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ORIGINAL ARTICLE

Advances in Sensory Science: From Perceptions to Consumer Acceptance

Differences in habitual eating speed lead to small differences in dynamic sensory perception of composite foods

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Abstract

Previous studies demonstrated that variability in oral processing behaviors impacts bolus properties and consequently texture and flavor perception. However, most studies followed a prescribed mastication protocol during the products' sensory evaluations. A better understanding of how variability in habitual eating behavior impacts sensory perception of foods is needed. The aim of this study was to investigate the effect of habitual eating speed (slow vs. fast eaters) on dynamic sensory perception of composite foods. Habitual oral processing behavior of different composite foods was quantified in 105 participants. Participants were divided in fast ($n = 53$) and slow ($n = 52$) eaters using a median split. Three formulations of strawberry jams varying in viscosity and sugar content (High Sugar/Low Pectin [Control], High Sugar/High Pectin, Low Sugar/Low Pectin) were used. Composite foods were prepared by spreading jams on breads. Dynamics of dominant sensory attributes of strawberry jams presented with and without breads were evaluated using Temporal Dominance of Sensations (TDS). Dynamic sensory perception of jams and jam–bread combinations differed only slightly for short periods of time between habitual slow and fast eaters. The addition of breads to jams reduced especially the ability of the fast eaters to discriminate between jams differing in formulation. Slow eaters discriminated between different formulations of jams better than fast eaters, regardless of whether jams were presented alone or in combination with breads. We conclude that differences in habitual eating speed between consumers lead to small differences in dynamic sensory perception and discrimination ability of composite foods.

KEYWORDS
composite foods, eating speed, oral processing behavior, sensory perception, TDS

1 INTRODUCTION

It is well known that sensory perception of foods varies greatly across individuals (Bachmanov & Boughter, 2012; Hayes & Keast, 2011). Factors contributing to interindividual variation in sensory perception include age, gender, ethnic origin, and phenotypes such as 6-*n*-propylthiouracil and thermal taster status (Bajec & Pickering, 2008; Hirokawa et al., 2006; Lim et al., 2008; Mojet et al., 2003; Pickering et al., 2010; Yang et al., 2014). Eating behaviors emerge and stabilize in early life (WHO, 2016). Eating speed is defined as the mass of food (g) consumed per time unit (min) and is expressed as eating rate (g/min). Variations in eating speed can already be observed at 2–4 weeks postpartum (Agras et al., 1990), are influenced by parental feeding practices (Fogel et al., 2019), are generally stable over time at an individual level and tend to be the same across foods (McCrickerd & Forde, 2017). There are many and very diverse factors leading to different habitual eating speeds, including genetics (Brunkwall et al., 2013; Dubois et al., 2013), energy requirements and basal metabolic rate (Henry et al., 2018), or lifestyle habits and environmental factors (Keski-Rahkonen et al., 2004; Wing et al., 2001). Research has shown that variations in oral processing behaviors and saliva properties may influence expected fullness and sensory perception (Ferriday et al., 2016; Ketel et al., 2019). Furthermore, a faster eating rate has been associated with higher energy intake (Robinson et al., 2014), and may also affect glycemic and insulin responses and postmeal satiety (Goh et al., 2021; Ranawana et al., 2011; Vega-López et al., 2007; Zhu et al., 2013). A broad variety of experimental techniques have been used to quantify oral processing behaviors and eating speed such as electromyography, electromyography combined with jaw-tracking, videofluorography, and ultrasonic echosonography (Boyar & Kilcast, 1986; Casas et al., 2003; Hennequin et al., 2005; Mioche et al., 2002; Vinyard & Fiszman, 2016). Video recordings of participants consuming foods followed by post hoc video annotations have been used frequently to code oral processing behaviors (Forde, van Kuijk, et al., 2013). In addition, video recordings for tracking jaw movements during food consumption have also been used (Aguayo-Mendoza et al., 2020; Forde, Bolhuis, et al., 2013; Ketel et al., 2019; van Eck et al., 2019). Skin surface markers are placed on the consumer's face to track automatically the movement of the chin or other facial features inferring the movement of the jaw during mastication (Jin et al., 2022; Wilson et al., 2016). Lastly, self-reporting of eating speed has been used to characterize oral and eating behaviors (Mochizuki et al., 2014; Petty et al., 2013).

Differences in eating speed and mastication behavior can also contribute to interindividual differences in sensory perception of foods. To date, only few studies addressed this matter. Tarrega et al. (2008) demonstrated that the number of chews, chewing work, and chewing strength correlated positively with flavor intensity of model cheeses, while chewing duration correlated negatively with flavor intensity (Tarrega et al., 2008). Luckett et al. (2016) and Luckett and Seo (2017) showed that the number of chews and chewing rate modulate the temporal dynamics of flavor perception of potato chips (Luckett et al., 2016; Luckett & Seo, 2017). Doyennette et al. (2019) showed that "chewers" consumed ice creams with a shorter consumption time and perceived aromas earlier and longer compared to "melters," who consumed ice creams slower (Doyennette et al., 2019). These studies demonstrated that variability in oral processing behavior impacts flavor and texture perception of foods. These studies have in common that participants were instructed to follow a prescribed mastication protocol during the products' sensory evaluations. This suggests that in these studies, the level of oral structural breakdown of foods differed during sensory evaluations depending on the instructed chewing behavior. These differences in oral structural breakdown and bolus properties induced by the different prescribed mastication protocols are likely to be sensed by the consumer, leading to differences in flavor and texture perception.

