise-cognition interaction. *Pharmacology Biochemistry and Behavior, 89*, 106-115.

McMorris, T. & Graydon, J. (1996). The effect of exercise on the decision-making performance of experienced and inexperienced soccer players. *Research Quarterly for Exercise and Sport, 67*, 109-114.

McMorris, T. & Graydon, J. (2000). The effect of incremental exercise on cognitive performance. *International Journal of Sport Psychology, 31*, 66-81.

McMorris, T., Myers, S., MacGillivary, W. W., Sexsmith, J. R., Fallowfield, J., Graydon, J. & Forster, D. (1999). Exercise, plasma catecholamine concentrations and decision-making performance of soccer players on a soccer-specific test. *Journal of Sports Sciences, 17*, 667-676.

McMorris, T., Sproule, J., Draper, S. & Child, R. (2000). Performance of a psychomotor skill following rest, exercise at the plasma epinephrine threshold and maximal intensity exercise *Perceptual and Motor Skills, 91*, 553-562.

McMorris, T., Sproule, J., Turner, A. & Hale, B. J. (2011). Acute, intermediate intensity exercise, and speed and accuracy in working memory tasks: A meta-analytical comparison of effects. *Physiology and Behavior, 102*, 421-428.

McMorris, T., Tallon, M., Williams, C., Sproule, J., Draper, S., Swain, J., Potter, J. & Clayton, N. (2003). Incremental exercise, plasma concentrations of catecholamines, reaction time, and motor time during performance of a noncompatible choice response time task. *Perceptual and Motor Skills, 97*, 590-604.

McNair, D. M., Lorr, M. & Droppleman, L. F. (1971). Profile of Mood States: manual. *San Diego, CA: Educational and Industrial Testing Service.* .

Meeusen, R., Piacentini, M. F. & De Meirleir, K. (2001). Brain microdialysis in exercise research. *Sports Medicine, 31*, 965-983.

Mekary, R. A., Giovannucci, E., Willett, W. C., van Dam, R. M. & Hu, F. B. (2012). Eating patterns and type 2 diabetes risk in men: breakfast omission, eating frequency, and snacking. *The American Journal of Clinical Nutrition, 95*, 1182-1189.

Mendelsohn, D., Riedel, W. J. & Sambeth, A. (2009). Effects of acute tryptophan depletion on memory, attention and executive functions: A systematic review. *Neuroscience and Biobehavioral Reviews, 33*, 926-952.

Micha, R., Rogers, P.J. and Nelson, M. (2010). The glycaemic potency of breakfast and cognitive function in school children. *European journal of clinical nutrition,* **64**(9), pp. 948-957.

Michaud, C., Musse, N., Nicolas, J. P. & Mejean, L. (1991). Effects of breakfast-size on short-term memory, concentration, mood and blood glucose. *Journal of Adolescent Health, 12*, 53-57.

Miles, L. (2007). Physical activity and health. *Nutrition Bulletin, 32*, 314-363.

Miller, E. T., Neal, D. J., Roberts, L. J., Baer, J. S., Cressler, S. O., Metrik, J. & Marlatt, G. A. (2002). Test–Retest Reliability of Alcohol Measures: Is There a Difference Between Internet-Based Assessment and Traditional Methods? *Psychology of Addictive Behaviors, 16*, 56-63.

Moore, R. D., Romine, M. W., O'Connor, P. J. & Tomporowski, P. D. (2012). The influence of exercise-induced fatigue on cognitive function. *Journal of Sports Sciences, 30*, 841-850.

Morgan, W. P. (1985). Affective beneficence of vigorous physical activity. *Medicine and Science in Sports and Exercise*.

Mori, D., Chaiken, S., & Pliner, P. (1987). "Eating lightly" and the self presentation of femininity. *Journal of Personality and Social Psychology, 53,* 693-702.

Musso, N. R., Gianrossi, R., Pende, A., Vergassola, C. & Lotti, G. (1990). Plasma dopamine response to sympathetic activation in man: a biphasic pattern. *Life Sciences, 47*, 619-626.

Nabb, S. & Benton, D. (2006). The influence on cognition of the interaction between the macro-nutrient content of breakfast and glucose tolerance. *Physiology and Behavior, 87*, 16-23.

Nehlig, A. (2010). Is caffeine a cognitive enhancer? *Journal of Alzheimer's Disease, 20*, 85-94.

Newsholme E.A., Acworth, I. N. & Blomstrand, E. (1987). Amino acids, brain neurotransmitters and a functional link between muscle and brain that is important in sustained exercise. *Benzi G, ed. Advances in myochemistry. , London: John Libby Eurotext Ltd*, 127-138.

Nilsson, A., Radeborg, K. & Bjorck, I. (2012). Effects on cognitive performance of modulating the postprandial blood glucose profile at breakfast. *European Journal of Clinical Nutrition, 66*, 1039-1043.

Noble, E. E., Billington, C. J., Kotz, C. M. & Wang, C. (2011). The lighter side of BDNF. *American Journal of Physiology - Regulatory, Integrative and Comparative Physiology, 300*, R1053-R1069.

O'Donovan, G., Owen, A., Kearney, E. M., Jones, D. W., Nevill, A. M., Woolf-May, K. & Bird, S. R. (2005). Cardiovascular disease risk factors in habitual exercisers, lean sedentary men and abdominally obese sedentary men. *International Journal of Obesity and Related Metabolic Disorders, 29*, 1063-1069.

O'Sullivan, T. A., Robinson, M., Kendall, G. E., Miller, M., Jacoby, P., Silburn, S. R. & Oddy, W. H. (2009). A good-quality breakfast is associated with better mental health in adolescence. *Public Health Nutrition, 12*, 249.

Odegaard, A. O., Jacobs, D. R., Steffen, L. M., Van Horn, L., Ludwig, D. S. & Pereira, M. A. (2013). Breakfast Frequency and Development of Metabolic Risk. *Diabetes Care*. *36*(10), *3100-3106.*

Owens, D. S., Parker, P. Y. & Benton, D. (1997). Blood Glucose and Subjective Energy Following Cognitive Demand. *Physiology and Behavior, 62*, 471-478.

Ozdogan, Y., Ozcelik, A. O., & Surucuoglu, M. S. (2010). The Breakfast Habits of Female University Students. *Pak J Nutr, 9*, 882-886.

Palmblad, M. & Tiplady, B. (2004). Electronic diaries and questionnaires: designing user interfaces that are easy for all patients to use. *Quality of Life Research, 13*, 1199-1207.

Pan, W., Banks, W. A., Fasold, M. B., Bluth, J. & Kastin, A. J. (1998). Transport of brain-derived neurotrophic factor across the blood–brain barrier. *Neuropharmacology, 37*, 1553-1561.

Park, C. R. (2001). Cognitive effects of insulin in the central nervous system. *Neuroscience and Biobehavioral Reviews, 25*, 311-323.

Park, S., Coull, J., McShane, R., Young, A., Sahakian, B., Robbins, T. & Cowen, P. (1994). Tryptophan depletion in normal volunteers produces selective impairments in learning and memory. *Neuropharmacology, 33*, 575-588.

Pasman, W. J., Blokdijk, V. M., Bertina, F. M., Hopman, W. P. M. & Hendriks, H. F. J. (2003). Effect of two breakfasts, different in carbohydrate composition, on hunger and satiety and mood in healthy men. *International Journal of Obesity Related Metabolic Disorders, 27*, 663-668.

Paul, G. L., Rokusek, J. T., Dykstra, G. L., Boileau, R. A. & Layman, D. K. (1996). Preexercise meal composition alters plasma large neutral amino acid responses during exercise and recovery. *American Journal of Clinical Nutrition, 64*, 778-786.

Penedo, F. J. & Dahn, J. R. (2005). Exercise and well-being: a review of mental and physical health benefits associated with physical activity. *Current Opinion in Psychiatry, 18*, 189-193.

Pereira, M., Erickson, E., McKee, P., Schrankler, K., Raatz, S., Lytle, L. & Pellegrini, A. (2011). Breakfast Frequency and Quality May Affect Glycemia and Appetite in Adults and Children *Journal of Nutrition, 141*, 163-168.

Petrlová, B., Rosolova, H., Hess, Z., Podlipný, J. & Šimon, J. (2004). Depressive disorders and the metabolic syndrome of insulin resistance. In *Seminars in vascular medicine* (Vol. 4, pp. 161-165): Copyright© 2004 by Thieme Medical Publishers, Inc., 333 Seventh Avenue, New York, NY 10001 USA.

