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Effects of aroma and taste, independently or in combination, on appetite sensation and subsequent food intake

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ABSTRACT

Food flavour is important in appetite control. The effects of aroma and taste, independently or in combination, on appetite sensation and subsequent food intake, were studied. Twenty-six females (24 ± 4 years, 20.9 ± 1.9 kg·m^{-2}) consumed, over 15 min period, one of four sample drinks as a preload, followed by an *ad libitum* consumption of a pasta meal (after 65 min). Sample drinks were: water (S1, 0 kcal), water with strawberry aroma (S2, 0 kcal), water with sucrose and citric acid (S3, 48 kcal) and water with strawberry aroma, sucrose and citric acid (S4, 48 kcal). Appetite sensation did not differ between the S1 (water), S2 (aroma) and S3 (taste) conditions. Compared with S1 (water), S2 (aroma) and S3 (taste), S4 (aroma + taste) suppressed hunger sensation over the 15 min sample drink consumption period (satiation) ($p < 0.05$). S4 (aroma + taste) further reduced hunger sensation (satiety) more than S1 at 5, 20 and 30 min after the drink was consumed ($p < 0.05$), more than S2 (aroma) at 5 and 20 min after the drink was consumed ($p < 0.05$), and more than S3 (taste) at 5 min after the drink was consumed ($p < 0.05$). Subsequent pasta energy intake did not vary between the sample drink conditions. S4 (aroma + taste) had the strongest perceived flavour. This study suggests that the combination of aroma and taste induced greater satiation and short-term satiety than the independent aroma or taste and water, potentially via increasing the perceived flavour intensity or by enhancing the perceived flavour quality and complexity as a result of aroma-taste cross-modal perception.

1. Introduction

Over-consumption of food, resulting in excessive energy intake, has contributed to the obesity pandemic. Appetite and food intake in humans are controlled by successive but also overlapping sensory, cognitive, hormonal and metabolic signals that influence eating as described in the satiety cascade (Blundell & Bellisle, 2013; Blundell, Rogers, & Hill, 1987). Within the satiety cascade, “Satiation” is the process which leads to the termination of eating; “Satiety” describes the inter-prandial period during which the feeling of fullness lingers before hunger returns (Benelam, 2009). Food flavour, an oral-sensory signal, may play an important role in affecting appetite sensation and food intake. On the one hand, flavour contributes to food palatability which has been shown to stimulate hunger and increase food intake (Bobroff & Kissileff, 1986; Hill, Magson, & Blundell, 1984; Spiegel, Shrager, & Stellar, 1989; Yeomans, 1996). On the other hand, flavour *per se* can also be a satiation cue that reduces meal size, and acts as a satiety cue to influence the size of the next meal, through both psychological and physiological mechanisms (Blundell & Bellisle, 2013; Blundell, Lawton, Cotton, & Macdiarmid, 1996). The flavour modality, which can comprise of both aroma or taste, has been shown to enhance the sensation of fullness, suppress hunger sensation and reduce food intake (Bolhuis, Lakemond, de Wijk, Luning, & de Graaf, 2011; Ramaekers, Luning, Ruijschop, Lakemond, & Van Boekel, 2011).

There is an increasing interest in the impact of aroma and odour on appetite sensation and food intake. Volatile compounds can reach the olfactory epithelium through one of two routes: orthonasal (via nostril) or retronasal delivery (via nasopharynx) delivery (Negoias, Visschers, Boelrijk, & Hummel, 2008). Orthonasal odour delivery may be linked to the identification and anticipation of a food reward while retronasal aroma delivery is typically associated with the flavour perception of food during an eating event (Small, Gerber, Mak, & Hummel, 2005). Orthonasal odour delivery has

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been reported to stimulate a specific appetite for food containing this aroma, and it had a relatively smaller appetising effect on other foods (Ramaekers, Boesveldt, Lakemond, van Boekel, & Luning, 2014). In contrast, retronasal aroma delivery has been shown to enhance the feeling of satiation and reduce food intake. A more intense retronasal aroma profile led to an increased sensation of satiation when compared with a less intense retronasal aroma profile in yoghurt products (Ruijschop, Boelrijk, De Ru, De Graaf, & Westerterp-Plantenga, 2008). The addition of a creamy aroma to the nasal cavity via a silicone tube (mimicking the retronasal delivery), while consuming a tomato soup, enhanced the sensation of satiation compared with the condition without the creamy aroma (Ramaekers et al., 2011). This resulted in a 9% reduction in the *ad libitum* intake in the soup with the delivery of a longer and more intense tomato aroma, compared with the same soup with a shorter and less intense tomato aroma (Ramaekers, Luning, et al., 2014).

