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Both a higher number of sips and a longer oral transit time reduce ad libitum intake

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ABSTRACT

Background: A higher eating rate leads to a higher food intake, possibly through shorter orosensory exposure to food. The transit time in the oral cavity and the number of bites or sips per gram (inversely related to bite or sip size) are main contributors that affect eating rate. The separate role of these two aspects on satiation and on orosensory exposure needs further clarification.
Objective: The objective of the first study was to investigate contributions of the number of sips per gram (sips/g) and oral transit time per gram (s/g) on ad libitum intake. The objective of the second study was to investigate both aspects on the total magnitude of orosensory exposure per gram food.
Methods: In study 1, 56 healthy male subjects consumed soup where the number of sips and oral transit time differed by a factor three respectively: 6.7 vs. 20 sips/100 g, and 20 vs. 60 s/100 g (2×2 cross-over design). Eating rate of 60 g/min was kept constant. In study 2, the effects of number of sips and oral transit time (equal as in study 1) on the total magnitude of orosensory exposure per gram soup were measured by time intensity functions by 22 different healthy subjects.
Results: Higher number of sips and longer oral transit time reduced ad libitum intake by respectively ~22% ($F(1, 157) = 55.9$, $P < 0.001$) and ~8% ($F(1, 157) = 7.4$, $P = 0.007$). Higher number of sips led to faster increase in fullness per gram food ($F(1, 157) = 24.1$, $P < 0.001$) (study 1). Higher number of sips and longer oral transit time both increased the orosensory exposure per gram food ($F(1, 63) = 23.8$, $P < 0.001$) and ($F(1, 63) = 19.0$, $P < 0.001$), respectively (study 2).
Conclusion: Higher number of sips and longer oral transit time reduced food intake, possibly through the increased the orosensory exposure per gram food. Designing foods that will be consumed with small sips or bites and long oral transit time may be effective in reducing energy intake.

1. Introduction

The current food supply consists of a majority of highly processed foods that support fast intake of energy and minimal oral processing, like energy-yielding beverages and foods low in fiber content (Cordain et al., 2005; Malik, Schulze, & Hu, 2006; Slimani et al., 2009). Foods that can be consumed quickly (i.e., fast eating rate, grams or energy per time unit) may facilitate over-consumption. A number of studies have shown that higher eating rate leads to higher energy intake (Coelho et al., 2006; De Wijk, Zijlstra, Mars, De Graaf, & Prinz, 2008; Haber, Heaton, Murphy, & Burroughs, 1977; Melanson, Greene, & Petty, 2011; Ponte, Melanson, & Greene, 2011; Viskaal-van Dongen, Kok, & de Graaf, 2011; Zijlstra, Mars, De Wijk, Westerterp-Plantenga, & De Graaf, 2008). Moreover, several studies suggest a positive relationship between eating rate and body weight status (Hill & McCutcheon, 1984; Llewellyn, van Jaarsveld, Boniface, Carnell, & Wardle, 2008; Maruyama et al., 2008; Otsuka et al., 2006; Sasaki, Katagiri, Tsuji, Shimoda, & Amano, 2003).

Hogenkamp, Mars, Stafleu, and de Graaf (2010) compared ad libitum intake of yoghurts low and high in energy density with different eating rates. Food intake was primarily influenced by eating rate, and not by energy density. We propose that shorter sensory exposure of food in the oral cavity (i.e., orosensory exposure) explains the increased food intake at a fast eating rate. A number of studies show the importance of orosensory exposure to food in establishing feedback signals of satiation (Davis & Smith, 2009; Lavin, French, Ruxton, & Read, 2002b; Weijzen, Smeets, & de Graaf, 2009; Wijlens et al., 2012; Zijlstra, De Wijk, Mars, Stafleu, & De Graaf, 2009). Direct infusions of food into the stomach or duodenum, thus bypassing the orosensory exposure, give much

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weaker responses of satiation compared to oral intake (Cecil, Francis, & Read, 1998; Cecil, Francis, & Read, 1999; French & Cecil, 2001; Lavin, French, & Read, 2002a).

There are two ways to slow down the eating rate (g/s), in order to increase the orosensory exposure per gram food and thereby decrease the amount of food intake, which are prolonging the transit time of the food in the oral cavity (i.e., oral transit time) or decreasing the bite/sip sizes. Previous studies have shown that bite size positively affected food intake and oral transit time negatively affected food intake (Bolhuis, Lakemond, de Wijk, Luning, & de Graaf, 2011; Weijzen et al., 2009; Zijlstra et al., 2009). However, in these studies the effects of bite size and oral transit time were confounded which did not allow the verification of individual contributions. In a natural way of eating, bite or sip size and oral transit time influence each other. Forde, van Kuijk, Thaler, de Graaf, and Martin (2012) showed that foods that are naturally consumed with smaller bite sizes are associated with longer oral transit times than foods that are consumed with larger bite sizes. Also within the same food, smaller bite/sip sizes lead to relatively longer oral transit time (Tracy et al., 1989).

The separate contributions of oral transit time and bite/sip size to satiation are not known. Longer oral transit time is expected to increase the orosensory exposure to food and decrease food intake. However, smaller bites/sips may also increase the total magnitude of orosensory exposure. For example, three sips of 5 g instead of one sip of 15 g, means a more pulsating exposure to food, which may increase orosensory exposure per gram food, and thereby influencing satiation. We use the term number of sips per gram (inversely related to sip size: g/sip) in this paper, because sip size influences the oral transit time in a natural way of eating.