Petruzzello, S. J., Landers, D. M., Hatfield, B. D., Kubitz, K. A. & Salazar, W. (1991). A meta-analysis on the anxiety-reducing effects of acute and chronic exercise. Outcomes and mechanisms. *Sports medicine (Auckland, N.Z.), 11*, 143-182.

Pierce, D., Kuppart, I. & Harry, D. (1979). Urinary epinephrine and norepinephrine levels in women athletes during training and competition. *European Journal of Applied Physiology, 36*, 1-6.

Plante, T. G., Gores, C., Brecht, C., Carrow, J., Imbs, A. & Willemsen, E. (2007). Does exercise environment enhance the psychological benefits of exercise for women? *International Journal of Stress Management, 14*, 88.

Pollitt, E. & Mathews, R. (1998). Breakfast and cognition: an integrative summary. *The American Journal of Clinical Nutrition, 67*, 804S-813S.

Pomerleau, M., Imbeault, P., Parker, T. & Doucet, E. (2004). Effects of exercise intensity on food intake and appetite in women. *American Journal of Clinical Nutrition, 80*, 1230-1236.

Pontifex, M., Hillman, C., Fernhall, B., Thompson, K. & Valentini, T. (2009). The effect of acute aerobic and resistance exercise on working memory. *Medicine+ Science in Sports+ Exercise, 41*, 927.

Pronk, N. P., Crouse, S. F., & Rohack, J. J. (1995). Maximal exercise and acute mood response in women. *Physiology & behavior*, *57*(1), 1-4.

Purslow, L. R., Sandhu, M. S., Forouhi, N., Young, E. H., Luben, R. N., Welch, A. A., Khaw, K.-T., Bingham, S. A. & Wareham, N. J. (2008). Energy Intake at Breakfast and Weight Change: Prospective Study of 6,764 Middle-aged Men and Women. *American Journal of Epidemiology, 167*, 188-192.

Raglin, J. S. & Morgan, W. P. (1985). Influence of vigorous exercise on mood state. *the Behavior Therapist, 8*, 179-183.

Rampersaud, G. C., Pereira, M. A., Girard, B. L., Adams, J. & Metzl, J. D. (2005). Breakfast Habits, Nutritional Status, Body Weight, and Academic Performance in Children and Adolescents. *Journal of the American Dietetic Association, 105*, 743-760.

Rasmussen, P., Brassard, P., Adser, H., Pedersen, M. V., Leick, L., Hart, E., Secher, N. H., Pedersen, B. K. & Pilegaard, H. (2009). Evidence for a release of brain-derived neurotrophic factor from the brain during exercise. *Experimental Physiology, 94*, 1062-1069.

Ray, C., Weir, W. R., Phillips, S., & Cullen, S. (1992). Development of a measure of symptoms in chronic fatigue syndrome: the profile of fatigue-related symptoms (PFRS). *Psychology and Health*, *7*(1), 27-43.

Reed, J. & Ones, D. S. (2006). The effect of acute aerobic exercise on positive activated affect: A meta-analysis. *Psychology of Sport and Exercise, 7*, 477-514.

Reeves, S., Halsey, L. G., McMeel, Y. & Huber, J. W. (2013). Breakfast habits, beliefs and measures of health and wellbeing in a nationally representative UK sample. *Appetite, 60*, 51-57.

Reynolds, R. M., Walker, B. R., Syddall, H. E., Whorwood, C. B., Wood, P. J. & Phillips, D. I. (2001). Elevated plasma cortisol in glucose-intolerant men: differences in responses to glucose and habituation to venepuncture. *Journal of Clinical Endocrinology and Metabolism, 86*, 1149-1153.

Richards, M. M. K. (1972). Studies on breakfast and mental performance. *Nutrition, 26,* 219-23.
Richardson, G. S. (2004). The human circadian system in normal and disordered sleep. *The Journal of clinical psychiatry, 66*, 3-9; quiz 42-43.

Robbins, T. W. (2005). Chemistry of the mind: neurochemical modulation of prefrontal cortical function. *Journal of Comparative Neurology, 493*, 140-146.

Rocheleau, C. A., Webster, G. D., Bryan, A. & Frazier, J. (2004). Moderators of the relationship between exercise and mood changes: Gender, exertion level, and workout duration. *Psychology & Health, 19*, 491-506.

Rogers, P. J., & Lloyd, H. M. (1994). Nutrition and mental performance. *Proceedings of the Nutrition Society*, *53*(2), 443.

Rogers, P. J., Martin, J., Smith, C., Heatherley, S. V. & Smit, H. J. (2003). Absence of reinforcing, mood and psychomotor performance effects of caffeine in habitual non-consumers of caffeine. *Psychopharmacology, 167*, 54-62.

Romans, S., Clarkson, R., Einstein, G., Petrovic, M., & Stewart, D. (2012). Mood and the Menstrual Cycle: A Review of Prospective Data Studies. *Gender Medicine, 9*(5), 361-384.

Romijn, J. A., Coyle, E. F., Sidossis, L. S., Gastaldelli, A., Horowitz, J. F., Endert, E. & Wolfe., R. R. (1993). Regulation of endogenous fat and carbohydrate metabolism in relation to exercise intensity and duration. *Endocrinology Metabloism, 28*, 380-391.

Rumbold, P. L. S., Dodd-Reynolds, C. J. & Stevenson, E. (2013). Agreement between paper and pen visual analogue scales and a wristwatch-based electronic appetite rating system (PRO-Diary), for continuous monitoring of free-living subjective appetite sensations in 7–10 year old children. *Appetite, 69*, 180-185.

Russell, J.A., Weiss, A, & Mendelsohn, G.A. (1989). Affect Grid: A single item scale of pleasure and arousal. *Journal of Personality and Social Psychology, 57*, 493-502.

Ruxton, C. H. S. & Kirk, T. R. (1997). Breakfast: a review of associations with measures of dietary intake, physiology and biochemistry. *British Journal of Nutrition, 78*, 199-213.

Saklofske, D., Blomme, G. & Kelly, I. (1992). The effects of exercise and relaxation on energetic and tense arousal. *Personality and Individual Differences, 13*, 623-625.

Salmon, P. (2001). Effects of physical exercise on anxiety, depression, and sensitivity to stress: a unifying theory. *Clinical Psychology Review, 21*, 33-61.

Sambeth, A., Blokland, A., Harmer, C. J., Kilkens, T. O., Nathan, P. J., Porter, R. J., Schmitt, J. A., Scholtissen, B., Sobczak, S. & Young, A. H. (2007). Sex differences in the effect of acute tryptophan depletion on declarative episodic memory: a pooled analysis of nine studies. *Neuroscience and Biobehavioral Reviews, 31*, 516-529.

Sánchez-Villegas, A., Galbete, C., Martinez-González, M. Á., Martinez, J. A., Razquin, C., Salas-Salvadó, J., Estruch, R., Buil-Cosiales, P. & Martí, A. (2011). The effect of the Mediterranean diet on plasma brain-derived neurotrophic factor (BDNF) levels: the PREDIMED-NAVARRA randomized trial. *Nutritional Neuroscience, 14*, 195-201.

Sanders, A. (1983). Towards a model of stress and human performance. *Acta Psychologica, 53*, 61-97.

Schlundt, D., Hill, J., Sbrocco, T., Pope-Cordle, J. & Sharp, T. (1992). The role of breakfast in the treatment of obesity: a randomized clinical trial. *The American Journal of Clinical Nutrition, 55*, 645-651.

Schmitt, J. A. J., Wingen, M., Ramaekers, J. G., Evers, E. A. T. & Riedel, W. J. (2006). Serotonin and Human Cognitive Performance. *Current Pharmaceutical Design, 12*, 2473-2486.

Schneider, S., Askew, C. D., Diehl, J., Mierau, A., Kleinert, J., Abel, T., Carnahan, H. & Strüder, H. K. (2009). EEG activity and mood in health orientated runners after different exercise intensities. *Physiology and Behavior, 96*, 709-716.

Schoeller, D. A. (1995). Limitations in the assessment of dietary energy intake by self-report. *Metabolism: Clinical and Experimental, 44, Supplement 2*, 18-22.

Scientific Advisory Committee on Nutrition (2011). *Dietary Reference Values for Energy*. Retrieved from http://www.sacn.gov.uk/pdfs/sacn_dietary_reference_values_for_energy.pdf.

