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Effects of food consistency on perceived intensity and eating behavior using soft gels with varying aroma inhomogeneity

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ABSTRACT

Our previous study demonstrated that human eating behavior was modified by aroma inhomogeneity (i.e. aroma contrast by changing spatial distribution) and perceived aroma intensity at a given texture. In the present study, effects of food consistency on perceived intensity and eating behavior were investigated using soft gels with varying aroma inhomogeneity. Similar to the previous study, gel samples used were consumable by tongue-palate compression without need of chewing with three consistency conditions. Eating behavior was investigated by electromyography (EMG) recording and bolus analyses, and perceived intensity of aroma, taste, and hardness during eating was examined by sensory evaluation. Data were processed statistically by correlation analysis, linear regression analysis, and analysis of variance. At each aroma inhomogeneity, EMG variables, including duration and activity of the suprahyoid musculature, generally increased with consistency, accompanied with decreased intensity of aroma and taste perception and with increased particle size and saliva content in bolus. Both EMG variables showed the highest correlation with perceived hardness intensity and the lowest with perceived aroma intensity. As aroma inhomogeneity was higher, increases in the EMG variables were less consistency-dependent, and perceived hardness intensity was lower for eating effort. No interaction was found in the EMG variables between consistency and aroma inhomogeneity.

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1. Introduction

Human eating behavior presented by the chewing force during first bite (Mioche & Peyron, 1995), the number of chewing cycles during eating (Engelen, Fontijn-Tekamp, & van der Bilt, 2005), and duration and activity of the chewing muscles during eating (Foster, Woda, & Peyron, 2006) can be modified by food texture and texture related mechanical properties. Using hydrocolloid gels, the number of chewing cycles and muscle activity for size reduction increase with increased either fracture stress or fracture strain, whereas effects on the amplitude of the jaw movement are different between fracture stress and fracture strain (Koc et al., 2014). At a given hardness (represented by the maximum compression stress till 50% deformation), irregular trajectory is orbited with larger amplitude of the jaw movement during eating for plastic caramel confectionary, whereas highly repeatable trajectory during eating for elastic gelatin gel (Foster et al., 2006).

Flavor (aroma & taste) perception during eating is also modified by food texture and texture related mechanical properties presented by viscosity for liquid and paste foods (Morris, 1993) and fracture stress for solid and semi-solid foods (Clark, 2002). Change in perceived flavor intensity can relate to the release rate of flavor compounds (Baek, Linforth, Blake, & Taylor, 1999; Boland, Delahunty, & van Ruth, 2006), the total amount of flavor compounds released (Repoux et al., 2012), and the cross-modal interaction between flavor and texture (Weel et al., 2002).

In relation to flavor perception, perceived taste intensity during eating is enhanced by inhomogeneous spatial distribution of tastants like sweetness (Holm, Wendin, & Hermansson, 2009; Mosca, Bult, & Stieger, 2013; Mosca, van de Velde, Bult, van Boekel, & Stieger, 2010) and saltiness (Mosca et al., 2013; Noort, Bult, Stieger, & Hamer, 2010; Noort, Bult, & Stieger, 2012) in solid foods. Similarly, perceived taste intensity during drinking is enhanced by pulsatile stimulation of tastants like sweetness (Burseg, Brattinga, de Kok, & Bult, 2010; Burseg, Camacho, Knoop, & Bult, 2010) and saltiness (Busch, Tournier, Knoop, Kooyman, & Smit, 2009; Meiselman & Halpern, 1973) in liquid foods. These observations can be explained by the prevention of the adaptation which

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occurs under prolonged and continuous exposure to taste stimulus particularly at high doses (Meiselman, 1972). Adaptation increases the response threshold of the receptor cells to the level of the stimulus and thus decreases the firing rate of the receptor cells (Moore, 1994). Discontinuous taste stimulus helps recover from adaptation and enhances taste perception during eating or drinking. Similar effects can be expected in aroma, and perceived aroma intensity during eating is enhanced by inhomogeneous spatial distribution of aroma compounds in gel samples (Nakao, Ishihara, Nakauma, & Funami, 2013a,b). Also, human eating behavior is modified by perceived aroma intensity caused by aroma inhomogeneity, and increased aroma inhomogeneity results in longer duration and greater activity of the suprahyoid musculature during eating at a given texture. Texture and flavor (aroma and taste) are thus important attributes for human eating behavior.

To the authors' knowledge, there have been a paucity of systematic research regarding the interaction between texture (oral tactics) and aroma (olfaction) in the context of food perception. Particularly for solid foods, it is worth investigating the effects of the combination of consistency and aroma condition on perceived intensity and eating behavior because it can lead to a better understanding of food design. It is obvious from previous studies that texture perception and eating behavior are affected by consistency; increase in consistency results in higher rate of hardness perception and requires longer time and greater muscle activity during eating. Similar effects of aroma inhomogeneity on eating behavior have been also investigated at a given consistency. Our hypothesis in the present study is that the effects of consistency on texture perception and eating behavior should be changed by aroma inhomogeneity. In detail, as aroma inhomogeneity is higher, perceived hardness intensity should be lower for eating effort, and eating behavior should be less consistency-dependent. This is based on the assumption that seeking aroma stimulus (chemical input) as a reward should weaken perceived texture intensity (mechanical output) during eating and should modulate eating behavior, particularly when harder sample is consumed. To see the interaction between consistency and aroma inhomogeneity should be another research interest, and the present study can lead to a new approach for food design through arrangement of texture and aroma conditions at the same time. As a test specimen, soft gels which do not require chewing but tongue-palate compression for size reduction were used, and this is aimed to provide food manufactures with a strategy for product development for elderly and dysphagia patients with chewing difficulty.

