The influence of a fruit smoothie or cereal and milk breakfast on subsequent dietary intake: A pilot study

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Abstract

Smoothies are popular breakfast foods. This study examined the effect of consuming Cereal & Milk (CM) or a nutritionally-comparable Fruit Smoothie (FS) for breakfast on daily energy intake (EI) in free-living adults and the extent to which individuals compensated for calories ingested in a High Energy Fruit Smoothie (HE). Ten participants (28.4±2.2y; 23.3±1.0kg·m^{-2}, Mean±SEM) attended the laboratory on 3 consecutive days per week for 3 weeks. Each week, they received a CM, FS or HE breakfast, then recorded all food/beverages consumed across the remainder of the day. The CM and FS were energy-matched to participants' usual breakfast (1675±283kJ), while the HE contained an additional 100kJ·kg^{-1} of maltodextrin (3019±335kJ). Mean 3-day EI was similar on CM and FS (7894±547 vs. 7570±463kJ, $p>0.05$), but elevated on HE (8861±726kJ, $p=0.012$). Thus, individuals who substitute CM for a FS breakfast should be mindful that energy-dense beverages may result in increased daily EI.

Keywords: smoothie; liquid meal; breakfast; dietary energy compensation; food form; energy density.

1.0 Introduction

Traditionally, breakfast is considered the most important meal of the day (O'Neil, Byrd-Bredbenner, et al. 2014). Studies of adults suggest that breakfast consumption may improve the distribution of food groups in the diet, nutritional intake and overall diet quality (Williams 2005; Kerver et al. 2006; Song et al. 2006; Deshmukh-Taskar 2010). Indeed, an analysis of National Health and Nutrition Examination Survey data identified increased intakes of fiber and some micronutrients (e.g. vitamin A, vitamins B1, 2, 9 and 12, calcium, phosphorus, magnesium, and potassium), as well as improved dietary intakes of fruit, grains/cereals and milk among breakfast consumers, compared to non-breakfast eaters (Deshmukh-Taskar 2010). Epidemiological studies also suggest that breakfast consumption may be associated with a lower body mass index (BMI) and waist circumference (Cho et al. 2003; Song et al. 2005; Kant et al. 2008; Azadbakht et al. 2013; Odegaard et al. 2013). However, these findings are not necessarily observed in randomized and controlled investigations involving breakfast interventions (Dhurandhar et al. 2014; Chowdhury et al. 2016).

The effect of different breakfast patterns on dietary intake and weight/adiposity status has not been well researched. However, some observational evidence does suggest that the benefits of breakfast consumption depend on the type of meal selected (Cho et al. 2003; Deshmukh-Taskar 2010; O'Neil, Nicklas, et al. 2014). One study reported that individuals who consumed meat/eggs, dairy or fats/sweets for breakfast had a BMI similar to non-breakfast eaters, while the consumption of ready-to-eat/cooked cereal or sweetened breads (e.g. pancakes, pastries and waffles) was associated with reduced BMI (Cho et al. 2003). A more recent investigation concluded that BMI and waist circumference were only lower among breakfast consumers when the breakfast meal contained high-quality grains/cereal (O'Neil, Nicklas, et al. 2014). Given that overweight and obesity represent a major public health issue, experimental studies investigating how different breakfast patterns contribute to caloric intake and influence broader dietary behavior are important.

While Western-style breakfasts have traditionally comprised of bread, ready-to-eat cereal and/or milk (Cordain et al. 2005; Williams 2005) many consumers appear to be opting for the convenience of liquid breakfast alternatives (Australian Bureau of Statistics 2014; The Neilson Company 2014), such as smoothies (i.e. blended beverages that typically contain fruit, yoghurt, milk, honey and fruit juice) (McCartney et al. 2018). Indeed, in a recent survey of Australian adults (n=833; 79% female; 78% 18–34 y), ~32% of individuals reported consuming ≥1 smoothie per week, with the majority of these (~57%) indicating this was consumed as a breakfast meal (i.e. without additional food) (McCartney et al. 2018).

Commercial reports also suggest that the "smoothie industry" has experienced considerable financial growth in many countries (e.g. Australia, New Zealand, the UK and the USA) (Gehtman 2008; Technavio 2016). Therefore, a greater understanding of the contribution smoothies make to the dietary intake of individuals is required.

Regular consumption of smoothies for breakfast may result in contrasting health outcomes for consumers. On one hand, it is possible that smoothies may provide a convenient vehicle for the consumption of foods and nutrients that are otherwise commonly inadequate in the diet (e.g. fruit, vegetables and/or dairy products) (Bates and Price 2015; McCartney et al. 2018). Indeed, Bates and Price (2015) recently demonstrated that offering smoothies (as opposed to whole-fruit, only) as part of a school breakfast program led to an increase in the number of adolescents consuming ≥1 serving of fruit (4.3 vs. 45.1%) and the average number of fruit serves consumed (<0.1 vs. 0.6 serves·student^{-1}). However, other characteristics of smoothies, specifically, their liquid form and energy density (ED), could possibly promote increased energy intake. For instance, some evidence suggests that caloric fluids evoke weaker satiation than nutritionally-comparable solid and semi-solid foods. Indeed, an analysis of >40 studies investigating acute appetitive responses to different dietary pre-loads demonstrated that, compared to solid foods, liquids increased energy consumption at the subsequent meal (Almiron-Roig et al. 2013), possibly due to several physiological (e.g. increased rate of ingestion and gastric emptying and reduced mastication) and cognitive factors (de Graaf 2011; Dhillon et al. 2016). Unlike many other fluids, however, smoothies are typically viscous, have a diverse nutrient profile (e.g. protein, fat and fiber) and are produced by blending whole ingredients, which may influence the appetitive responses that they provide (Clegg et al. 2013). The concentration of fruit, dairy foods and other ingredients (e.g. protein supplements, honey, nuts and fruit juice) in smoothies may also result in the formulation of an energy-dense beverage (McCartney et al. 2018). Survey data indicate that many consumers do not feel confident in their ability to predict the energy content of these products (McCartney et al. 2018), meaning that they may depend on internal cues to regulate energy intake following consumption of a smoothie. Previous research suggests that individuals are generally poor at compensating for excess calories consumed in energy dense foods or beverages (Wooley et al. 1972; Louis-Sylvestre et al. 1994). However, it is currently unclear if individuals inherently modify their dietary intake to compensate for excess energy consumed when the ED of a breakfast smoothie is unknown.

