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Coconut and sunflower oil ratios in ice cream influence subsequent food selection and intake

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Abstract

The effect of coconut oil (CO, containing mainly medium chain triglycerides - MCTs) and sunflower oil (SO, containing mainly long chain triglycerides - LCTs) used as fat source (10% fat ice cream) in different ratios (25% CO and 75% SO - 25CO:75SO, 50% CO and 50% SO - 50CO:50SO, 75% CO and 25% SO - 75CO:25SO) was investigated to assess differences in appetite and *ad-libitum* (evening and snack) food intake using a single blind design. 36 healthy female participants consumed a fixed portion (150g) of ice cream 45 minutes before an *ad-libitum* dinner and snacks. Appetite sensations were tracked across the day. Participants ate significantly less fat after 75CO:25SO than 25CO:75SO (p= 0.007) and there was also a trend for lower fat intake in this condition as compared to 50CO:50SO (p= 0.068). High fat savoury snack intake significantly decreased after 75CO:25SO in comparison with both 25CO:75SO (p= 0.038) and 50CO:50SO (p= 0.008). Calorie intake from snacks was also found to be significantly lower after 25CO:75SO and 50CO:50SO than 75CO:25SO (p= 0.021 and 0.030 respectively). There was no effect of condition on appetite or desire ratings over the day. Eating a standard portion of ice cream containing different ratios of MCTs and LCTs can modestly influence acute food selection and intake, with MCTs manifesting their effect earlier and LCTs later due to differences in the absorption and metabolism of these lipids. However, the differences evident in the present study were small, and require further research before firm conclusions can be drawn.

Keywords: Ice cream, medium chain triglycerides, long chain triglycerides, food intake, appetite.

1. Introduction

Fats are an important source of energy and should account for 30% of daily calorie intake (Zúñiga & Troncoso, 2012) due to their essential role in the absorption of fat-soluble vitamins. Most fatty foods are energy dense and palatable, but they exert a weak effect on satiety and satiation compared with protein- and carbohydrate-rich foods (Gerstein *et al.,* 2004; Johnstone *et al.,* 1996; Karhunen *et al.,* 2008; Chambers *et al.,* 2015). The consumption of a high fat diet may therefore contribute to weight gain and obesity, which is linked to a variety of co-morbidities (Lee, 2013). One means of preventing the potential for weight gain from fat sources is by replacing or reducing the amount of fat in food. This usually leads to a considerable reduction in palatability which is likely to reduce consumption (German & Watzke, 2004). Another possible approach may be to maintain the fat content and vary instead the type of fat consumed to one that may enhance satiation and satiety. For instance, using fats with different carbon chain lengths or saturation levels may influence pre- and post-absorptive mechanisms (Beardshall *et al.,* 1989; Lawton *et al.,* 2000; Feltrin *et al.,* 2008; Rolls *et al.,* 1988; Van Wymelbeke *et al.,* 1998, 2001). This would maintain palatability and intake while altering satiety and satiation properties to potentially reduce subsequent intake.

Low fat diets are a generally accepted means of weight loss, but recent meta-analyses suggest they are a poor means of weight loss maintenance (Tobias *et al.,* 2015) due to their low palatability which may contribute to low levels of satisfaction and therefore adherence (Hetherington *et al.,* 2013; Halford & Harrold, 2012). Instead, it may be more useful to maintain healthy levels of functional fats within the diet which are palatable and act to increase satiation and satiety whilst also decreasing food intake. For instance, it has been shown that unsaturated fats, in comparison to saturated fats, lead to a greater release of satiety-related gastrointestinal hormones such as GLP-1 and CCK (Beardshall *et al.,* 1989; Hirasawa *et al.,* 2005) and are absorbed and oxidised faster than saturated fats (Small, 1991). However, fat saturation has rarely been shown to have an effect on food intake (Lawton *et al.,* 2000), with many more experiments finding no such effect (Flint *et al.,* 2003; Casas-Agustench *et al.,* 2009; Strik *et al.,* 2010). Fats with different chain lengths are also absorbed and metabolised differently. In particular, medium chain triglycerides (MCTs) are hydrolysed faster and more completely than long chain triglycerides (LCTs) due to their smaller

molecular weight, thus increasing lipase efficiency and allowing them to be absorbed intact. Unlike LCTs, which are packed into chylomicrons and enter the lymphatic system, MCTs enter the portal system and reach the liver more rapidly where they are readily oxidised, causing the production of Ketone bodies (Bach & Babayan, 1982). A decrease in food intake has been associated both with hepatic fat oxidation (Langhans, 1996) and the presence of Ketone bodies (Le Foll *et al.*, 2014), suggesting that MCTs may reduce food intake more than LCTs. Indeed, a variety of studies have shown that an intestinal infusion (Feltrin *et al.*, 2008), a preload (Rolls *et al.*, 1988) or a meal (Van Wymelbeke *et al.*, 1998, 2001) containing MCTs led to a reduction in food intake in a subsequent meal as compared to LCTs. Nevertheless, other authors have failed to show an effect of carbon chain length on food intake and appetite after a substantial delay (210-300 min) between the manipulation and subsequent meal; this is likely due to hunger overriding any observable effect (Poppitt *et al.*, 2010; Bendixen *et al.*, 2002).

