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Enhancing expected food intake behaviour, hedonics and sensory characteristics of oil-in-water emulsion systems through microstructural properties, oil droplet size and flavour

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ABSTRACT

Food reformulation, either to reduce nutrient content or to enhance satiety, can negatively impact upon sensory characteristics and hedonic appeal, whilst altering satiety expectations. Within numerous food systems, perception of certain sensory attributes, known as satiety-relevant sensory cues, have been shown to play a role in food intake behaviour. Emulsions are a common food structure; their very nature encourages reformulation through structural design approaches. Manipulation of emulsion design has been shown to change perceptions of certain sensory attributes and hedonic appeal, but the role of emulsions in food intake behaviour is less clear. With previous research yet to identify emulsion designs which promote attributes that act as satiety-relevant sensory cues within emulsion based foods, this paper investigates the effect of oil droplet size ($d_{4,3}$: 0.2–50 μm) and flavour type (Vanilla, Cream and No flavour) on sensory perception, hedonics and expected food intake behaviour. By identifying these attributes, this approach will allow the use of emulsion design approaches to promote the sensory characteristics that act as satiety-relevant sensory cues and/or are related to hedonic appeal. Male participants ($n = 24$) assessed the emulsions. Oil droplet size resulted in significant differences ($P < 0.05$) in ratings of Vanilla and Cream flavour intensity, Thickness, Smoothness, Creamy Mouthfeel, Creaminess, Liking, Expected Filling and Expected Hunger in 1 h's time. Flavour type resulted in significant differences ($P < 0.05$) in ratings of Vanilla and Cream flavour intensity, Sweetness and Liking. The most substantial finding was that by decreasing oil droplet size, Creaminess perception significantly increased. This significantly increases hedonic appeal, in addition to increasing ratings of Expected Filling and decreased Expected Hunger in 1 h's time, independently of energy content. If this finding is related to actual eating behaviour, a key target attribute will have been identified which can be manipulated through an emulsions droplet size, allowing the design of hedonically appropriate satiating foods.

1. Introduction

With the increasing prevalence of global obesity and its related non-communicable diseases, new strategies to promote weight loss and reduce the risk of weight gain are urgently needed. The food industry is increasingly being encouraged to contribute to the alleviation of the obesity burden through product reformulation and the development of the next generation of foods (Norton, Moore, & Fryer, 2007). One approach involves increasing the satiating power of foods and beverages, reducing consumption quantity, and thus energy intake (Blundell, 2010; van Kleef, Van Trijp, Van Den Borne, & Zondervan, 2012).

Prandial experienced sensory characteristics have been shown to impact upon consumption (de Graaf, 2012). Even subtle differences in sensory characteristics have an impact on eating behaviour (de Graaf & Kok, 2010; McCrickerd, Chambers, Brunstrom, & Yeomans, 2012; Yeomans & Chambers, 2011; Zijlstra, de Wijk, Mars, Stafleu, & de Graaf, 2009a; Zijlstra et al., 2009b). This indicates that certain sensory characteristics, such as Thickness (Hogenkamp, Stafleu, Mars, Brunstrom, & de Graaf, 2011; Mattes & Rothacker, 2001; McCrickerd et al., 2012; Zijlstra et al., 2009b), and the degree to which these are perceived during the prandial experience, act as satiety-relevant sensory cues, changing the food or beverages capacity to generate satiety expectations. Identifying satiety-relevant sensory cues and designing foods with these sensory attributes should increase their satiating power.

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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, when presented with similar stimuli, expectations are made about how satiating the food or drink will be. Therefore, an indication of how a food may impact on actual food intake behaviour can be acquired by simply presenting a sensory stimulus and measuring the resulting expectations on food intake behaviour.

Nonetheless, disadvantages of using satiety-relevant sensory cues as a reformulation or design approach have been highlighted: (1) as learned sensory cues are associated with a given caloric value and satiety expectation, producing low-energy dense foods with sensory characteristics (such as Thickness and Creaminess) indicative of a greater energy content, which is not delivered by the food, typically results in compensatory intake (Yeomans & Chambers, 2011); and (2) palatability has been shown to be inversely correlated to satiating power (de Graaf, de Jong, & Lambers, 1999; Drewnowski, 1998; Holt, Brand Miller, Petocz, & Farmakalidis, 1995), a commercial disadvantage when we consider that hedonic appeal is a driver in consumer purchasing habits (Dhar & Wertenbroch, 2000).

If hedonic properties can be maintained, or even enhanced, an effective formulation or design approach would be to increase the satiating power of foods independently of energy content. Typically, energy dense foods associated with nutrients such as fat have a strong hedonic appeal (Prentice & Jebb, 2003). Within food systems, fat is often structured in the form of an emulsion. An emulsion is comprised of two immiscible liquids, the most common food emulsion being oil dispersed in water (e.g. mayonnaise, milk, dressings, creams), known as an oil-in-water emulsion.