The primary aim of this pilot study was to investigate the effect of consuming cereal (Cereal & Milk) versus a nutritionally-comparable smoothie (Fruit Smoothie) for breakfast on the dietary behavior of free-living adults over 3 consecutive days. Further, a subsequent aim of this study was to determine the extent to which individuals compensated for the additional calories ingested when the ED of the smoothie was increased (High Energy Fruit Smoothie). We hypothesized that participants' daily energy intake would be higher following Fruit Smoothie consumption than Cereal & Milk, and that individuals would fail to reduce their calorie intake sufficiently to offset the additional energy consumed in the High Energy Fruit Smoothie.

2.0 Materials and Methods

2.1 Participant Characteristics

Eleven volunteers aged between 18 and 50 y agreed to take part in this study. One volunteer failed to adhere to the pre-experimental conditions on two separate occasions and was removed from the study prior to completion. The 10 remaining participants (n=5 males; n=5 females) successfully completed all nine experimental trial days (age: 28.4±2.2 y; weight: 67.2±5.1 kg; BMI: 23.3±1.0 kg·m^{-2}; Mean±SEM). Participants were fully informed of the nature and possible risks of the study before providing written informed consent. The investigation was approved by the University's Human Research Ethics Committee (GU ref number 2015/818) and the procedures were conducted in accordance with the principles outlined by the agreement of Helsinki.

2.2 Study Design

This study was conducted as a pilot investigation. While research has previously investigated the effect of food form (i.e. liquid vs. solid pre-loads) on dietary behavior (Almiron-Roig et al. 2013), this is the first study to do so using *fruit smoothies*, specifically. Given their unique characteristics (i.e. viscosity, nutritional profile and the fact they are produced by blending whole ingredients), we felt it would be inappropriate to calculate a sample size using previous data (Almiron-Roig et al. 2013). Thus, we explored the effects based on available resources (e.g. finances, equipment) to examine the feasibility of detecting differences in dietary behavior following the consumption of fruit smoothie or cereal breakfasts.

The study design is displayed in Figure 1. Participants attended the research laboratory for breakfast on three consecutive mornings per week (Tuesday, Wednesday and Thursday) for three consecutive weeks. Each week, they received one of three different breakfasts in a repeated-measures design: (1) Cereal & Milk (CM); (2) Fruit Smoothie (FS); or (3) HE Fruit Smoothie (HE). Breakfasts were randomized (individually) and counterbalanced for order using an incomplete Latin-square design. Trials were conducted on weekdays to avoid the confounding effects associated with consuming a poorer quality diet on weekends (e.g. higher fat, total energy and alcohol intake) (McCarthy 2014). Each 3 d test period was separated by a 4 d washout period. Following breakfast, participants were required to photograph and record all food/beverages consumed for the remainder of the day. Diet records were analyzed to determine estimated total daily energy intake (EI) under each of the experimental conditions. EI under the CM vs. FS and FS vs. HE (specifically) were compared to investigate the effect of food form (i.e. solid vs. liquid meal) and added energy on dietary behaviour, respectively.

2.3 Deception

To minimize bias during dietary reporting, participants were told that the purpose of the investigation was to explore the impact of consuming liquid breakfasts made with "new blender-technologies" (e.g. Nutribullet®) claiming to "*unlock hidden nutrition from food*" on markers of health and nutritional status, and that the diet records would be used to quantify participants' habitual intake of "health promoting" constituents (e.g. antioxidants). To reinforce the deception, participants were instructed to collect a first-morning urine sample on trial days and told that the specimen would be used to assess urinary biomarkers of health and nutritional status. Blood glucose level (BGL) and seated blood pressure (BP) were also measured using a finger-prick blood sample (Accucheck Advantage II, Roche) and automated monitor device (OMRON, HEM-7203), respectively prior to breakfast administration on trial mornings.

2.4 Preliminary Screening

All volunteers presented to the laboratory where eligibility to participate was assessed. First, individuals provided a description of their usual breakfast behavior. Those classified as "habitual breakfast consumers" (i.e. ≥500 kJ within 2 h of waking ≥4 $d \cdot week^{-1}$) were eligible to participate in this study. A BMI was calculated from height and weight measurements taken using digital scales (SECA 804 digital scales, ECOMED Trading Pty Ltd) and a stadiometer. To be eligible, participants were required to have a BMI<30.0 $kg \cdot m^{-2}$ (non-obese) and not have followed an energy-restricted diet in the previous 6 months. Volunteers then completed a medical history questionnaire and the Eating Attitudes Test-26 (EAT-26)

(Constain et al. 2014). Individuals were excluded from this study if they scored >20 on the EAT-26, indicating probable disordered eating (Garner & Garfinkel 1979); as were volunteers who self-reported an allergy, intolerance or dislike toward any of the breakfast constituents (unless a nutritionally-comparable ingredient could be substituted). Once eligibility was verified, participants completed the R18 Three-Factor Eating Questionnaire (de Lauzon et al. 2004) (i.e. to measure cognitive, behavioural and emotional influencers of eating behavior) and a short written survey on usual smoothie consumption behaviors. Participants were required to indicate how frequently they consumed smoothies and report the extent to which they agreed with the statement '*smoothies are as (or more) filling than cereal*' on a 3-point Likert scale (agree, unsure, disagree). Finally, eligible participants were trained to keep a written diet record (i.e. specific item, estimated quantity and brand name, where applicable) and digital diet record (see *Post-Experimental Procedures* for further details) and instructed to maintain their regular weekly physical activity regime for the duration of the study.

