Time will tell

Dynamic sensory characteristics, hedonic perceptions and food-evoked emotions from first to last bite

Roelien van Bommel

PROPOSITIONS

1. Sensory evaluations of single bites do not represent consumer's sensory perception of food portions. *(this thesis)*

2. Food-evoked emotions solely reflect hedonic perceptions and do not provide additional product information beyond liking. *(this thesis)*

3. Laptops should be banned from lecture rooms as learning is more effective when notes are taken by handwriting than by keyboard typing (Mueller et al. (2014) Psychological Science, 25(6), 1159-1168).

4. Messy desks should be encouraged to stimulate creativity (Vohs et al., (2013) Psychological Science, 24(9), 1860-1867).

5. Motivation is a better indicator of success than intelligence.

6. Passports from all countries should have same rights to travel.

Propositions belonging to the PhD thesis, entitled:

"Time will tell: Dynamic sensory characteristics, hedonic perceptions and food-evoked emotions from first to last bite."

Roelien van Bommel

Wageningen, 10 September 2020

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Roelien van Bommel

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Dynamic sensory characteristics, hedonic perceptions and food-evoked emotions from first to last bite

Roelien van Bommel

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"Success is not final, failure is not fatal: it is the courage to continue that counts."

Winston Churchill

CONTENTS

CHAPTER 1

General introduction

1. GENERAL INTRODUCTION

We all know that we have to eat healthy, but our food choices are often different. Often we choose foods based on the immediate reward we get from it and do not think about future consequences of our food choices. Eating high caloric foods generally results in a positive energy balance. On the long term, overconsumption can cause obesity which is associated with serious health consequences such as cardiovascular diseases, diabetes and reduced quality of life. Worldwide, obesity nearly tripled since 1975 (WHO, 2020). To avoid further increase in obesity, it is important to help people change their eating behaviour to stay healthy.

Food choice behaviour is a complex construct, which involves physiological, cognitive and social factors (Shepherd & Raats, 2006). Figure 1.1. visualizes factors affecting food choice and intake. Products that are highly liked are more often chosen than less liked products (Gutjar et al., 2015a; Gutjar et al., 2015b). Nevertheless, products with similar liking scores can still perform differently on the commercial market, and there is a high failure rate of newly launched food products. There is more to food choice than liking alone. Sensory characteristics, such as taste, texture and odour, are key determinants that drive food choice. In sensory and consumer research, preference maps are used to link hedonic liking scores to analytical sensory ratings to guide new product development and predict food choice. Food choices are learned behaviours and are formed throughout life upon repeated exposure and from past experiences (Shepherd & Raats, 2006). Consumers eat food products that generate positive affective experiences. It has been suggested that knowledge of food-evoked emotions adds to the understanding of food choice behaviour and discriminate products more effectively than hedonic measurements alone (Dalenberg et al., 2014). Food-evoked emotion profiling could assist in understanding underlying mechanisms of affective experiences to create healthy product experiences.

Most methods that measure food-evoked emotions, sensory and hedonic perceptions are assessed immediately after tasting. However, food perceptions are dynamic and change over time during consumption due to mastication, oral structural breakdown of food and salivation (Hutchings & Lillford, 1988). Dynamic sensory perceptions might lead to changes in hedonic ratings and, consequently, to the unfolding of different food-evoked emotions during consumption. How sensory perceptions change during consumption and how this influences hedonic perceptions and food-evoked emotions are important questions addressed in this thesis.

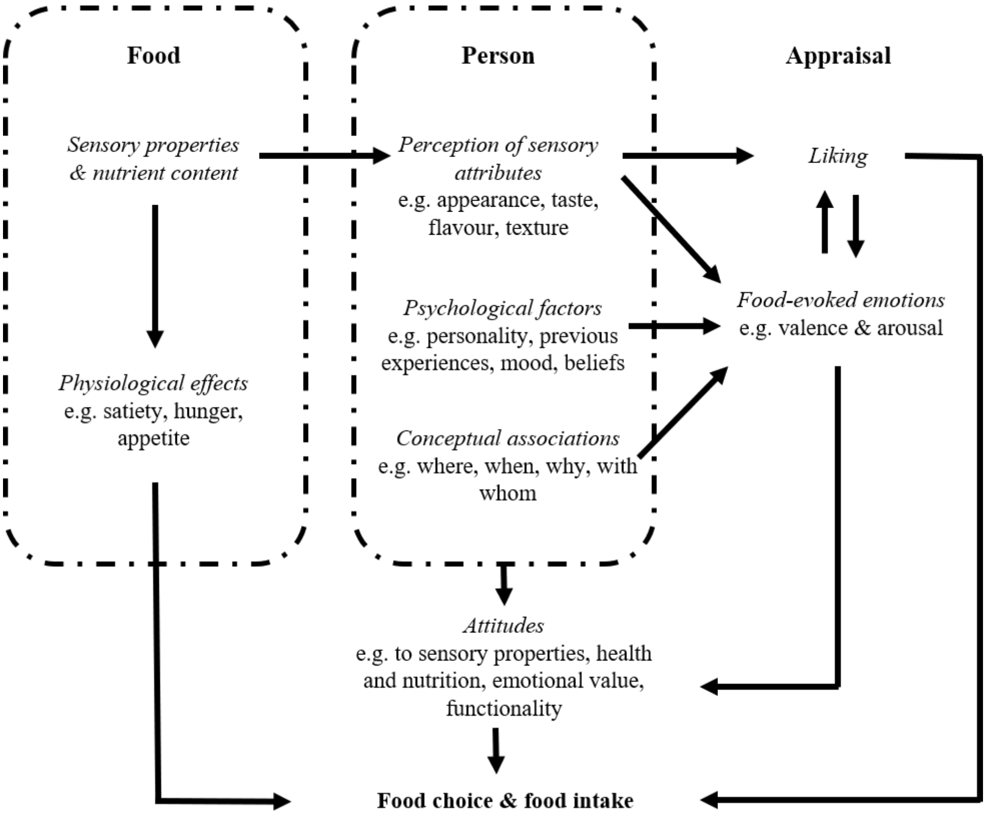

Figure 1.1. Factors affecting food choice and intake (modified based on (Shepherd, 1999)).

1.1. From static to dynamic sensory measurements

Quantitative Descriptive Analysis (QDA) is the golden standard in sensory science to obtain static sensory profiles generated by trained panellists (Stone et al., 2008). In QDA, trained assessors rate the intensity scores of sensory attributes of a product to generate a descriptive sensory profile by providing an overall impression of an attribute's maximum or averaged intensity. These descriptive profiles are then coupled to the liking ratings scored by untrained consumers to predict the success of the new or reformulated product on the commercial market.

QDA provides limited dynamic information. In QDA often instructions are used to rate i.e. some attributes right after tasting and other attributes after swallowing. Hence, there can be some dynamic, time resolved sensory information, although limited and typically with poor time resolution and, therefore, QDA is generally considered to be static. Sensory perceptions of food and beverages change over time due to chewing, structural breakdown, and the incorporation of saliva to form a bolus (Hutchings & Lillford, 1988). Sensory methods that measure the sensory characteristics of a food product at a fixed and static moment in time might, therefore, miss some significant product information. The Time Intensity (TI) technique was developed to measure the temporal evolution of the intensity of a sensory attribute over time (Lee & Pangborn, 1986). TI allows trained panellists to score the intensity of a single sensory attribute over a predetermined mastication time. However, sensory perceptions are complex and during consumption there are taste-flavour interactions which might lead to halo and dumping effects in TI method. Processes such as mastication, salivation, tongue movements and swallowing can change or even enhance the release of taste, flavour and texture perceptions. Dual Attribute Time Intensity (DATI) was developed, allowing trained panellists to continuously rate the intensity of two sensory attributes at each moment in time (Duizer et al., 1996, 1997). However, reporting dynamic intensity ratings of 2 sensory attributes over time seemed too ambitious and too difficult to perform, even for highly trained panellists. To bridge the gap between the simultaneous assessment of several sensory attributes at the same time and to identify dynamic changes in sensory characteristics at each moment in time, rapid temporal sensory profiling techniques, such as Temporal Dominance of Sensations (TDS) (Pineau et al., 2009) and Temporal Check-All-That-Apply (TCATA) (Castura et al., 2016) were introduced. Figure 1.2 represents the conceptual differences and similarities between QDA, TI, TSD and TCATA. TDS and TCATA share the temporality characteristics of the TI method and the multidimensional characteristics of QDA. These rapid dynamic sensory methods are relatively new, and there is still much to be discovered about an assessor's performance of the TDS and TCATA method.