Even though it has been shown that eating speed is relatively consistent within individuals across different foods and meals (McCrickerd & Forde, 2017), little is known about how differences in habitual eating behavior affect sensory perception of foods. To the best of our knowledge, only two studies characterized the impact of habitual eating speed on dynamic sensory perception. De Lavergne et al. (2015) showed that dynamic texture perception of sausages was similar between habitual slow and fast eaters during the first half of mastication but differed between groups in the second half of mastication. Differences in sausage bolus properties were caused by differences in eating speed and led to differences in dynamic texture perception (de Lavergne et al., 2015). Aguayo-Mendoza et al. (2020) showed that dynamic texture perception of sausages was similar for consumers differing in age, gender, and ethnicity at the beginning and end of mastication and strongly correlated with bolus properties that were mediated by mastication time. Minor differences in dynamic texture perception between consumer groups were observed only during the middle stages of mastication with low dominance rates. It was concluded that variations in habitual consumption time led to considerable differences in bolus properties but only small differences in dynamic texture perception of sausages (Aguayo-Mendoza et al., 2020). In both studies (Aguayo-Mendoza et al., 2020; de Lavergne et al., 2015), participants were characterized according to

TABLE 1 Overview of strawberry jams and composite foods (jam-bread combinations)

Group \ Jams	High sugar/Low pectin (Control C)	High sugar/High pectin (HP)	Low sugar/Low pectin (LS)
°Brix	60	60	45
Viscosity at shear rate 1 s^{-1} (Pa·s)	48 ± 6	78 ± 2	18 ± 3
 Jam alone (A) (mean weight: 6.0 ± 0.3 g)	A-C	A-HP	A-LS
 Jam–bread (B) 3 × 3 × 1 cm (Bread: 2.2 ± 0.5 g; Spread: 6 g)	B-C	B-HP	B-LS

their habitual eating speed, which decreased when sensory evaluations were performed. A better understanding of how variability in naturally occurring mastication behavior impacts sensory perception of foods is needed. The aim of this study was to investigate the effect of habitual eating speed (slow vs. fast eaters) on dynamic sensory perception of composite foods. Composite foods are defined as the combination of single foods differing in composition and properties (Scholten, 2017). In this study, we first categorized consumers based on their habitual eating speed of two composite foods (jam on bread and wafer filled with hazelnut-chocolate spread) as slow and fast eaters. Then, we determined (i) how dynamic sensory perception of foods differs between consumers differing in habitual eating speed and (ii) how participants adapt their oral behavior during sensory evaluations. We hypothesized that dynamic sensory perception is affected by habitual eating speed as habitual slow eaters break down the food bolus into more and smaller bolus fragments, which facilitates flavor release from the food, compared to fast eaters.

2 | MATERIALS AND METHODS

2.1 | Samples

Table 1 provides an overview of all samples used in the study. Three strawberry jams varying in sugar content and viscosity were used (Menz & Gasser, Italy). All jams consisted of strawberries, glucose–fructose syrup, sugar, pectin, citric acid, and elderberry juice concentrate. The strawberry jam used as control (C) had a sugar content of 60 °Brix and a viscosity of $\eta_{1\ s^{-1}} = 48 \pm 6$ Pa·s and is categorized as High sugar–Low pectin jam (Table 1). The High sugar–High pectin (HP) strawberry jam had a sugar content of 60 °Brix and a viscosity of $\eta_{1\ s^{-1}} = 78 \pm 2$ Pa·s. The Low sugar–Low pectin (LS) jam had a sugar content of 45 °Brix and a viscosity of $\eta_{1\ s^{-1}} = 18 \pm 3$ Pa·s (Table 1). Reformulation of the strawberry jams remained within realistic product reformulation boundaries to warrant close resemblance to reformulated, commercially available products. To obtain composite foods, 6.0 g of strawberry jam was spread on a piece of white bread without crust (3 × 3 × 1 cm; 2.2 g; Bruschelle mini, Morato, Italy).

2.2 | Participants

For this study, 124 participants were recruited. Recruitment was done through posters, social media posts, and emails. An online questionnaire was used to exclude participants with swallowing, mastication, olfactory, and gustatory disorders. Inclusion criteria included good dental health, nonsmoking, no missing teeth (except wisdom teeth), no piercings or braces in the mouth, no recent dental surgery, not being on a calorie restricted diet, no food allergy to any of the ingredients present in bread, wafer, and jam, no partial or complete denture, and not being pregnant or lactating.

Out of the 124 participants, 105 (age: 24.8 ± 4.73 years, body mass index [BMI]: 22.8 ± 2.49 kg/m^2, 38% male) completed the study. Using a median split, participants were divided in two groups according to their natural eating speed (consumption time per bi) of standardized bite sizes of different composite foods (Section 2.3). A group referred to as fast eaters ($n = 53$, age: 24.5 ± 4.83 years, BMI: 22.6 ± 2.16 kg/m^2, 43.4% male) and a group referred to as slow eaters ($n = 52$, age: 25.2 ± 4.65 years, BMI: 23.0 ± 2.80 kg/m^2, 28.8% male) were obtained. No significant differences were observed for age and BMI between fast and slow eaters according to Welch's t-test ($p > 0.05$).