2. Materials and methods

2.1. Materials

As texturizing agents, KELCOGEL® (deacylated gellan gum) and CARRAGEENAN CS-599 (iota-carrageenan) were used for gelation, and SAN ARTIST® PG (microbial fibrous cellulose) was used for dispersion. As aroma compounds, O/W emulsions were prepared using Pepper Oil SV-1700 as an oil phase (20% in the emulsion) and gum arabic as an emulsifier (25% in the emulsion). As a food color, SAN-RED® 3743-EM (a red cabbage extract) was used to dye gels. This color product is composed of double-emulsions, and the migration from gels unlikely occurs by controlling the droplet size. Lactose was used as a marker for weighting gel particles in expectorated bolus (see *2.6.* for the details). It was confirmed that the addition of the food color or lactose did not change mechanical properties (i.e. fracture stress and strain) of gel samples or eating behavior (i.e. electromyography variables). All these ingredients were food grade commercial products (San-Ei Gen F.F.I., Inc., Osaka, Japan). Other agents, including maltodextrin (dextrose equivalent: 16.0–19.0) as a dispersing aid, sodium chloride as a tastant, and calcium lactate pentahydrate for gelling promotion, were also food grade, and the purity of each agent was more than 99%. Concentration represents w/w% unless otherwise specified.

2.2. Gel samples preparation

Gel samples with varying consistency and aroma inhomogeneity were prepared (Fig. 1 & Table 1). The gel samples had a gel-in-gel configuration, in which small gel cubes were dispersed in the matrix gel. The matrix gel was formulated by 0.15% KELCOGEL® and 0.1% CARRAGEENAN, whereas the dispersed gels were formulated by various concentrations of KELCOGEL® (0.1%, 0.15%, and 0.2%) and 0.1% CARRAGEENAN. One whole gel sample contains 15 cubes as the dispersed gels, and the weight ratio of the dispersed gels (sum of 15 cubes) in one whole gel sample was 50%. Aroma concentration in either the dispersed gels or the matrix gel was arranged to produce three different aroma conditions although mean concentration in one whole gel sample was fixed at 0.08%. G_N represents a series of gel samples with homogeneous aroma distribution, in which both the dispersed gels and the matrix gel contained 0.08% aroma compounds. G_L represents a series of gel samples with the lower aroma inhomogeneity, in which all dispersed gels contained 0.16% aroma compounds but the matrix gel did not contain aroma compounds. G_H represents a series of gel samples with the higher aroma inhomogeneity, in which 40% of the dispersed gels (Fr. 1) contained 0.4% aroma compounds but remaining 60% of the dispersed gels (Fr. 2) or the matrix gel did not contain aroma compounds. The food color and lactose were used at the minimum requirement level for each (i.e. 0.15% in the dispersed gels for the food color and 1.5% in both the dispersed gels and the matrix gel for lactose).

For the dispersed gels, SAN ARTIST® PG (0.6%) was dispersed in de-ionized water (1000 g) at 20 °C using a propeller type mixer (composed of four blades, approx. 60 mm in width) at 1300 rpm and then homogenized at 15 MPa. Pre-mixture (in powder form) of maltodextrin (5%), KELCOGEL® (0.1%, 0.15%, or 0.2%), and CARRAGEENAN (0.1%) was added to the SAN ARTIST® dispersion (750 g) and heated at 90 °C for 10 min with stirring at 1300 rpm. Calcium lactate pentahydrate (0.1%), sodium chloride (0.2%), and the aroma compounds (0%–0.4%) were added to the mixture, and the weight was adjusted to 1000 g using de-ionized water. The mixture was poured into cylindrical plastic containers of 65 mm in diameter and 25 mm in height, sealed hermetically, and cured in a water bath at 8 °C for 2 h for gelation. Gels were cut into 6 mm-cubes.

A cylindrical glass container of 25 mm in diameter and 15 mm in height was placed in a plastic cup of 61 mm in diameter and 65 mm in height. After 15 cubes were placed in the glass container, the container was filled up with solution for the matrix gel at 75 °C (above gelling temperature). The solution for the matrix gel was prepared in the same manner as that for the dispersed gels. A plastic board was placed onto the top of the container as a partition, and another glass container of the same size was placed onto the partition board. The same procedure was repeated 3 times (i.e. 4 glass containers in one plastic cup), and the plastic cup was finally filled up with the solution for the matrix gel. After sealed hermetically, the cups were heated at 85 °C for 30 min and cured in a water bath at 8 °C for 2 h. Gel samples obtained (cylinder of 25 mm in diameter and 15 mm in height) were refrigerated at 5 °C for 16 h and subsequently at 20 °C for 2 h prior to each test. Time interval between the completion of sample preparation and the beginning of each test was always 18 h.

For pH measurement, each gel sample was homogenized at 13200 rpm for 20 s in 10-fold volume of de-ionized water using a

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