There are five detectable tastes by humans, including sweet, salty, sour, bitter, umami and a number of potential other tastes including fatty (Chandrashekar, Hoon, Ryba, & Zuker, 2006; Mattes, 2009). It is now widely agreed that in humans food intake is controlled by learned satiety (conditioned satiety) whereby we associate the sensation of taste with its metabolic consequences through instinct or learned experiences (Booth, 2009). For instance, the learned association between sweet taste and the ingestion of carbohydrates, or between umami and the ingestion of protein, may contribute to the control of meal size (Chandrashekar et al., 2006; Hogenkamp, Stafleu, Mars, Brunstrom, & de Graaf, 2011). Of all taste, the effect of sweet taste on appetite sensation and food intake is the most studied. Nutritive sweeteners, such as sugars, may not only promote satiation and satiety via their sweetness, but also, via physiological mechanisms due to their post-ingestive feedback (Bellisle, Drewnowski, Anderson, Westerterp-Plantenga, & Martins, 2012). For example, sucrose (135 g), when presented in a drink, increased the subsequent feeling of fullness compared with a water control (J. H. Lavin, French, & Read, 2002). Prolonged consumption of sucrose, over 10 min, decreased the subsequent food intake to a greater extent when compared to the condition where sucrose was consumed over 2 min, suggesting that the temporal profile of sweetness perception may modulate subsequent food intake (J. H. Lavin, French, Ruxton, & Read, 2002). A non-nutritive aspartame sweetened drink also suppressed subsequent food intake compared with a water control, but the reduction in food intake after aspartame was smaller than that after sucrose (65 kcal or 90 kcal). This provides the evidence that the post-ingestive consequence of sugars plays a part in providing satiety (Birch, Mcphee, & Sullivan, 1989) although this was in children. Although the sweet taste *per se* can contribute to satiation and satiety, sweet taste often plays a key role in determining the palatability of food or drink which has been shown to stimulate hunger (Bellisle et al., 2012). In some studies, sweet taste had no effect or even increased hunger sensation and food intake, which was potentially due to the palatability from the sweet taste neutralising or even overriding the satiation and satiety signals (Black, Leiter, & Anderson, 1993; Blundell & Hill, 1986; Holt, Sandona, & Brand-Miller, 2000; King, Appleton, Rogers, & Blundell, 1999).

Flavour perception is the combination of multisensory modalities, of which aroma and taste are the two primary drivers (Auvray & Spence, 2008; Wallace, 2015). Taste or aroma does not only affect the perceived flavour as an independent modality, but the combination of taste and aroma can also change both the intensity and quality of the perceived flavour as a result cross-modal association (Wallace, 2015). Congruent taste and aroma modalities, when presented together, increased the perceived flavour intensity more than the sum of the independent taste and aroma (Hewson, Hollowood, Chandra, & Hort, 2009; Pfeiffer, Hort, Hollowood, & Taylor, 2006). Aroma-taste cross-modal association was supported by neural imaging studies. Overlapping areas in the insula, orbitofrontal cortex (OFC), amygdala and anterior cingulate cortex (ACC) have been shown to be activated by taste or aroma modality (Rolls, 2015; Small, Jones-Gotman, Zatorre, Petrides, & Evans, 1997; Small et al., 2005), whereas a lateral anterior region of the OFC was activated only by the combination of aroma and taste but not by a single aroma or taste modality (de Araujo, Rolls, Kringelbach, McGlone, & Phillips, 2003). Potentially, aroma and taste do not only affect appetite and food intake independently but also as a synergistic combination of both modalities. Warwick, Hall, Pappas, and Schiffman (1993) reported that the combination of vanilla aroma and aspartame in a meal decreased the subsequent hunger sensation, compared with a nutritionally same but unflavoured meal. However, the effect of the combination of aroma and taste modalities, in comparison to the independent effect of aroma or taste modality, on appetite sensation and food intake has not been reported previously, as far as the authors are aware.

The objective of this study was, therefore, to investigate the impact of aroma and taste, independently and in combination, on appetite sensation and subsequent food intake. A flavoured drink model was constructed with different combinations of strawberry aroma and taste substances (sucrose and citric acid). Appetite sensation was evaluated during and after consumption, and food intake at the next meal measured. Sucrose and citric acid may interact with some aroma at a physicochemical level, resulting in changes in the aroma delivery to the nasal cavity. Therefore, the atmospheric pressure chemical ionisation mass spectrometry (APCI-MS) was used to measure any change in the in-vivo strawberry aroma release which may influence appetite sensation and food intake (Taylor, Linforth, Harvey, & Blake, 2000).

2. Materials and methods

2.1. Study design for evaluating appetite sensation and subsequent pasta intake

The study was a single-blind, randomised crossover experiment. A “preloading paradigm” was used to investigate the effects of aroma and taste, independently and in combination, in a liquid preload, on self-reported appetite sensation and subsequent pasta meal intake. Water without any taste or aroma substances was used as a control preload in parallel to the three sample drinks. This study was approved by the Medical Ethical Committee of the University of Nottingham (ethics reference number: R14032013 SBS Food, 15/03/2013).

2.2. Participants for evaluating appetite sensation and subsequent pasta intake

A recruitment email with the inclusion and exclusion criteria was sent to prospective participants. They were asked to participate voluntarily in the study by replying to the email. Male participants were excluded from this study to reduce any variation caused by gender differences in flavour perception, appetite sensation and food intake (Olofsson & Nordin, 2004; Sudo, Sekiyama, Watanabe, Bokul, & Ohtsuka, 2004). Inclusion criteria were that participants were 19–40 years healthy non-smoking females, with a normal BMI within 18.5–24.9 $kg \cdot m^{-2}$, who were neither pregnant nor breastfeeding, and not taking any medication except the oral contraceptive pills. Exclusion criteria included a weight loss or gain of more than 4 kg in the past six months, self-reported abnormal gustatory and olfactory senses, any allergy or intolerance to the food ingredients, a score >7 for the restraint factor on the Three-