All participants were familiar with the test foods. All participants gave written informed consent prior to the study and received financial compensation for their participation. The study did not meet the requirements to be reviewed by the Medical Research Ethical Committee of The Netherlands according to the "Medical Research Involving Human Subjects Act" of The Netherlands (WMO in Dutch). The study was conducted in agreement with the ethics regulations laid out in the Declaration of Helsinki (2013).

2.3 | Characterization of habitual eating speed

Habitual oral processing behavior of three standardized bite sizes of different foods was quantified in 105 participants using a video camera (Canon IXUS-180) placed on a tripod. The first food used to determine habitual eating speed consisted of 6 g of commercial cherry jam (Zwarte Kers, Hero, Netherlands) and was served on a spoon; the second food (bite size: 8.2 ± 0.7 g) consisted of 6 g of cherry jam spread on a piece of white bread without crust (2.8 g; 3.5 × 3.5 × 1.0 cm; Casino Wit, Jumbo, Netherlands); and the third food (bite size: 7.6 ± 0.5 g) consisted of a piece of wafer (1.6 g; 1.0 × 4.0 × 2.0 cm) filled with 6 g of hazelnut-chocolate spread (B-ready, Fererro, Italy). The three samples were presented to the participants in randomized order. Participants were seated individually in front of the video camera, and were instructed to put the whole sample in their mouth and start chewing as they normally do. Participants were asked to raise their hand when they swallowed. Between samples, participants could drink a sip of water.

To measure oral processing behaviors, stickers were placed on the face of participants following the procedure previously described (Aguayo-Mendoza et al., 2019; Ketel et al., 2019; van Eck et al., 2019). Two stickers were placed 5 cm apart on the forehead of participants to calibrate the software with the number of pixels that represented 5 cm. Two additional stickers were placed on the nose and chin. The sticker on the nose was used as reference point and the one on the chin as mobile point. During the recording, participants were asked to not block the stickers with their hands and limit their head movements while eating the sample. Videos were analyzed using Kinovea software (version 0.8.15), a motion analysis software that tracks changes in the spatial position of specific markers in video recordings. The movement of the nose and chin stickers relative to each other was extracted as X–Y coordinates over time. Consumption time per bite (s) defined as average time from putting the sample in the mouth until swallowing was extracted from video recordings and eating rate (g/min) was calculated for each sample. The habitual eating rate (g/min) of both composite foods (wafer filled with hazelnut-chocolate spread; cherry jam on white bread without crust) was calculated for each participant by adding the weights w (g) of the composite foods and dividing it by the sum of the consumption times t (min) of the composite foods.

Categorization of participants as slow and fast eaters was based on the median split of the habitual eating rate of the wafer filled with hazelnut-chocolate spread and the cherry jam on white bread combination. Contrary to the cherry jam served alone, these foods required mastication as they included a solid food component. It was decided to use the habitual eating rate obtained from the consumption of both composite foods (wafer filled with hazelnut-chocolate spread; cherry jam on white bread without crust) instead of averaging the eating rate over both composite foods since these composite foods were very different in mechanical and texture properties. The two composite foods used to determine habitual eating rate (wafer filled with hazelnut-chocolate spread; cherry jam on white bread without crust) were different from the foods used in the sensory evaluation (strawberry jams differing in sugar content and viscosity served alone and with bread) but belonged to the same product category of sweet spreads.

2.4 | Dynamic sensory perception

2.4.1 | Attribute list

Sensory attributes to describe jam and bread were obtained from previous studies (Alves et al., 2008; Kurotobi et al., 2018; Oliver et al., 2018; Panouille et al., 2014; van Eck et al., 2019) and validated with a pilot test with consumers ($n = 10$ women, age: 21.8 ± 1.3 years) not participating in the main study. A Check-All-That-Apply (CATA) methodology was used. The bread and the control strawberry jam were evaluated individually. Participants of the pilot test were given two lists of attributes, one for each product. The attributes that were most frequently selected were included in the final attribute list used in the main study (Table 2). Eight attributes were selected for the evaluation of jam alone and ten for the jam–bread evaluation. The list of attributes and their definitions are summarized in Table 2.

2.4.2 | Temporal Dominance of Sensations (TDS)

Dynamic sensory perception was assessed using Temporal Dominance of Sensations (TDS). Dominance was defined as the most striking sensation, which catches the attention

TABLE 2 List of sensory attributes and definitions used for the TDS evaluation of jam and jam–bread combinations

Attribute	Definition	Jam	Jam–bread
Sweet	Sweet taste, associated with sugar.	×	×
Sour	Sour taste, associated with sour ingredients such as lemon.	×	×
Strawberry flavor	Strawberry flavor associated with strawberries.	×	×
Fruity flavor	Fruity flavor associated with all fruits except strawberry.	×	×
Bread flavor	Flavor associated with bread and grain flour.		×
Sticky	Feeling of stickiness in the mouth. The jam sticks to the mouth.	×	×
Smooth	Sensation of smoothness, defined as the feeling of smooth jelly in the mouth.	×	×
Melting	The speed of the jam mixing with saliva in the mouth.	×	×
Soft	Sensation of softness described as no or little force required to deform the jam.	×	×
Chewy	Sensation of chewiness described as resistance to chewing/breakdown.		×

of the assessor at a given moment in time (Pineau et al., 2009). TDS data collection started the moment participants put the sample in their mouth and pressed the start button and ended 90 s thereafter. An attribute was dominant until another attribute was chosen. Attributes could be dominant several times during the evaluation and not all attributes had to be selected as dominant. Participants were instructed to indicate the moment they swallowed the sample by clicking on a "Swallow" button. After swallowing, participants could continue selecting the most dominant attributes. When they did not perceive anything anymore, they were instructed to click on "Do not perceive anything anymore" button and wait until time was up. No chewing protocol was prescribed during the TDS evaluations. Attributes were presented in randomized order across participants but maintained for each panelist between samples.