2.5 Experimental Procedures

For Day 1 of each treatment condition, participants were instructed to fast ~10 h (overnight) and refrain from drinking water before breakfast. On arrival at the laboratory (~6:00 and 8:00 AM), they verbally acknowledged compliance to the pre-trial conditions and self-reported sleep duration. BM (inclusive of light clothing) was measured using digital scales (SECA 804 digital scales, ECOMED Trading Pty Ltd). Participants then submitted their urine sample (collected prior to arrival) and completed the BGL and BP measurements. Visual analog scales (VAS) (0–100 mm) were used to evaluate subjective hunger (not at all hungry – hungry as I have ever felt), desire to eat (not at all interested in food – very interested in food), and fullness (not at all full – full as I have ever felt), immediately prior to, and following consumption of, the test-breakfast. VAS were administered via a computerized modifiable software program, (Adaptive Visual Analog Scales, Marsh-Richard et al. (2009)) on a laptop computer. On subsequent days for each treatment condition, these procedures were repeated but participants were not required to fast overnight.

2.6 Post-Experimental Procedures

Following breakfast, participants were instructed to keep a written record of all food and beverages they consumed for the remainder of the day and to capture images of the items consumed using their smart phone device. A 3.8 × 2.5 × 1.0 cm fiducial marker was included in each image assisting the investigator to estimate the size of the item photographed. Similar methodology has demonstrated good reliability and validity in adult populations (Ngo et al. 2009). Food records and accompanying images were submitted to an investigator after each collection period and checked for completeness (e.g. quantities, brand names, missing condiments). Diet records were analyzed using FoodWorks® Version 8 (Xyris Software Pty Ltd, Spring Hill, Australia) to determine EI. All diet records were analysed separately by two trained dietitians to provide an indication of measurement error (i.e. coefficient of variation (CV)). A limit of 2 standard alcoholic drinks (i.e. 20 g ethanol) was imposed on trial days, as higher levels of alcohol intake (i.e. ≥24 g ethanol) may be influential on appetitive responses (Hetherington et al. 2001).

2.7 Breakfast Composition and Administration

2.7.1 The Eating Environment

Each participant received an individualized test-breakfast that was energy-matched to their usual intake (except for the HE), determined from descriptions of usual breakfast collected during screening. The macronutrient profile, fiber content and water content of the CM and FS were closely matched per unit energy (Table 1) to ensure that differences in nutritional composition did not influence feelings of satiety or subsequent dietary intake. Participants were encouraged to consume the meal at their own pace, however the amount of time taken to consume the meal was monitored covertly. The meals were typically administered in a group setting (maximum of 4 participants). Those individuals receiving the same treatment were permitted to interact, however other distractions (e.g. laptop computers and mobile phones) were prohibited from use in the eating environment.

2.7.2 Fruit Smoothie and HE Fruit Smoothie

The FS contained the following ingredients (in order of energy contribution): Full cream milk (Woolworths Select®, Australia) (42.4%), banana (26.2%), blueberries (Creative Gourmet™, Patties Foods®, Australia) (14.5%), yoghurt (Vaalia™, Parmalat Australia Ltd®) (11.3%), skim-milk powder (Woolworths Select®, Australia) (3.0%), psyllium husk (Woolworths Select®, Australia) (2.5%) and water. Ingredients were blended together for 60 s immediately prior to serving. The HE was prepared and administered as per the standard FS beverage. However, maltodextrin powder (Poly-Joule™) containing 20% of the recipients' estimated daily energy requirements (estimated as 100 $kJ \cdot kg^{-1}$) was also added (Mean±SEM: 83.2±6.4 g; Range: 58.8 – 122.7 g). Participants were not told of the manipulation. All beverages were presented in identical disposable cups. As the extent to which a vessel is filled can influence feelings of satiety (Wansink and van Ittersum 2013), the volume of fluid required dictated the use of either a small (500 mL) or large (710 mL) vessel, all of which were filled to >70% capacity.

2.7.3 Cereal & Milk Breakfast

The CM contained the following ingredients (in order of energy contribution): Hi-Bran Weet Bix™ (Sanitarium®, Australia) (39.1%), full cream milk (Woolworths Select®, Australia) (31.8%), blueberries (Creative Gourmet™, Patties Foods®, Australia) (17.7%) and yoghurt (Vaalia™, Parmalat Australia Ltd®) (11.4%). Water was served alongside the test-breakfast to match the water content of the Fruit Smoothie. Again, the food was delivered in a small or large bowl filled to >70% capacity. The breakfasts were modified on two occasions due to one participant disliking cow's milk and another reporting lactose intolerance. In these instances, soymilk (So Good Regular™ Sanitarium®, Australia) and lactose-free milk (Zymil Full Cream™ Pauls®, Australia) were substituted for the milk component of the FS, HE and CM.

2.8 Statistical Analyses

All statistical procedures were performed using IBM SPSS Statistical Software, Version 22.0 (SPSS Inc., Chicago, IL). All measures were examined for normality (Shapiro-Wilk, p's>0.05) and sphericity (Mauchly's test, p's>0.05), respectively. Planned comparisons were performed to investigate: (1) the impact of consuming an isocaloric solid (i.e. CM) vs. liquid (i.e. FS) breakfast on EI; and (2) the capacity of individuals to compensate for additional energy ingested when the caloric content of the smoothie is altered (i.e. HE vs. FS). EI was calculated as the energy content of the test-breakfast plus the energy content of the food and beverages consumed for the remainder of the day (i.e. diet record). Analyses of EI were performed using 2 (treatment, i.e. CM vs. FS or FS vs. HE) × 3 (Day, i.e. day 1, 2 and 3) repeated-measures analysis of variance (ANOVA). The percentage of added energy that was compensated for on the HE treatment (i.e. by a reduction in EI over the remainder of the day) on days 1, 2 and 3 (i.e. 24 h %EC) and in total (i.e. 3 d %EC), were calculated (relative to EI on the FS condition) using the following equation:

$$\mathrm{EC}(\%) = \left\{\frac{(\text{Diet Record EI }_{[\text{FS}]} - \text{Diet Record EI }_{[\text{HE}]})}{(\text{Test Meal EI }_{[\text{HE}]} - \text{Test Meal EI }_{[\text{FS}]})}\right\} \times 100$$

