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The effect of breakfast on appetite regulation, energy balance and exercise performance

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The belief that breakfast is the most important meal of day has been derived from cross-sectional studies that have associated breakfast consumption with a lower BMI. This suggests that breakfast omission either leads to an increase in energy intake or a reduction in energy expenditure over the remainder of the day, resulting in a state of positive energy balance. However, observational studies do not imply causality. A number of intervention studies have been conducted, enabling more precise determination of breakfast manipulation on indices of energy balance. This review will examine the results from these studies in adults, attempting to identify causal links between breakfast and energy balance, as well as determining whether consumption of breakfast influences exercise performance. Despite the associations in the literature, intervention studies have generally found a reduction in total daily energy intake when breakfast is omitted from the daily meal pattern. Moreover, whilst consumption of breakfast supresses appetite during the morning, this effect appears to be transient as the first meal consumed after breakfast seems to offset appetite to a similar extent, independent of breakfast. Whether breakfast affects energy expenditure is less clear. Whilst breakfast does not seem to affect basal metabolism, breakfast omission may reduce free-living physical activity and endurance exercise performance throughout the day. In conclusion, the available research suggests breakfast omission may influence energy expenditure more strongly than energy intake. Longer term intervention studies are required to confirm this relationship, and determine the impact of these variables on weight management.

Breakfast skipping: Satiety: Gut hormones

Overweight and obesity are defined as a BMI of 25–29·9 and >30 kg/m^2, respectively, and are positively associated with several chronic diseases, representing a substantial health and economic burden on society[1,2]. Obesity is a growing concern with the worldwide prevalence of obesity more than doubling between 1980 and 2008[3]. It has also been shown that BMI increases continuously throughout adulthood[4] suggesting that long-term behavioural changes are required to curtail this pattern of weight gain. This necessitates the study of both lean and overweight populations, to ensure that dietary interventions are applicable for both reducing BMI in overweight and obese populations, and preventing the increase of BMI in lean populations.

Breakfast can be defined as the first meal of the day, consumed within 2 h of waking, before commencing daily activities, and has been suggested to contain 20–35 % of daily estimated energy requirements[5]. Breakfast has long been considered an integral part of a healthy balanced diet[6]. This is partly due to associations in the literature that show individuals who regularly omit breakfast have a higher BMI[7,8] and increased prevalence of obesity-related chronic diseases[5], including type-2 diabetes[9] and CHD[10]. Despite this, breakfast omission is

Abbreviations: AEE, activity energy expenditure; GLP-1, glucagon-like peptide-1; PYY, peptide YY.
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becoming more common in Western society[11], and it was recently reported that 36 % of the UK population either sometimes or always omit breakfast[12]. Interestingly, a major reason given for omitting breakfast is weight management, which would appear to contradict a proportion of the scientific evidence[13].

Fundamentally, weight gain occurs when energy intake exceeds energy expenditure over a prolonged period of time. Refraining from eating at a prescribed meal time will inevitably create an energy deficit; however, it is thought that the appetite regulatory system will counter perturbations in energy intake, with behavioural and metabolic modifications that target both energy intake and expenditure[14]. It is therefore appropriate to determine whether omitting breakfast in the morning will be compensated for by an increased energy intake in both the short and long terms. However, in order to fully understand the influence of breakfast on energy balance, energy expenditure must also be considered, particularly given the overwhelming evidence that physical activity can reduce the risk of developing numerous chronic diseases[2]. Inclusion of exercise alongside energy restriction improves the long-term adherence to, and success of a dietary strategy[15], and therefore it is important to consider the effect that a given dietary strategy, i.e. breakfast omission, has on the ability and willingness to perform exercise. This may be particularly relevant for exercisers concerned with both weight management and maximising exercise performance.

Whilst the efficacy of controlling energy intake via breakfast omission appears to contradict scientific evidence, individuals who regularly consume breakfast often exhibit other healthy lifestyle factors, such as increased physical activity[16], improved dietary profiles[17] and reduced consumption of snacks[18]. Therefore, it is difficult to determine whether improved weight control is mediated through breakfast consumption *per se*, or whether this may be the result of other lifestyle factors. A recent study also found that presumptions and beliefs about the importance of breakfast on health may predispose studies to biased reporting, further confounding the matter[19]. This demonstrates a need for causal data from breakfast intervention trials, and a number of studies have recently been performed, helping to elucidate causal links between breakfast and energy balance.