Ice cream is a highly palatable, high-fat dessert comprised of a solid foam made up of air bubbles, ice crystals, and a network of fat globules surrounded by an unfrozen serum of sugars, proteins, polysaccharides and water (Goff, 1997). The fats used to make up ice cream can be unsaturated or saturated, allowing for a stable food matrix to compare MCTs (such as coconut oil - CO) to LCTs (such as sunflower oil - SO).

In the previous literature, standard quantities of fat were in the range of 30-40g (Lawton *et al.*, 2000; Van Wymelbeke *et al.*, 1998, 2001; Rolls *et al.*, 1988), which exceeds the amounts normally found in foods. This may be problematic as, firstly, such quantities are not realistic to incorporate into everyday use; and secondly, these amounts of fat may be more harmful than helpful in the long term (Lee, 2013). The present research assesses the effects of different fats (CO, containing mainly MCTs and SO, containing mainly unsaturated LCTs) in different ratios (25% CO and 75% SO - 25CO:75SO, 50% CO and 50% SO - 50CO:50SO, 75% CO and 25% SO - 75CO:25SO) as part of a fixed portion ice cream; a palatable, well accepted, complex food product with 10% (15g) fat (a standard ice cream fat content) to determine how differing fat ratios influence appetite and *ad-libitum* dinner and snack intake. Such research in this area is novel because it assesses the effect of these fats when ingested in more typical quantities. It is important to highlight that in this study, as well as in other studies (Rolls *et al.*,

1988; Van Wymelbeke *et al.*, 2001; Barbera *et al.*, 2000), fats with both different chain length (MCTs and LCTs) and saturation (in particular saturated MCTs and unsaturated LCTs) were compared because 1) much research comparing fatty acid saturation levels (when keeping the chain length constant) on appetite and food intake has not shown any difference in effect; 2) MCTs have been shown to reduce food intake in comparison with both unsaturated and saturated LCTs (Van Wymelbeke *et al.*, 1998) and 3) a variety of food products (including ice cream) use a combination of vegetable-based saturated fat (like CO and palm oil, rich in MCTs) and vegetable-based unsaturated fat (like SO, rich in unsaturated LCTs). Thus understanding the effects of such fats in differing ratios on appetite and energy intake are invaluable. We predicted that due to the faster absorption of MCTs, the high ratio MCT condition would elicit a reduction in appetite and food intake more strongly than the high ratio LCT condition.

2. Material and methods

2.1 Participants

Thirty six healthy female volunteers were recruited to the study through advertisements at the University of Liverpool. Volunteers were asked to provide informed consent and were then screened. Exclusion at the screening session included: volunteers aged <18 years or >55 years; with a BMI <18.5 kgm^{-2} or >25 kgm^{-2}; who were taking medication known to affect appetite; who disliked more than 25% of the study foods; who were smokers or had recently stopped smoking; who reported food allergies or intolerances; who were currently dieting or about to embark a diet; who had significantly changed their physical activity in the past 4 weeks or intended to change it during the course of the study; who did not eat breakfast regularly; who dislike coconut flavoured ice cream; and who showed disordered eating behaviours (score > 4 on the Dutch Eating Behaviour Questionnaire Restraint, DEBQ-R (Van Strien *et al.*, 1986) or >27 on the Binge Eating Scale, BES (Gormally *et al.*, 1982)). The study was conducted in accordance to the guidelines laid down in the Declaration of Helsinki and all procedures involving human participants were approved by the University of Liverpool Committee on Research Ethics. Written informed consent was obtained from all subjects. Participants were compensated for their time and travel to the laboratory.

2.2 Study foods

2.2.1 Study products

The study products were three fixed quantity ice cream portions (150 g) different in ratios of CO to SO; 25% CO and 75% SO (25CO:75SO), 50% CO and 50% SO (50CO:50SO), 75% CO and 25% SO (75CO:25SO). Ice cream ingredients are shown in Table 1 and the nutritional profile is shown in Table 2. Each ice cream portion provided 270 calories, 6 grams of proteins, 15 grams of fats and 27 grams of carbohydrates. The typical composition of the fats used was as follows; SO is composed of palmitic acid (16:0; 5%), stearic acid (18:0; 6%), oleic acid (18:1; 30%), linoleic acid (18:2; 59%), whereas CO of caproic acid (6:0; 0.4-0.6%), caprylic acid (8:0; 7-9%), capric acid (10:0; 6-8%), lauric acid (12:0; 46-50 %), myristic acid (14:0; 17-19%), palmitic acid (16:0; 8-10 %), stearic acid (18:0; 2-3 %), oleic acid (18:1; 5-7 %), linoleic acid (18:2; 1-2%). A separate pilot sensory test with thirty participants showed that the ice creams used were sensory matched for creaminess, thickness, hardness, meltdown speed (time taken to melt in the mouth) and fattiness using VAS scale measures.

Ingredient	Percentage (wt%)
Fat	10
Skim milk powder	11
Sucrose	18
Guar gum	0.3
Distilled monoglycerides	0.2
Water	60.5

Table 1 Ice cream composition.