Where 0% EC indicates the energy difference between test-meals was not compensated for and 100% EC indicates complete compensation. Values <0% suggest that subsequent EI was *greater* following HE than FS. Paired *t*-tests were used to compare total 3 d EI across treatments. The time trend in % EC across the 3 d was investigated using a one-way repeated-measures ANOVA. Pre- and post-breakfast subjective ratings were investigated using 2 (Treatment) × 2 (Time, i.e. pre- vs. post- meal) × 3 (Day, i.e. day 1 – 3) repeated measures ANOVAs. One-way repeated-measures ANOVA were performed to compare the pre-trial conditions (i.e. sleep duration and BM) *within* each treatment (i.e. across days 1 to 3 of a single treatment). No statistically significant differences were observed within each treatment. Therefore, the mean 3 d value for each variable was taken and used to compare pre-trial conditions across all three treatments. The time taken to consume CM vs. FS, and FS vs. HE treatments were compared via 2 (treatment, i.e. CM vs. FS and FS vs. HE) × 3 (Day, i.e. days 1 – 3) repeated-measures ANOVA. Pairwise comparisons were performed where significant main effects were present. Significant differences were accepted as $p<0.05$. Each of the 18 items on the Three Factor Eating Questionnaire was given a score between 1 and 4 and item scores were summed into raw scores for cognitive restraint, uncontrolled eating, and emotional eating. The raw scale scores were then transformed to a 0–100 scale [((raw score − lowest possible raw score)/possible raw score range) × 100]. Higher scores in the respective scales are indicative of greater cognitive restraint, uncontrolled, or emotional eating (Anglé et al. 2009). All data are presented as Mean±SEM.

3.0 Results

3.1 Participant Characteristics and Pre-Trial Conditions

Of the 10 participants that took part in this study, *n*=6 indicated that they usually consumed ≥1 smoothie$\cdot$week^{-1} (3.5±0.9$\cdot$week^{-1}) (most often as a snack between meals (*n*=2), as a breakfast (*n*=3) or as an accompaniment to meal (*n*=1)) and *n*=4 consumed smoothies infrequently (>1$\cdot$year^{-1}). Half of the participants (*n*=5) *agreed* that smoothies would be *"as filling (or more filling) than a cereal and milk*", whereas the remaining participants either *disagreed* (*n*=3) or indicated they were *unsure* (*n*=2) about the satiating effects of smoothies. According to the Three Factor Eating Questionnaire, no participant exceeded clinical thresholds for cognitive restraint, uncontrolled eating or emotional eating. All participants verbally acknowledged compliance to the pre- and post- experimental procedures upon arrival at the laboratory. Mean sleep duration; $F(2,18)=1.09$, $p=0.358$; and BM, $F(2,18)=1.14$, *p*=0.341; were similar across all three experimental treatments (CM: 7.1±0.3 h, 66.6±5.0 kg; FS: 6.6±0.4 h, 66.8±5.0 kg; HE: 7.0±0.3 h, 66.9±5.1 kg).

3.2 Breakfast Characteristics

The energy content of participants' usual breakfast was estimated as 1673±283 kJ. Hence, the energy content of the CM and FS reflected this (Table 2). The HE provided approximately 3019±335 kJ. All participants voluntarily consumed the entire contents of each test-meal.

3.3 Cereal & Milk vs. Fruit Smoothie: Effects of Food Form

3.3.1 Subjective Ratings and Eating Time

2 (Treatment) × 2 (Time) × 3 (Day) analyses of mean subjective hunger, desire to eat, and fullness ratings revealed a significant main effect of time on each scale, $F(1,9)=66.3$; $F(1,9)=38.9$; $F(1,9)=70.7$, respectively (all *p*'s<0.001), such that consuming a test-breakfast significantly decreased hunger (71±5 vs. 18±4 mm) and desire to eat (77±5 vs. 24±6 mm), whilst increasing fullness (16±4 vs. 70±5 mm). No other significant main effects or interactive effects were observed (all *p*'s>0.05). The amount of time taken to consume the CM (8.5±1.3 min) vs. FS (7.8±1.3 min) was not significantly different by treatment or day (*p*'s>0.05).

3.3.2 Estimated Energy Intake

Daily EI across the 3 d intervention period under the CM and FS treatments is indicated in Table 3. A 2 (Treatment) × 3 (Day) analysis of EI failed to indicate a significant main effect of treatment, time or treatment × time interaction (all *p*'s>0.05). Total 3 d EI was also similar between experimental treatments matched for energy intake (*p*=0.182). Hence, food form was not significantly influential on EI.

3.4 Fruit Smoothie vs. HE Fruit Smoothie: Effects of Added Energy

3.4.1 Subjective Ratings and Eating Time

2 (Treatment) × 2 (Time) × 3 (Day) analyses of mean subjective hunger, desire to eat, and fullness ratings revealed a significant main effect of time on each scale, $F(1,9)=59.4$; $F(1,9)=54.6$; $F(1,9)=54.8$, respectively (all *p*'s<0.001), such that consuming a test-breakfast significantly reduced hunger (68±5 vs. 17±4 mm) and desire to eat (77±5 vs. 24±5 mm), whilst increasing fullness (18±5 vs. 73±5 mm). No other significant main effects or

interactive effects were observed (all p's>0.050). The amount of time taken to consume the FS (7.8±1.3 min) vs. HE (7.8±1.3 min) was not significantly different by treatment or day (all p's>0.05).