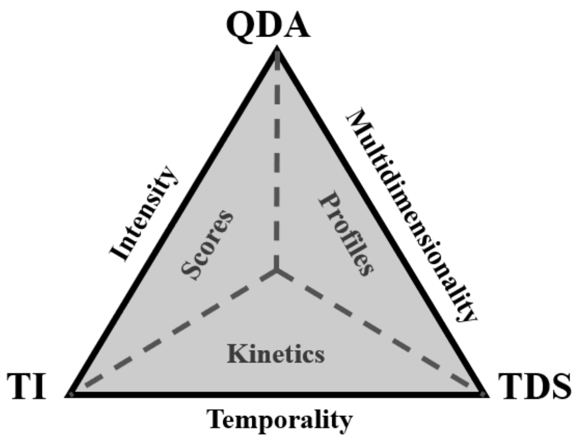

Figure 1.2. Conceptual differences between Quantitative Descriptive Analysis (QDA), Time-Intensity (TI), Temporal Dominance of Sensations (TDS) and Temporal Check-All-That-Apply (TCATA) (Schlich & Pineau, 2017).

1.1. Temporal Dominance of Sensations

The Temporal Dominance of Sensations (TDS) method is the most frequently used method to measure dynamic changes in sensory perceptions over time during consumption. Assessors are presented with a total of 8 to 12 taste and/or texture attributes on a computer screen, see figure 1.3a (left screen) for a configuration of the TDS task. Assessors are instructed to put the sample into their mouth and simultaneously press the start button, allowing time recording to start. Then, they select the dominant attribute (i.e. the one that catches most of the attention at each moment in time). Dominance recording of that attribute starts from then and remains until a new dominant attribute is selected. Assessors keep selecting dominantly perceived sensory attributes until perception ends, then they click the stop button, allowing time recording to stop (Pineau et al., 2009). Assessors can select as many dominant sensory attributes as they like, using the same attributes several times or never select a sensory attribute during the evaluation time.

In the early stages of the TDS development, trained panellists were instructed to select a dominant sensory attribute and give a corresponding intensity score (Labbe et al., 2009). However, to make TDS more suitable for untrained assessors, such as consumers, since 2011 TDS started to rely on the concept of dominance without intensity scoring (Schlich, 2017). In literature, different definitions for dominance are provided, such as "*the new sensation popping* *up, not necessarily the most intense*" (Pineau et al., 2009; Rodrigues et al., 2016), "*the sensation catching the attention of the assessors at a given time, not necessarily being the one with the highest intensity*" (Bruzzone et al., 2013), "*the one that triggers the most attention at a point in time*" (Lenfant et al., 2009), and "*the most intense sensation*" (Albert et al., 2012; Labbe et al., 2009). To date, the question remains whether these unique descriptions of dominance lead to different dynamic sensory profiles and whether they require different interpretations of TDS data.

Dominance is a complex construct and sensory evaluations are related to multiple aspects of perception, such as attentional capture, intensity and changes in sensory perceptions (Di Monaco et al., 2014; Varela et al., 2018). Consumers are not trained on the identification of dominant sensory attributes in TDS and there could be individual differences in sensory attribute selection strategies between product evaluations (Varela et al., 2018). Heterogeneity in sensory attribute selection strategies within and between consumers might lead to different product evaluations and could compromise panel agreement and panel repeatability. Little is known about a consumer's sensory attribute selection strategy and whether consumers are capable of replicating product evaluations of the same product.

For most foods, multiple sensory characteristics are perceived at the same time. TDS assumes that there can only be one dominant sensory attribute at each moment in time, and that a dominant sensory attribute remains dominant until a new one is selected. Hence, only one sensory attribute is defined as dominant, while there might be several sensory attributes that are perceived at that same moment which stand out. Competing sensory perceptions or response restrictions in TDS can lead to hesitation and delays in the selection of the dominantly perceived sensory attribute. Moreover, assessors might need some processing time to switch between selections of dominantly perceived sensory attributes. The psychology of consumers' test behaviour using sensory tests is an area that has received relatively little attention in sensory science. Up till now, it is unclear if there are moments of no-dominance, or whether assessors always perceive at least one sensory attribute to be dominant at each moment in time during consumption.

Taken together, there are still unanswered questions about the conceptual ideas and processes behind the concept of dominance and the performance of consumers using the TDS method. This thesis provides insights in the conceptualization of dominance, test re-test reliability of consumers using TDS method and the presence or absence of implicit no-dominance durations.

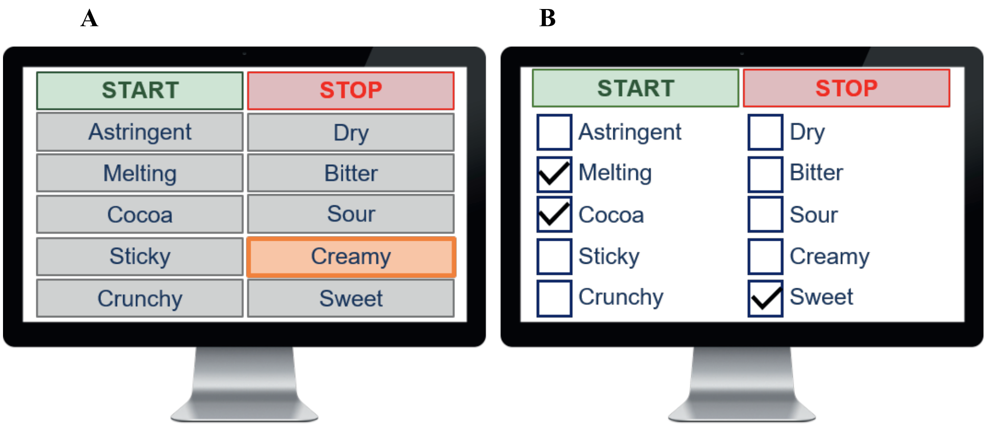

Figure 1.3. Configuration of Temporal Dominance of Sensations task (A) and Temporal Check-All-That-Apply task (B) on computer screen.

1.3. Temporal Check-All-That-Apply

To overcome the limitation of a single attribute selection at each moment in time in TDS, Temporal Check-All-That-Apply (TCATA) was introduced. TCATA originates from the Check-All-That-Apply (CATA) method, and allows assessors to keep track of all sensory attributes that are applicable at each moment in time. Figure 1.3b visualizes the TCATA task as presented to the assessor on a computer screen. Participants are instructed to put the sample into their mouth and simultaneously click the start button, allowing time recording to start. Then, they select the attributes that are applicable at each moment in time and uncheck selected attributes when they no longer apply during consumption (Castura et al., 2016). Time recording of the applicable attribute starts upon selection and remains until this attribute is unchecked. When perception ends, participants click the stop button, allowing time recoding to stop. Participants can select as many attributes as they liked, using the same attributes several times or never select an attribute during the consumption time.

TCATA has the advantage that it allows the consumer to identify multiple sensory attributes form multiple sensory dimensions (such as taste and texture) at the same time. TCATA is suggested to provide better product descriptions and product discrimination compared to TDS (Ares et al., 2017; Ares et al., 2016). However, keeping track of the presence and absence of sensory attributes during mastication time can be a difficult and fatiguing task to perform (Ares et al., 2016). A study that compared TCATA and CATA observed that average citation proportions increase from first to second quarter of mastication and then reach a plateau (Alcaire et al., 2017). Moreover, maximum citation proportions observed with TCATA were largely similar to the static citation proportions observed with CATA, suggesting a lack of temporality and resolution in TCATA. This thesis will add to the understanding of the temporality of TCATA by investigating a consumer's ability to simultaneously select and deselect applicable sensory attributes during product evaluations using TCATA.