2.4.3 | Procedure

Sensory sessions took place at Centrum voor Smaakonderzoek Wageningen (CSO, The Netherlands) and took approximately 30 min. Samples were labeled with random three-digit codes and served at room temperature. The order of samples was counterbalanced, so that half of the participants evaluated the strawberry jam without carrier first and the other half started with the strawberry jam–bread combinations. The order of the different formulations, control (C), high pectin (HP), and reduced sugar (LS), was randomized across participants. When served on its own, jam was served on a spoon, while the jam–bread combinations were served on a paper plate. Participants were seated individually with 1.5 m distance from each other. They were instructed to not eat, drink, or brush their teeth 2 h prior to the session.

At the beginning of the sensory session, a short introduction was given to explain the principle of the TDS methodology. The attribute list was provided, and participants were instructed to familiarize themselves with the attributes before starting the evaluation. Each participant was given a tablet on which the test was performed.

Before the main TDS evaluation, participants performed a practice TDS evaluation with a cracker. In this way, participants familiarized themselves with the TDS methodology and the software used. After the familiarization phase, they continued with the TDS evaluation of the test samples. For each sample, participants were instructed to put the whole sample in their mouth, click on the start button, and start selecting the most dominant attribute during consumption. After each TDS evaluation, participants evaluated liking of the sample using a 100-mm visual analogue scale (VAS) anchored with the words "extremely dislike" to "extremely like." Participants were instructed to cleanse their palate with water between samples. Data were acquired using TimeSens software (Version October 2020, ChemoSens, France).

2.5 | Data analysis

2.5.1 | Characterization of oral processing behavior

To determine whether habitual oral behavior captured with video recordings differed between slow and fast eaters, mean consumption time and eating rates were calculated and a linear mixed model (LMM) analysis was performed for each parameter individually. Samples (cherry jam, cherry jam with bread, wafer filled with hazelnut-chocolate spread, and both composite foods), group (slow/fast), gender, and the interaction between samples and group were considered as fixed effects, while participant was treated as random effect. When $p < 0.05$, post hoc pairwise comparisons with Tukey's correction

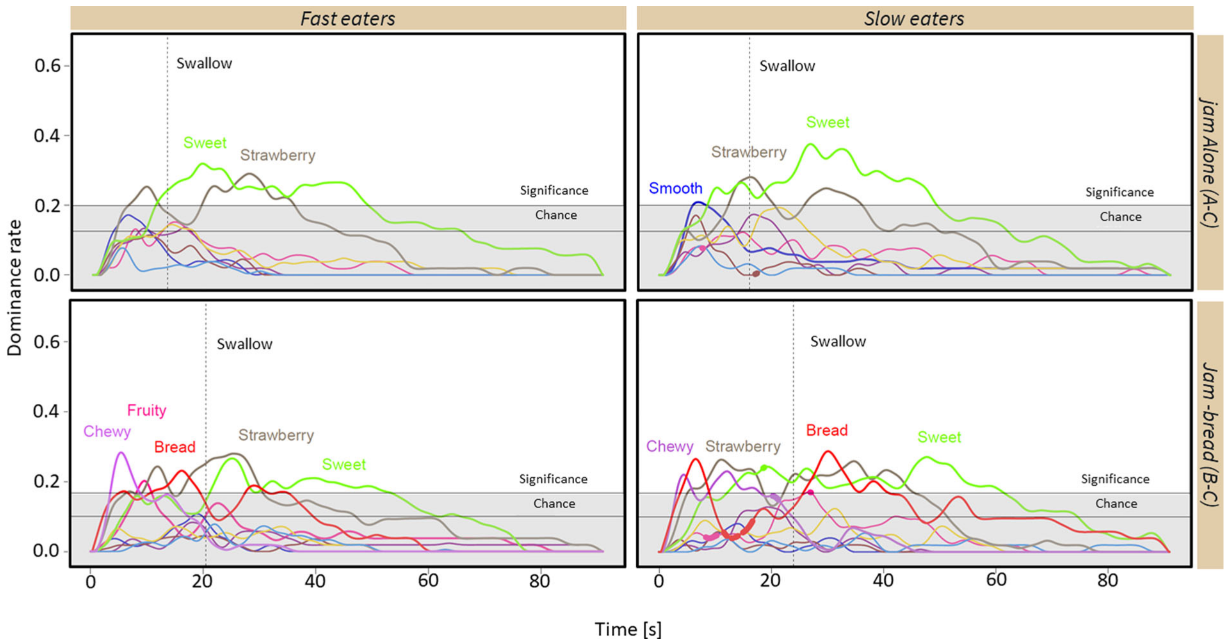

FIGURE 1 TDS curves for fast ($n = 53$) and slow ($n = 52$) eaters for the strawberry jam served alone (A-C) and jam–bread combination (B-C). Periods of significant differences ($p < 0.05$) of dominance rates between slow and fast eaters are indicated by highlighted thick sections. The vertical dotted line represents the average swallowing moment

were used to determine where differences existed between groups.