Scully, D., Kremer, J. & Meade, M. M. (1998). Physical exercise and psychological well being: a critical review. *British Journal of Sports Medicine, 32*, 111-120.

Scully, D., Kremer, J., Meade, M. M., Graham, R. & Dudgeon, K. (1998). Physical exercise and psychological well being: a critical review. *British Journal of Sports Medicine, 32*, 111-120.

Shibuya, K.-i., Tanaka, J., Kuboyama, N. & Ogaki, T. (2004). Cerebral oxygenation during intermittent supramaximal exercise. *Respiratory Physiology and Neurobiology, 140*, 165-172.

Sibley, B. A., Etnier, J. L. & Le Masurier, G. C. (2006). Effects of an acute bout of exercise on cognitive aspects of Stroop performance. *Journal of sport and exercise psychology, 28*, 285-299.

Silber, B. Y. & Schmitt, J. A. J. (2010). Effects of tryptophan loading on human cognition, mood, and sleep. *Neuroscience and Biobehavioral Reviews, 34*, 387-407.

Silberstein, L. R., Striegel-Moore, R. H., Timko, C. & Rodin, J. (1988). Behavioral and psychological implications of body dissatisfaction: Do men and women differ? *Sex Roles, 19*, 219-232.

Silliman, K., Rodas-Fortier, K. & Neyman, M. (2004). A Survey of Dietary and Exercise Habits and Perceived Barriers to Following a Healthy Lifestyle in a College Population *Calif J Health Prom, 2*, 10-19.

Smith, A. P. (1998). Breakfast and mental health. *International Journal of Food Sciences and Nutrition, 49*, 397-402.

Smith, A. P. (1999). Breakfast cereal consumption and subjective reports of health. *International Journal of Food Sciences and Nutrition, 50*, 445-449.

Smith, A. P. (2003). Breakfast Cereal Consumption and Subjective Reports of Health by Young Adults. *Nutritional Neuroscience, 6*, 59-61.

Smith, A. P. (2011a). Breakfast and Adult's and Children's Behavior. *Diet, Brain, Behavior: Practical implications, Eds: R.B.Kanarek & H.R.. Lieberman. Taylor & Francis.*, 772S-778S.

Smith, A. P. (2011b). Breakfast Cereal, Digestive Problems and Well-being. *Stress and Health, 27*(5), 388-394.

Smith, A.P., Bazzoni, C., Beale, J., Elliott-Smith, J., & Tiley, M. (2001). High fibre breakfast cereals reduce fatigue. *Appetite, 37*, 249–250.

Smith, A. P. Clark, R., & Gallagher, J. (1999). Breakfast Cereal and Caffeinated Coffee: Effects on Working Memory, Attention, Mood, and Cardiovascular Function. *Physiology and Behavior, 67*, 9-17.

Smith, A. P., Kendrick, A. M. & Maben, A. L. (1992). Effects of breakfast and caffeine on performance and mood in the late morning and after lunch. . *Neuropsychobiology, 26*, 198-204.

Smith, A., Kendrick, A., Maben, A. & Salmon, J. (1994). Effects of breakfast and caffeine on cognitive performance, mood and cardiovascular functioning. *Appetite, 22*, 39-55.

Smith, A., Ralph, A. & McNeill, G. (1991). Influences of meal size on post-lunch changes in performance efficiency, mood, and cardiovascular function. *Appetite, 16*, 85-91.

Smith, A. P. & Stamatakis, C. (2010). Cereal Bars, Mood and Memory. *Current Topics in Nutraceutical Research 8*.

Smith, A. P. & Wilds, A. (2009). Effects of cereal bars for breakfast and mid-morning snacks on mood and memory. *International Journal of Food Sciences and Nutrition, 60*, 63-69.

Smith, M. A., Riby, L. M., Van Eekelen, J. A. M. & Foster, J. K. (2011). Glucose enhancement of human memory: A comprehensive research review of the glucose memory facilitation effect. *Neuroscience and Biobehavioral Reviews, 35*, 770-783.

Smits, J. A. J., Berry, A. C., Rosenfield, D., Powers, M. B., Behar, E. & Otto, M. W. (2008). Reducing anxiety sensitivity with exercise. *Depression and Anxiety, 25*, 689-699.

Sobczak, S., Honig, A., Schmitt, J. & Riedel, W. (2003). Pronounced cognitive deficits following an intravenous L-tryptophan challenge in first-degree relatives of bipolar patients compared to healthy controls. *Neuropsychopharmacology: official publication of the American College of Neuropsychopharmacology, 28*, 711-719.

Song, W. O., Chun, O. K., Obayashi, S., Cho, S. & Chung, C. E. (2005). Is Consumption of Breakfast Associated with Body Mass Index in US Adults? *Journal of the American Dietetic Association, 105*, 1373-1382.

Spielberger, C. D., Gorsuch, R. L., & Lushene, R. E. (1970). *Manual for the State-Trait Anxiety Inventory.*Palo Alto, Calif.: Consulting Psychologists Press.

Sparling, P., Giuffrida, A., Piomelli, D., Rosskopf, L. & Dietrich, A. (2003). Exercise activates the endocannabinoid system. *Neuroreport, 14*, 2209-2211.

Spring, B., Maller, O., Wurtman, J., Digman, L. & Cozolino, L. (1982). Effects of protein and carbohydrate meals on mood and performance: Interactions with sex and age. *Journal of Psychiatric Research, 17*, 155-167.

Stanek, K., Gunstad, J., Leahey, T., Glickman, E., Alexander, T., Spitznagel, M. B., Juvancic-Heltzel, J. & Murray, L. (2008). Serum brain-derived neurotrophic factor is associated with reduced appetite in healthy older adults. *The Journal of Nutrition Health and Aging, 12*, 183-185.

Stein, A. D., Rivera, J. M. & Pivarnik, J. M. (2003). Measuring Energy Expenditure in Habitually Active and Sedentary Pregnant Women. *Medicine and Science in Sports and Exercise, 35*, 1441-1446.

Steinberg, H. & Sykes, E. A. (1985). Introduction to symposium on endorphins and behavioural processes; Review of literature on endorphins and exercise. *Pharmacology Biochemistry and Behavior, 23*, 857-862.

Steinberg, H., Sykes, E. A., Moss, T., Lowery, S., LeBoutillier, N. & Dewey, A. (1997). Exercise enhances creativity independently of mood. *British Journal of Sports Medicine, 31*, 240-245.

Stensel, D. (2010). Exercise, Appetite and Appetite-Regulating Hormones: Implications for Food Intake and Weight Control. *Annals of Nutrition and Metabolism, 57*, 36-42.

Steptoe, A., Kearsley, N. & Walters, N. (1993). Acute mood responses to maximal and submaximal exercise in active and inactive men. *Psychology and Health, 8*, 89-99.

Stevenson, E. J., Astbury, N. M., Simpson, E. J., Taylor, M. A. & Macdonald, I. A. (2009). Fat oxidation during exercise and satiety during recovery are increased following a low-glycemic index breakfast in sedentary women. *The Journal of nutrition, 139*, 890-897.

Stote, K. S., Baer, D. J., Spears, K., Paul, D. R., Harris, G. K., Rumpler, W. V., Strycula, P., Najjar, S. S., Ferrucci, L. & Ingram, D. K. (2007). A controlled trial of reduced meal frequency without caloric restriction in healthy, normal-weight, middle-aged adults. *The American journal of clinical nutrition, 85*, 981-988.

Strohle, A. (2009). Physical activity, exercise, depression and anxiety disorders. *Journal of Neural Transmission, 116*, 777-784.

Stubbs, R. J. (1998). Appetite, feeding behaviour and energy balance in human subjects. In *PROCEEDINGS-NUTRITION SOCIETY OF LONDON*, *57*, 341-356: Cambridge Univ Press.

Stunkard, A. J. & Messick, S. (1985). The three factor eating questionnaire to measure dietary restraint, disinhibition and hunger. *Journal of Psychosomatic Research, 29*, 71-81.

Svebak, S., & Murgatroyd, S. (1985). Metamotivational dominance: A multimethod validation of reversal theory constructs. *Journal of Personality and Social Psychology, 48*, 107-116.

Tanaka, M., Mizuno, K., Fukuda, S., Shigihara, Y. & Watanabe, Y. (2008). Relationships between dietary habits and the prevalence of fatigue in medical students. *Nutrition, 24*, 985-989.