1.4. Measuring food-evoked emotions

Food-evoked emotions have been suggested to provide additional information about a food product to predict food choice behaviour beyond hedonic and sensory characterization (Gutjar et al., 2015a). The circumplex model of affect categorizes emotions in two dimensions, valence (pleasure and displeasure) and arousal (activation level) (Jaeger et al., 2018; Russell, 1980). Positive emotions with high activation levels can be experienced as pleasant, while negative emotions with high activations level can be experienced as disgusting. An emotion process is triggered by a person's encounter with a stimulus (e.g. food product). If the product is appraised as meaningful an emotion response will occur. An emotion response can be characterized by a set of changes in physiological behaviours, facial and bodily expressions, and subjective experiences, i.e. the emotion one becomes aware of (Jager, 2016; Scherer, 2005, 2009). Subjective emotion experiences are most commonly measured using explicit self-report measurements, such as questionnaires and rating scales (Kaneko et al., 2018). Self-report measurements require consumers to verbally express their emotion response of the product experiences, which requests conscious processing of the emotion experience. Most perceptions and decisions are based on unconscious processes and are automatically processed outside conscious awareness (Kahneman, 2003; Köster, 2003; Köster & Mojet, 2015; Scherer, 2005, 2009). Explicit self-report measures only reveal the emotion experience one becomes aware of. Implicit measures, such as heart rate, blood pressure, skin conductance and facial expressions, have been suggested to measure the unconsciously emotion response to a food product and could provide a more fundamental understanding of how consumers respond to food products

(De Wijk, He, Mensink, Verhoeven, & De Graaf, 2014; Schacht & Sommer, 2009). Implicit measures have the advantage that they measure dynamic emotion responses during the consumption of food, while most explicit food-evoked emotions measurements include evaluations immediately after tasting a product. Dynamic changes in sensory perceptions during consumption may elicit a change in hedonic and emotion evaluations. Temporal Dominance of Emotions (TDE) method was introduced to allow consumers to self-report dynamic changes in emotion perceptions during tasting (Jager et al., 2014). Different components of the emotion process are complementary, and linking implicit to explicit emotion measurements over time will generate novel insights on how to interpret consumers' affective responses in relation to food and eating behaviour.

Most implicit measures, such as facial expression analysis, have been applied to products with large differences in liking (de Wijk et al., 2012; He et al., 2014, 2016). However, when we want to predict a consumer's food choice behaviour, we are not interested in the choice between product categories but more about the food choice within a product category (e.g. low vs. high sugar cereals). It is important to explore the emotion responses of more realistic food products with subtle differences. In this thesis we will narrow this research gap and investigate the sensitivity and discrimination ability of facial expression analysis for products from the same category with similar ingredients but different textural properties and compare the performance and emotional characterization of implicit (facial expressions) and explicit (TDE) emotion measurements.

1.5. Sensory testing under more realistic conditions

Central location tests (CLT) are most commonly used in sensory and consumer research because they provide high control over the test conditions during the evaluation. However, CLTs poorly reflect natural eating behaviours due to the high amount of control over the test variables which interfere with natural eating behaviour and product experiences. Consumption contexts and eating occasions can change our perception and hedonic evaluations of the foods we eat. Home-use tests (HUT) were introduced to test a consumer's product perception in more natural settings and eating conditions and are assumed to yield more realistic consumer data (Boutrolle et al., 2005). Extrinsic contextual information has been suggested to influence a product's hedonic perceptions and shape reward outcomes (Bangcuyo et al., 2015). Immersive environments are used in sensory and consumer science to mimic consumption contexts and better reflect realistic contextual information. Increasing ecological validity of sensory tests might provide a better predictability of a consumer's food choice behaviour.

Methodological alterations to existing testing strategies have the potential to improve the reliability of consumer data. In classical sensory and consumer tests, assessors typically take one bite of a food and then evaluate the food-evoked emotion, sensory and hedonic properties. However, this is very different from normal eating behaviour, where people consume foods in its entirety and eat multiple subsequent bites/sips. Few studies have investigated the dynamic changes in sensory and hedonic perceptions using multiple bite assessments. Dynamic changes in sweetness, sourness and bitterness were observed from first to third sip of artificial sweetened orange juices (Zorn et al., 2014), and a built up of fatty sensations was observed from first to twelfth spoon of oil-in-water emulsions (Appelqvist et al., 2016). Changes in perception for artificial sweetened products or fat containing emulsions from first to subsequent bites are expected due to lingering of sweetness and formation of in mouth-coatings.

It is plausible that if dynamic changes in sensory perceptions exist, liking changes due to the decrease of desired sensory perceptions or the increase of undesired sensory perceptions. Thomas et al. (2015) pointed out that in classic single bite hedonic assessments, consumers provide their liking scores even before they have swallowed the food product. They suggest that consumers rate liking too soon, and do not take into account the full dynamic perception of a food product. Few studies have investigated dynamic changes in liking. Thomas et al. (2016) reported a decrease in liking from first to last sip of the consumption of a full portion of oral nutritional supplements (ONS). Additionally, Galmarini et al. (2015) observed a significant decrease in liking of chewing gum over a period of 10 minutes.

Little is known about the differences in food perceptions between 'tasting', as in a single bite, versus eating a food product in its entirety with multiple bites. It is unclear if built-ups and changes in sensory and hedonic perceptions from first to subsequent bites/sips can be generalized to a broader group of products, such as semi-solids, solids and/or plain food products. In this thesis, changes in sensory perceptions and liking are explored over multiple bites using dynamic measurements such as TCATA and TDS.

1.6. Aim and thesis outline

This thesis aims (i) to investigate conceptual ideas and processes underlying selection of sensory attributes during Temporal Dominance of Sensations (TDS) and Temporal Check-All-That-Apply (TCATA), (ii) to investigate dynamic changes in food-evoked emotions, sensory and hedonic perceptions within and between multiple bites of food consumption, and (iii) to compare the performance of dynamic implicit and explicit food-evoked emotion measurements.

Figure 1.4 provides an overview of the methods, intakes, products, research aims and main outcomes of the research papers included in this thesis. In the first study, we investigated the conceptualization of dominance by consumers, and assessed consumers' repeatability when using TDS (chapter 2). Furthermore, we investigated whether consumers perceive periods of no-dominance during TDS evaluations (chapter 3). The observation of dynamic sensory perceptions in a single bite, lead to the extension of the TDS method to investigate dynamic changes in sensory perceptions over multiple bites (chapter 4). In chapter 5 we aimed to generalize our multiple bite findings to a broader range of product categories, and compared the performance and different cognitive processes that underlie the selection of a dominant attribute in TDS and the selection and deselection of applicable attributes in TCATA. Because food is thought to be 'emotion', we extended our knowledge about the dynamic measurements of food-evoked emotions and compared self-reported food-evoked emotions (TDE) with facial expressions which reflect the implicit emotion experience of a food product (chapter 6). Finally, the main findings are discussed and directions for future research are presented in a General Discussion (chapter 7).