Typical values	100 g contains
Energy	180 Kcal
Protein	4 g
Fat	10 g
CHO	18 g

Table 2 Nutritional profile of ice cream provided (g – grams; Kcal – calories; CHO - carbohydrate).

2.2.2 Test meals and snack box

All participants were provided with a fixed-load breakfast, fixed-load lunch, fixed-load ice cream and *ad-libitum* dinner and snacks. A preliminary pilot study was conducted to adjust the fixed load and *ad-libitum* meal quantities to ensure the participants could comfortably consume the fixed load meals and that the *ad-libitum* items were more than they could possibly eat in one sitting. The nutritional profile of the fixed-load meals is shown in Table 3. 250g of water was provided for breakfast (as either tea, coffee or pure water) and lunch and 500g water was provided for dinner. If participants requested tea or coffee at breakfast they received the same beverage on each study day (with sugar or sweetener if requested). The *ad-libitum* dinner provided a range of high and low fat savoury and sweet options which consisted of pasta with bolognese sauce, medium grated cheese, garlic bread, strawberry jelly and chocolate mousse. After the dinner, participants were given a snack box containing a range of pre-weighed high and low fat sweet and savoury options (see Table 4 for nutritional information of the snacks provided). Participants were instructed to consume as much or little of these foods as they wished for the rest of the evening, to save the packages and/or the peel of the products eaten in the snack box and to return the pack on their next visit. Snack intake was used as a measure of 'snacking' behaviour and to cover all eating occasions (breakfast, lunch, dinner and snacks).

Meal	**Energy (Kcal)**	**Protein (g)**	**CHO (g)**	**Fat (g)**
Breakfast	415	12	65	11
Lunch	337	14	45	10

Table 3 Nutritional profile of the fixed-load meal (g – grams; Kcal – calories; CHO - carbohydrate).

Item	**Energy (Kcal)**	**Protein (g)**	**CHO (g)**	**Fat (g)**
Cheese crackers (HFSV) – 25g	131	2.7	12.9	7.5
Salt and vinegar rice crackers (LFSV) – 22g	89	1.5	17	1.6
Caramel biscuit chocolate bar (HFSW) – 23g	114	1	14.9	5.5
Marshmallow – 250g	825	11.5	195	trace
Fruit (Apple/Banana) ~100g	~55/84	~0.3/1.2	~13.8/20.3	~0.2/0.3

Table 4 Nutritional profile of the snack box foods provided (g – grams; Kcal – calories; CHO - carbohydrate). Weight of the fruit could vary.

2.3 Study design

A single blind within-subjects design was used to assess the effect of ice creams containing different CO to SO ratios (25CO:75SO, 50CO:50SO, 75CO:25SO) on subsequent *ad-libitum* dinner and snack intake and the experience of appetite. Each study visit was separated by one week and participants were provided with the three conditions in a randomised order. Power calculations were performed using G*Power for a repeated measures design using a medium (0.25) effect size and powering to 90% power which indicated that 30 participants were required. 40 participants were recruited to prevent any possible withdrawal or exclusions.

2.4 Appetite, palatability and sensory measures

Participants' appetite ratings (hunger, fullness, prospective consumption, desire to eat, satisfaction), palatability of the meals (pleasantness, fillingness, saltiness, familiarity, palatability, sweetness and tastiness of the food) and sensory attributes of the different ice creams (creaminess, thickness, meltdown speed, sweetness, fattiness) were evaluated using validated visual analogue scales (VAS) (Flint *et al.*, 2000) made up of 100 mm line with two extreme anchors: "not at all" and "extremely". Participants were asked to draw a vertical line to indicate their ratings. Appetite VAS were completed before and after each meal and at hourly intervals throughout the test day. Palatability and sensory ratings were included to ensure acceptance of the product and to determine whether any sensory differences between the ice creams were perceived which may influence appetite such as creaminess ("How creamy was the ice cream?"), fattiness ("How fatty was the ice cream?"), thickness ("How thick was the ice cream?"), and meltdown speed ("How long did the ice cream take to melt in your mouth?").

2.5 Universal Eating Monitor (UEM)

The Sussex Ingestion Pattern Monitor (SIPM) is a Universal Eating Monitor (UEM) which uses an automated method to measure food intake and subjective ratings of appetite and palatability. The SIPM is made up of a hidden scale connected to a computer, which measures the weight of the plate at 2-second intervals as the participant consumes their meal.

Participants' appetite ratings before and after ice cream consumption as well as palatability and the sensory attributes of the different ice creams were evaluated using on-screen visual analogue scales (VAS). The use of mixed paper and pen and computerised VAS has been validated elsewhere (Thomas *et al.*, 2013).