3.4.2 Estimated Energy Intake and Dietary Energy Compensation

Daily EI across the 3 d intervention period under the FS and HE treatments is indicated in Table 3. A 2 (Treatment) × 3 (Day) analysis of mean daily EI revealed a significant main effect of treatment, $F(1,9)=9.751$, $p=0.012$, such that the HE increased (+1290±413 kJ) EI, compared to the FS treatment. No significant main effect of time, $F=(2,18)=0.138$, $p=0.872$; or treatment × time interaction, $F(2,18)=0.394$, $p=0.680$ was detected. Total 3 d EI also differed between the experimental treatments ($p=0.012$). The percentage of added energy compensated for on the HE (i.e. by a reduction in EI over the remainder of the day) on days 1, 2, 3 and in total is indicated in Table 4; total EC by individual participants over the 3 d period is indicated in Figure 2. The mean percentage of 3 d total EC was 17.7±28.7%. There was no significant time-trend for EC across the 3 d period of intervention with the HE, $F(2,18)=0.842$, $p=0.447$. Two out of ten participants compensated sufficiently to offset the total amount of additional energy, whereas four participants ingested more energy in the period following consumption of the HE compared to FS.

3.5 Measurement Error and Treatment Order Effects

The co-efficient of variation (CV) for EI was calculated as 11.3% (between the two trained dietitians). Analysis indicated no significant effects of treatment order on 3 d mean EI over the study duration, $F(2,18)=0.572$, $p=0.573$. An additional paired t-test comparing 3 d mean EI on trials that *preceded* vs. *followed* the HE in the 6 participants that received this breakfast either first or second (i.e. where it could potentially impact dietary behavior on a subsequent treatment) also did not reveal a significant trial order effect, $t(5)=1.23$, $p=0.275$.

4.0 Discussion

This pilot study investigated the effect of consuming ready-to-eat cereal (CM) or a nutritionally-comparable smoothie (FS) for breakfast on the dietary behaviour of free-living adults over a 3 d period. This study also examined individuals' capacity to compensate for additional calories ingested when the ED of the smoothie was increased (HE). Overall, results indicate that participants' total daily EIs were similar when consuming CM vs. FS at breakfast. However, the response to the additional energy consumed in the HE condition was highly variable, with very little compensation observed, resulting in an increased energy intake associated with this treatment. Thus, consuming a smoothie instead of cereal at breakfast does not appear to predispose consumers to excess energy intakes across the remainder of the day. However, individuals concerned about weight-management should be cautious of energy dense formulations.

Contrary to our hypothesis, the results of the present study indicate that participants' total daily EIs were similar when consuming CM vs. FS at breakfast (7894±547 vs. 7570±463 $kJ{\cdot}d^{-1}$). Furthermore, although not statistically significant (p=0.182), total 3 d EI was ~1000 kJ *lower* when participants consumed the FS. This observation contrasts previous acute "preload test-meal" studies, which demonstrate that caloric liquids (e.g. milkshakes, fruit juice, liquid yoghurt and soft drinks) generally promote EI at a subsequent meal (when compared to solid foods) (Almiron-Roig et al. 2013). One factor that may have contributed to the current result is the type of "test-food" investigated. In contrast to other fluids, smoothies are viscous, have a diverse nutrient profile (e.g. protein, fat and fiber) and are produced by blending whole ingredients into small liquefied particles. These characteristics may affect the appetitive responses that smoothies provide (Clegg et al. 2013). Indeed, soup, the only liquid that has so far been demonstrated to elicit stronger satiety sensations than other solid foods (Mattes 2005; Clegg et al. 2013), shares these characteristics. The viscous consistency of soup contributes to "fullness" by delaying gastric emptying and increasing gastric distention (Santangelo et al. 1998; Marciani et al. 2012; Clegg et al. 2013). Specifically, gastric emptying of solid food involves the separation of solid and liquid particulate, leading to accelerated emptying of the liquid component (Clegg et al. 2013). When the solid and liquid particulate are combined in a thick consistency, this separation is delayed and gastric distention is increased (Marciani et al. 2012). Some data also suggest that the small particles of food in soup increase nutrient availability in the duodenum, which may potentiate secretion of satiety hormones, compared to solid foods (Santangelo et al. 1998; Clegg et al. 2013). Whilst the present study did not assess gastric emptying or hormonal responses to the test-breakfasts, it is conceivable that smoothies may elicit similar physiological effects. Furthermore, these mechanisms could potentially explain the non-significant reduction in total 3 d EI with Fruit Smoothie consumption.

The inability to detect differences in dietary intake following the consumption of solid vs. liquid breakfasts in the present study may reflect a Type II error due to the low-sensitivity of the dietary assessment tools employed in free-living situations (Burke et al. 2001). It is important to acknowledge that acute studies (conducted in controlled laboratory environments) facilitate direct observation of eating and are therefore likely to involve fewer sources of assessment error (e.g. reporting bias) than studies utilizing prospective diet records. While these protocols may facilitate the detection of difference in dietary behaviour, they often lack ecological validity by controlling many factors (e.g. food preferences, availability and accessibility) which may influence dietary intake (Stubbs et al. 1998).

To our knowledge, only three studies have attempted to determine longer-term (e.g. ≥24 h) consequences of substituting solid foods with liquid alternatives in free-living individuals. Of these (Hulshof et al. 1993; DiMeglio and Mattes 2000; Houchins et al. 2012), only one (DiMeglio and Mattes 2000) has produced results that are consistent with acute "preload test-meal" studies, whereby consumption of a caloric beverage increased energy intake compared to a solid food. In this study (DiMeglio and Mattes 2000), lean participants (n=15) were supplemented solid vs. liquid carbohydrate (~1.9 $MJ \cdot d^{-1}$) over a 28 d period. Mean daily EI was significantly lower with the solid food (~1.7 MJ). However, the change in BM that occurred pre- to post-intervention did not differ between treatments, which appears to contradict the large change in dietary energy intake reported. In a study conducted over a 56 d period, Houchins et al. (2012) failed to detect a significant difference in mean daily EI or change in BM amongst overweight/obese (n=19) or lean (n=15) individuals who were provided solid vs. liquid fruits and vegetables (400–550 $kcal \cdot d^{-1}$). Finally, Hulshof et al. (1993) found that individuals (n=33) receiving a solid vs. liquid breakfast consumed similar diets for the following 48 h. Collectively, these observations appear consistent with the present investigation in that, the consumption of an isocaloric liquid vs. solid meal does little to influence total energy intake in free-living individuals.