To comprehensively examine energy balance, several determinants of energy intake and energy expenditure must be considered. Whilst absolute energy consumed can be assessed through *ad libitum* buffet meals and food records, energy intake data collected by food records should be treated with caution[20]. In addition, the evaluation of breakfast on appetite control has important implications for energy intake. Appetite regulation can be assessed by subjective appetite sensations, as well as through alterations in peripheral appetite hormone concentrations, and these measures might provide insight into the potential effect of breakfast omission outside of rigid experimental control (i.e. laboratory confinement, defined eating times, etc.). Similarly, energy expenditure can be determined from BMR or RMR, dietary-induced thermogenesis and physical activity energy expenditure (AEE). However, perception of effort and performance during exercise are also important considerations that may influence adherence to exercise training and consequently energy expenditure in the long term. This review therefore aims to summarise scientific evidence from breakfast intervention studies, investigating breakfast omission or consumption and energy balance in adults, and will attempt to identify causal mechanisms between morning eating behaviour and energy balance. For the purpose of this review paper, we defined breakfast as containing $\geqslant$10 % of daily estimated energy requirements.

Effect of breakfast on subjective appetite

It is generally believed that omission of breakfast will increase appetite, causing overeating at subsequent meals, resulting in weight gain[21]. In research, visual analogue scales have been used to assess appetite sensations, such as hunger and fullness, and can provide a reproducible and reliable assessment of subjective appetite[22]. As would be expected, a well-established pattern of appetite suppression has been observed during the morning when breakfast is consumed, compared with when breakfast is omitted[23–31]. However, it is interesting to note that the subjective appetite response to subsequent meals appears to be unaffected by prior omission of breakfast, suggesting that consumption of breakfast only provides a transient suppression of appetite[23,24,26–29]. This was recently investigated in two studies that were designed to determine how 24 h subjective appetite profiles responded to breakfast consumption or omission, with *ad libitum*[28] or standardised[29] lunch and dinner meals. In these studies, breakfast (25 % estimated energy requirements) was consumed at 08·00 hours, with lunch and dinner meals consumed at 12·30 and 18·00–19·00 hours. These studies found a reduction in appetite throughout the morning when breakfast was consumed compared with when breakfast was omitted. However, the consumption of an *ad libitum* lunch meal offset appetite to the same extent, independent of breakfast consumption, and this effect persisted throughout the remainder of the day. The same response was observed when standardised lunch (35 % estimated energy requirements) and dinner (40 % estimated energy requirements) meals were provided, consequently preserving the energy deficit created by breakfast omission. Similar studies have also observed a transient suppression of appetite after breakfast consumption in both lean[24,26] and obese[27] subjects, with subjective appetite appearing to be offset independent of breakfast consumption, after an *ad libitum* lunch meal. Results from these studies demonstrate an imprecise regulation of subjective appetite in response to an energy deficit. However, it should be noted that subjective appetite sensations do not always predict subsequent energy intake[32,33].

Effect of breakfast on peripheral appetite hormones

Part of the regulation of appetite may involve several gut peptides, including the appetite stimulatory hormone

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ghrelin and hormones associated with satiation and satiety, such as peptide YY (PYY), glucagon-like peptide-1 (GLP-1), glucose-dependent insulinotropic polypeptide, cholecystokinin and leptin. Understanding the response of these hormones to energy balance fluctuations may provide valuable information about whether dietary interventions (such as breakfast omission) will be tolerable outside of the laboratory environment. Astbury *et al.*[23] found that anorexigenic hormones (GLP-1; PYY) were greater up to 30 min after consumption of a 1050 kJ liquid meal 2·5 h after breakfast consumption, compared with after breakfast omission. However, no differences in the orexigenic hormone ghrelin were observed. Additionally, breakfast omission caused an increase in glucose and insulin response to the liquid meal, compared with breakfast consumption. This dampened glycaemic response to the second meal of the day, is known as the 'second meal effect' which may be related to glycogen storage[34]. Gonzalez *et al.*[25] similarly found a tendency for an increased glucose and insulin response to a 1500 kJ liquid meal consumed 3 h after omission, compared with consumption of breakfast, although active GLP-1 concentrations were not different between trials. The different GLP-1 findings may be due to whether total[23] or active GLP-1[25] was measured. Additionally, Thomas *et al.*[30] examined whether habitual breakfast patterns influence the hormonal regulation of appetite, in response to a standard lunch consumed 4 h after breakfast consumption/omission. Ghrelin concentrations were not affected by the omission or consumption of breakfast, but elevated concentrations of PYY and GLP-1 were reported. Additionally, this study found that the glycaemic response to a standardised lunch was attenuated in habitual breakfast omitters, suggesting some metabolic adaptation may occur over time. In a similar study, Clayton *et al.*[29] found no difference in acylated ghrelin or GLP-1 concentrations either 1·5 or 3·5 h after a standardised lunch. Collectively, these studies suggest breakfast minimally affects the orexigenic appetite hormone ghrelin, with some evidence that breakfast may increases anorexigenic hormone profiles, in response to subsequent standardised feeding. However, breakfast omission may affect eating behaviour, and the provision of standardised meals does not allow for appetite hormone profiles to be assessed under these circumstances.