Understanding the individual contributions of number of sips and oral transit time per gram food on intake will lead to more insight in the process of satiation. The aim of the first study is to investigate the separate effects of the number of sips and oral transit time on ad libitum intake at a constant eating rate. Possibly, a greater orosensory exposure to food, as a result of higher number of sips and longer oral transit time, may explain the effects on satiation. Therefore, a second study was executed to investigate whether and to what extent the number of sips and oral transit time affect the total magnitude of orosensory exposure to food.

2. Subjects and methods

2.1. Study 1

2.1.1. Subjects

Fifty-nine male subjects were recruited for participation. Fifty-six subjects completed the study, two subjects dropped out before the start of the study and one subject missed three ad libitum intake sessions. Subjects were healthy, had a normal weight (BMI 18.5–25 kg/m^2, mean ± SD: 22 ± 2 kg/m^2), were aged between 18 and 35 years (mean ± SD: 22 ± 3 years) and liked creamy tomato soup (pleasantness score >5 on a 9-point hedonic scale). Exclusion criteria were restrained eating behavior (Dutch eating behavior questionnaire (DEBQ) score >2.89), following an energy-restricted diet during the last two months, gained or lost >5 kg weight during the last year, having a lack of appetite, smoking, suffering from gastrointestinal illness, diabetes, thyroid disease or any other endocrine disorder, hypertension and kidney diseases. Subjects were informed that the aim of the research was to investigate the effect of sip size on flavor perception of soup. This study was conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures involving human subjects were approved by the Medical Ethical Committee of Wageningen University. All subjects signed an informed consent form before participation.

2.1.2. Experimental design

The study consisted of a 2 × 2 crossover design. Subjects came five times to the lab, including a ‘‘practice session’’ (first session), to consume soup in each of the four conditions (Fig. 1). The eating rate was set in all four conditions at 60 g/min. The oral transit time was three times longer in the ‘‘long’’ conditions (Long-LS and Long-HS) compared to the ‘‘short’’ conditions (Short-LS and Short-HS), 60 s/100 g vs. 20 s/100 g, respectively. The number of sips per gram was three times higher in the ‘‘high number of sips’’ conditions (HS) compared to the ‘‘low number of sips’’ conditions (LS), 20 vs. 6.7 sips/100 g, respectively.

2.1.3. Test foods

Tomato soup was used as test product in this study. One kilogram of soup was made from 333 g sieved tomatoes (Heinz, Elst, The Netherlands), 662.7 g water, and 4.7 g salt (NaCl). The mixture was heated until 60 °C. The calculated nutrient composition from the used ingredients was: 0.57 g protein, 1.6 g carbohydrates, 0.03 g fat, 253 mg sodium and 38 kJ (9.1 kcal) energy per 100 g soup.

Raisin buns (local bakery) were used as preload. The nutrient composition was: 8 g protein, 52 g carbohydrates, 3 g fat, 300 mg sodium and 1120 kJ (268 kcal) energy per 100 g, according to the Dutch Food Composition Database (NEVO, version 2009/1.0). Each raisin bun weighed 22 g (246 kJ). The number of raisin buns as preload was calculated for each subject at half of the energy provided by an average lunch in the Netherlands (Hulshof et al., 2003), that is equal to 11% energy of the daily energy need. The daily energy need for each subject was estimated by the Schofield I equation (WHO, 1985), taking into account: gender, age, weight and a physical activity level of 1.6. Thirty subjects received 5 buns and 27 subjects received 6 buns. Subjects were instructed to eat all the raisin buns they were served.

2.1.4. Control of sip sizes, intervals and swallowing

To control the sips and intervals, subjects consumed the soup through a food-grade silicon tube that was connected to a peristaltic pump (Watson-Marlow, type 323Du, Watson-Marlow Bredel, Wilmington, MA, USA). The tube ended in a pan of soup that was placed on a balance (Kern, type 440-49A, KERN & Sohn GmbH, Balingen, Germany) to record the amount consumed. The pump, the pan and the balance were all located at the experimenters' side of the sensory booths, thus subjects did not see the experimental setup.

The moment the pump started driving, subjects heard an auditory signal to prepare them that they would receive soup in their mouths (Fig. 1). They heard a double auditory signal at the moment they had to swallow. Before the start of each session, subjects were instructed that it was very important to swallow at the double auditory signal.

2.1.5. Ad libitum intake sessions

Subjects came four times during lunch for the ad libitum intake of soup, with one week in between sessions. The four conditions were presented at random. Subjects started with consumption of the preload that consisted of raisin buns. A preload was used so that subjects would be in a less hungry state prior to soup consumption. A hungry state may overrule sensory factors to terminate consumption (Bolhuis, Lakemond, de Wijk, Luning, & de Graaf, 2012). They were instructed to consume all served raisin buns and they were allowed to drink water. After that, subjects paused for 30 min. Subjects were allowed to study or read, but were not allowed to leave the sensory room.

After the pause, subjects received a tube from which they had to consume soup. Subjects received instructions and questions via a computer screen. After answering several appetite