2.6 Procedure

A schematic representation of the study is shown in Fig. 1 and uses a standardised approach used widely in the literature (Lawton *et al.*, 2000; Harrold *et al.*, 2014). Participants were asked to keep each pre-study evening similar in terms of exercise and food intake and to avoid both alcohol consumption and vigorous exercise. They were also asked to record their food intake and activities in a provided standardised diary from 5 pm the day preceding the study visit to ensure compliance. Participants were instructed not to eat or drink anything except water from midnight the day preceding the study visit. Preceding each meal at the study centre, participants were seated in individual cubicles. They were given appetite VAS questionnaires before being served a meal (fixed-load breakfast, lunch, preload or *ad-libitum* dinner). For the breakfast and lunch, participants were asked to consume the entire meal within twenty minutes. After each meal participants completed further appetite and sensory VAS questionnaires. After breakfast and lunch, participants were free to leave the study centre and were instructed not to eat or drink anything except the water provided by the researcher until they returned for their next meal. They were provided with VAS questionnaires to complete hourly until their next meal. Lunch was provided four hours after the breakfast and the preload was given three hours and fifteen minutes after lunch. After ice cream consumption and VAS questionnaire completion participants were asked to remain in a waiting room before being served the *ad-libitum* dinner 45 minutes after they received the preload. Participants were asked to eat and drink from the choice of foods and water offered until they felt comfortably full, taking as long as they wished. Following dinner, participants were given a snack box with instructions to eat as much or as little of the foods provided as they wished for the rest of the evening. Participants were also given a retrospective appetite questionnaire and a gastrointestinal questionnaire to complete before retiring to bed. Participants were asked not to consume any alcohol for the rest of the evening.

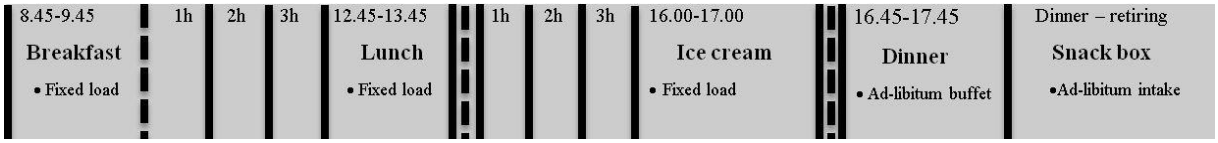

Fig. 1 Schematic representation of the study design. Solid lines represent appetite VAS scale completion; dash lines represent palatability/sensory VAS scale completion.

2.7 Statistical analysis

Analyses were performed using SPSS for Windows Version 22. One-way within subject repeated measures Analysis Of Variance (ANOVA) were conducted for appetite ratings with condition (25CO:75SO, 50CO:50SO and 75CO:25SO) and time (pre-ice cream, post-ice cream, and pre-dinner) as within-subject factors. Area under the curve (AUC) hunger, sensory meal ratings and retrospective appetite and the GI questionnaire were also assessed in this way. Intake at the *ad-libitum* meal and of the snack box provided was analysed in terms of grams, calories and macronutrients consumed. Total intake of *ad-libitum* dinner and snack box was also analysed (calories and grams consumed). Exact amounts consumed were calculated weighting the food (comprised of crockery/packets) before and after the eating episodes. Condition order was also analysed as a between-subjects factor. In cases of violated sphericty, Greenhouse Geisser values were reported. Contrast effects were assessed using paired samples t-tests where significant interactions were evident. Bonferroni corrected values are provided where sphericity assumptions were violated. All data are presented as means ± standard error of the mean (SEM).

3. Results

3.1 Participants

In total, 72 participants were screened and 40 were recruited. Three participants withdrew for personal reasons with a total of 37 participants who completed the study. One participant was excluded during the analysis as an outlier (due to intake exceeding 2 standard deviations above the mean), resulting in 36 available cases. The demographic and anthropometric characteristics of the completing participants are shown in Table 5.

	Participant characteristics
Gender	Female
Age	29.7 (4)
Height (cm)	149.8 (6.2)
Weight (kg)	66.4 (4.9)
BMI	21.7 (0.3)
DEBQ- Restraint	2.4 (0.1)
Binge Eating Score	7.7 (1)

Table 5 Mean (±SEM) gender, age, anthropometrics, and psychometric trait characteristics of participants.

3.2 Sensory perception and palatability of ice cream

The sensory and palatability ratings of the ice cream are shown in Table 6. There was no effect of condition on tastiness, pleasantness, sweetness, meltdown speed and fattiness. A significant effect of condition was found for creaminess (ANOVA main effect: F [2, 68]= 3.302, p= 0.043) and thickness (ANOVA main effect: F [2, 68]= 3.333, p= 0.042). In particular, ratio 75CO:25SO was perceived as significantly creamier than 50CO:50SO (t [34]= -2.485, p= 0.018) and there was a trend for a creamier perception of this ratio as compared to 25CO:75SO (t [35]= -1.810, p= 0.079). Ratio 75CO:25SO was also rated as significantly thicker than 25CO:75SO (t [35]= -2.150 , p= 0.039) and 50CO:50SO (t [34]= -2.461, p= 0.019). These results differed from our pilot sensory test. This may be due to participants receiving a larger quantity of ice cream in the present experiment which meant that the ice cream may have partially melted, making certain sensory attributes (such as creaminess or thickness) more prominent.

	Ratio		
	25CO:75SO	**50CO:50SO**	**75CO:25SO**
Tastiness	76.3 (4.2)	76.3 (4.2)	76.2 (4.4)
Pleasantness	79.5 (3.8)	77.2 (4.3)	79 (4.2)
Creaminess	71.3 (3.5) [ab]	69.2 (4.4) [a]	78.8 (3.4) [b]
Sweetness	63.5 (3.8)	62.2 (4.1)	65.9 (3.9)
Meltdown speed	34.1 (4.1)	38.6 (4.2)	36.3 (4.1)
Fattiness	47.7 (5.1)	47.6 (5)	50.9 (4.5)
Thickness	63.5 (4) [a]	64.8 (3.9) [a]	72 (3) [b]

Table 6 Mean (±SEM) sensory and palatability assessments of ice creams provided. Means in a row without a common letter differ ($p \leq 0.05$).