This was investigated as part of the Bath Breakfast Project[35]. In these studies, the glycaemic, orexigenic and anorexigenic hormonal responses 3 h after breakfast consumption/omission and 3 h after an *ad libitum* lunch were determined in both lean[26] and obese[27] subjects. Consumption of breakfast suppressed acylated ghrelin, with concomitant increases in PYY, GLP-1, insulin and glucose, compared with breakfast omission, in both lean[26] and obese[27]. After an *ad libitum* lunch, elevated concentrations of PYY were maintained although no differences in GLP-1 (measured in lean group only) were observed. Paradoxically, acylated ghrelin concentrations were greater in the breakfast consumption trial after lunch in both the lean and obese groups. Similar responses have been reported in another study, with breakfast consumption in the morning appearing to have no effect on acylated ghrelin or GLP-1, 4 h after an *ad libitum* lunch[28].

Further research is required before definitive conclusions can be made regarding the effects of breakfast on the hormonal regulation of appetite. Current research suggests that hormonal markers of appetite are transiently suppressed by breakfast, but differences between breakfast omission/consumption appear to be diminished following lunch, which is in line with subjective appetite sensations. This results in similar hormone concentrations in the afternoon, independent of breakfast consumption. However, there is some evidence of a prolonged anorexigenic response to breakfast, particularly with PYY. Further research is required to determine the long-term effect of breakfast on the hormonal regulation of appetite. This has been partly addressed, with one study finding impaired post-prandial insulin sensitivity after 2 weeks of breakfast omission[36] and another finding no change in fasted insulin sensitivity as well as no difference in fasted acylated ghrelin, PYY, GLP-1 or leptin after 6 weeks of either consuming or omitting breakfast[37].

Effect of breakfast on *ad libitum* energy intake

Single exposure studies

The association of regular breakfast omission with a higher BMI[7,8] has led to the widespread belief that breakfast omission causes overeating at subsequent meals and greater daily energy intake[21]. However, the weight of evidence from well-controlled laboratory intervention studies (Table 1) does not support this belief[24–28,38]. The majority of single exposure studies have reported either no difference[24,25,27], or an increase[23,24,26,28,38] in energy intake, at the first meal consumed after breakfast (i.e. lunch). However, with the exception of one study[23] the increase in energy intake at lunch was not sufficient to fully compensate for the energy omitted at breakfast, resulting in a reduced gross energy intake (i.e. breakfast + lunch energy intake)[24–28,38]. With the exception of Astbury *et al.*[23], who reported 78 % compensation at lunch for the energy omitted at breakfast, studies have generally reported compensation in the range 0–35 %[24–28,38]. The amount of compensation observed at lunch might, in part, be related to the energy content of the breakfast supplied. Consuming a low-energy breakfast has been shown to be more accurately compensated for at subsequent meals[39] and might explain why Astbury *et al.*[23] observed almost complete compensation, whilst others reported much less compensation[24–28,38]. Whilst it may be possible to increase food intake to compensate for a small energy deficit, a certain threshold may exist, above which complete energetic compensation at a subsequent meal (or meals) is unlikely.