Terry, P. C., Lane, A.M. & Jackson, A. (2004). Prefferred modality influences on exercise induced mood changes. *J Sports Sci Med, 5*, 195-200.

Thayer, R.E. (1986) Activation-deactivation adjective check list: current overview and structural analysis. *Psychological Reports*: *58*, 607-614.

Thomas, K., Morris, P. & Stevenson, E. (2009). Improved endurance capacity following chocolate milk consumption compared with 2 commercially available sport drinks. . *Applied Physiology, Nutrition, and Metabolism, 34*, 78-82.

Thorén, P., Floras, J. S., Hoffmann, P. & Seals, D. R. (1990). Endorphins and exercise: Physiological mechanisms and clinical implications. . *Medicine and Science in Sports and Exercise, 22*, 417-428.

Tiggemann, M. & Williamson, S. (2000). The effect of exercise on body satisfaction and self-esteem as a function of gender and age. *Sex roles, 43*, 119-127.

Timlin, M. T. & Pereira, M. A. (2007). Breakfast frequency and quality in the etiology of adult obesity and chronic diseases. *Nutrition Reviews, 65*, 268-281.

Tomporowski, P. D. (2003). Effects of acute bouts of exercise on cognition. *Acta Psychologica, 112*, 297-324.

Tsai, S. J., Cheng, C. Y., Yu, Y. W. Y., Chen, T. J. & Hong, C. J. (2003). Association study of a brain-derived neurotrophic-factor genetic polymorphism and major depressive disorders, symptomatology, and antidepressant response. *American Journal of Medical Genetics Part B: Neuropsychiatric Genetics, 123*, 19-22.

Tsofliou, F., Pitsiladis, Y. P., Malkova, D., Wallace, A. M. & Lean, M. E. J. (2003). Moderate physical activity permits acute coupling between serum leptin and appetite-satiety measures in obese women. *International Journal of Obesity and Related Metabolic Disorders, 27*, 1332-1339.

Tyler, W. J., Alonso, M., Bramham, C. R. & Pozzo-Miller, L. D. (2002). From Acquisition to Consolidation: On the Role of Brain-Derived Neurotrophic Factor Signaling in Hippocampal-Dependent Learning. *Learning and Memory, 9*, 224-237.

Vanecek, J. (1998). Cellular mechanisms of melatonin action. *Physiological Reviews, 78*, 687-721.

Vaynman, S. & Gomez-Pinilla, F. (2005). License to run: exercise impacts functional plasticity in the intact and injured central nervous system by using neurotrophins. *Neurorehabilitation and Neural Repair, 19*, 283.

Vermorel, M., Bitar, A., Vernet, J., Verdier, E. & Coudert, J. (2003). The extent to which breakfast covers the morning energy expenditure of adolescents with varying levels of physical activity. *European Journal of Clinical Nutrition, 57*, 310-315.

Walters, R. S., Hatfield, B., Haufler, A., Lockwood, P. & Hung, T. (2002). Effect of Exercise-Induced Hypoglycemia on CNS Function in Elite Cyclists. *Medicine and Science in Sports and Exercise, 34(5)*, 119.

Watson, D., Clark, L.A, & Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: The PANAS scales. *Journal of Personality and Social Psychology,54,*1063-1070.

Watson, P., Hasegawa, H., Roelands, B., Piacentini, M. F., Looverie, R. & Meeusen, R. (2005). Acute dopamine/noradrenaline reuptake inhibition enhances human exercise performance in warm, but not temperate conditions. *The Journal of Physiology, 565*, 873-883.

Welsh, R. S., Mark, D. J., Burke, J. R. & Williams, H. G. (2002). Carbohydrates and physical/mental performance during intermittent exercise to fatigue. *Medicine and Science in Sports and Exercise, 34*, 723-731.

Wesnes, K. A., Pincock, C., Richardson, D., Helm, G. & Hails, S. (2003). Breakfast reduces declines in attention and memory over the morning in schoolchildren. *Appetite, 41*, 329-331.

Wightman, E. L., Haskell, C. F., Forster, J. S., Veasey, R. C. & Kennedy, D. O. (2012). Epigallocatechin gallate, cerebral blood flow parameters, cognitive performance and mood in healthy humans: a double-blind, placebo-controlled, crossover investigation. *Human Psychopharmacol, Clinical and Experimental, 27*, 177-186.

Williams, C., Nute, M. G., Broadbank, L. & Vinall, S. (1990). Influence of fluid intake on endurance running performance. A comparison between water, glucose and fructose solutions. *European Journal of Applied Physiology and Occupational Physiology, 60*, 112-119.

Winter, B., Breitenstein, C., Mooren, F. C., Voelker, K., Fobker, M., Lechtermann, A., Krueger, K., Fromme, A., Korsukewitz, C., Floel, A. & Knecht, S. (2007). High impact running improves learning. *Neurobiology of Learning and Memory, 87*, 597-609.

Wisse, B. E. & Schwartz, M. W. (2003). The skinny on neurotrophins. *Nature Neuroscience, 6*, 655-656.

Wurtman, R. J. & Wurtman, J. J. (1986). Carbohydrate craving, obesity and brain serotonin. *Appetite, 7, Supplement*, 99-103.

Wyatt, H.R., Grunwald, G.K., Mosca, C.L., Klem, M.L., Wing, R.R., Hill, J.O. (2002). Long-term weight loss and breakfast in subjects in the National Weight Control Registry. *Obesity Research, 10*(2),78-82.

Yeung, R. R. (1996). The acute effects of exercise on mood state. *Journal of Psychosomatic Research, 40*, 123-141.

Young, S. N., & Leyton, M. (2002). The role of serotonin in human mood and social interaction: insight from altered tryptophan levels. *Pharmacology Biochemistry and Behavior*, *71*(4), 857-865.

Zeng, Y.-C., Li, S.-M., Xiong, G.-L., Su, H.-M. & Wan, J.-C. (2011). Influences of protein to energy ratios in breakfast on mood, alertness and attention in the healthy undergraduate students. *Health, 3*, 383-393.

Zervas, Y., Ekkekakis, P., Emmanuel, C., Psychoudaki, M. & Kakkos, V. (1993). The Acute Effects of Increasing Levels of Aerobic Exercise Intensity on Mood States.

Zigmond, A.S., & Snaith, R.P. (1983). The Hospital Anxiety and Depression Scale. *Acta* Psychiatrica Scandinavica, 6 7, 361–370.

Zilberter, T. & Zilberter, E. Y. (2013). Breakfast and cognition: sixteen effects in nine populations, no single recipe. *Frontiers in Human Neuroscience, 7*.

Appendices

Appendix A

PARTICIPANT INFORMATION.

TITLE OF PROJECT: The interactive effect of breakfast omission and exercise on metabolism, appetite and cognitive performance later in the day.

Principal Investigators: Javier Gonzalez/Rachel Veasey

Investigator contact details: 0191 2437012/7253 Email: Javier.gonzalez@northumbria.ac.uk/r.veasey@northumbria.ac.uk

This project is funded by: Northumbria University

Number of participant points / payment: £100

INFORMATION TO POTENTIAL PARTICIPANTS

1. What is the purpose of the project?

Breakfast consumption is in decline, yet eating breakfast has each been shown to have numerous benefits for health. Separately, exercise has also been shown to be beneficial although information regarding the combination of the two is lacking. Therefore, the aim of this study is to investigate whether exercise can influence some of the effects of not eating breakfast.

2. Why have I been selected to take part?

You have been asked to participate because you are male and aged between 18 and 40 years. You will also be regularly physically active and be able to run for 60 minutes at a moderate intensity, non stop.

3. Do I have to take part?

It is up to you to decide to join the study. Before you decide to take part we will describe the study and go through this information sheet with you. If you agree to take part, we will then ask you to sign a consent form. However, if at any time you decide you no longer wish to take part in the study you are free to withdraw, without giving a reason. This would not affect the standard of care you receive.

4. What will I have to do?

For this experiment you will have to visit the laboratory on 5 occasions. The first visit will last around 2 hours. Subsequent visits will last around 7 hours.