3.3 Ad-Libitum Meal Intake

Dinner intake is shown in Table 7. There was a significant difference between conditions in both the total consumption of fat (from main meal and dessert) and high fat savoury (HFSV) food selection (ANOVA main effect for fat: F [2, 70]= 3.774, p= 0.028 and HFSV: F [2, 70]= 0.4333, p= 0.017) with participants consuming significantly less fat after 75CO:25SO than 25CO:75SO (t [35]= 2.879, p= 0.007) and a trend for lower fat intake after this ratio in comparison with 50CO:50SO (t [35]= 1.883, p= 0.068). The consumption of HFSV options significantly decreased after 75CO:25SO as compared to both 25CO:75SO (t [35]= 2.153, p=0.038) and 50CO:50SO (t [35]= 2.800, p= 0.008). Dinner calorie intake also decreased as CO concentration increased but this was only found to be a trend in the data (F [2, 70]= 0.822, p= 0.444).

	Ratio		
	25CO:75SO	**50CO:50SO**	**75CO:25SO**
Dinner (g)	591.7 (31.4)	587(30.993)	562.7 (31.3)
Dinner (Kcal)	1980.6 (123.8)	1957.4 (120.3)	1883.6 (120.5)
PRO (g)	74.7 (4.4)	74 (4.3)	70.5 (4.2)
PRO (%)	15.2 (0.2)	15.3 (0.1)	15.2 (0.2)
CHO (g)	385.8 (24)	384.7 (23.1)	368.3 (23.1)
CHO (%)	78.1 (0.6)	79 (0.7)	78.7 (0.8)
Fat (g)	31.419 (1.5)[a]	30.9 (1.5) [ab]	28.8 (1.4) [b]
Fat (%)	15.2 (0.7)	15(0.6)	14.8 (0.7)
HFSV (g)	89.3 (4.9) [a]	90.7 (4) [a]	81.6 (4.3) [b]
LFSV (g)	431.3 (29.6)	429.3 (28.4)	412.8 (28.5)
HFSW (g)	33.7 (4.8)	27.8 (4.7)	24.8 (4.6)
LFSW (g)	37.4 (8.8)	39 (8.9)	43.5 (9.3)

Table 7 Means (±SEM) of energy (g - grams; and Kcal - calories) and macronutrient (PRO – protein; CHO – carbohydrate; and fat) intake, food selection (HFSV – high fat savoury; LFSV – low fat savoury; HFSW – high fat sweet; LFSW – low fat sweet) of dinner (main meal and dessert) items provided. Means in a row without a common letter differ ($p \leq 0.05$).

Snack energy intake (Table 8) significantly differed by condition (ANOVA main effect: F [2, 70]= 4.137, p= 0.020) with fewer calories consumed after 25CO:75SO and 50CO:50SO as compared to 75CO:25SO. Indeed, participants ate significantly less protein, carbohydrate and reduced their low fat sweet (LFSW) food selection after these conditions as compared to 75CO:25SO. Fruit consumption was also significantly higher after 50CO:50SO and a trend was also apparent after 25CO:75SO as compared to 75CO:25SO (see supplementary materials for detailed results). This suggests that the higher calorie intake at the dinner was compensated for in subsequent snack intake after 25CO:75SO and 50CO:50SO, with lower energy intake and healthier snack choices.

Overall intake of the *ad-libitum* dinner and snack box is shown in Table 9. There was no effect of condition on overall *ad-libitum* calorie (ANOVA main effect: F [2, 70] = 0.148, P= 0.863) and gram (ANOVA main effect: F [2, 70]= 0.017, P= 0.983) intake.

	Ratio		
	25CO:75SO	**50CO:50SO**	**75CO:25SO**
Snack Box (g)	141.5 (16.2)	144.7 (16.1)	165.3 (20.886)
Snack Box (Kcal)	376.1 (48)[a]	369.9 (43)[a]	494.6 (66) [b]
PRO (g)	4.8 (0.7) [a]	4.6 (0.6) [a]	6.4 (0.9) [b]
PRO (%)	4.3 (0.3)	4.4 (0.3)	4.7 (0.3)
CHO (g)	63(8.3) [a]	60.9 (7.7) [a]	87.6 (13.4) [b]
CHO (%)	65.6 (5.1)	66.1 (6.4)	64 (5.3)
fat (g)	14.7 (2.5)	15.2 (2.1)	15.8 (2.1)
fat (%)	29.9 (3.8)	35.4 (5.4)	33.5 (5.6)
HFSV (g)	13.5 (4.6)	11.8 (3)	15.4 (4)
LFSV (g)	8 (1.8)	8.6 (1.8)	10.4 (1.8)
HFSW (g)	30.1 (3.9)	32.2 (4)	30.5 (4.1)
LFSW (g)	22.6 (8.8) [a]	17.2 (7.6) [a]	54.4 (14.8) [b]
Fruit (g)	67.3 (10) [ab]	74.9 (10.7) [a]	54.5 (9.5) [b]

Table 8 Means (±SEM) of energy (g - grams; and Kcal - calories) and macronutrient (PRO – protein; CHO – carbohydrate; and fat) intake, food selection (HFSV – high fat savoury; LFSV – low fat savoury; HFSW – high fat sweet; LFSW – low fat sweet) of snack box items provided. Means in a row without a common letter differ (p ≤ 0.05).

