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Comparison of oro-sensory exposure duration and intensity manipulations on satiation☆

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HIGHLIGHTS

- Oro-sensory exposure duration and taste intensity were manipulated using model foods.
- Increased oro-sensory exposure duration decreased meal size.
- Increased taste intensity did not affect meal size.
- Microstructure of eating behavior characteristics may explain differences in intake.

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ABSTRACT

Oro-sensory exposure (OSE) is an important factor in the regulation of food intake with increasing OSE leading to lower food intake. Oral processing time and taste intensity both play an important role in OSE but their individual contribution to satiation is unknown. We aimed to determine the independent and combined effects of oral processing time and taste intensity on satiation.

Fifty eight participants (23 ± 9 y, BMI 22 ± 2 kg/m^2) participated in a 2 × 2 factorial randomized crossover study in which they consumed one of four gel-based model foods until satiation during four sessions. Model foods were offered *ad libitum* and differed in texture (soft or hard texture, yielding shorter and longer oral processing time) and sweetness (low or high intensity). Model foods were isocaloric and were matched for flavor and palatability. Outcome measures were intake of the model food and the microstructure of eating behavior, such as number of chews and eating rate.

There was an overall significant effect of texture ($p < 0.001$) but not sweetness ($p = 0.33$) on intake with a 29.2% higher intake of the soft model foods compared to the hard model foods. After correction for palatability the difference in intake between the soft and hard model foods was 21.5% ($p < 0.001$).

The number of chews was significantly lower for the soft (10.1 ± 6.2) than for the hard (26.9 ± 6.2) model foods ($p < 0.001$), which resulted in a significantly lower eating rate (soft, 26.3 ± 10.2 and hard, 15.3 ± 7.1 g/min, $p < 0.001$).

These results show that increasing texture hardness of gel model foods decreases food intake independent of sweet taste intensity. The higher number of chews and faster eating rate may cause this effect. In conclusion, oro-sensory exposure duration rather than taste intensity appears to be the main determinant of food intake.

1. Introduction

The abundance of palatable, high-energy dense foods in modern society is a major contributor to the obesity problem [1]. This obesogenic environment offers many foods that can be eaten quickly [2–6]. The fast rate by which consumers can ingest calories, results in overconsumption and weight gain, and has been associated with obesity [7–10]. This rapid eating of food is associated with a short oral transit time and reduced oro-sensory exposure (OSE) to food. OSE is the collective

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stimulation of receptors on the tongue and in the oral cavity and is important for meal termination [11–15].

Oro-sensory stimulation affects intake and depends on food properties such as shape, odor, flavor, texture and taste [16–20]. Enhanced sensory stimulation through taste and texture increases OSE and leads to early meal termination and limits food intake [11–13]. Food texture does not only provide sensory stimulation *per se* but it also determines the duration of OSE by affecting the oral processing time that is needed to produce a food bolus that is safe to swallow [21]. This may be the key reason why people easily consume more of foods that can be ingested quickly ('fast foods'). For example, Zijlstra et al. showed that participants consumed 30% more of a liquid compared to a semi-solid product that was similar in palatability, energy density and macronutrient composition [22]. Moreover, the same authors showed that when oral processing time was increased, food intake decreased [23]. This difference in intake has also been found comparing intake of solid foods with different hardness levels. Subjects lowered their lunch meal intake with 13% when given hard lunch meal foods compared to soft lunch meal foods [24]. However, the difference between soft and hard textures should be of a certain size in order to affect intake [25].

In addition to oral processing time, which determines the duration of oro-sensory stimulation, the degree of OSE is also determined by taste intensity [26]. Foods containing low salt or sugar levels will provide less oro-sensory stimulation as they generally have low taste intensity [27–29]. This effect of taste intensity on satiation has been shown for both sweet and salty foods [30,31]. One of the mechanisms behind this might be that low taste intensity signals low energy density and, therefore, these types of food are perceived as being less satiating [26].

Oral processing time and taste intensity are not independent; De Wijk et al. found that increased sweetness results in increased oral processing time and oral movements [32]. Thus, the duration of OSE is not only determined by the food's texture but also by its taste intensity [33,34]. Likewise, texture determines the duration of the taste sensation in the mouth and influences the perception of taste intensity [35,36]. For example, solid foods require up to 200% more sugar to be perceived as being equally sweet as liquids [35,36]. It is therefore not surprising that texture and taste also interact in their effect on satiation or food intake. This has been demonstrated by Forde et al. who found an interactive effect of high savory taste and texture hardness on food intake [37].