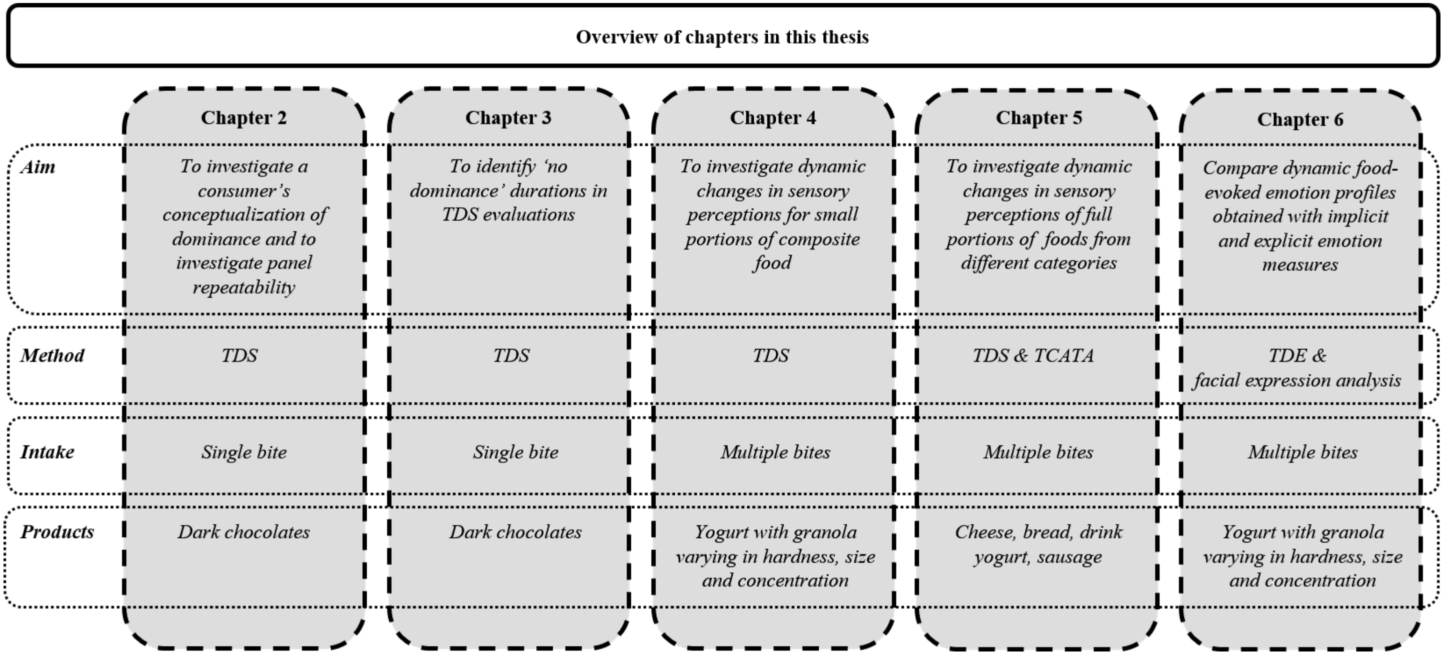

Figure 1.4. Overview of the studies described in this thesis, including the aims, methods, intakes and products.

1

CHAPTER 2

Instructions do not matter much:

Definition of dominance (attentional capture vs. intensity) provided to consumers in Temporal Dominance of Sensations (TDS) does not influence dynamic sensory profiles

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Submitted for publication.

ABSTRACT

Temporal Dominance of Sensations (TDS) is based on the concept of dominance. Dominance covers attentional capture, changes in sensory perceptions and intensity. This broad definition of dominance has been suggested to lead to heterogeneity in sensory attribute selection. Focussing on one dimension of dominance could assist consumers to be more consistent, agreeing and repeatable in their sensory attribute selections. This study compared dynamic sensory profiles obtained with dominance defined as the sensation catching most of the attention (attentional capture, TDS-a) versus the most intense sensation (TDS-i), and investigated panel repeatability by comparing dynamic sensory profiles of the same product obtained with 7-day interval. One hundred thirty-seven consumers evaluated four dark chocolates employing TDS-a (n=69) or TDS-i (n=67), using a between subjects design. Similar dynamic sensory profiles were observed for three out of four chocolates between TDS-a and TDS-i evaluations. Good panel agreement was observed between evaluations with a 7-day interval. At the end of the second session, consumers were asked to define dominance or intensity and to describe their strategies to select sensory attributes. Consumers used similar descriptors to define dominance and intensity, such as the *predominant* sensation, the most *present* sensation, the most *striking* sensation and the sensation that *pops up*. Consumers indicated they selected sensory attributes based on *intuition, hedonic perceptions, previous experiences* and *expectations* of the product. We conclude that the definition of dominance provided to consumers using TDS hardly influences the dynamic sensory profiles, and panel repeatability is not compromised by the subjective conceptualization of dominance in TDS.

1. INTRODUCTION

Temporal Dominance of Sensations (TDS) is one of the most commonly used methods in sensory and consumer science to obtain dynamic sensory profiles. TDS is based on the concept of dominance. Dominance includes several aspects and covers attentional capture, sudden changes in sensory characteristics and sensory intensity (Di Monaco et al., 2014; Varela et al., 2018). Over the years, different definitions for dominance have been used, such as "*the new sensation popping up, not necessarily the most intense*" (Pineau et al., 2009; Rodrigues et al., 2016), "*the sensation catching the attention of the assessors at a given time, not necessarily being the one with the highest intensity*" (Bruzzone et al., 2013), "*the one that triggers the most attention at a point in time*" (Lenfant et al., 2009), and "*the most intense sensation*" (Albert et al., 2012; Labbe et al., 2009). The broad conceptualization of dominance might lead to heterogeneity in strategies assessors use to select sensory attributes during TDS. To date, the question remains how different definitions of dominance provided to the assessors influence dynamic sensory profiles and whether different definitions can be used interchangeably.

To shed light on the conceptualization of dominance by consumers, Varela et al. (2018) instructed consumers to select *"the sensation catching most of the attention at a given time"* for a single chocolate. Afterwards they asked the consumers three questions (i) why did the attributes you selected catch your attention?; (ii) did you perceive any other sensations simultaneously?; and (iii) what made you change your selection of attributes? They observed that consumers selected the most intense sensation (30%), followed by the most striking sensation (20%), the sensation that popped up (19%), the sensation that did not fit previous expectations (15%), and the sensations they liked/disliked (11%). Because the concept of 'dominance' gives rise to a wide range of interpretations, Varela et al. (2018) suggested to reduce individual differences by focussing the assessor's attention to one of the dimensions of dominance, i.e. the most intense attribute at each moment in time or 'big' changes in sensory characteristics during consumption.

It is likely that consumers do not use the same attribute selection criteria within the same product evaluation, and might use different attribute selection strategies between product evaluations. Consequently, heterogeneity in the selection of the dominant sensory attribute could lead to low panel agreement (Ares et al., 2015) and poor panel repeatability when evaluating the same product. Instructing consumers to focus on the selection of the sensation catching most of the attention, here referred to as 'TDS-attentional capture (TDS-a)', or the most intense sensation, here referred to as 'TDS-intensity (TDS-i), could narrow down and simplify the sensory attribute selection for consumers. We hypothesize that dynamic sensory profiles deviate based on the definition of dominance (i.e. attentional capture vs. intensity) provided to the consumer. Moreover, we expect that a focus on one aspect of the conceptualization of dominance could assist consumers to be more consistent, agreeing and repeatable in their sensory attribute selections. This study aims to (i) compare the dynamic sensory profiles of dark chocolates obtained with different task instructions for dominance (i.e. attentional capture vs. intensity) employing TDS-a and TDS-i, and (ii) to investigate panel repeatability by comparing dynamic sensory profiles of the same products obtained with 7-day interval employing TDS-a and TDS-i, using a between subjects design.

2. METHODS

2.1. Participants

One hundred thirty-seven healthy (self-reported) Dutch consumers, aged 18-65 years, were recruited for this study from a database with volunteers to participate in research of the Division of Human Nutrition and Health of Wageningen University, The Netherlands. All participants were consumers of dark chocolate, without allergies or intolerances for milk or lactose and with normal abilities to taste and smell (self-reported). None of the participants was familiar with the TDS methodology or had any previous training in sensory evaluation of chocolates. After inclusion, participants were randomly divided into two groups, employing either TDS-a (n = 69, age 27.3 ± SD 12.3, 19 men, BMI 21.7 ± SD 2.0) or TDS-i (n = 67, age 28.7 ± SD 14.1, 21 men, BMI 22.0 ± SD 2.4). No significant differences were observed for age, gender and BMI between the two participant groups ($p > 0.05$). Participants received a monetary incentive for their participation, and gave written informed consent before the start of the study. The experimental protocol was submitted to and exempted from ethical approval by the Medical Ethics Committee of Wageningen University.

