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Emulsion oil droplet size significantly affects satiety: A pre-ingestive approach

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ABSTRACT

Previous research has demonstrated that the manipulation of oil droplet size within oil-in-water emulsions significantly affects sensory characteristics, hedonics and expectations of food intake, independently of energy content. Smaller oil droplets enhanced perceived creaminess, increased Liking and generated greater expectations of satiation and satiety, indicating that creaminess is a satiety-relevant sensory cue within these systems. This paper extends these findings by investigating the effect of oil droplet size ($d_{4,3}$: 2 and 50 μm) on food intake and appetite. Male participants (n = 34 aged 18–37; BMI of 22.7 ± 1.6 kg/m^2; DEBQ restricted eating score of 1.8 ± 0.1.) completed two test days, where they visited the laboratory to consume a fixed-portion breakfast, returning 3 h later for a "drink", which was the emulsion preload containing either 2 or 50 μm oil droplets. This was followed 20 min later with an *ad libitum* pasta lunch. Participants consumed significantly less at the *ad libitum* lunch after the preload containing 2 μm oil droplets than after the 50 μm preload, with an average reduction of 12% (62.4 kcal). Despite the significant differences in intake, no significant differences in sensory characteristics were noted. The findings show that the impact that an emulsion has on satiety can be enhanced without producing significantly perceivable differences in sensory properties. Therefore, by introducing a processing step which results in a smaller droplets, emulsion based liquid food products can be produced that enhance satiety, allowing covert functional redesign. Future work should consider the mechanism responsible for this effect.

1. Introduction

Fat is the most energy dense macronutrient at 9 kcal per gram (Atwater & Woods, 1896, pp. 47) and consequently is of interest in the redesign of food products to tackle the "obesogenic" food environment. Reducing fat content within foods has been a commonly proposed method to reduce consumers' energy intake. However, this is typically detrimental to the food product's sensory properties (Norton, Moore, & Fryer, 2007; Roller & Jones, 2001).

Increasing the functionality of the fat to reduce intake could be a novel alternative to produce inherently "healthier" fat based foods (Himaya, Fantino, Antoine, Brondel, & Louis-Sylvestre, 1997). Increasing a food product's impact on satiety may lead to a reduction in overall energy intake through inhibition of appetite after consumption (Chambers, McCrickerd & Yeomans, 2015; Hetherington et al., 2013).

Designing food structures for functional benefits is a growing area of interest. Redesigning foods that are high in fat (such as emulsions) to impact on appetite has added importance because fat is considered to be the least satiating macronutrient (Blundell, Green, & Burley, 1994; Blundell & Macdiarmid, 1997; Blundell & Tremblay, 1995). Emulsions are common fat based food structures that are found within a variety of commercially available food products, such as sauces, condiments, spreads, dressings and desserts. Emulsions are formed by mixing two immiscible liquids, such as oil and water, so one liquid is dispersed within the other as droplets stabilised by an emulsifier.

Previous research considering emulsion structures has predominantly considered gastro-intestinal structuring, in an attempt to achieve satiety via post-ingestive and post-absorptive mechanisms, with emulsion oil droplet size and emulsifier type being the two main properties investigated (Armand et al., 1999; Golding & Wooster, 2010; Ludin, Golding & Wooster, 2008; Maljaars et al., 2012; Mun, Decker, & McClements, 2007; Peters et al., 2014;

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Seimon et al., 2009; Singh, Ye, & Horne, 2009; van Aken, Bomhof, Zoet, Verbeek, & Oosterveld, 2011). However, structuring emulsions to achieve satiety via pre-ingestive approaches (i.e. considering sensory mechanisms) has recently been considered and highlighted as potentially effective (Lett, Yeomans, Norton, & Norton, 2015). In that study, decreasing the oil droplet size within an oil-in-water emulsion model drink, increased creaminess, which in turn increased liking and expectations of satiation and satiety, independent of energy content (Lett et al., 2015). creaminess within emulsions was therefore highlighted as a hedonic sensory cue, and a potential satiety-relevant sensory cue, which agrees with other findings that high-energy beverages are more satiating when creamy sensory characteristics are present (McCrickerd, Chambers, & Yeomans, 2014; Yeomans & Chambers, 2011). The mechanism by which satiety-relevant sensory cues appear to work suggests that people learn to associate sensory characteristics with the subsequent experience of satiety post-consumption (Brunstrom, Shakeshaft, & Scott-Samuel, 2008; Yeomans, McCrickerd, Brunstrom, & Chambers, 2014). As such, it is thought that creaminess, which is typically associated with high fat content (de Wijk, Rasing, & Wilkinson, 2003; Frost & Janhoj, 2007), generates expectations of satiety typically achieved after the consumption of fat containing energy dense foods, with the intensity of creaminess being a predictive marker of energy content.