Two studies[24,28] also assessed energy intake beyond a single meal (Table 1). Consistent with other findings, an increase in energy intake was observed at lunch following the omission of breakfast. Both studies also found no additional energetic compensation occurred at subsequent eating occasions, and therefore gross energy intake (including breakfast) was reduced by 1885[24] and 2740 kJ[28]

Table 1. Intervention studies assessing energy intake after a single breakfast omission

Reference	Breakfast	Study design	Results
Hubert *et al.*[38]*	BC: 2090 (175) kJ	EI assessed at AL lunch 4 h post BO/BC	EI at lunch ~655 kJ greater during BO ($P<0·05$)
	BO: 270 (30) kJ		Gross EI ~1165 kJ greater during BC ($P<0·05$)
Astbury *et al.*[23]	BC: ~1080 kJ	EI assessed at AL lunch 4·5 h post BO/BC	EI at lunch ~860 kJ greater during BO ($P<0·01$)
	BO: 0 kJ		Gross EI not different between trials ($P>0·05$)
Levitsky *et al.*[24]	BC (high CHO): 1400 kJ	EI assessed at AL lunch 3·5 h post BO/BC	EI at lunch not different between trails ($P>0·05$)
	BC (high fibre): 1415 kJ		Gross EI ~1435 kJ greater during BC ($P<0·05$)
	BO: 0 kJ		
Levitsky *et al.*[24]	BC: 2610 (300) kJ	EI assessed at AL lunch 3 h post BO/BC, and afternoon snack, dinner and evening snack	EI at lunch ~730 kJ greater during BO ($P<0·05$)
	BO: 0 kJ		No difference at other AL meals ($P>0·05$) Gross EI ~1885 kJ greater during BC ($P<0·01$)
Gonzalez *et al.*[25]	BC: 1859 kJ	EI assessed at AL lunch 4·5 h post BO/BC	EI at lunch not different between trails ($P=0·78$)
	BO: 0 kJ		Gross EI ~1393 kJ greater during BC ($P<0·001$)
Chowdhury *et al.*[26]	BC: 1963 (238) kJ	EI assessed at AL lunch 3 h post BO/BC	EI at lunch ~640 kJ greater during BO ($P<0·01$)
	BO: 0 kJ		Gross EI ~1326 kJ greater during BC ($P<0·001$)
Chowdhury *et al.*[27]	BC: 2183 (393) kJ	EI assessed at AL lunch 3 h post BO/BC	EI at lunch not different between trials ($P=0·10$)
	BO: 0 kJ		Gross EI ~1964 kJ greater during BC ($P<0·01$)
Thomas *et al.*[30]	BC: ~2085 kJ	Standardised lunch provided 4 h post BO/BC. EI assessed at AL dinner 5 h post lunch and evening snacks	No difference in dinner or snack EI ($P>0·05$)
	BO: 0 kJ		Gross EI not different between trials ($P>0·05$)
Clayton *et al.*[28]	BC: 3095 (195) kJ	EI assessed by AL lunch and dinner, 4·5 and 10 h post BO/BC, respectively	EI at lunch ~834 kJ greater during BO ($P<0·01$)
	BO: 0 kJ		EI at dinner tended to be greater during BC ($P=0·052$)
			Gross EI ~2740 kJ greater during BC ($P<0·05$)

Where available, energy intake at breakfast is presented as mean (SD). Otherwise, mean or absolute intake is presented, as appropriate.
BO, breakfast omission; BC, breakfast consumption; EI, energy intake; AL, *ad libitum*; CHO, carbohydrate.
* This study compared a very small with a large breakfast, rather than the complete omission of breakfast.

following breakfast omission. Similarly, Thomas *et al.*[30] also reported no difference in energy intake at an *ad libitum* dinner, provided 5 h after a standardised lunch, independent of breakfast consumption in the morning. In this study, gross energy intake was reduced by approximately 710 kJ when breakfast was omitted, but this did not reach statistical significance. Collectively, these studies suggest that energy intake is not accurately regulated in the short term[40], and that omission of a single breakfast meal is unlikely to lead to compensation later in the day.