2.2. Products

Four varieties of commercially available dark chocolates from the Lindt Excellence series (70% mild, 70% cocoa, 85% cocoa and 90% cocoa) were chosen to allow comparison with previous literature (Jager et al., 2014; van Bommel, 2019b; Visalli, Lange, Mallet, Cordelle, & Schlich, 2016). Participants received unbranded pieces of chocolate of approximately 3 g per sample, presented in small transparent plastic bags coded with 3-digits. Products were presented in sequential monadic order according to a Williams Latin Square design (Williams, 1949) and product order was randomized between participants and sessions. A warm-up sample, Lindt Excellence 78% cocoa, was included to familiarize participants with the study procedures.

2.3. Attribute selection

Sensory attributes were selected based on attributes and definitions used by Jager et al. (2014), Visalli et al. (2016) and van Bommel et al. (2019b), who used chocolate products from the same Lindt Excellence series. The following ten sensory attributes were included: *astringent, bitter, cocoa, creamy, crunchy, dry, melting, sour, sticky* and *sweet.*

2.4. Temporal methods

Participants were instructed to put the sample into their mouth and simultaneously click the start button, allowing time recording to start. Participants who evaluated the products with TDS-a were instructed to select the *dominant* attribute, defined as *the sensory attribute that catches most of their attention at each moment in time*. Participants who evaluated the products with the TDS-i method were instructed to select the *most intense* attribute, defined as *the attribute that is perceived most strongly at each moment in time*. Recording of attribute selection started from then and remained until a new attribute was selected. When perception ended, participants clicked the stop button, allowing time recording to stop (Pineau et al., 2009). Participants could select as many attributes as they liked, using the same attributes several times or never select an attribute during the consumption time. Procedures for TDS-a and TDS-i were similar apart from the instruction on attribute selection (i.e. attentional capture vs. intensity). TDS tests were designed using TimeSens software (version 1.1.601.0, ChemoSens, Dijon, France).

2.5. Procedure

Figure 2.1 shows an overview of the experimental procedure. Participants evaluated four dark chocolates, employing either TDS-a or TDS-i. Participants repeated product evaluations with an interval of 7 days between sessions. Sessions lasted about 30 minutes and were scheduled between 13.00 and 17.00h. Sessions took place in sensory booths (Restaurant of the Future, Wageningen, The Netherlands). A live demonstration of the study procedures was given at the start of each session. The first sample of each session was a warm-up sample to acquaint the participants with the test method. Participants were instructed to consume the whole sample at once (about 3 g of chocolate) for product evaluation. After each sensory evaluation participants indicated their liking of the product on a 9-point hedonic scale with end anchors 'dislike extremely' and 'like extremely'. A neutralisation period of 2 min was included between samples, and participants were instructed to eat a piece of cracker and rinse their mouth with water. At the end of the second session, consumers were asked to answer the following three open-ended questions: (i) how did you select the attributes during the test?, (ii) what made you change your attribute selection during the task?, and (iii) how do you define dominance/intensity? (depending on the group they were assigned to).

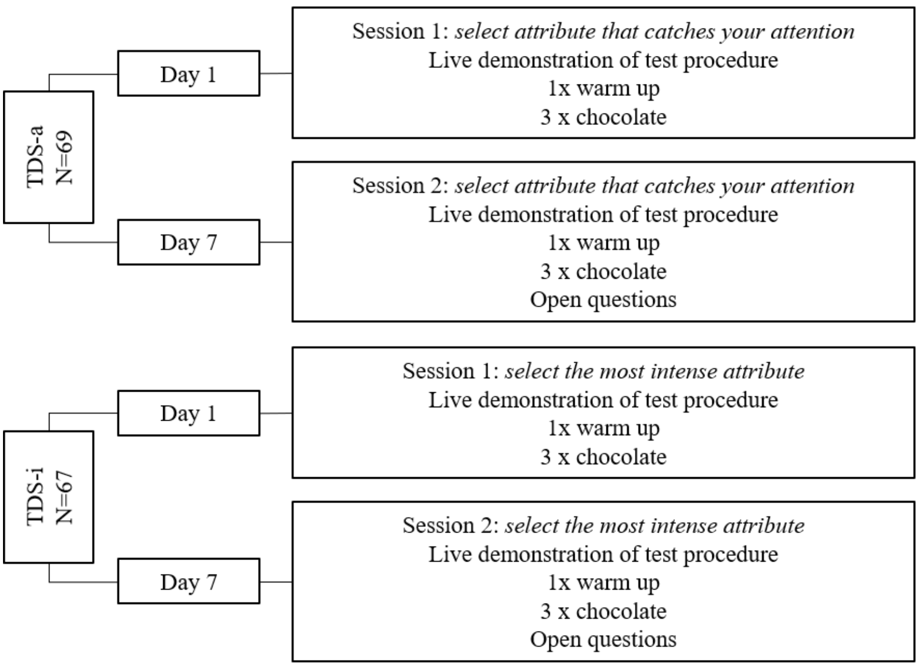

Figure 2.1. Schematic overview of study design.

2.6. Data analysis

All figures were plotted using TimeSens software (version 1.1.601.0, ChemoSens, Dijon, France). Statistical analysis was performed using R (R version 3.4.2, RStudio team, 2016). Data was pre-processed by standardizing time between 0 (first attribute selection) and 1 (click on the stop button) (Lenfant et al., 2009). Results of this study were considered significant at an alpha level of 0.05.

2.6.1. Temporal Dominance curves

Temporal sensory curves were generated per product by session for the sensory profiles obtained with the TDS-a and TDS-i task. Temporal dominance curves represent the proportion (%) of participants that cited an attribute at that moment in time (Lenfant et al., 2009; Pineau et al., 2009). A significance line at $p = 0.05$ was calculated according to the equation proposed by Pineau et al. (2009). Temporal sensory curves were visually inspected and compared among products, sessions and task instruction (attentional capture vs. intensity). Significant differences in temporal sensory profiles between sessions and between TDS-a and TDS-i were visualized in Temporal difference curves. Temporal difference curves represent significant differences (at $p = 0.05$) in panel agreement at each moment of mastication time for each attribute. Lines that are shown in the Temporal difference curve represent sensory attributes that are significantly higher in panel agreement at that moment of mastication time in relation to the comparative product. Significant differences in temporal sensory profiles between two sessions were visualized in the temporal dominance curves of each product by dotted lines.

2.6.2. Canonical Variance Analysis

Canonical Variance Analysis (CVA) was performed on non-standardized data of the sensory attribute durations for TDS-a and TDS-i separately. Attributes included in the CVA plots are significant at $p < 0.15$. CVA plots include ellipses representing 95% confidence intervals (CI) for each product. Hotelling-Lawley MANOVA tests were performed for pairwise product comparison (Peltier et al., 2015a).

2.6.3. Product discrimination and panel repeatability

Means and standard errors of the mean were calculated for dominance duration of each sensory attribute by test (TDS-a and TDS-i), session (session 1 and 2) and product. For TDS-a and TDS-i separately, a mixed model ANOVA was performed with product, session and product rank order as fixed effects, and subject and its interactions with product and session as random effects. The product by session interaction effect indicates the panel repeatability and if the average dominance duration of a sensory attribute was similar between two sessions. Significance of a product by session interaction effect indicates that the panel performance is not repeatable from one session to the other. Upon significance of the ANOVA, Tukey's HSD pairwise comparison was performed.

2.6.4. Test behaviour and liking

Means and standard errors of the mean were calculated for each product by test (TDS-a and TDS-i), session (session 1 and 2) and product for liking, evaluation duration, latency between start and first attribute selection, total number of attribute selections and the number of distinct attribute selections. A mixed model ANOVA was performed for TDS-a and TDS-i separately, with product, session and product rank order as fixed factors, and subject and its interactions with all fixed factors as random effects. A Tukey's HSD pairwise comparison was performed upon significance of the ANOVA.