Visit 1 (Suitability, cognitive training and $\dot{V}O_2max$ test): Initially you will complete a health-history questionnaire concerning your past and present health status in private. It is important to be entirely honest and point out any known health problems, even if they seem trivial. We will also need to know if you have been on medication at any time during the four weeks prior to the study. At this time we will also ask you to fill out a questionnaire regarding your training habits. Any answers you give will be kept in strict confidence

Providing that you are suitable for the study and you feel that you want to be involved, you will then be trained on the cognitive tasks you will be completing during each main trial (these assess attention and performance; they do not measure any aspect of intelligence or personality) and will perform a treadmill exercise test to volitional exhaustion in order to determine your maximum aerobic capacity($\dot{V}O_2max$). We will collect gas samples from you (you will wear a mask and we will collect your expired air) and record your heart rate. Visit one will last no more than 2 hours will usually take place in the afternoon.

Visits 2-5 (Main Trials): For the main trials you will be asked to arrive at the laboratory at 7:30 am. First, your compliance to the study restrictions will be assessed and a cannula (small tube for collecting blood samples) will be inserted into a vein by a trained phlebotomist and a 10 ml blood sample will be taken. You will then complete a baseline run through of the cognitive tasks and have an expired air sample taken. You will then be provided with breakfast (syrup flavour porridge and milk) on two trials and nothing more than water on two trials. You will then rest for 2 hours. One hour into and directly after this rest period you will complete the cognitive tasks again. After this period a blood sample will be taken and, on two occasions you will perform exercise for about 40 mins (until you have expended 411 kcals) at 60% of your $\dot{V}O_2max$, and for the remaining two occasions you will remain at rest for the equivalent amount of time as you will exercise for. Immediately after this period you will complete the cognitive tasks again and a blood sample will be drawn. You will then be provided with a chocolate milkshake. In the 1.5 hour period following this you will complete the cognitive tasks at 30 and 75 minutes and blood samples will be drawn at 5 minute intervals for the first 30 min, and at 20 min intervals thereafter. Following this, you will be provided with a pasta with tomato sauce meal which you must eat until you are satisfied to a normal level. Throughout all trials, we will be taking expired air and will also ask you to answer some questions regarding your appetite and mood. Heart rate will also be recorded from a chest strap. After leaving the laboratory we will ask you to complete a food diary for the remainder of the day.

Pre-Test Preparation:
Prior to the first trial, we will ask you to keep a food and fluid intake, and training diary for 24 h which you should replicate before all subsequent trials. We will also ask you to abstain from alcohol, caffeine and any vigorous physical activity above normal daily tasks for 24 h prior to all trials and to refrain from eating and drinking anything other than water, from 8 pm onwards on the day preceding the trial. Please do not cycle or run into the lab on trial days, you can walk in slowly but if you live a substantial distance away then transport can be arranged for you. At all visits you will be asked to fill in a health questionnaire to confirm your fitness to participate in the study on that day.

During each visit approximately 125 ml of blood will be collected (a total of 500 ml – less than a pint across the course of the whole study).

5. What are the exclusion criteria (i.e. are there any reasons why I should not take part)?
Exclusion criteria include smoker (within the previous 5 years), being unaccustomed to running non-stop for 1 hour, any previous or current eating disorders, metabolic disorders, food allergies, or any contraindications of exercise. You must also not be taking any prescription or over the counter medication or herbal/dietary supplements, have a history of/current head trauma, learning difficulties, ADHD, dyslexia, migraines or any gastric problems. Due to the nature of the cognitive tasks, you must also have a good standard of English, equivalent to that of a native English speaker. You should also not take part if you are unhappy to, or have had problems in the past, giving blood samples. If you are unsure about your eligibility then please email one of the researchers and we can discuss any issues or ambiguity.

6. Will my participation involve any physical discomfort?
High intensity treadmill exercise will cause breathlessness. The maximum oxygen uptake test will lead to physical exhaustion but you should recover within a few minutes. Cannulation may result in some light, local bruising which is normal, but this will be minimised by good practice and samples being carried out by trained, experienced personnel. This procedure is much more comfortable than finger prick blood sampling and pain will be minimal.
You may also experience some discomfort sitting at a computer whilst completing the cognitive tasks. However, the duration of each set of tasks is fairly short, and all procedures have been fully risk assessed.

7. Will my participation involve any psychological discomfort or embarrassment?
No

8. Will I have to provide any bodily samples (i.e. blood, saliva)?
We will require venous blood samples take from a cannula in the arm at various intervals throughout the day. The maximum amount of blood we will be taking across the whole day is 125 ml which is well within safe guidelines.

9. Will my taking part be confidential?
You will only be known by a number to protect anonymity. All data will be kept in a locked cabinet or computerised and accessed via a password which will be done in accordance with the Data Protection Act.

10. Who will have access to the information that I provide?
Only the principal investigator and supervisor will have access to information that you provide. All records will be kept confidential except for review by Northumbria University Ethics Committee representatives and regulatory authorities.

11. What will happen to the results of the study?
All personal, identifiable data will be kept in a locked cabinet. All information and data gathered during this research will be stored in line with the Data Protection Act and will be destroyed 15 years following the conclusion of the study. Participants are able to access any data on themselves on request. Data may be used for publication in the form of a scientific paper, presented at a conference or both. In the meantime, if you wish to find out what effect the treatments had, we will email/ post a summary of the results to you approximately four weeks after the study finishes. Blood (plasma and serum) samples collected and stored during this study will be kept for no longer than three years and then disposed of. Any data used cannot be linked to you.

12. Who has reviewed the study?
This study has received ethical approval from the School of Life Sciences Ethics committee. If you require confirmation of this please contact the Chair of this Committee, stating the title of the research project and the name of the principle investigator:

Chair of School of Life Sciences Ethics Committee,
Northumberland Building,
Northumbria University,
Newcastle upon Tyne,
NE1 8ST

13. Will I receive any financial rewards / travel expenses for taking part?
An inconvenience allowance of £100 will be offered upon completion of the study. You will also be provided with breakfast on two occasions, a milkshake snack and a pasta lunch on all occasions as part of the study design.

14. How can I withdraw from the project?
If you wish to withdraw from the project, you can inform one of the researchers by email, telephone or in person. You can withdraw from the project at any point without providing reasons for doing so and without prejudice. If, for any reason, you wish to withdraw your data please contact the investigator within a month of your participation. After this date, it may not be possible to withdraw your individual data as the results may already have been published. As all data are anonymised, your individual data will not be identifiable in any way.

15. What happens if there is a problem?

Complaints

If you have a concern about any aspect of the study you should ask to speak to the researchers who will do their best to answer any questions you may have. If they are unable to resolve your concern, or you wish to make a complaint regarding the study, please contact the chair of the ethics committee:

Chair of School of Life Sciences, Ethics Committee, Northumberland Building, Northumbria University, Newcastle upon Tyne, NE1 8ST.

Harm

In the event that something does go wrong and you are harmed during the research, you may have grounds for legal action for compensation against Northumbria University, but you may have to pay your legal costs. (Please ask if you would like more information on this).

16. Who is funding and organising the study?

The study is organised and funded by Northumbria University. The researchers conducting these studies are salaried and therefore gain no additional financial incentive from

17. If I require further information who should I contact and how?
If you would like further information on the study please contact the principal investigators on the contact emails listed above. If you would like to discuss the study, withdraw your data or register a complaint please contact the chair of the ethics committee:
Chair of School of Life Sciences Ethics Committee,
Northumberland Building,
Northumbria University,
Newcastle upon Tyne, NE1 8ST.

Appendix B

GENERAL HEALTH QUESTIONNAIRE

Subject number: …………………

As you are participating in exercise within this laboratory, please can you complete the following questionnaire. Your co-operation is greatly appreciated.

All information within this questionnaire is considered confidential.

Where appropriate please circle your selected answer.

How would you describe your current level of activity?

Sedentary / Moderately Active / Highly Active

How would you describe your current level of fitness?

Very Unfit / Moderately Fit / Trained / Highly Trained

How would you describe your current body weight?

Underweight / Ideal / Slightly Overweight / Very Overweight

Smoking Habit: -

Currently a non-smoker Yes / No

Previous smoker Yes / No

If previous smoker, how long since you stopped? ………Years

Regular smoker Yes / No of …… per day

Occasional smoker Yes / No of …… per day

Alcohol Consumption: -

Do you drink alcohol? Yes / No

If yes then do you - have an occasional drink Yes / No

Have a drink every day? Yes / No

Have more than one drink per day? Yes / No

Have you consulted your doctor within the last 6 months?

Yes / No

If yes, please give details to the test supervisor

Are you currently taking any medication (including anti-inflammatory drugs)?