Accordingly, foods that have a semi-liquid texture are less satiating and eaten in larger quantities compared to hard textured foods. In addition, low taste intensity foods seem to be less satiating compared to high taste intensity foods. However, the evidence for an effect of taste is not as strong as evidence for an effect of texture on food intake [12,13,38–41]. The separate and interactive effects of oral processing time and taste intensity on satiation have yet to be studied.

To manipulate foods such that their properties promote lower food intake it is important to understand how food properties interact and which property contributes most to satiation; oral processing time or taste intensity. Therefore, the objective of this study was to determine the independent contributions of oral processing time and taste intensity and their combined effect on satiation. Our secondary aim was to explore how taste intensity and oral processing time affect microstructure eating behavior and whether this may explain the differences in satiation.

To study this we performed a 2 × 2 factorial randomized crossover study in which the degree of OSE stimulation was varied through different levels of texture hardness and sweetness. A higher degree of OSE (high taste intensity, hard texture) was hypothesized to lower food intake. In addition we expected that increased taste intensity and texture hardness would lead to a higher number of chews, longer oral processing time and slower eating rate.

2. Participants and methods

2.1. Participants

The study was performed at Wageningen University, The Netherlands. Participants were recruited from the surroundings of Wageningen using flyers and posters. In addition, emails were sent to persons in a database of volunteers who had previously expressed an interest in participating in nutrition studies. Participants had to be healthy, between 18 and 50 years old, and have a BMI between 18.5 and 27 kg/m^2. Participants were excluded if they indicated that they had a lack of appetite or had dental, chewing or swallowing problems. Participants were also excluded if they followed an energy-restricted diet or if they had gained or lost >5 kg of body weight during the past two months. In addition, they were not allowed to participate if they were high restrained eaters according to the Dutch Eating Behavior Questionnaire (DEBQ): score >2.89 for men and >3.39 for women [42]. Personnel of the Division of Human Nutrition were omitted from participation together with students writing their Master thesis at the same division.

Potential participants were invited to a screening visit at Wageningen University. Height and body weight were measured. In addition, pre-defined hedonic and sensory attributes of the model foods were rated. Participants were excluded from participation if they disliked one of the model foods (score <4 on a nine point hedonic Likert scale) or had a stronger preference for one of the model foods (>2 point difference on a nine point hedonic Likert scale).

The study was approved by the Medical Ethical Committee of Wageningen University (ABR54634) and registered under NTR5523 (http://www.trialregister.nl). All participants signed informed consent prior to the screening. Participants were not informed on the exact aim until after the study, instead they were told that the study aimed to investigate eating behavior in general. Participants received a financial compensation.

174 participants participated in the screening. After the screening, 66 participants were found eligible. However, three of them were not able to participate in the test sessions because of lack of time, three did not want to participate anymore and two were lost to follow up.

In total, 58 participants (14 men) completed the study. Participants were 23 ± 9 years old, had a mean (±SD) body mass index of 22 ± 2 kg/m^2, men had an average DEBQ restraint score of 1.6 ± 0.4 and women had an average score of 2.8 ± 0.6 [42].

2.2. Experimental design

The study had a 2 × 2 factorial, randomized crossover-design where the models foods (MF) were formulated to have two levels of oral processing time (soft or hard texture), and two levels of sweetness (low or high). The MFs were similar in caloric content and palatability. During lunch visits, participants ate a portion of one of the four MFs, that is hard sweet- hard non-sweet, soft sweet or soft non-sweet. Treatment order was randomized, following a Latin square Williams design. Based on previous studies [10,20,29] we estimated an effect size of 15 g with a within subject standard deviation of 30 g. Including an estimated dropout rate of 10% we aimed to enroll 65 participants.

2.3. Model foods

The foods used in the study were strawberry flavored model food gels, and were comparable with MFs used in previous studies [32,43]. To manipulate the oral processing time, the hardness of the gels was manipulated by altering the concentration of the thickening agents carrageenan (type CHP-2) and locust-bean gum (LBG). Thickening agents were added in the following amounts: 0.22/0.22 wt% carrageenan/LBG for the soft and 0.66/0.88 wt% carrageenan/LBG for the hard MF.

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