When participants were exposed to the HE condition, EC was poor and the extent to which it occurred was highly variable. The majority of participants demonstrated little or no compensation, however, two participants demonstrated complete compensation (i.e. EC >100%) across the 3 d period (Figure 2). This observation is consistent with prior research that indicates that EC behavior is likely to be influenced by a variety of factors, including age (Appleton et al. 2011), gender (Davy et al. 2007), BMI (Houchins et al. 2012), physical activity level (Long et al. 2007), genetic polymorphisms (Cecil et al. 2006), familiarity (Appleton et al. 2011) and eating style (e.g. rate of intake) (Robinson et al. 2014). Studies have also documented considerable day-to-day variation in energy intake (Tarasuk and Beaton 1992). Therefore, despite conducting trials on the same days each week (i.e. in an effort to minimize dietary variability), it is likely that fluctuations in dietary behavior (unrelated to this study) contributed to the observed result. It is also important to note that the current study used a commercial maltodextrin powder to manipulate the ED of the HE Fruit Smoothie. Maltodextrin was used because it has little impact on the sensory properties of the beverage (i.e. facilitating blinding). In reality, however, ingredients that increase the ED of smoothies (e.g. ice-cream, honey, nuts/seeds and fruit juice, and sugar) are likely to alter the taste, texture and/or appearance of the product. Therefore, even consumers with no prior knowledge of a smoothie's energy content, may receive sensory inputs that influence the perceived nutrient content (e.g. sweetness or creaminess), and thus, dietary energy compensation. It is also worthwhile noting that, under "real world" conditions (i.e. where the breakfast meal is not strictly prescribed), palatability is likely to play an important role in determining the quantity of food (and thus, dietary energy) ingested by an individual. Therefore, future research should investigate *ad libitum* breakfast consumption behaviours as well as individuals' capacity to compensate for additional calories ingested via energy-dense smoothies which also differ in their organoleptic properties.

Acute feeding studies generally indicate that EC is weak at a subsequent meal (Stubbs and Whybrow 2004). However, limited research has examined longer-term (e.g. ≥24 h) consequences of manipulation to EI in free-living individuals. This is important because corrective responses to deviations from average EI may take several days to occur (Bray et al. 2008) and evidence suggests that the short-term effects of ED on EI do not translate into the longer term (Stubbs and Whybrow 2004). The present results indicate that EC was highly variable. While, the mean results support a temporal effect of changing ED on EI, (i.e. ~40% compensation observed on days 1 and 2, while day 3 ~-30%) at the individual level, responses appeared inconsistent. This is likely to reflect the multifactorial determinants of EI in free-living individuals.

The present investigation does contain several limitations. First, as this was a pilot study, it involved a relatively small number of participants (*n*=10). Future investigations can use the current data to inform sample size calculations that enable extension of this work. Second, while participants were instructed to maintain their regular physical activity regime for the duration of this study, we did not monitor participants' activity levels directly. Thus, differences in energy expenditure may have affected the results, particularly given that dietary manipulations may influence daily physical activity (Chowdhury et al. 2016). Future studies should employ objective measures to allow quantification of energy expenditure and control for variations should they exist. Finally, studies that rely on self-reported dietary intakes can be influenced by under-reporting and altered feeding behavior. However, as this was a counterbalanced repeated-measures design (in which participants were required to provide photographic evidence to support their diet record), these biases would be likely to affect all treatment arms similarly. In addition, as subjects were informed that the diet records would be used to quantify intakes of other “health promoting” constituents, the emphasis on dietary energy intake should have been reduced. Nonetheless, a logical extension of the current work would be a laboratory investigation with measurement of appetite hormones and hedonic responses, which would provide valuable mechanistic information.

5.0 Conclusion

Results from the current investigation suggest that substituting ready-to-eat cereal with an isocaloric smoothie at breakfast may not predispose consumers to excess energy intakes across the remainder of the day. However, individuals are unlikely to offset additional calories consumed in energy-dense beverages. Therefore, individuals interested in weight-management should be cautious of these formulations. Future studies should consider obtaining data from a larger participant population (including both lean and overweight/obese individuals) over a longer intervention duration to gain a better understanding of the appetitive responses that smoothies provide.

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Reference List

Almiron-Roig E, Palla L, Guest K, Ricchiuti C, Vint N. 2013. Factors that determine energy compensation: a systematic review of preload studies. Nutrition Reviews. 71(7):458-473.

Anglé S, Engblom J, Eriksson T, Kautiainen S, Saha M-T, Lindfors P, Lehtinen M, Rimpelä A. 2009. Three factor eating questionnaire-R18 as a measure of cognitive restraint, uncontrolled eating and emotional eating in a sample of young Finnish females. The International Journal of Behavioral Nutrition and Physical Activity. 6:41-41.

Appleton KM, Martins C, Morgan LM. 2011. Age and experience predict accurate short-term energy compensation in adults. Appetite. 56(3):602-606.

Australian Bureau of Statistics. 2014. 4364.0.55.003-Australian Health Survey: updated results, 2011–2012. Available from: www.abs.gov.au/ausstats/abs@.nsf/Lookup/4364.0.55.003Chapter12011-2012.

Azadbakht L, Haghighatdoost F, Feizi A, Esmaillzadeh A. 2013. Breakfast eating pattern and its association with dietary quality indices and anthropometric measurements in young women in Isfahan. Nutrition (Burbank, Los Angeles County, Calif). 29(2):420-425. eng.

Bates D, Price J. 2015. Impact of fruit smoothies on adolescent fruit consumption at school. Health Education & Behavior. 42(4):487-492.

Bray GA, Flatt JP, Volaufova J, Delany JP, Champagne CM. 2008. Corrective responses in human food intake identified from an analysis of 7-d food-intake records. The American Journal of Clinical Nutrition. 88(6):1504-1510. eng.