2.6.5. Conceptualization of dominance and intensity

Consumers answered a series of three open-ended questions after the last product evaluation of the last session, (i) why did you select the attributes during the test?, (ii) what made you change your attribute selection during the task?, and (iii) how do you define dominance/intensity? Consumers who evaluated products with TDS-a got the question how they defined dominance, whereas consumers who evaluated products with TDS-i answered the question how they defined intensity. The qualitative data of the consumer responses was content analysed (Miles et al., 1994), meaning that the data was coded for key words, fragments and sentences. Responses were categorized into definition of dominance or intensity and strategies to select sensory attributes using TDS. Word frequencies were counted and relations between categories were explored. Word frequencies were visualised as word clouds, where words in larger font sizes represent words that were mentioned with higher frequency compared to words with smaller font size.

3. RESULTS

3.1. Dynamic sensory profiles

Figure 2.2 depicts the temporal curves of sensations when consumers were instructed to indicate the dominant (left side figures) and most intense (right side figures) sensory attributes at each moment in time during the consumption of four dark chocolates. Dotted lines in Figure 2.2 represent significant differences in panel repeatability between the first and second session. Despite some short significant differences in panel repeatability, overall panel performance was repeatable from first session to second session 7 days later.

Figure 2.3 depicts the significant differences in dynamic sensory profiles between TDS-a (top pane) and TDS-i (bottom pane) for the four dark chocolates. Very similar dynamic sensory profiles between TDS-a and TDS-i were observed for the 90% cocoa chocolate. Only small differences for very short time periods (<10% standardized consumption time) in dynamic sensory profiles were observed for the 70% mild and 70% cocoa chocolate. Panel agreement was significantly higher for *melting* sensation between 60-75% of mastication time for the 70% mild and between 30-40% of mastication time for the 70% cocoa chocolate when consumers evaluated products using the TDS-a task. A difference in attribute selection between TDS-a and TDS-i was observed for the 85% cocoa chocolate. Panel agreement and dominance duration for the 85% cocoa chocolate was significantly ($p < 0.05$) higher of *sour* at 30-75% of mastication time when consumers were instructed to select the most intense attribute, while dominance durations of *bitter* were significantly higher at 30-40% and 60-100% of mastication time when consumers were instructed to select the sensory attribute that caught most of their attention. To summarize, for three out of four dark chocolates similar TDS profiles were obtained although task instructions differed. For one out of four dark chocolates the difference in task instructions lead to significant differences in dominance rates for two sensory attributes for a period of more than 10% of mastication time.

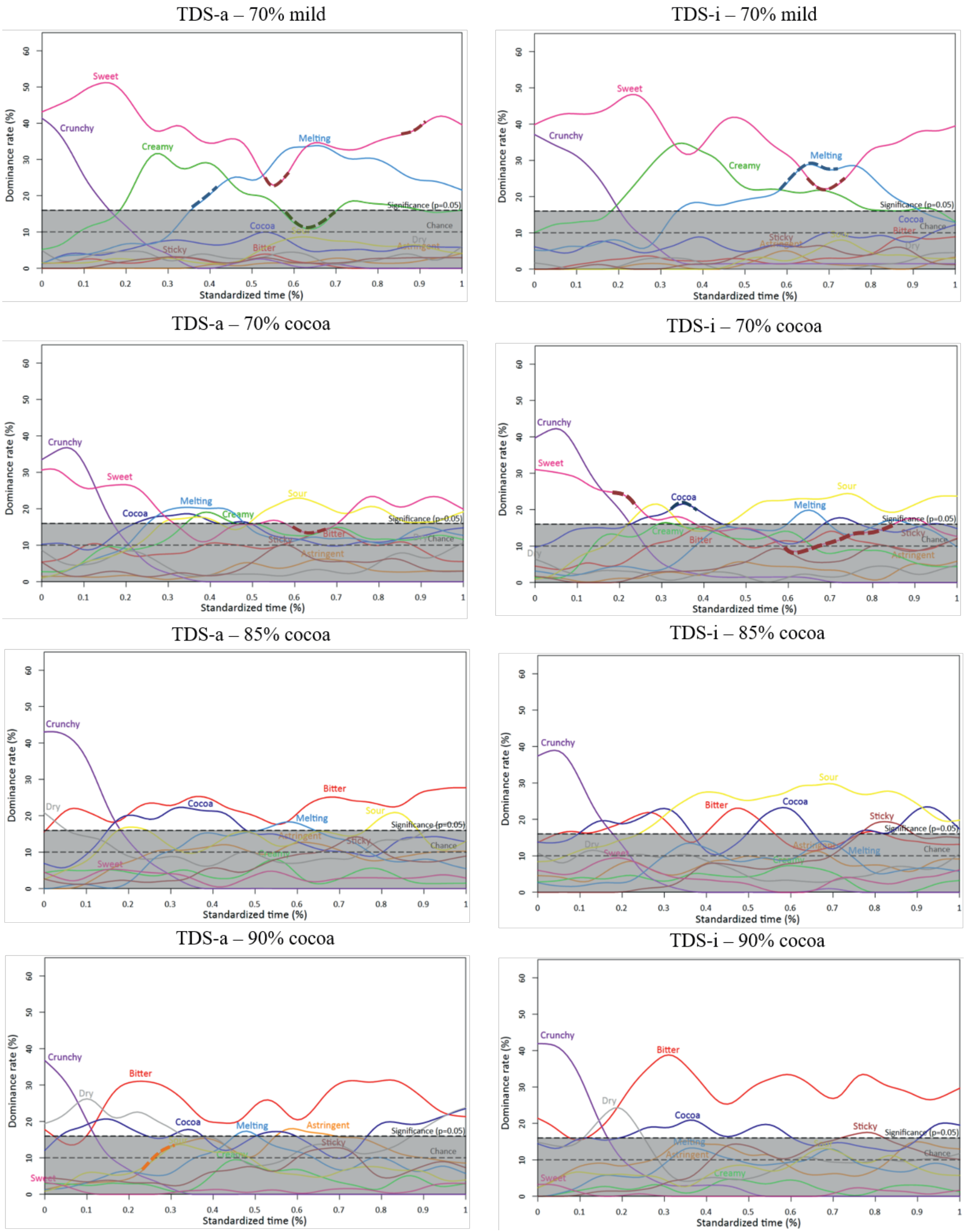

Figure 2.2. Graphical representation of the sequence of dominant sensations for TDS-a (left column) and TDS-i (right column) for all four chocolate products. Areas under the significance line are coloured grey. Dotted lines represent significant differences ($p < 0.05$) in dynamic sensory profiles for each product between first and second session.