Multiple exposure studies

In a descriptive study, Schusdziarra *et al.*[39] measured energy intake of 380 subjects over 10 d, finding that daily energy intake was associated with the amount of energy consumed at breakfast. Specifically, lower energy intake at breakfast was indicative of a reduced daily energy intake. A number of intervention studies have investigated breakfast omission over longer periods of time, often using food records to estimate daily energy intake (Table 2). Whilst the results of these studies are slightly more varied, once again the weight of evidence suggests that omission of breakfast in the morning will reduce daily energy intake in the longer term[14,37,41]. In one of these studies, a reduction in energy intake was observed in a 6 week between groups breakfast intervention study. Subjects were instructed to consume ⩾2930 kJ before 11·00 hours, or abstain from food completely until 12·00 hours. Timing, type and quantity of foods ingested

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Table 2. Intervention studies assessing energy intake after multiple breakfast omissions

Reference	Breakfast	Duration	Study design	Results
Taylor & Garrow[43]	BC: 1400 kJ (2 meals) BO: 0 kJ	2 d	EI assessed at AL meals after 12·00	No difference in daily EI between trials ($P = 0{\cdot}40$)
Halsey *et al.*[42]	BC: AL 08·00–09·00 BO: Fasted until 12·00	1 week	EI assessed from 3 d food records	No difference in daily EI between trials ($P = 0{\cdot}131$)
Reeves *et al.*[41]	BC: Ate within 1 h of waking BO: Fasted until 12·00	1 week	EI assessed from 7 d food records	Daily EI ~670 kJ greater during BC ($P < 0{\cdot}05$)
Martin *et al.*[14]*	BC: 2964 (SD 8) kJ BO: 464 (SD 8) kJ	2 weeks	EI assessed from food records	Daily EI ~1483 kJ greater during BC ($P < 0{\cdot}05$)
Farshchi *et al.*[36]	BC: 1080 kJ BO: Fasted until 10·30	2 weeks	A 1080 kJ breakfast was consumed at 12·00 during BO only. EI assessed from 3 d food records from 12·30	Daily EI ~380 kJ greater during BO ($P < 0{\cdot}01$)
Betts *et al.*[37]	BC: ⩾2930 kJ before 11·00 BO: Fasted until 12·00	6 weeks	EI assessed from food records	Daily EI ~2255 kJ greater during BC ($P < 0{\cdot}01$)

Where available, energy intake at breakfast is presented as mean (SD). Otherwise, mean or absolute intake is presented, as appropriate.
BO, breakfast omission; BC, breakfast consumption; EI, energy intake; AL, *ad libitum*.
* This study compared a very small with a large breakfast, rather than the complete omission of breakfast.

after 12·00 hours were unaffected by consumption or omission of breakfast in the morning, resulting in a reduced energy intake of approximately 2300 kJ/d when breakfast was omitted[37].

In contrast to this, Halsey *et al.*[42] found no difference in daily energy intake, independent of consumption or omission of an *ad libitum* breakfast. In a study designed primarily to investigate glycaemic control, Farshchi *et al.*[36] found that daily energy intake was increased during 2 weeks of breakfast omission, compared to breakfast consumption. In this study, the authors balanced energy intake in both conditions by providing cereal and milk at a traditional breakfast time (07·00–08·00 hours; breakfast consumption) or later in the day (12·30 hours; breakfast omission). A chocolate-covered cookie was also consumed at 10·30 hours on both trials, and therefore subjects only fasted about 2·5 h longer during the breakfast omission period. The study was designed this way to determine whether the timing of food intake influenced glycaemic control and energy intake, independent of the amount of energy consumed. The experimental design may at least partially explain why the results of this study differ from the majority of the literature.

Surprisingly, there is a sparsity of studies that have investigated breakfast omission in overweight or obese individuals. One study investigated whether daily meal pattern would affect energy intake in obese subjects. Meals were provided as either six meals daily (constituting 4200 kJ) or, four meals daily (constituting 2800 kJ), with the two remaining meals omitted during the morning requiring subjects to fast until 12·00 hours. In addition to the provided meals, subjects were permitted to eat *ad libitum* after 13·00 hours. This study found a non-significant reduction (approximately 960 kJ) in daily energy intake when meals were provided as four meals daily[43]. Reeves *et al.*[41] reported that during 1 week of breakfast omission, energy intake was increased between 12·00 and 18·00 hours in lean subjects and between 12·00 and 21·00 hours in overweight subjects, compared with during 1 week of breakfast consumption. Furthermore, habitual breakfast omitters consumed more after 21·00 hours than habitual breakfast consumers. Despite differing eating patterns, absolute energy intake was reduced by approximately 670 kJ/d during breakfast omission compared with breakfast consumption.