Microstructural reformulation approaches have been shown to alter sensory characteristics and hedonics in model and applied emulsion food systems (Akhtar, Murray, & Dickinson, 2006; Akhtar, Stenzel, Murray, & Dickinson, 2005; de Wijk & Prinz, 2005; Kilcast & Clegg, 2002; Lett, Norton, Yeomans, & Norton, in preparation; Mela, Langley, & Martin, 1994; Moore, Langley, Wilde, Fillery-Travis, & Mela, 1998; van Aken, Vingerhoeds, & de Wijk, 2011; Vingerhoeds, de Wijk, Zoet, Nixdorf, & van Aken, 2008). Subsequently, through the manipulation of microstructural properties, the capability to change the capacity to which satiety expectations are generated could be realised, through altering perception intensity of sensory characteristics that act as satiety-relevant cues.

We report: (1) how microstructural differences in emulsion based food systems change perceptions of sensory attributes; (2) sensory attributes that promote hedonic appeal; and (3) sensory attributes that act as satiety-relevant sensory cues, within emulsion systems. Taking a multidisciplinary approach, combining understanding of food engineering, sensory science, nutrition and food psychology, the work identifies the microstructural properties of emulsion food systems that promote individual sensory attributes and expected food intake behaviours. Most importantly, we aim to identify emulsion designs which may be used to maintain or enhance sensory and hedonic properties, but increase the satiating power of emulsion based foods.

2. Materials and methods

2.1. Design and participants

The present study investigated the effect of oil droplet size and flavour type within model oil-in-water emulsions on the perception of sensory attributes, hedonics and expected food intake behaviours.

Male participants were recruited via advertisement and screened for food allergies, smoking habits, body mass index (BMI), current medical status and dietary habits (restricted eating) via Dutch eating behaviour questionnaire (DEBQ) (van Strien et al., 1986). Females were excluded as they typically practice significantly higher levels of restricted eating and other eating behaviours than males (Wardle, 1987). The restricted eating DEBQ consisted of 10 questions having a five-option response format: never (1), seldom (2), sometimes (3), often (4), and very often (5). A restraint score was obtained by summing the scores for the 10 items and dividing by 10. A higher score indicates greater dietary restraint. 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 indicative of the participant occasionally or more often exercising restricted eating behaviour. 24 respondents met the study criteria and were included in the study. Participants were aged 18–26, with a mean BMI of 22.8 ± 1.7 kg/m^2 and DEBQ restricted eating score of 1.8 ± 0.2. All participants gave written informed consent prior to participation. To guard against expectancy effects, the study was described as an investigation into the sensory analysis of emulsions. Ethical approval for the study was obtained from the University of Birmingham ethics committee.

2.2. Test samples

Samples consisted of an oil-in-distilled water emulsion (1 wt.% sodium caseinate (Excellion EM7, DMV International, The Netherlands)), 2 wt.% sucrose (Silverspoon granulated, British Sugar Plc, UK) and 15 wt.% sunflower oil (Tesco Plc, UK) with one of three flavours dependent on flavour condition: 1 wt.% vanilla extract (Nielsen-Massey Vanillas International LLC, The Netherlands), 0.05 wt.% cream flavouring (Frontier Natural Products Co-op., USA) and No flavour.

Emulsions were produced using two different methods dependent upon the required mean droplet size of the emulsion being produced: a high shear mixer (Silverson L5M, Silverson machines Ltd.,, UK) or a high-pressure homogeniser (GEA Niro Soavi Panda Plus 2000, GEA Niro Soavi, Italy). In a 600 ml beaker, 15 wt.% sunflower oil was added to 85 wt.% aqueous phase (1.1 wt.% NaCas, 2.2 wt.% sucrose, 96.6 wt.% distilled water solution). The whole sample was then emulsified for 5 min using the high shear mixer. Dependent on oil droplet size being produced the sample was subjected to a different rotational speed (rpm) and emulsor screen (fine (0.8 mm pores) or medium (1.6 mm pores)) (50 μm: 2500 rpm *medium screen*, 40 μm: 3500 rpm *medium screen*, 20 μm: 5000 rpm *fine screen* and 11 μm: 9000 rpm *fine screen*). For emulsions produced using the high-pressure homogeniser, first a pre-emulsion was produced using the high shear mixer at 9000 rpm with a fine emulsor screen for 5 min using the high shear mixer. The pre-emulsion was then subjected to homogenisation, differing in pressure and number of passes (6 μm: 20 Bar 3 passes, 2 μm: 100 Bar 2 passes and 0.2 μm: 1250 Bar 4 passes). All samples were produced in 400 g batches, under clean and hygienic conditions on the day of evaluation and stored under refrigerated conditions at 2–5 °C.

2.3. Measurement of sensory perception and expected food intake behaviours

Test sessions were scheduled between 10 am and 12 am or 2 pm and 4 pm, Monday to Friday, with sessions lasting 1 h to