	Ratio

	25CO:75SO	50CO:50SO	75CO:25SO
Overall grams	733.2 (43.1)	731.6 (37.7)	728 (44.8)
Overall kcal	2356.7 (156.3)	2327.3 (137.6)	2378.2 (160.2)

Table 9 Overall mean (±SEM) energy intake (grams and kcal - calories) of dinner and snack box.

3.4 Rated Appetite and associated questionnaires

There was no effect of condition on hunger (F [4, 140]= 0.510, p= 0.729), fullness (F [4, 140]= 1.633, p= 0.169), prospective consumption (F [4, 140]= 0.141, p= 0.966), satisfaction (F [4, 140]= 1.691, p= 0.155) or desire to eat (F [4, 140]= 2.232, p= 0.069 (Fig. 2) over the time lapse from pre-ice cream to pre-dinner**.** Similarly, AUC hunger ratings also showed no effect of condition (F [2, 70]= 1.292, p= 0.281). Retrospective questionnaires revealed no effect of condition on appetite, digestive experiences or mood suggesting that all the conditions were equally accepted by the participants and there were no unpleasant symptoms (see supplementary materials for detailed results).

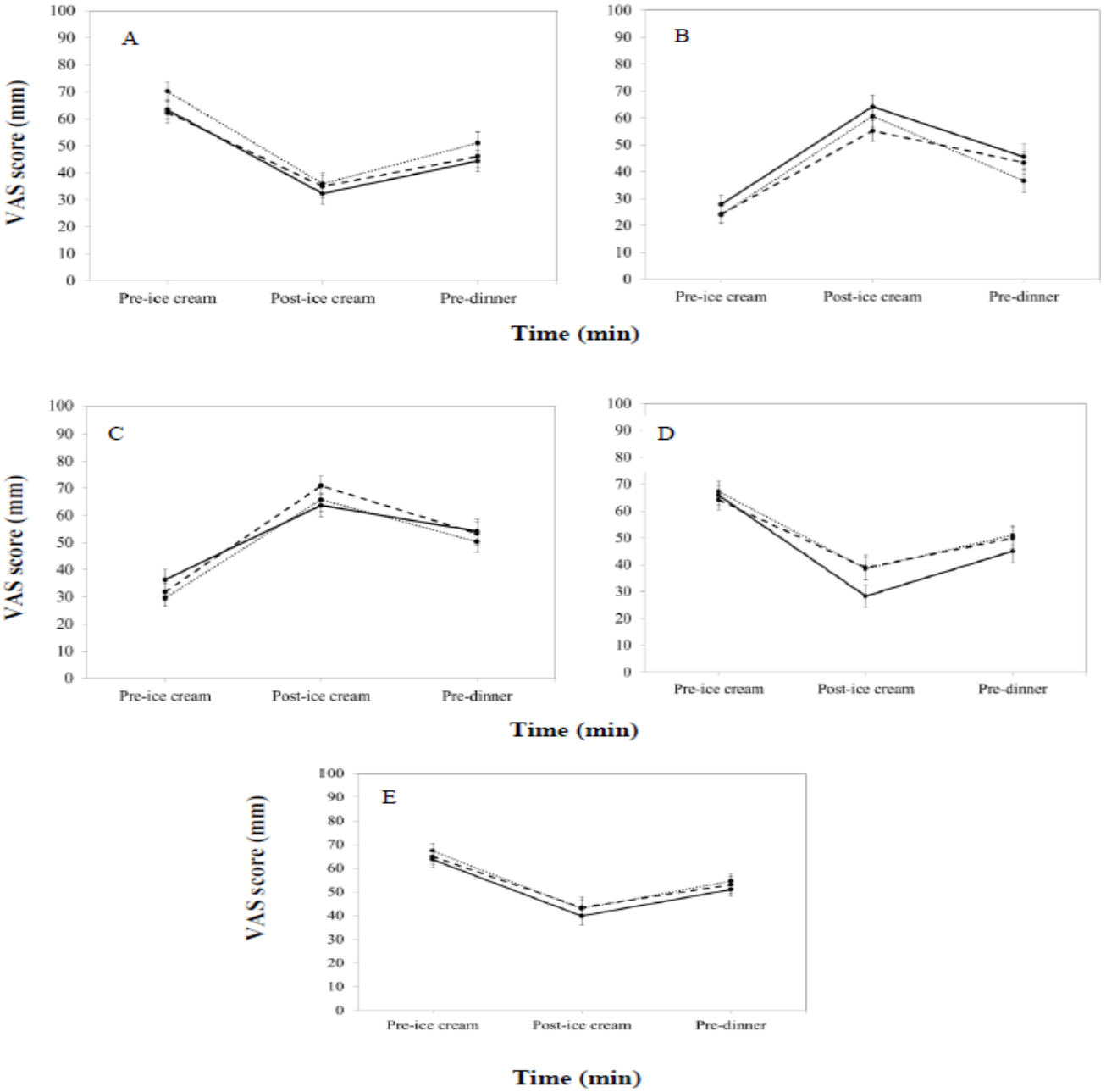

Fig. 2 Appetite ratings over time from pre-ice cream to pre-dinner. A-hunger, B-fullness, C-satisfaction, D-desire to eat and E- prospective consumption. Dash lines represent ratio 25CO:75SO, round dot lines ratio 50CO:50SO and solid lines ratio 75CO:25SO. Error bars represent means ±SEM.