2.5.2 | TDS curves

TDS curves were constructed following the procedure described by Pineau et al. (2009). The dominance rate for each attribute at a given moment (every 0.1 s) was determined as the proportion of participants for which the given attribute was selected as dominant sensation. TDS curves were not standardized for time. Chance and significance lines were calculated at $\alpha = 0.05$ and added to the TDS curves as described by Pineau et al. (2009). For a better visualization, smoothing of TDS curves was performed using the smooth function of the TempR package of R (software version 3.1.1).

TDS curves are presented per. Pairwise comparison between the dominance rates of the slow and fast eaters was done using a Fisher's exact test (Castura et al., 2016), independent of the significance level of the TDS attribute curves. Highlighted sections in the TDS curves (bold lines) represent periods during which significant differences between slow and fast eaters were observed ($p < 0.05$). The TDS curves of the control jam alone (A-C) and the control jam combined with bread (B-C) are shown in Figure 1, whereas the TDS curves of the four other samples (A-HP, B-HP, A-LS, B-LS) are shown in Figures S1 and S2.

2.5.3 | Duration analysis

For each group (slow and fast eaters), an LMM analysis was performed with mean dominance durations for a specific attribute as response. Samples ($n = 6$) were set as fixed factor and participants as random factor. Principal component analysis (PCA) with confidence ellipses of 0.90 was performed for each product for slow and fast eaters separately to analyze the relationships between sensory attributes within the different formulations and carrier addition. Only attributes that were significantly different ($p < 0.05$) are shown in the PCA.

2.5.4 | Comparison of eating speed between video recordings and TDS

To determine differences in eating rate across eating speed groups and between video recordings (habitual eating) and TDS evaluations, means of eating rate of cherry jam and cherry jam with bread from the video recordings were compared to the eating rates calculated from the consumption time of strawberry jam (A-C) and strawberry jam with bread (B-C) during the TDS evaluation. A LMM was performed with group (slow/fast), gender, method (video recording/TDS), and their interactions as fixed effects, while participant was treated as random effect. Pairwise comparisons were conducted using Tukey

TABLE 3 Oral processing parameters extracted from video recordings of 105 participants for cherry jam alone (bite size: 6.0 ± 0.2 g), cherry jam–bread combination (bite size: 8.2 ± 0.7 g), wafer filled with hazelnut-chocolate spread (bite size: 7.6 ± 0.5 g), and both composite foods (bite size: 15.79 g) and Tukey's Student *t*-tests for pairwise comparisons of the interaction effect sample × group (slow/fast eaters) from LMM

	Slow eaters ($n = 52$)		Fast eaters ($n = 53$)		Consumption time		Eating rate	
Sample	Consumption time (s)	Eating rate (g/min)	Consumption time (s)	Eating rate (g/min)	*t* ratio	*p*	*t* ratio	*p*
Cherry jam alone	11 ± 5	42 ± 25	6 ± 3	71 ± 38	−2.907	0.0771	8.91	<0.0001
Cherry jam with bread	22 ± 7	24 ± 6	12 ± 3	45 ± 11	−7.229	<0.0001	6.449	<0.0001
Wafer with hazelnut-chocolate spread	31 ± 9	16 ± 4	19 ± 4	25 ± 5	−8.129	<0.0001	2.919	0.0717
Both composite foods (Jam–bread and wafer with hazelnut-chocolate spread)	52 ± 15	19 ± 4	30 ± 4	32 ± 5	−15.499	<0.0001	4.038	0.0017

post hoc tests when significant differences were present ($p < 0.05$).

2.5.5 | Liking scores

To determine differences in liking between slow and fast eaters, an LMM analysis was performed with liking scores as response. Samples ($n = 6$), gender, group (slow/fast), and the interaction between samples and group were set as fixed factors and participants as random factor. When $p < 0.05$, post hoc pairwise comparisons with Tukey's correction were used to determine where differences existed between groups.

3 | RESULTS AND DISCUSSION

3.1 | Characterization of participants according to their habitual eating speed of composite foods

The median split that categorized participants as slow or fast eaters was based on their habitual eating rate of two composite foods (cherry jam with bread and wafer with hazelnut-chocolate spread) (Section 2.3). Consumption time (s) and eating rate (g/min) of cherry jam, cherry jam with white bread, wafer with hazelnut-chocolate spread, and both composite foods combined (used to categorize participants as slow and fast eaters based on median split) are summarized in Table 3. For consumption time and eating rate, the interaction between samples and group was significant (consumption time $F(3{,}309) = 76.09$, $p < 0.001$; eating rate $F(3{,}309) = 8.41$, $p < 0.001$). Except for jam alone, consumption time of all samples differed significantly between slow and fast eaters ($p < 0.05$). In general, eating rate differed significantly ($p < 0.05$) between slow and fast eaters except for wafer filled with hazelnut-chocolate spread. Fast eaters habitually consumed jam alone, jam with bread, wafer filled with hazelnut-chocolate spread, and both composite foods at higher eating rates (69%, 87%, 56%, and 68% higher, respectively) than slow eaters. This demonstrates that the slow and fast eaters differed considerably in their habitual eating speed of these foods.

As expected, cherry jam alone was consumed at highest eating rate by the slow and fast eaters compared to the composite foods (cherry jam with bread; wafer with hazelnut-chocolate spread), which contained a solid carrier ($p < 0.05$). Cherry jam with bread was consumed at significantly higher eating rate than the wafer with hazelnut-chocolate spread ($p < 0.05$) by the slow and fast eaters.