Burke LM, Cox GR, Culmmings NK, Desbrow B. 2001. Guidelines for daily carbohydrate intake: do athletes achieve them? Sports Medicine. 31(4):267-299.

Cecil JE, Watt P, Palmer CN, Hetherington M. 2006. Energy balance and food intake: The role of PPARγ gene polymorphisms. Physiology & Behavior. 88(3):227-233.

Cho S, Dietrich M, Brown CJ, Clark CA, 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). The Journal of the American College of Nutrition. 22(4):296-302.

Chowdhury EA, Richardson JD, Holman GD, Tsintzas K, Thompson D, Betts JA. 2016. The causal role of breakfast in energy balance and health: a randomized controlled trial in obese adults. The American Journal of Clinical Nutrition.

Clegg ME, Ranawana V, Shafat A, Henry CJ. 2013. Soups increase satiety through delayed gastric emptying yet increased glycaemic response. European Journal of Clinical Nutrition. 67(1):8-11.

Constain GA, Ricardo Ramirez C, de los Angeles Rodriguez-Gazquez M, Alvarez Gomez M, Marin Munera C, Agudelo Acosta C. 2014. Diagnostic validity and usefulness of the Eating Attitudes Test-26 for the assessment of eating disorders risk in a Colombian female population. Atencion Primaria. 46(6):283-289.

Cordain L, Eaton SB, Sebastian A, Mann N, Lindeberg S, Watkins BA, O'Keefe JH, Brand-Miller J. 2005. Origins and evolution of the Western diet: health implications for the 21st century. The American Journal of Clinical Nutrition. 81(2):341-354.

Davy BM, Van Walleghen EL, Orr JS. 2007. Sex differences in acute energy intake regulation. Appetite. 49(1):141-147.

de Graaf CC. 2011. Why liquid energy results in overconsumption. Proceedings of the Nutrition Society. 70(2):162-170.

de Lauzon B, Romon M, Deschamps V, Lafay L, Borys JM, Karlsson J, Ducimetiere P, Charles MA, Grp FS. 2004. The three-factor eating questionnaire-R18 is able to distinguish among different eating patterns in a general population. Journal of Nutrition. 134(9):2372-2380.

Deshmukh-Taskar PR. 2010. Do breakfast skipping and breakfast type affect energy intake, nutrient intake, nutrient adequacy, and diet quality in young adults? NHANES 1999–2002. The Journal of the American College of Nutrition. 29(4):407-418.

Dhillon J, Running CA, Tucker RM, Mattes RD. 2016. Effects of food form on appetite and energy balance. Food Quality and Preference. 48:368-375.

Dhurandhar EJ, Dawson J, Alcorn A, Larsen LH, Thomas EA, Cardel M, Bourland AC, Astrup A, St-Onge M-P, Hill JO et al. 2014. The effectiveness of breakfast recommendations on weight loss: A randomized controlled trial. The American Journal of Clinical Nutrition. 100(2):507-513.

DiMeglio DP, Mattes RD. 2000. Liquid versus solid carbohydrate: effects on food intake and body weight. International Journal of Obesity. 24(6):794-800.

Gehtman D. 2008. Smoothies – Market Intelligence Report. London: Mintel Group.

Garner DM, Garfinkel PE. 1979. The Eating Attitudes Test: An index pf the symptoms of anorexia nervosa. Psychological Medicine. 9(2):273-279.

Hetherington MM, Cameron F, Wallis DJ, Pirie LM. 2001. Stimulation of appetite by alcohol. Physiology & Behavior. 74(3):283-289. eng.

Houchins JA, Burgess JR, Campbell WW, Daniel JR, Ferruzzi MG, McCabe GP, Mattes RD. 2012. Beverage vs. solid fruits and vegetables: Effects on energy intake and body weight. Obesity. 20(9):1844-1850.

Hulshof T, De Graaf C, Weststrate JA. 1993. The effects of preloads varying in physical state and fat content on satiety and energy intake. Appetite. 21(3):273-286.

Kant AK, Andon MB, Angelopoulos TJ, Rippe JM. 2008. Association of breakfast energy density with diet quality and body mass index in American adults: National Health and Nutrition Examination Surveys, 1999–2004. The American Journal of Clinical Nutrition. 88(5):1396-1404.

Kerver JM, Yang EJ, Obayashi S, Bianchi L, Song WO. 2006. Meal and snack patterns are associated with dietary intake of energy and nutrients in US adults. Journal of the American Dietetic Association. 106(1):46-53.

Long SJ, Hart K, Morgan LM. 2007. 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(5):517-523.

Louis-Sylvestre J, Tournier A, Chapelot D, Chabert M. 1994. Effect of a fat-reduced dish in a meal on 24-h energy and macronutrient intake. Appetite. 22(2):165-172.

Marciani L, Hall N, Pritchard SE, Cox EF, Totman JJ, Lad M, Hoad CL, Foster TJ, Gowland PA, Spiller RC. 2012. Preventing gastric sieving by blending a solid/water meal enhances satiation in healthy humans. Journal of Nutrition. 142(7):1253-1258.

Marsh-Richard DM, Hatzis ES, Mathias CW, Venditti N, Dougherty DM. 2009. Adaptive Visual Analog Scales (AVAS): a modifiable software program for the creation, administration, and scoring of visual analog scales. Behavior Research Methods. 41(1):99-106.

Mattes R. 2005. Soup and satiety. Physiology & Behavior. 83(5):739-747.

McCarthy S. 2014. Weekly patterns, diet quality and energy balance. Physiology & Behavior. 134:55-59.

McCartney D, Rattray M, Desbrow B, Khalesi S, Irwin C. 2018. Smoothies: Exploring the attitudes, beliefs and behaviours of consumers and non-consumers. Current Research in Nutrition and Food Science. 6(2).

Ngo J, Engelen A, Molag M, Roesle J, Garcia-Segovia P, Serra-Majem L. 2009. A review of the use of information and communication technologies for dietary assessment. The British Journal of Nutrition. 101:S102-112.