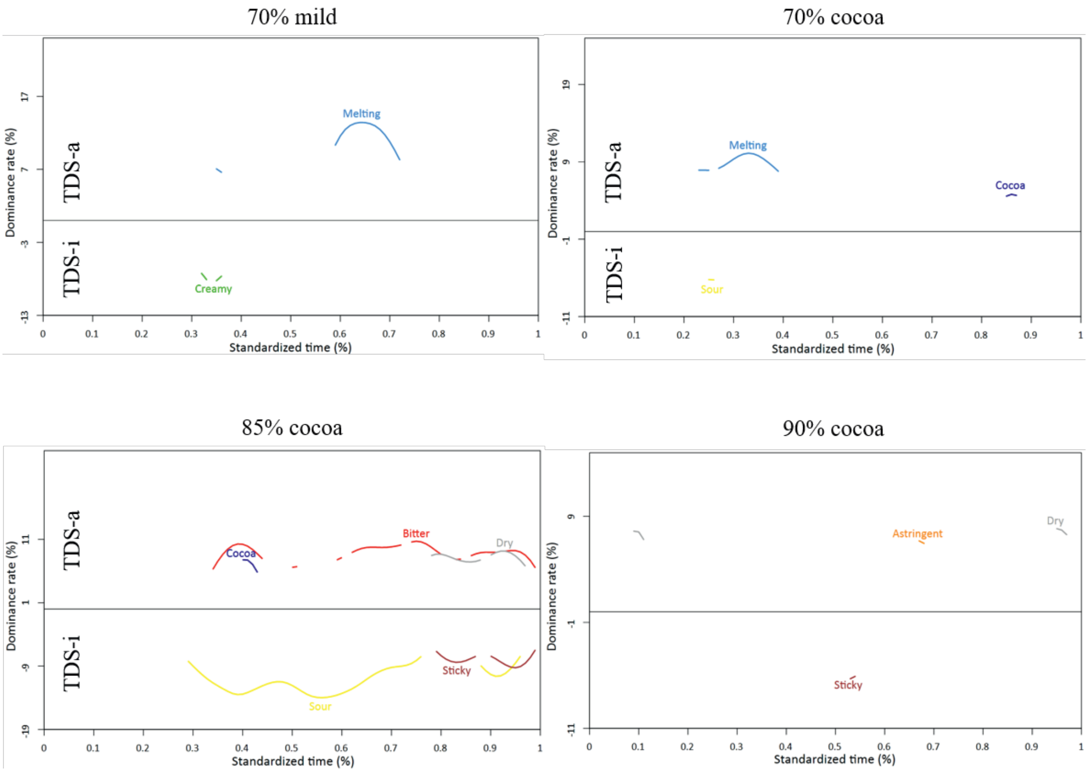

Figure 2.3. Graphical representation of the significant differences (p<0.05) in temporal sensory profiles between TDS-a (top pane) and TDS-i (bottom pane) per product.

3.2. Product discrimination

Table 2.1 represents the ANOVA results for product, session and their interaction effects based on the mean durations of attribute selections (in % of standardized mastication time) by TDS-a and TDS-i. Product effects represent the product discrimination per task instruction. Both tasks discriminated the products on *astringent, bitter, cocoa, creamy, dry, melting, sour, sticky* and *sweet*. Additionally, consumers who used TDS-a discriminated the products on *crunchy* sensations.

Session and session by product interaction effects for the mean durations of attribute selections (in % of standardized time) indicate the panel repeatability over the two test sessions by task instruction. Good panel repeatability (i.e. non-significant session and session by product interaction effects), was observed for *astringent, bitter, cocoa, creamy, crunchy, melting, sour* and *sticky* when consumers evaluated products using TDS-a task. Significant session effects were observed for *dry* ($F(1, 62) = 13.2$, $p < 0.001$) and *sweet* ($F(1,59) = 6.5$, $p = 0.013$), whereas dominance durations of *dry* sensations significantly decreased from session 1 to session 2 and *sweet* sensations significantly increased from session 1 to session 2 when consumers used the TDS-a task. When consumers used the TDS-i task, good panel repeatability was observed for *astringent, creamy, crunchy, dry, melting, sour* and *sticky*. A session by product interaction effect was observed for *sweet* ($F(3,183)=3.9$, $p = 0.01$), whereas consumers significantly increased the duration of *sweet* attribute selection from session 1 compared to session 2 for the 70% cocoa chocolate. No significant differences ($p > 0.05$) for *sweet* sensations were observed from session to session for any of the other chocolates that were evaluated with the TDS-i task. Moreover, significant session effects were observed for *bitter* ($F(1,62) = 5.0$, $p = 0.03$) and *cocoa* ($F(1.62) = 8.0$, $p = 0.006$), whereas selection durations for *bitter* and *cocoa* significantly decreased from session 1 to session 2.

Table 2.1. ANOVA results for product, session and their interaction based on the mean durations of attribute selections (in % of standardized time).

	TDS-a			TDS-i		
	Fproduct	Fsession	Fproduct*session	Fproduct	Fsession	Fproduct*session
Astringent	**25.6*** **	0.5	0.5	**27.3*** **	1.0	0.9
Bitter	**71.5*** **	0.8	0.3	**64.8*** **	**5.0***	0.4
Cocoa	**11.6*** **	0.3	0.4	**7.6*** **	**8.0** **	0.9
Creamy	**32.5*** **	0.4	2.7	**65.8*** **	1.0	2.5
Crunchy	**3.4***	2.3	1.7	0.9	0.6	1.2
Dry	**37.5*** **	**13.2*** **	1.0	**22.8*** **	0.3	0.7
Melting	**26.1*** **	0.5	0.7	**14.9*** **	0.2	0.6
Sour	**15.8*** **	0.7	0.3	**29.3*** **	0.1	0.9
Sticky	**10.8*** **	1.4	0.3	**7.9*** **	0.4	0.1
Sweet	**152.4*** **	**6.5***	1.1	**125.7*** **	**8.6** **	**3.9** **

Significant at (*) 0.05, (**) 0.01, (***) 0.001.

CVA maps on sensory attribute durations obtained with TDS-a (left map) and TDS-i (right map) are depicted in Figure 2.4. Confidence ellipses are presented at 90%, and numbers in the maps indicate the first (1) and second (2) session of the evaluation of the same product. Each of the maps account for 99% of the explained variances. TDS-a and TDS-i maps represent a MANOVA F-statistic magnitude of 18.3 and 22.9, respectively. Hotelling-Lawley test showed that for all products, the evaluations between sessions within the same product were similar to each other ($p > 0.05$). When consumers were instructed to select the most intense attribute using

TDS-i they were able to discriminate all four products from each other ($p < 0.05$). However, when consumers were instructed to select the attribute that caught their attention using TDS-a, the 85% and 90% cocoa chocolates were perceived as similar ($p > 0.05$). Regardless of the test instruction given to the consumers, products were characterized and discriminated in a similar manner, whereas products were mainly discriminated along the first dimension of the CVA plots which differentiates the products on their cocoa content.

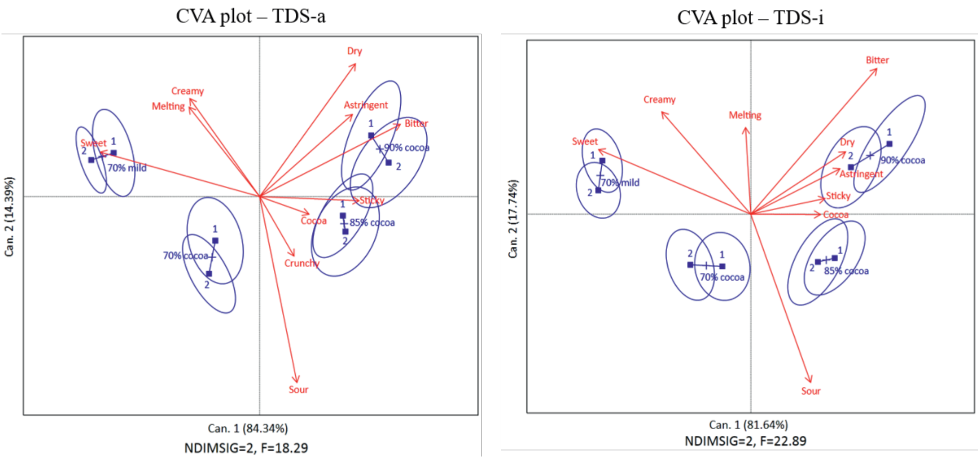

Figure 2.4. CVA maps of dominance durations of sensations by Temporal Dominance of Sensations (TDS-a, left map) and Temporal Intensity of Sensations (TDS-i, right map). Numbers represent the first (1) and second (2) session. Confidence ellipses at 90% and F-values significant at $p < 0.001$. NDIMSIG represents the number of significant dimensions.

3.3. Test behaviour

Table 2.2 shows overall duration, latency between start and first attribute selection, total number of attribute selections and the number of distinct attribute selections at panel level per task (TDS-a and TDS-i), product and session. Both tasks showed that the evaluation duration significantly increased ($p < 0.05$) upon the increase of cocoa content in the chocolate, with the 70% cocoa chocolates having the shortest and the 90% cocoa chocolate the longest evaluation duration. Not surprisingly, consumers selected significantly more sensory attributes for products with significantly longer evaluation durations. No significant session by product interaction effects were observed for any of the test behaviours ($p > 0.05$), indicating good panel repeatability in terms of evaluation duration and attribute selection behaviour.