It is well known that food texture and degree of lubrication affect eating rate (Bolhuis et al., 2014; Forde, van Kuijk, et al., 2013; Lasschuijt et al., 2017; McCrickerd et al., 2017; Zijlstra et al., 2009). Foods that require more chewing and lubrication take more time to be orally processed and are therefore consumed with lower eating rates. In our study, it may be that due to its lower moisture content, the wafer might have required an increased mastication time. Overall, our findings are in agreement with previous studies that demonstrated that toppings assisted saliva in bolus formation of different solid foods (bread, crackers, pasta, milk gels), leading to shorter oral processing times (Gonzalez-Estanol, Libardi, et al., 2022; van Eck et al., 2019).

3.2 | Impact of habitual eating speed on dynamic sensory perception

Figure 1 displays the TDS curves for the control strawberry jam alone (A-C) and control strawberry jam–bread combination (B-C) for slow and fast eaters. The vertical black line represents the average swallowing moment of the samples during the TDS evaluations for each group. It should be noted that the TDS curves were not time standardized.

Dynamic sensory perception of the control strawberry jam without carrier (A-C) was characterized by prolonged dominance of strawberry and sweetness sensations with only minor significant differences for short periods of time between slow and fast eaters. Sweetness was the dominant sensation after swallowing for the fast eaters, while it was the dominant sensation before and after swallowing for the slow eaters. Similarly, strawberry flavor was the dominant sensation before and after swallowing for fast eaters, while it was only the dominant sensation around the swallowing moment for slow eaters. Similar to the control jam alone (A-C), the TDS curves for the reduced-sugar (A-LS) and high-viscosity (A-HP) jams alone showed only minor differences in dominant sensations for short periods of time between slow and fast eaters (Figure S1). Fast eaters perceived texture sensations such as soft and sticky as dominant sensation at the beginning of mastication for the reduced sugar (A-LS) and high viscosity (A-HP) jams, respectively. Slow eaters perceived sour as the dominant sensation for a short period of time after swallowing for the reduced sugar (A-LS) and high viscosity (A-HP) jams. For both groups, strawberry and sweetness were the dominant sensations for the rest of the evaluation time. We hypothesized that differences in habitual eating speed between slow and fast eaters lead to differences in dynamic sensory perception. Overall, we observed only minor differences, that is, differences that were significant but only for short time periods, typically for less than 4 s, in dynamic sensory perception of jams and jam–bread combinations between habitual slow and fast eaters. This is in general agreement with Aguayo-Mendoza et al. (2020) who showed that dynamic texture perception of sausages was similar for consumers differing in age, gender, and ethnicity at the beginning and end of mastication and only minor differences in dynamic texture perception between consumer groups were observed during the middle stages of mastication with low dominance rates. We speculate that variations in habitual consumption time might cause considerable differences in bolus properties but do not necessarily lead to considerable difference in dynamic sensory perception. It is important to note that sugar reduction and addition of pectin remained within realistic product reformulation boundaries and were small. This could partly explain why the degree of reformulation in our study was not sufficient to cause larger differences in perception of dominant sensations between products. The main objective of the study was to investigate the effect of habitual eating speed (slow vs. fast eaters) on dynamic sensory perception of composite foods rather than to quantify the impact of product formulation on dynamic sensory perception.

As expected, the dynamic sensory perception of the jam was strongly affected by the addition of bread (B-C) for slow and fast eaters. In the beginning of mastication, perception was dominated by sensations related to the carrier (chewy and bread flavor). Slow eaters perceived these sensations as dominant for slightly longer periods than fast eaters. At later stages of mastication, sensations related to the jams (strawberry and sweetness) were dominant. Overall, similar results were obtained for the low-sugar and high-viscosity jams combined with bread (B-LS and B-HP) for slow and fast eaters (Figure S2). In general, our findings regarding the temporal sequence of dominant sensations of composite foods are in agreement with previous studies where different solid carriers (bread, wafer, carrots) were combined with various toppings (hazelnut-chocolate spread, mayonnaise). At the beginning of consumption, sensations related to the flavor and texture of the carriers were dominant, whereas sensations related to the toppings were dominant at later stages of consumption (Gonzalez-Estanol, Cliceri, et al., 2022; van Eck et al., 2019).

To determine differences in eating rate across eating speed groups and between video recordings and TDS evaluations, means of eating rate of cherry jam alone and cherry jam with bread from the video recordings were compared to the eating rates of strawberry jam (A-C) and strawberry jam with bread (B-C) from the TDS evaluation (Table 4). For both sets of products, the interaction between group (slow/fast) and method (video recording/TDS) was significant (jam with bread $F(3,309) = 8.41$, $p < 0.001$; jam alone $F(1,101) = 11.78$, $p < 0.001$). During the video recordings, habitual eating speed of cherry jam and cherry jam with bread was significantly different between slow and fast eaters ($p < 0.05$). During the TDS evaluation, slow and fast eaters increased their consumption time, which implies that their eating rate decreased when performing an analytical sensory evaluation compared to their habitual eating speed. This is in line with previous studies that demonstrated that when participants focus on an analytical sensory task that they presumably want to perform well, they extend their consumption time (de Lavergne et al., 2015, 2016). Consequently, differences in eating rate of jams alone and jam–bread combinations between slow and fast eaters were reduced from 68% and 86% during habitual mastication to 37% and 20% during TDS evaluation, respectively (Table 4). Thus, the differences in eating rate of jams alone between slow and fast eaters were no longer significant ($p > 0.05$).