O'Neil CE, Byrd-Bredbenner C, Hayes D, Jana L, Klinger SE, Stephenson-Martin S. 2014. The role of breakfast in health: Definition and criteria for a quality breakfast. Journal of the Academy of Nutrition and Dietetics. 114(12):S8-S26.
O'Neil CE, Nicklas TA, Fulgoni VL. 2014. Nutrient intake, diet quality, and weight/adiposity parameters in breakfast patterns compared with no breakfast in adults: National Health and Nutrition Examination Survey 2001-2008. Journal of the Academy of Nutrition and Dietetics. 114(12):S27-S43.
Odegaard AO, Jacobs DR, Steffen LM, Van Horn L, Ludwig DS, Pereira MA. 2013. Breakfast frequency and development of metabolic risk. Diabetes Care. 36(10):3100-3106.
Robinson E, Almiron-Roig E, Rutters F, de Graaf C, Forde CG, Tudur Smith C, Nolan SJ, Jebb SA. 2014. A systematic review and meta-analysis examining the effect of eating rate on energy intake and hunger. The American Journal of Clinical Nutrition. 100(1):123-151.
Santangelo A, Peracchi M, Conte D, Fraquelli M, Porrini M. 1998. Physical state of meal affects gastric emptying, cholecystokinin release and satiety. British Journal of Nutrition. 80(6):521-527.
Song WO, Chun OK, Kerver J, Cho S, Chung CE, Chung SJ. 2006. Ready-to-eat breakfast cereal consumption enhances milk and calcium intake in the US population. Journal of the American Dietetic Association. 106(11):1783-1789.
Song WO, Chun OK, Obayashi S, Cho S, Chung CE. 2005. Is consumption of breakfast associated with body mass index in US adults? Journal of the American Dieteti Association. 105(9):1373-1382.
Stubbs RJ, Johnstone AM, O'Reilly LM, Poppitt SD. 1998. Methodological issues relating to the measurement of food, energy and nutrient intake in human laboratory-based studies. The Proceedings of the Nutrition Society. 57(3):357-372.
Stubbs RJ, Whybrow S. 2004. Energy density, diet composition and palatability: influences on overall food energy intake in humans. Physiology & Behavior. 81(5):755-764.
Tarasuk V, Beaton GH. 1992. Day-to-day variation in energy and nutrient intake: evidence of individuality in eating behaviour? Appetite. 18(1):43-54.
Technavio. 2016. Global Smoothies Market 2016-2020. Technavio.
The Neilson Company. 2014. From breakfast to ‘breakfaster’: Liquid breakfast buyers double over past 5 years. New York, USA
Wansink B, van Ittersum K. 2013. Portion size me: plate-size induced consumption norms and win-win solutions for reducing food intake and waste. Journal of Experimental Psychology Applied. 19(4):320-332.
Williams P. 2005. Breakfast and the diets of Australian adults: an analysis of data from the 1995 National Nutrition Survey. International Journal of Food Sciences and Nutrition. 56(1):65-79.
Wooley OW, Wooley SC, Dunham RB. 1972. Can calories be perceived and do they affect hunger in obese and nonobese humans? Journal of Comparative and Physiological Psychology. 80(2):250-258.

Tables 1 – 4:

Table 1. Nutritional composition of the Fruit Smoothie (FS) and Cereal & Milk (CM).

	CM	FS	Difference (%)
Carbohydrate ($g \cdot MJ^{-1}$)	32.7	32.6	0.1
Protein ($g \cdot MJ^{-1}$)	9.3	9.6	3.3
Fat ($g \cdot MJ^{-1}$)	6.4	6.2	2.9
Dietary Fibre ($g \cdot MJ^{-1}$)	6.3	6.5	3.2
Water ($g \cdot MJ^{-1}$)	360	365	1.2

Table 2. Nutritional composition of participants' usual breakfast and experimental breakfasts.

	Usual Breakfast	CM	FS	HE
Total Energy (kJ)	1673 ± 283	1675 ± 283	1675 ± 283	3019 ± 335
CHO (g)	46.5 ± 7.0	54.6 ± 9.2	54.7 ± 9.2	143 ± 14.5
Protein (g)	22.4 ± 7.6	16.2 ± 2.7	15.6 ± 2.6	15.6 ± 2.6
Fat (g)	11.5 ± 2.6	10.4 ± 1.8	10.7 ± 1.8	10.7 ± 1.8
Fibre (g)	6.9 ± 1.2	10.9 ± 1.8	10.5 ± 1.8	10.5 ± 1.8

Table 3. Mean daily EI across the 3 d with Cereal & Milk (CM), Fruit Smoothie (FS) and High Energy FS (HE).

	CM (kJ)	FS (kJ)	HE (kJ)
Day 1	7982 ± 559	7859 ± 568	8858 ± 1,098
Day 2	7856 ± 582	7536 ± 650	8602 ± 670
Day 3	7842 ± 626	7315 ± 661	9122 ± 707
3 d Total	23681 ± 1,640	22710 ± 1,389	26583 ± 2,178
3 d Mean	7894 ± 547	7570 ± 463	8861 ± 726

Table 4. The percentage of added energy compensated for on the High Energy Fruit Smoothie (HE).

	% EC
Day 1	45.5 ± 52.0
Day 2	38.4 ± 44.1
Day 3	-30.7 ± 60.2
3 d Total	17.7 ± 28.7

Figure Captions:

Figure 1. Schematic representation of the study design employed.

Figure 2. Percentage of the total energy added to the HE compensated for by each participant over the 3 d intervention period compared to the FS. 0% EC indicates the energy difference between test-meals was not compensated for, and 100% EC indicates complete compensation. Values <0% suggest that subsequent EI was greater following HE than FS. Each bar represents one individual subject. Corresponding characteristics of individual participants are tabulated below. Expected satiety value reflects participants' responses to the following statement "*smoothies are as (or more) filling than cereal*". A: Agree; D: Disagree; F: Female Subject; M: Male Subject; P1 – 10: Participants 1 – 10; U: Unsure. 3-Factor Eating Questionnaire Scores are presented as a percentage of maximum score for each domain.