4. Discussion

This study aimed to elucidate the impact of a fixed quantity ice cream preload containing different ratios of MCTs and LCTs (mainly unsaturated) on subsequent *ad-libitum* energy intake and experience of appetite. Fat and HFSV food intake was significantly lower after ratio 75CO:25SO than all other conditions. However, evening snack energy intake was significantly lower after 25CO:75SO and 50CO:50SO with less protein, carbohydrate, and LFSW food intake and higher fruit intake than that observed after 75CO:25SO. This indicates a potential earlier effect on macronutrient intake exerted by a high concentration of MCTs (fat and HFSV intake at *ad-libitum* dinner) and a delayed effect on food intake by a high concentration of LCTs (snack intake), which complements the differences found between MCTs and LCTs with respect to their absorption and metabolism by the body. However, it must be noted that while these differences were statistically significant and consistent across participants, the effects were small. No impact of condition on subjective appetite and desire was evident, indicating that participants were similarly satisfied irrespective of condition.

The bi-phasic effect found of MCTs suppressing fat intake earlier whilst LCTs reduced later snack intake may be explained by the differences in metabolism of these fats by the body. As previously stated, MCTs are absorbed by the enterocytes more rapidly (Bruce, 2010) and reach the liver faster than LCTs (Westergaard & Dietschy, 1976), directly entering the portal system. On the other hand, LCTs are incorporated into chylomicrons (structures with a lipid core of triglycerides, cholesterol, phospholipids, and fat-soluble vitamin esters coated by proteins), which are much larger and require time to reduce in size (releasing fatty acid) before they reach the liver. LCTs also require an additional carnitine transporter in order to pass the mitochondrial hepatic wall (Barret & Raybould, 2010) whilst MCTs do not require a transporter, thus they are readily oxidised. This β-oxidisation process synthesises Ketone bodies, which have been related to decreases in food intake (Le Foll *et al.*, 2014; Davis *et al.*, 1981; Carpenter & Grossman, 1983) as well as the β-oxidisation process itself (Feltrin *et al.*, 2008; Friedman & Tordoff, 1986; Friedman *et al.*, 1990). Thus, MCTs are likely to generate satiation faster than LCTs because they are absorbed and oxidised faster than LCTs and lead to the production of Ketone bodies. LCTs, in turn, may have an effect on later satiety as a longer period of time elapses before LCTs become available for β-oxidation (as they are

absorbed at a slower rate, reach the liver at a later point and have a rate-limiting step in oxidation). Similarly, the differences in fat and HFSV intake observed may also be influenced by the sensory experience of the ice creams as the 75CO:50SO ice cream was rated as creamier and thicker than 25CO:75SO and 50CO:50SO. This lends further support to previous research indicating that higher subjective creaminess ratings result in acute reduced intake and appetite (Bertenshaw *et al.,* 2009; Yeomans & Chambers, 2011; Bertenshaw *et al.,* 2013; McCrickerd *et al.,* 2012; McCrickerd *et al.,* 2014).

These results partially support previous findings showing that MCTs (intestinal infused, administered as a preload or added to a test meal) reduce acute food intake in comparison with LCTs (Feltrin *et al.,* 2008; Rolls *et al.,* 1988; Van Wymelbeke *et al.,* 1998, 2001) whilst LCTs can reduce subsequent intake at a delayed (240 min) eating occasion (Lawton *et al.,* 2000). Although there was no reduction in total *ad-libitum* intake, differences in fat and HFSV intake were apparent between conditions after the high MCT condition and reduced snack box intake after the high LCT conditions were also evident, despite being small. The discrepancies between the present work and previous literature in total *ad-libitum* dinner energy intake may be due to the higher fat quantities used in the previously mentioned studies (30-40 g). Nevertheless, the present results suggest that consumers may be able to modestly reduce their fat intake after eating an ice cream portion containing a standard amount of fat. Without reducing the amount of fat there wouldn't be a decrease in the palatability of the product so that consumers wouldn't be discouraged to consumption.

To our knowledge this is the first time that this (albeit small) bi-phasic effect of MCTs and LCTs has been shown in the literature. Moreover, current trends suggest that the recommended fat intake of 30% energy per day is being exceeded in the UK with poor quality saturated fats such as butter (Harwood *et al.,* 2007) which has been reported to be harmful to health (O'Sullivan *et al.,* 2013). Despite the small effects on subsequent fat intake seen here, it is important to highlight the quality of the fats used in the present research. Although CO is a saturated fat, it also contains a high amount of MCTs which have received considerable attention for their potential health benefits (Nagao & Yanagita, 2010) and the unsaturated fat profile of SO has also been found to show health benefits (Li *el al.,* 2015).