Yes / No

If yes, please give details to the test supervisor

Do you, or have you ever suffered from:-

Diabetes Yes / No

Asthma Yes / No

Epilepsy Yes / No

Bronchitis Yes / No

Elevated cholesterol Yes / No

High Blood Pressure Yes / No

Do you suffer from, or have you ever suffered from any heart complaint or pains in your chest, either associated with exercise or otherwise?

Yes / No

Is there a history of heart disease in your family?

Yes / No

Do you feel faint or have spells of severe dizziness when undertaking exercise or otherwise?

Yes / No

Do you currently have any form of muscle joint injury?

Yes / No

Have you ever suffered from any knee joint injury or thigh injury?

Yes / No

Do you currently take any form of nutritional supplement (e.g. creatine, whey and casein protein, HMB, etc)?

Yes / No

If yes, please give details to the test supervisor

Do you have any food allergies?

Yes/No

If yes, please give details to the test supervisor

Are you currently on any special diet? (e.g. weight loss/ high protein)

Yes/No

If yes, please give details to the test supervisor

Is there anything to your knowledge that may prevent you from successfully completing the test that has been explained to you?

Yes / No

If yes, please give details to the test supervisor

Please provide any further information concerning any condition/complaint that you suffer from and any medication that you may be taking by prescription or otherwise.

……………………………………………………………………………………………………
………………………………………………………………………………

Signature of Subject: …………………………

Signature of test supervisor: …………………

Date: ……………………

Study Days

Please read the above and sign below to conform that your health status has not changed from the initial screen.

	Visit 1	Visit 2	Visit 3
Sign			
Date			

Appendix C

brain, performance and nutrition research centre
food and diet neuroscience at northumbria university

northumbria UNIVERSITY

INSTRUCTION FOR USING THE FOOD DIARY

Everything that you eat and drink over the course of the day should be weighed and the weight and type of food or drink recorded.

For solid foods, the food should be placed on the scale on a plate or container. The plate or container must be weighed empty first and the scales can then be zeroed. Each item of food can then be added to the plate and weighed individually, returning the scales to zero between each item.

e.g.	Add Plate	zero scale
	Add Roast Beef	100g (record) zero scale
	Add Potato	150g (record) zero scale
	Add Gravy	30g (record)

For drinks, a cup or glass must first be weighed and then the scale can be returned to zero and the drink added. Please remember to record separately the weight of **<u>tea, milk and sugar</u>** put into a drink.

Do not forget to weigh and record second helpings and between meal snacks.

Any leftovers (eg. apple cores, banana skins) should also be weighted and recorded in the leftovers column.

<u>Eating Out</u> – Most people eat foods away from home each day, please do not forget to record these. Take your diary and scales with you where ever it is possible. If this is too inconvenient just record the type of food eaten with an estimated weight – but please say when a weight has been estimated.

Most snack foods will have the weight of the food on the packet so they do no need weighing if you eat the whole packet yourself.

Names and descriptions of foods should be as detailed as possible, including the brand name and any other information available.

e.g. Cheese – is insufficient information.
Cheese, cheddar (Shape reduced fat) – is sufficient information.

Record each item on a separate line. Record the time of day in the first column of each line.
e.g. 10:30 am McVities Digestive Biscuits (2) 50g

The space provided at the foot of each page for general comments is for you to give any further information about your diet and your training/activity for that day.

e.g. Steady run, morning 1 hour.
Missed lunch due to stomach pains

Pre-study Day 1

Date: / /

Please use a separate line for each item eaten

A	B		C	D	E	F	**Office Use**
Time	Food eaten		Brand name of each item (except fresh food)	Full description of each item including: -whether fresh, frozen, dried, canned -cooked: boiled, grilled, fried, roasted. -what type of fat food fried in	Weight Served	Weight of Leftovers	Actual Weight
am/pm	home	away			(gms)	(gms)	(gms)

GENERAL COMMENTS and ACTIVITY UNDERTAKEN:

Appendix D

The Exercise and Dietary Practices of Habitually Active Women

Participant Number: ______________________ **Date:** ______________________

This survey has been designed to find out information about the exercise and dietary practices of **HABITUALLY ACTIVE WOMEN aged 18-45.**

For the purposes of this survey, "habitually active" is defined as:
"Being physically active* for at least 30 minutes a day at least 3 times a week for at least the previous 6 months."

*This does not include periods of walking unless you consider walking as an exercise session in its own right and not as a means of commuting. It does include active commuting if you run or cycle and you consider this to be a main part of your exercise routine.

N.B. Please *do not* fill out this survey if:

- **the above definition does not describe you**
- **you take part in competitive sporting events more than twice a year which *train* for**
- **you consider yourself to be an athlete**

All answers are confidential; **please do not put your name on the survey**. Before completing the survey, read through the participant information sheet attached and return the completed survey with the ***signed consent form*** (also attached) to the researcher.

Section 1: Demographic information

Date of Birth (dd/mm/yyyy): ____/____/________

Height:	**cms**	________	**OR**	**ft, inchs:**	________
Weight:	**kg**	________	**OR**	**Sts, lbs:**	________

Work/study pattern
(please circle one):

- 9 'til 5 (or similar)
- Evenings
- Nights
- House wife/Mother
- Weekends
- Shift work
- Other (please specify)..

Number of hours worked per week *(please state):* ________ **hours**

Normal waking time *(please state):* ________ **am/pm**

Marital status
(please circle one): Single Married Living with partner

Section 2: Dietary Habits, Appetite and Mood

1. Typically, how often do you eat breakfast? *(circle **one** answer):*

a) Everyday b) 5-6 times per week c) 4-5 times per week

d) 2-3 times per week e) <once per week ***(go to question 3)***

2. Please describe the type of breakfast you eat most regularly and state how many times per week you would eat that breakfast *(e.g. Cereal, milk and coffee - 2 times per week)* ***Describe more than one if applicable***:

Items in Breakfast	***Frequency***	
		times per week
		times per week
		times per week

Please turn over for next question

To what extent do you agree/disagree with the following statements? *Circle **one** response for each statement:*

	Strongly Disagree	Disagree	Neither agree nor disagree	Agree	Strongly Agree
3. I feel hungrier during rest days which follow an exercise day.	**1**	**2**	**3**	**4**	**5**
4. I find my mood is better after exercising.	**1**	**2**	**3**	**4**	**5**
5. I feel my mood is worse if I skip meals.	**1**	**2**	**3**	**4**	**5**
6. I feel exercising improves my concentration.	**1**	**2**	**3**	**4**	**5**
7. I feel exercising makes me feel more alert.	**1**	**2**	**3**	**4**	**5**
8. I feel exercising makes me feel less tired.	**1**	**2**	**3**	**4**	**5**
9. I feel exercising improves my ability to perform well: at work/when studying/in doing my daily tasks.	**1**	**2**	**3**	**4**	**5**
10. If I skip breakfast, my mood is much worse.	**1**	**2**	**3**	**4**	**5**
11. If I skip breakfast, my concentration is much worse.	**1**	**2**	**3**	**4**	**5**
12. If I skip breakfast, my appetite increases for the rest of the day	**1**	**2**	**3**	**4**	**5**
13. I feel hungrier in the 4 hours following an exercise session compared to if I have not exercised.	**1**	**2**	**3**	**4**	**5**
14. I feel I eat more in the 4 hours following an exercise session compared to if I have not exercised.	**1**	**2**	**3**	**4**	**5**

15. If you answered **strongly agree/agree** to question 14, what is the **main** reason for this? *(circle **one** answer - if you did not answer strongly agree/agree, **go to question 16**):*

a) I feel hungrier

b) I feel I should replace the energy I have expended

c) To recover more quickly

d) As a reward for exercising

e) Other (please specify)..

Please turn over for next question

16. If you answered **disagree/strongly disagree** to <u>question 14</u>**,** what is the **<u>main</u>** reason for this? *(circle **<u>one</u>** answer - if you answered neither agree nor disagree,* ***go to next section****):*

a) I don't feel hungry

b) I don't want to replace the calories I have expended

c) I don't have time

d) Other (please specify)..

<u>Section 3: General exercise habits</u>

For the next sections, please answer the questions with regards to your MAIN exercise sessions each week. <u>Do not</u> include periods of walking unless walking is an exercise session in its own right for you and not a means of commuting. You can include active commuting if you run or cycle and you consider this to be a <u>main</u> part of your exercise routine.