Moreover, there were significant differences in eating rate of jam alone and jam with bread between video recordings and TDS evaluation for fast eaters ($p < 0.05$). On the other hand, only the eating rate of the jam alone

TABLE 4 Summary of eating rate (mean ± SD) obtained from video recordings (habitual consumption) and from TDS evaluations for jams served alone and jam–bread combinations. Superscript letters indicate significant differences ($p < 0.05$) between means within each sample obtained from Tukey's Student *t*-tests for pairwise comparisons of the interaction effect group (slow/fast) × method (video recording/TDS) from LMM

		Eating rate (g/min) video recording	Eating rate (g/min) TDS
Jam	Slow	42 ± 25^{B}	26 ± 10^{C}
	Fast	71 ± 38^{A}	33 ± 14^{BC}
Jam–bread	Slow	24 ± 6^{bc}	22 ± 7^{c}
	Fast	45 ± 11^{a}	27 ± 8^{b}

Note: Upper case superscripts represent comparison between jam samples. Lower cases superscripts represent comparison between jam–bread samples.

TABLE 5 Liking scores (mean ± SD) of all samples for slow and fast eaters and Tukey's Student *t*-tests for pairwise comparisons of the interaction effect samples (A-C, A-LS, A-HP, B-C, B-LS, B-HP) × group (slow/fast) from LMM

Sample	Slow eaters ($n = 52$)	Fast eaters ($n = 53$)	*t* ratio	*p*
A-C	6.0 ± 2.0	6.2 ± 2.2	0.84	0.99
A-LS	6.0 ± 2.1	6.2 ± 2.1	0.47	1
A-HP	5.7 ± 2.2	6.1 ± 2.1	0.92	0.99
B-C	6.9 ± 1.8	5.6 ± 2.1	0.09	1
B-LS	6.0 ± 1.7	5.8 ± 1.9	−0.57	1
B-HP	5.8 ± 1.7	5.8 ± 1.9	−0.33	1

was significantly different between video recordings and TDS evaluation for the slow eaters ($p < 0.05$), which suggests that fast eaters adapted their habitual eating speed more during the sensory evaluation than slow eaters. These changes in eating rate differences between habitual slow and fast eaters may explain the limited differences in dynamic sensory perception observed between these groups.

Liking of all jams and composite foods did not differ significantly between slow and fast eaters ($F(5,505.68) = 0.75$, $p = 0.6$) (Table 5). The absence of differences in liking between slow and fast eaters is consistent with the absence of large differences in dynamic sensory perception between the two groups.

3.3 | Duration analysis

PCA of the mean dominance durations for slow and fast eaters is shown in Figure 2 to summarize perceptual differences between samples. The correlation circles (Figure 2a,c) visualize the mean dominance durations of the sensory attributes that were significantly different ($p < 0.05$) between samples for the fast and slow eaters. The individual factor maps (Figure 2b,d) show the representation of all samples with confidence ellipses of 0.90.

For both groups, control jam (A-C) was perceived similar to the low-sugar jam (A-LS) as indicated by the overlapping confidence ellipses, while the high-viscosity (A-HP) jam (depicted in pink) was perceived significantly different from A-C and A-LS as indicated by non-overlapping confidence ellipses. However, this discrimination between jams was influenced in different ways by the addition of bread across groups. Fast eaters' ability to discriminate between jams differing in formulation decreased, as the confidence ellipses of B-C, B-LS, and B-HP overlap (Figure 2b). This is in line with previous studies where perceptual differences between spreads or toppings disappeared upon addition of carriers since sensitivity to detect sensory differences between them may decrease (Cherdchu & Chambers, 2014; Gonzalez-Estanol, Cliceri, et al., 2022; Nguyen & Wismer, 2020; van Eck et al., 2021). In contrast, slow eaters were able to better discriminate between the different jam formulations when the jams were combined with breads (Figure 2d). Slow eaters selected on average one attribute more as dominant sensation than fast eaters (slow eaters: 8.0 ± 3.2; fast eaters: 7.1 ± 4.4), suggesting that habitual slow eaters described the dynamic sensory perception of the samples in more detail.

While previous studies with specific chewing protocols demonstrated that eating speed had a strong effect on bolus properties, flavor release, and consequently on texture and flavor perception (Luckett & Seo, 2017; Tarrega et al., 2008), our study shows that large differences in habitual eating speed have limited effect on dynamic sensory perception, which is in line with previous studies