There are a range of limitations to the present research which should be addressed. For instance, the potential for compensation should not be ignored. Indeed, it may instead be that the lower snack intake observed after 25CO:75SO and 50CO:50SO may be due to participants compensating for the lower energy intake at the *ad-libitum* dinner. Future research should aim to further elucidate the mechanism for action of the MCT/LCT ratio assessed here to understand these changes in food intake. It must also be noted that an all-female sample was used and considerations regarding menstrual cycle stage were not taken into account as any potential variance in appetite seen here was expected to be accounted for during the randomisation stage. The inclusion of a male sample would also improve understanding about the conclusions drawn but was not possible in the current research. This trial also utilized a single-blind design due to the nature of the study product making double blinding not possible. The research is also limited in the conclusions drawn due to the healthy sample assessed with further research with an overweight and obese sample required to understand the differences that may occur in this group. Similarly, extending the assessment period to further understand whether the small changes in fat intake and snack selection found here remain consistent, or are compensated for over time, would be efficacious to understand the clinical relevance of the present study.

5. Conclusion

Overall, the present research suggests that eating a standard portion of ice cream (150g, 10% of fat) containing different fat ratios of MCTs and LCTs can modestly affect fat intake and snack selection at subsequent *ad-libitum* eating occasions. High concentrations of MCTs (saturated) manifested their effects earlier, modestly but consistently decreasing fat intake, whereas high concentrations of LCTs (unsaturated) manifested their effects later, reducing subsequent snack intake. This may be due to differences in the absorption and metabolism of these fats. To our knowledge, this is the first study to report such a bi-phasic action of triglycerides. Nevertheless, the observed differences, being slight and only observed after an acute dose, require further research utilizing repeated dosing to understand whether this may be clinically meaningful.

6. Acknowledgments

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7. Authorship

JCGH, JAH, and UM designed the study; GR carried out the research, analysed the results and wrote the manuscript; UM helped with the analysis; JCGH and UM commented on the manuscript; JCGH, JAH, UM and GR approved the final manuscript. JEN acted as primary supervisor to GR.

8. Supplementary materials

Snack energy intake

Interaction: 25CO:75SO * 75CO:25SO t [35] = -2.423, p= 0.021;

Interaction: 50CO:50SO * 75CO:25SO t [35]= -2.261, p= 0.030.

Snack protein intake

Condition * protein intake main effect: F [2, 70] = 4.325, p= 0.017;

Interaction: 25CO:75SO * 75CO:25SO t [35]= -2.526, p= 0.016;

Interaction: 50CO:50SO * 75CO:25SO t [35]= -2.421, p= 0.021.

Snack carbohydrate intake

Condition * carbohydrate intake main effect: F[2, 70] = 5.002, p= 0.009;

Interaction: 25CO:75SO * 75CO:25SO t [35]= -2.514, p= 0.017;

Interaction: 50CO:50SO * 75CO:25SO t [35]= -2.345, p= 0.025.

Snack LFSW intake

Condition * LFSW intake main effect: F [1.238; 43.339] = 5.002, p= 0.00;

Interaction: 25CO:75SO * 75CO:25SO t [35]= -2.808, p= 0.024;

Interaction: 50CO:50SO * 75CO:25SO t [35]= -2.792 p= 0.025.

Snack fruit intake

Condition * fruit intake F [2, 70] = 4.149, p= 0.020;

Interaction: 25CO:75SO * 75CO:25SO t [35]= 1.921, p= 0.063;

Interaction: 50CO:50SO * 75CO:25SO t [35] = 2.872, p= 0.007.

Retrospective questionnaires

Condition * Hunger main effect: F [2, 70]= 0.304, p= 0.739;

Condition * nausea main effect: F [1.577; 55.192]= 0.950, p= 0.374;

Condition *abdominal main effect: discomfort F [2, 70]= 0.673, p= 0.514;

Condition *fullness main effect: F [2, 70]= 0.857, p= 0.429;

Condition *irritability main effect: F [2, 70]= 0.216, p= 0.807;

Condition *mental alertness main effect: F[2, 70]= 0.043, p= 0.958;

Condition *contentedness main effect: F [2, 70]= 0.735, p= 0.483;

Condition *food pleasantness main effect: F [2, 70]= 0.035, p= 0.966;

Condition *difficulty to consume the food main effect: F [2, 70]= 0.847, p= 0.433;

Condition *bloatedness main effect: F [2, 70]= 0.902, p= 0.410;

Condition *comfortableness main effect: F [2, 70]= 1.226, p= 0.300;

Condition *flatulence main effect: F [2, 70]= 1.226, p= 0.300;

Condition *stomach tightness main effect: F [2, 70]= 1.835, p= 0.167.

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Highlights

- The effect of different triglycerides on appetite and food intake was investigated
- Medium chain triglycerides reduced fat intake at an *ad-libitum* dinner
- Long chain triglycerides reduced later food intake in *ad-libitum* snacking
- These differences were attributed to the absorption and metabolism of these lipids