17. How many times *<u>per week</u>* do you exercise? *(circle **<u>one</u>** answer):*

a) <1 b) 1-2 c) 3-4 d) 5+

18. Do you ever exercise more than once per day? <u>Do not include walking to commute</u> *(circle **<u>one</u>** answer):*

a) Yes b) No ***(go to question 20)***

19. If yes, how many times per week do you exercise more than once a day? *(circle **<u>one</u>** answer):*

a) <1 b) 1-2 c) 3-4 d) 5+

20. What are the *<u>main</u>* reasons that you exercise? *(Please rank in order your main **<u>3</u>** reasons for exercising by **<u>labelling 1,2 and 3</u>**):*

a) Weight control............. b) Fitness................ c) Health............. d) To improve body tone............

e) Social reasons................ f) To improve mood............. g) Enjoyment...........

h) Flexibility/agility........... i) Other (please specify)...

For the purpose of the next sections, please use the following guidelines: - a *<u>snack</u>* is anything eaten which is not part of a main meal
- a *<u>main meal</u>* is anything which you consider your breakfast, lunch or dinner

Please turn over for next question

Section 4: Morning Exercise

21. Do you exercise in the morning (between 6am-11am) regularly (**i.e. at least once a week**)? *(circle **one** answer):*

a) Yes

b) No ***(go to Section 5 on page 7)***

22. How many times per week do you usually exercise in the morning? *(circle **one** answer):*

a) <1 b) 1-2 c) 3-4 d) 5+

23. Typically, how long would you exercise for in your morning session? *(circle **one** answer):*

a) <30 mins b) 30-60mins c) 60-90mins d) 90mins+

24. What type of exercise do you participate in on a regular basis in the morning (**i.e. at least twice a month**)? *(circle **any that apply**)*

a)Running (alone)	b) Running (Club)	c) Aerobics (taught class)
d) Aerobics (home DVD)	e) Rowing	f) Cross-trainer
g) Step machine	h) Cycling (outside)	i) Stationary bike
j) Yoga	k) Pilates	l) Weight training
m) Swimming	n) Power walking	

o) Other (please specify)...

25. Typically, at what intensity do you exercise during your morning session? *(circle **one** answer):*

Very Low (you breathe normally)		Moderate (you breathe somewhat harder than normal)		Very High (you breathe much harder than normal)
1	**2**	**3**	**4**	**5**

26. What is the *main* reason that you exercise in the morning?*(circle **one** answer):*

a) The gym is less busy at this time

b) I work out with friends at this time

c) This is the only time I can work out

d) It is the best time for me to work out

e) I prefer to work out at this time

f) The exercise I do is part of my journey to/from work

g) This is the only time my exercise class is available

h) Other (please specify)...

Please turn over for next question

27. Do you eat anything after waking and <u>before</u> your morning exercise session? (*circle* ***<u>one</u>*** *answer*):

a) Yes b) No ***(go to question 30)***

28. If yes, what do you eat and how long before your session do you consume it? *(circle* ***<u>all</u>*** *that apply below - if you have more than one snack, specify when you have your 1st snack and 2nd snack):*

a) Breakfast:	<30mins	<1hr	1-2hrs	2-3hrs	3-4hrs	4-5hrs	5+ hrs
b) Snack *(1st):*	<30mins	<1hr	1-2hrs	2-3hrs	3-4hrs	4-5hrs	5+ hrs
c) Snack *(2nd):*	<30mins	<1hr	1-2hrs	2-3hrs	3-4hrs	4-5hrs	5+ hrs

29. If you eat a meal or snack before you exercise in the morning (consumed within 4 hours of exercising), what is the *<u>main</u>* reason for this? *(circle* ***<u>one</u>*** *answer and* ***go to question 31****):*

a) I feel that I perform better

b) It makes exercise feel more comfortable (i.e. prevents sickness or stitches)

c) I feel like I'm burning more calories

d) I feel I have more energy

e) Other (please specify)..

f) Not applicable

30. If you exercise in the morning on an empty stomach (no food eaten for >4 hours prior to exercising), what is the *<u>main</u>* reason for this? *(circle* ***<u>one</u>*** *answer):*

a) I feel that I perform better

b) It makes exercise feel more comfortable (i.e. prevents sickness or stitches)

c) I feel like I'm burning more calories

d) I don't have time to eat before my workout

e) I feel I have more energy

f) Other (please specify)..

31. Do you eat anything after your morning exercise session and before lunch? (*circle* ***<u>one</u>*** *answer*):

a) Yes b) No ***(go to question 34)***

32. If yes, what do you eat and how long after your session do you consume it? *(specify* ***<u>all</u>*** *that apply below - if you have more than one snack, specify when you have your 1st snack and 2nd snack):*

a) Breakfast:	<30mins	<1hr	1-2hrs	2-3hrs	3-4hrs	4-5hrs	5+ hrs
b) Snack *(1st):*	<30mins	<1hr	1-2hrs	2-3hrs	3-4hrs	4-5hrs	5+ hrs
c) Snack *(2nd):*	<30mins	<1hr	1-2hrs	2-3hrs	3-4hrs	4-5hrs	5+ hrs

Please turn over for next question

33. If you eat after your morning exercise session, why is this? *(circle* ***<u>one</u>*** *answer and* ***go to question 35****):*

a) I feel hungry

b) I feel I should replace the energy I have expended

c) To recover more quickly

d) As a reward for exercising

e) Other (please specify)...

34. If you do not eat anything after your morning exercise session**,** why is this? *(circle **one** answer):*

a) I don't feel hungry

b) I don't want to replace the calories I have expended

c) I don't have time

d) Other (please specify)...

Section 5: Mid-day Exercise

35. Do you exercise during the day (between 11am-5pm) regularly (**i.e. at least once a week**)? *(circle **one** answer):*

a) Yes

b) No ***(go to Section 6 on page 9)***

36. How many times per week do you exercise during the day? *(circle **one** answer):*

a) <1 b) 1-2 c) 3-4 d) 5+

37. Typically, how long would you exercise for in your day time session? *(circle **one** answer):*

a) <30 mins b) 30-60mins c) 60-90mins d) 90mins+

38. What type of exercise do you participate in on a regular basis during the day (i.e. at least twice a month)? *(circle **any that apply**)*

a)Running (alone)
b) Running (Club)
c) Aerobics (taught class)
d) Aerobics (home DVD)
e) Rowing
f) Cross-trainer
g) Step machine
h) Cycling (outside)
i) Stationary bike
j) Yoga
k) Pilates
l) Weight training
m) Swimming
n) Power walking
o) Other (please specify)...

39. Typically, what intensity do you exercise at during your day time session? *(circle **one** answer):*

Very Low (you breathe normally)		Moderate (you breathe somewhat harder than normal)		Very High (you breathe much harder than normal)
1	**2**	**3**	**4**	**5**

40. What is the *main* reason that you exercise during the day? *(circle **one** answer):*

a) The gym is less busy at this time

b) I work out with friends at this time

c) This is the only time I can work out

d) It is the best time for me to work out

e) I prefer to work out at this time

f) The exercise I do is part of my journey to/from work

g) This is the only time my exercise class is available

h) Other (please specify)..

41. Do you eat anything after waking and before your daytime exercise session? *circle **one** answer):*

a) Yes b) No ***(go to question 44)***

42. If yes, what do you eat and how long before your session would you consume it? *(circle **all** that apply below- if you have more than one snack, specify when you have your 1st snack, 2nd snack etc):*

a) Breakfast:	<30mins	<1hr	1-2hrs	2-3hrs	3-4hrs	4-5hrs	5+ hrs
b) Lunch:	<30mins	<1hr	1-2hrs	2-3hrs	3-4hrs	4-5hrs	5+ hrs
c) Snack *(1st):*	<30mins	<1hr	1-2hrs	2-3hrs	3-4hrs	4-5hrs	5+ hrs
d) Snack *(2nd):*	<30mins	<1hr	1-2hrs	2-3hrs	3-4hrs	4-5hrs	5+ hrs
e) Snack *(3rd):*	<30mins	<1hr	1-2hrs	2-3hrs	3-4hrs	4-5hrs	5+ hrs

43. If you eat a meal or a snack before you exercise during the day (consumed within 4 hours of exercising), what is the *main* reason for this? *(circle **one** answer and* ***go to question 45****):*

a) I feel that I perform better

b) It makes exercise feel more comfortable (i.e. prevents sickness or stitches)

c) I feel like I'm burning more calories

d) I feel I have more energy

e) Other (please specify)..