Although not directly assessing energy intake, three further studies assessed the impact of breakfast on weight loss in overweight and obese subjects[44,45]. Schlundt *et al.*[45] investigated a prescribed energy restricted diet in two groups, with equal energy provisions provided in either two (breakfast omission) or three (breakfast consumption) meals daily. Whilst subjects in both groups lost weight, no difference in weight loss was observed between groups after 12 weeks. The authors also stratified subjects according to their habitual breakfast habits, and found that subjects who changed their breakfast habits lost more weight than those who maintained their breakfast habits. This suggests that the success of a dietary regime might be governed, in part, by the degree in which that regime differs to an individual's normal dietary behaviour. However, this study involved a degree of dietary restriction beyond the consumption or omission of breakfast in the morning, and as such may not reflect true alterations in eating behaviour. Dhurandhar *et al.*[46] investigated the effect of recommendations to consume or omit breakfast, in free-living adults attempting to lose weight. Subjects (n 283) were randomly assigned to either consume or omit breakfast for 16 weeks, and results were compared with a control group. Although subjects in this study were attempting to lose weight, in contrast to Schlundt *et al.*[45] this study did not impose any dietary restraint on subjects after 11·00 hours. Results found that either consuming or omitting breakfast did NS affect weight change over a 16 week period[46]. In another study, Geliebter *et al.*[44] found that 4 weeks consuming water in the morning (i.e. breakfast omission) reduced body weight to a greater extent than when 1470 kJ high- or low-fibre breakfasts were consumed.

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Overall, these findings do not support the notion that omission of breakfast causes overeating at subsequent meals. Indeed several studies have found that energy intake is not sufficiently increased to compensate for omission of breakfast in the morning, therefore at least partially preserving the energy deficit achieved by breakfast omission.

Effect of breakfast on energy expenditure

It is interesting to note that some of the aforementioned longer term breakfast intervention studies have failed to observe a reduction in body weight[37,45], despite observing reductions in energy intake when breakfast is omitted. This may be due to underreporting of energy intake as opposed to a genuine reduction[20], but also could suggest an interaction between breakfast and energy expenditure. The intake of food in the morning will inevitably increase morning energy expenditure due to an increase in dietary-induced thermogenesis[47]. Consumption of breakfast has been shown to increase RMR during the morning, compared with when no breakfast was provided[14,29,30]. Beyond lunch, breakfast does not appear to affect RMR, whether the energy deficit from breakfast omission is recovered at subsequent meals[48] or if the energy deficit is sustained by matching energy intake at lunch across trials[29,30]. Typically, daily energy expenditure has been assessed using a calorimetry chamber[43,48] or indirect calorimetry[14,29,30]. However, the most malleable component of energy expenditure, physical activity, may be underestimated from these studies, as confined testing spaces and experimental control is likely to restrict free-living physical activity.

Wyatt *et al.*[16] administered physical activity questionnaires during a cross-sectional study, and reported an association between breakfast consumption and greater physical activity. However, there are very few studies that have directly investigated the effect of breakfast on physical activity, particularly in adults. Two studies used pedometers to estimate free-living physical activity and found no difference after 1 week of breakfast consumption or omission[31,42]. Stote *et al.*[49] used accelerometers to estimate physical activity, and similarly found no difference when food was provided as one evening meal or three (breakfast/lunch/dinner) meals daily. Verboeket-van der Venne *et al.*[50] used doubly labelled water to determine energy expenditure, and also found no difference in AEE when energy was provided in two or seven meals daily. Whilst these studies provide some information about free-living physical activity, the methodology employed in the studies limits their interpretation or makes it difficult to apply the findings directly to breakfast habits. The measurement tools used in some of these studies[31,42,49] may lack reliability and sensitivity when applied to free-living environments[51] or these studies have assessed daily meal patterns[49,50], as opposed to the consumption or omission of breakfast.

Recently, the first data suggesting that breakfast consumption in the morning may have a causal effect on AEE in adults was reported[37]. Using a combined heart rate and accelerometer device, this study found a reduction in AEE, attributable primarily to a decline in light intensity physical activity, during 6 weeks of breakfast omission compared with breakfast consumption[37]. Whilst this reduction in AEE (1885 kJ/d) was not sufficient to fully offset the decrease in energy intake (2300 kJ/d), this study does demonstrate that appreciation of both energy intake and energy expenditure is essential to fully understand the implications of breakfast omission on energy balance. No detectable changes in body weight were observed between groups over the 6 week intervention period, and therefore future studies should look to extend this monitoring period, to determine whether any further behavioural changes occur.