If the enhanced expectation of satiety through altering oil droplet size also impacts on the experience of post-ingestive satiety, this could confirm this type of restructuring as a valuable approach to product development. Early pre-ingestive satiety signals, such as sensory properties integrate with post-ingestive and post-absorptive signals (Blundell, Rogers, & Hill, 1987), and adjust digestive and absorptive mechanisms accordingly, at least partly through anticipatory physiological responses (Power & Schulkin, 2008; Smeets, Erkner, & De Graaf, 2010).

The present study aimed to extend previous findings from Lett et al. (2015). We hypothesised that reducing the average oil droplet size of an oil-in-water emulsion will enhance satiety, through pre-ingestive sensory-mediated routes by increasing the perception of the identified satiety-relevant sensory cue, creaminess.

2. Materials and methods

2.1. Design

A repeated-measures single-blind randomised cross-over design preload paradigm was used to investigate the satiating effects of two oil-in-water emulsion based drinks, varying in oil droplet size, but with equal energy content. Test meal intake and subjective ratings (Visual analogue scales: VAS) were used to assess food intake behaviour. Ethical approval for the study was obtained from the University of Birmingham ethics committee (ERN_14-0807, Approved: 14/08/2014).

2.2. Participants

Thirty-four healthy male adults participated in the study. Sample size was determined on the basis of the effect size needed to find a difference in satiety between two emulsions with different average oil droplet sizes (2 and 50 μm). These emulsions were produced in a preliminary study in which oil droplet size of an emulsion beverage had been manipulated, changing sensory properties (Lett et al., 2015). To estimate participant numbers, we examined the outcome of previous preload studies where a difference in creaminess, similar in size to that in our recent emulsion study, was associated with a significant reduction in intake at a similar test meal. One such study where a difference in creaminess was associated with reduced intake was Yeomans and Chambers (2011), where less was consumed after a preload with higher rated creaminess (achieved primarily by varying viscosity) than after an isoenergetic less creamy preload. Based on the intake data in that study, one-tailed significance ($P < 0.05$, predicted reduction with more creamy preload) and power = 0.8, indicated that a sample of 34 would be required. All participants were staff or students at the University of Birmingham, who had expressed an interest in participating in a research study investigating “The effect of mood on appetite”, as to mask any expectancy effects concerning the true nature of the investigation. Prospective participants were contacted by a recruitment email via an email database and were asked to reply if they were interested in participation and considered themselves to be a healthy, non-smoking, normal weight (BMI: 18.5–25) male with no food allergies or intolerances. Females were excluded as they typically practice significantly higher levels of restricted eating and other eating behaviours than males (Arganini, Saba, Comitato, Virgili, & Turrini, 2012; Fortes, Kakeshita, Almeida, Gomes, & Ferreira, 2014; Wardle, 1987), and males who do not restrict their eating behaviour were chosen, as this cohort demonstrates the most accurate regulation of food intake (Rolls et al., 1994). Respondents to the recruitment email were provided with an information sheet and enrolled in the study if they were still interested in participation. Prior to the start of a session, participants were screened for food allergies, smoking habits and current medical status via a health questionnaire, body mass index (BMI), calculated as kg/m^2 (with height and weight measurements) being obtained with participants wearing light clothes and in a fasted state using a freestanding stadiometer (Seca 213, Birmingham, UK) and digital calibrated weighing scales (Seca 813, Birmingham, UK) and dietary restraint measured using the restraint scale from the Dutch eating behaviour questionnaire (DEBQ) (van Strien, Frijters, Bergers, & Defares, 1986). Potential participants were prevented from participating if they indicated any food allergies, history of smoking, had a BMI above 24.9 kg/m^2 or below 18.5 kg/m^2, were taking medication known to interfere with sensory perception or food intake or had a DEBQ restricted eating score of >2.4. One potential participant was prevented from participating, based on the recruitment criteria. Additionally, participants were given the opportunity to ask any questions about the study and its protocol to clarify issues or queries before the study began. The test cohort was made up of 34 men aged 18–37, with a mean BMI of 22.7 ± 1.6 kg/m^2 and DEBQ restricted eating score of 1.8 ± 0.1. All participants gave written informed consent prior to participation.

2.3. Procedure

Participants attended 2 sessions on non-consecutive days. Study protocol was identical on each test day, with only the preload varying (See Fig. 1). Participants arrived at a scheduled date and time between 08.30 and 10.30 am, Monday to Friday. Participants arrived having consumed only water from 11.00 pm the night before. All testing was carried out in an individual booth containing a PC computer running Sussex Ingestion Pattern Monitor (SIPM). SIPM was used to collect VAS scores of all mood and appetite questions throughout the study and preload sensory scores, and monitor food intake at lunch with a digital balance concealed by a placemat (Sartorius BP 4100). All VASs used within the study, collecting data on mood, appetite and preload sensory ratings were randomised differently for all participants. SIPM equipment and software were developed at the University of Sussex, based on a modification of the Universal Eating Monitor developed by Kissileff, Kilngsberg, and Van Italie (1980), and has been used extensively in