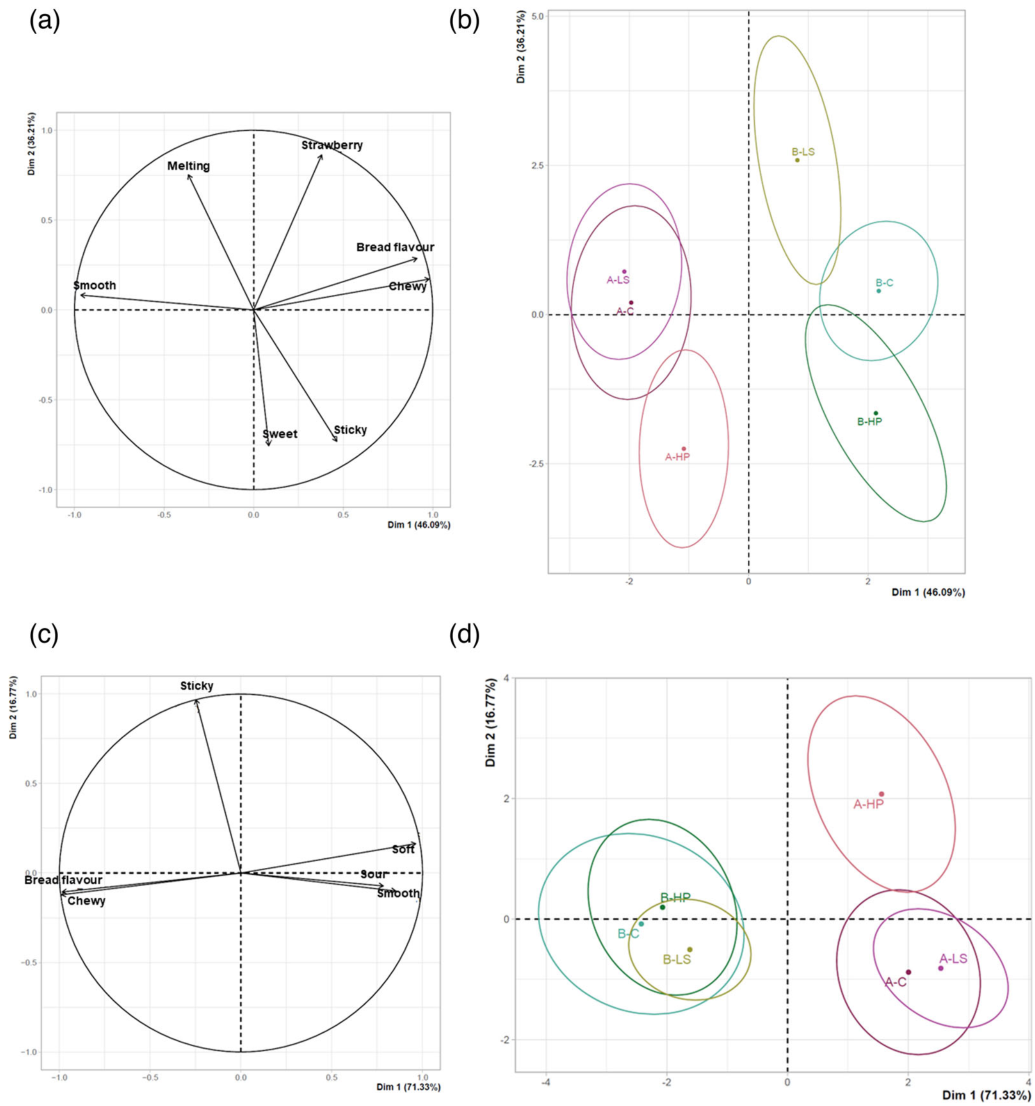

FIGURE 2 Principal component analysis (PCA) of the durations of dominant sensations from the TDS data with confidence ellipses of 0.90. Biplot showing dimensions 1 and 2 represents the sensory profiles of the jams and jam–bread combinations (A-C, A-LS, A-HP, B-C, B-LS, B-HP) for fast eaters (a, b) and slow eaters (c, d). Only the attributes that were significantly different ($p < 0.05$) are shown

that categorized consumers according to their natural consumption time (Aguayo-Mendoza et al., 2020; de Lavergne et al., 2015). Even though habitual slow eaters showed a better discrimination ability than habitual fast eaters, it seems that eating speed explains interindividual variability in dynamic sensory perception of foods only to a limited extent.

As mentioned in Section 2.3, a median split was applied to categorize participants (n = 105) into slow and fast eaters. It is worth noting that a quartile split of participants was performed, too. The lowest and highest quartile consisted of participants with lowest eating rate (n = 26, 15.89 ± 3.06 g/min) and highest eating rate (n = 26, 35.91 ± 3.31 g/min), respectively. When TDS curves were compared for the various foods between the slow and fast eaters obtained by quartile split (data not shown), the results and conclusions were very similar to those obtained from the median split. The number of observations for the median split was 53 per group compared to 26 per group for the quartile split. Thus, it was decided to use the median split classification for the study.

4 | CONCLUSIONS

Previous studies demonstrated that eating speed impacts bolus properties and consequently texture and flavor perception. Investigating the relationships between eating speed and sensory perception of foods further may assist in better understanding interindividual differences in sensory perception. Without any prescribed eating speed protocol and based on the habitual consumption time of participants, we demonstrated that dynamic sensory perception of jams and jam–bread combinations showed only minor differences (significant difference for very short periods of time) in dominant sensations between habitual slow and fast eaters. Slow eaters discriminated better between different formulations of jams, regardless of whether the jam was presented alone or in combination with bread, than fast eaters. We conclude that differences in habitual eating speed of consumers have limited effect on dynamic sensory perception of composite foods.

AUTHOR CONTRIBUTIONS

Karina Gonzalez-Estanol: Conceptualization; Investigation; Writing – original draft; Methodology; Visualization; Writing – review & editing; Formal analysis. **Marieke van Bruinessen**: Data curation; Formal analysis; Software; Investigation. **Franco Biasioli**: Writing – review & editing; Supervision. **Markus Stieger**: Writing – review & editing; Supervision; Formal analysis; Conceptualization; Methodology; Visualization.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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