Effect of breakfast on exercise performance

It has been reported that weight loss interventions that combine both dietary restriction and exercise are more successful in the long term[15]. Therefore, it is important to consider the effect that a given dietary intervention, such as breakfast omission, has on the capability and desire to perform exercise. Traditional western breakfasts tend to be high in carbohydrate, and previous studies have observed that omission of breakfast alters dietary profiles, primarily through a reduction in daily carbohydrate intake[52,53]. Therefore, it appears that breakfast could play a crucial role in meeting daily carbohydrate requirements and thus maximising carbohydrate availability[54]. Whilst individuals concerned purely with weight management may not be overly concerned about carbohydrate availability, consuming adequate carbohydrate is of primary importance to individuals wanting to maximise athletic performance[55,56].

Several studies have demonstrated that consumption of carbohydrate in the morning can improve exercise performance compared with performing exercise in the overnight fasted state[57–63]. However, the majority of these studies provided carbohydrate drinks rather than a typical breakfast meal, and therefore may not accurately represent breakfast consumption and omission *per se*. Chryssanthopoulos *et al.*[63] demonstrated that consumption of a high-carbohydrate breakfast meal 3 h before exercise, increased exercise capacity by approximately 9 % compared with when no breakfast was provided. This would likely be due to the effect of an overnight fast on glycogen stores. An overnight fast results in a substantial (approximately 40 %) reduction in liver glycogen[64], therefore decreasing endogenous glucose availability. Consumption of a high-carbohydrate breakfast will replenish liver glycogen content[65], and has also been shown to increase muscle glycogen concentrations by 11–17 %[66,67]. Therefore, the omission of breakfast may limit glycogen availability for muscle metabolism, and potentially reduce exercise performance[68].

This evidence would suggest that individuals performing exercise in the morning should aim to consume breakfast between 1 and 4 h before exercise in order to avoid any decrements in exercise performance.

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However, it has been reported that exercise in the evening may be more acceptable and tolerable than exercise in the morning[69], suggesting that this may be a more preferable time to exercise for those exercising for weight management. Therefore, it would be of interest to determine whether the detrimental effect of breakfast omission on exercise performance is exclusive to the morning, or whether these effects continue throughout the day. This has been determined in one study, in which breakfast was provided or omitted at 08·00 hours, with an *ad libitum* lunch provided at 12·30 and a 60 min bout of exercise performed at 17·00 hours. Despite the breakfast intervention occurring 9 h before exercise and consumption of an *ad libitum* lunch 4·5 h prior to exercise in both trials, a 4·5 % decrement of exercise performance was observed after breakfast omission[28]. This data suggest that the effects of breakfast may be prolonged and therefore consumption of breakfast appears to be important for individuals aiming to maximise exercise performance.

Conclusions

The weight of evidence from breakfast intervention studies suggests that the omission of breakfast may lead to an increase in energy intake at subsequent meals. However, this increase has rarely been shown to fully compensate for the energy omitted at breakfast, and therefore daily energy intake appears to be reduced when breakfast is omitted from the daily meal pattern. Additionally, whilst the omission of breakfast will lead to an increase in subjective appetite and associated hormonal profiles during the morning, this appears to be transient, and can be offset by the first meal consumed after breakfast. This suggests that food intake is not accurately regulated, at least in the short term, and the observed trend for a higher BMI amongst breakfast omitters does not appear to be augmented by dietary compensation. There is some evidence to suggest an interaction between breakfast and energy expenditure, specifically, reductions in low-intensity physical activity have been observed. However, over a 6 week period, this reduction in energy expenditure did not completely offset the reduction in energy intake produced by breakfast omission, therefore generating a state of negative energy balance. Longer term intervention studies are required to confirm whether this negative energy balance is maintained, and whether this would lead to meaningful weight loss. Finally, omission of breakfast appears to reduce exercise performance throughout the day and therefore individuals aiming to maximise exercise performance should consume breakfast.

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Conflicts of Interest

None.

Authorship

D. J. C. conceived and wrote the manuscript with assistance from L. J. J. Both authors approved the final manuscript.

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