44. If you exercise during the day on an empty stomach (no food eaten for >4 hours prior to exercising), what is the *main* reason for this? *(circle **one** answer):*

a) I feel that I perform better

b) It makes exercise feel more comfortable (i.e. prevents sickness or stitches)

c) I feel like I'm burning more calories

d) I don't have time to eat before my workout

e) I feel I have more energy

f) Other (please specify)..

Please turn over for next question

45. Do you eat anything <u>after</u> your daytime exercise session and before your evening meal? *(circle **one** answer):*

a) Yes b) No ***(go to question 48)***

46. If yes, what do you eat and how long after your exercise session would you consume it? *(circle **all** that apply below - if you have more than one snack, specify when you have your 1st snack, 2nd snack etc):*

a) Lunch:	<30mins	<1hr	1-2hrs	2-3hrs	3-4hrs	4-5hrs	5+ hrs
b) Snack *(1st):*	<30mins	<1hr	1-2hrs	2-3hrs	3-4hrs	4-5hrs	5+ hrs
c) Snack *(2nd):*	<30mins	<1hr	1-2hrs	2-3hrs	3-4hrs	4-5hrs	5+ hrs
d) Snack *(3rd):*	<30mins	<1hr	1-2hrs	2-3hrs	3-4hrs	4-5hrs	5+ hrs

47. If you eat after your day time exercise session, why is this? *(circle **one** answer and **go to question 49**):*

a) I feel hungry
b) I feel I should replace the energy I have expended
c) To recover more quickly
d) As a reward for exercising
e) Other (please specify)..

48. If you do not eat anything after your day time exercise session**,** why is this? *(circle **one** answer):*

a) I don't feel hungry
b) I don't want to replace the calories I have expended
c) I don't have time
d) Other (please specify)..

Section 6: Evening Exercise

49. Do you exercise in the evening (between 5pm-11pm) regularly (**i.e. at least once a week**)? *(circle **one** answer):*

a) Yes b) No ***(go to Section 7 on page 12)***

50. How many times <u>per week</u> do you exercise in the evening? *(circle **one** answer):*

a) <1 b) 1-2 c) 3-4 d) 5+

51. Typically, how long would you exercise for in your evening session? *(circle **one** answer):*

a) <30 mins b) 30-60mins c) 60-90mins d) 90mins+

Please turn over for next question

52. What type of exercise do you participate in on a regular basis in the evening (i.e. at least twice a month)? *(circle **any that apply**)*

a)Running (alone)	b) Running (Club)	c) Aerobics (taught class)
d) Aerobics (home DVD)	e) Rowing	f) Cross-trainer
g) Step machine	h) Cycling (outside)	i) Stationary bike
j) Yoga	k) Pilates	l) Weight training
m) Swimming	n) Power walking	

o) Other (please specify)...

53. Typically, what intensity do you exercise at during your evening session? *(circle **one** answer):*

Very Low (you breathe normally)		Moderate (you breathe somewhat harder than normal)		Very High (you breathe much harder than normal)
1	**2**	**3**	**4**	**5**

54. What is the *main* reason that you exercise in the evening?*(circle **one** answer):*

a) The gym is less busy at this time

b) I work out with friends at this time

c) This is the only time I can work out

d) It is the best time for me to work out

e) I prefer to work out at this time

f) The exercise I do is part of my journey to/from work

g) This is the only time my exercise class is available

h) Other (please specify)...

55. Do you eat anything after waking and before your evening exercise session? *(circle **one** answer):*

a) Yes b) No ***(go to question 58)***

56. If yes, what do you eat and how long before your evening exercise session would you consume it? *(specify **all** that apply below - if you have more than one snack, specify when you have your 1st snack, 2nd snack etc):*

a) Breakfast:	<30mins	<1hr	1-2hrs	2-3hrs	3-4hrs	4-5hrs	5+ hrs
b) Lunch:	<30mins	<1hr	1-2hrs	2-3hrs	3-4hrs	4-5hrs	5+ hrs
c) Dinner:	<30mins	<1hr	1-2hrs	2-3hrs	3-4hrs	4-5hrs	5+ hrs
d) Snack *(1st):*	<30mins	<1hr	1-2hrs	2-3hrs	3-4hrs	4-5hrs	5+ hrs
e) Snack *(2nd):*	<30mins	<1hr	1-2hrs	2-3hrs	3-4hrs	4-5hrs	5+ hrs
f) Snack *(3rd):*	<30mins	<1hr	1-2hrs	2-3hrs	3-4hrs	4-5hrs	5+ hrs

Please turn over for next question

57. If you exercise in the evening following a meal or snack (consumed within 4 hours of exercising), what is the *main* reason for this? *(circle **one** answer and* ***go to question 59****):*

a) I feel that I perform better

b) It makes exercise feel more comfortable (i.e. prevents sickness or stitches)

c) I feel like I'm burning more calories

d) I feel I have more energy

e) Other (please specify)..

58. If you exercise in the evening on an empty stomach (no food eaten for >4 hours prior to exercising), what is the *main* reason for this? *(circle **one** answer):*

a) I feel that I perform better

b) It makes exercise feel more comfortable (i.e. prevents sickness or stitches)

c) I feel like I'm burning more calories

d) I don't have time to eat before my workout

e) I feel I have more energy

f) Other (please specify)..

59. Do you eat anything after your evening exercise session and before going to bed? *(circle **one** answer):*

a) Yes b) No ***(go to question 62)***

60. If yes, what do you eat and when? *(specify **all** that apply below - if you have more than one snack, specify when you have your 1st snack, 2nd snack etc):*

a) Dinner	<30mins	<1hr	1-2hrs	2-3hrs	3-4hrs	4-5hrs	5+ hrs
b) Snack *(1st)*	<30mins	<1hr	1-2hrs	2-3hrs	3-4hrs	4-5hrs	5+ hrs
c) Snack *(2nd)*	<30mins	<1hr	1-2hrs	2-3hrs	3-4hrs	4-5hrs	5+ hrs
d) Snack *(3rd)*	<30mins	<1hr	1-2hrs	2-3hrs	3-4hrs	4-5hrs	5+ hrs

61. If you eat after your evening exercise session, why is this? *(circle **one** answer and go on to* ***Section 7 on page 12)****:*

a) I feel hungry

b) I feel I should replace the energy I have expended

c) To recover more quickly

d) As a reward for exercising

e) Other (please specify)...

62. If you do not eat anything after your evening exercise session**,** why is this? *(circle **one** answer):*

a) I don't feel hungry

b) I don't want to replace the calories I have expended

c) I don't have time

d) Other (please specify)...

Please turn over for next question

Section 7: Comments

If you would like to add any extra comments regarding the information you have just given, please include those here (referring to specific questions if necessary)**:**

Thank you for your participation –
Please turn over and detach the Debrief Sheet

Appendix E

Exercise Log

Study Code: 29AP1 **Participant Number:** .... **Initials:** ....

Please complete this exercise log as soon as possible after finishing your exercise session (immediately after if possible). Please note, your exercise session should be undertaken **in the morning, finishing by 11am at the latest**.

Date: ....

Start time of exercise session: ....

End time of exercise session: ....

Time of completing this log: ....

Mode of Exercise (i.e. running, using weights, cross trainer, exercise class) Please specify all:
....
....
....
....
....

*Please rate your answers to the following questions by marking each scale with a **single, vertical line***

How would you rate the intensity of your exercise session today?

Very Low (you breathe normally) |————————————| Very High (you breathe much harder than normal)

How enjoyable was your exercise session today?

Not at all |————————————| Extremely

How tense do you feel?

Not at all |————————————| Extremely

How hungry do you feel?

Not at al |————————————| Never more hungry

How mentally fatigued do you feel?

Not at all |———| Extremely

How relaxed do you feel?

Not at all |———| Extremely

How much do you think you can eat?

Nothing |———| A lot

How tired do you feel?

Not at all |———| Extremely

How jittery do you feel?

Not at all |———| Extremely

How hungry do you feel?

Not at all |———| Never more hungry

How full do you feel?

Not at all |———| Totally Full

How thirsty do you feel?

Not at all |———| Extremely

How bad is your headache?

Not at all |———| Extremely

How alert do you feel?

Not at all |———| Extremely

How satisfied do you feel?

Completely empty |———| Can't eat another bite.

How would you rate your overall mood?

Very bad |———| Very good