Table 2.2. ANOVA results of test behaviour for product, session and their interactions based on mean duration, latency before first selection, number of attribute selections and number of distinct attribute selections.

Test	Parameter	$F_{product}$	70% mild	70% cocoa	85% cocoa	90% cocoa	$F_{session}$	Session 1	Session 2	$F_{product*session}$
TDS-a	Overall duration (s)	**31.4*** **	49.1 ± 3.0^{a}	50.7 ± 3.0^{a}	55.7 ± 3.0^{b}	58.5 ± 3.0^{b}	0.6	54.1 ± 2.9	52.9 ± 2.9	0.6
	Latency between start and first attribute selection (s)	2.1	3.9 ± 0.4	4.7 ± 0.4	4.4 ± 0.4	3.9 ± 0.4	**11.3** **	4.7 ± 0.4^{b}	3.8 ± 0.4^{a}	0.7
	Total number of attribute selections	**16.2*** **	6.4 ± 0.4^{a}	7.0 ± 0.4^{b}	7.6 ± 0.4^{c}	7.6 ± 0.4^{c}	**5.35***	6.8 ± 0.4^{a}	7.4 ± 0.4^{b}	0.9
	Number of distinct attribute selections	**31.0*** **	4.0 ± 0.2^{a}	4.8 ± 0.2^{b}	5.1 ± 0.2^{c}	5.0 ± 0.2^{bc}	1.1	4.7 ± 0.1	4.8 ± 0.1	0.6
TDS-i	Overall duration (s)	**29.9*** **	49.2 ± 3.0^{a}	49.7 ± 3.0^{a}	55.1 ± 3.0^{b}	59.5 ± 3.0^{c}	**15.7*** **	55.6 ± 3.0^{a}	51.1 ± 3.0^{b}	1.5
	Latency between start and first attribute selection (s)	**3.6***	3.7 ± 0.4^{a}	4.7 ± 0.4^{b}	4.8 ± 0.4^{c}	4.5 ± 0.4^{bc}	0.5	4.5 ± 0.4	4.3 ± 0.4	1.9
	Total number of attribute selections	**18.0*** **	6.7 ± 0.4^{a}	6.8 ± 0.4^{a}	7.8 ± 0.4^{b}	8.1 ± 0.4^{b}	**4.8***	7.1 ± 0.4^{a}	7.6 ± 0.4^{b}	0.3
	Number of distinct attribute selections	**22.9*** **	4.2 ± 0.2^{a}	4.7 ± 0.2^{b}	5.2 ± 0.2^{c}	5.0 ± 0.2^{bc}	1.0	4.7 ± 0.1	4.8 ± 0.1	0.5

Significant at (*) 0.05, (**) 0.01, (***) 0.001.

3.4. Liking

Figure 2.5 represents liking scores per product obtained after TDS-a (left figure) and TDS-i (right figure) evaluations. No significant product by session effects were observed for liking scores after TDS-a ($F(3,181) = 0.88$, $p = 0.45$) and TDS-i ($F(3,179) = 1.9$, $p = 0.13$) evaluations, indicating good repeatability of liking scores over sessions for each product. Consumers used a slightly wider range of the liking scale after TDS-a evaluations, which led to better product discrimination when liking was scored after product evaluation with TDS-a ($F(3,187) = 63.1$, $p < 0.001$) compared to TDS-i ($F(3,192) = 41.8$, $p < 0.001$). Nevertheless, similar trends were observed for liking scores in TDS-a and TDS-i. The 90% cocoa chocolate was significantly least liked, followed by the 85% cocoa chocolate and the 70% cocoa chocolates were significantly most liked.

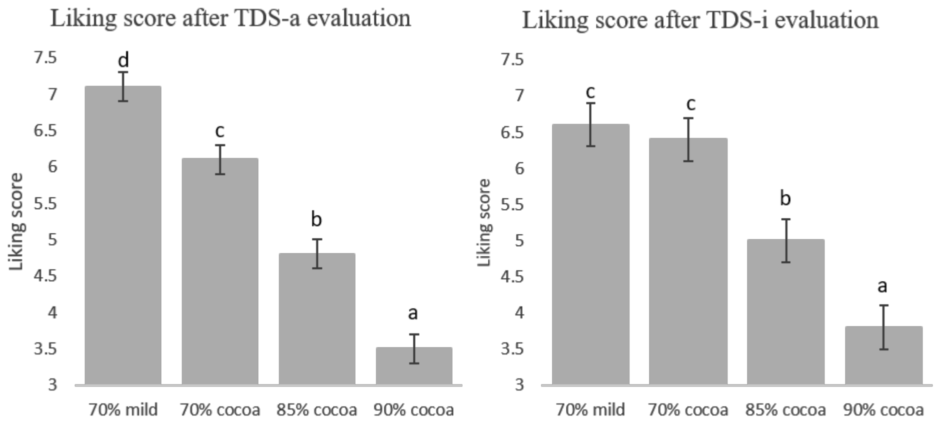

Figure 2.5. Mean liking scores and standard errors of the mean by product after TDS-a (A) and TDS-i (B) evaluations. Means with different letters indicate significant differences ($p < 0.05$) between products according to Tukey's HSD at 95% confidence.

3.5. Conceptualization of dominance and intensity by consumers

Figure 2.6 represents a word cloud based on the answers to the open questions. Each consumer used on average two distinct words to define dominance and intensity. The type of words with which consumers described dominance and intensity were similar. Most common words to describe dominance and intensity were the *predominant* sensation, the most *present* sensation, the sensation that *pops up* and the sensations that is most *striking*, as illustrated by the following comments: *"[The sensation that is] predominant over other tastes and textures, the one that is* *most present. It catches your attention because suddenly it is different than before, a change in taste/texture (S117 TDS-i).",* and *"At the transitioning of sensations, often a taste that suddenly pops up (S062 TDS-i).".*

Consumers mentioned more often that they selected sensory attributes intuitively when they evaluated products with TDS-a task, as exemplified by the following sentence: *"I intuitively selected the sensations. I thought carefully about what I was perceiving, but the sensation I selected came to me unconsciously and automatically (S020 TDS-a).".* Furthermore, hedonic perceptions and previous exposure to- and experience with the product were drivers of attribute selections for some consumers. Consumers who used TDS-a mentioned more often that the liking or disliking of a specific sensory attribute made this perception stand out and was therefore a driver for attribute selection, as expressed by the following answers: *"I changed attribute selection when the taste became more or less tasty (S031 TDS-a)."* and *"The taste or texture that made me like or dislike a particular chocolate (S034 TDS-a).".* Other consumers explained that they selected sensory attributes based on previous experiences and the confirmation or disconfirmation of their expectations of the product, as illustrated by the following sentences: *"The sensation that jumps out and pops up, or a weaker sensation that is surprising and, therefore, striking (S055 TDS-i)."* and *"[I chose sensory attributes] based on my frame of reference for chocolate (S068 TDS-i).".*

Additionally, consumers explained why they changed their attribute selection during product evaluation with TDS-a and TDS-i. Consumers most frequently described that they changed attribute selections due to perceived changes in sensory characteristics during mastication. Interestingly, some consumers pointed out that they experienced competition of two or more sensory attributes at the same time, and explained that they then quickly alternated between the selection of these simultaneously perceived sensory attributes, as illustrated by the following comments: *"Often I noticed that there were multiple sensations perceivable at the same time, like sweet and creamy. On these moments, I clicked back and forward between these options (S069 TDS-i).", "Taste and texture were sometimes equally dominant, then I choose first for texture and then taste (S021 TDS-a).",* and *"Changing quickly [between attributes] means that both sensations were very present (S131 TDS-i).".*

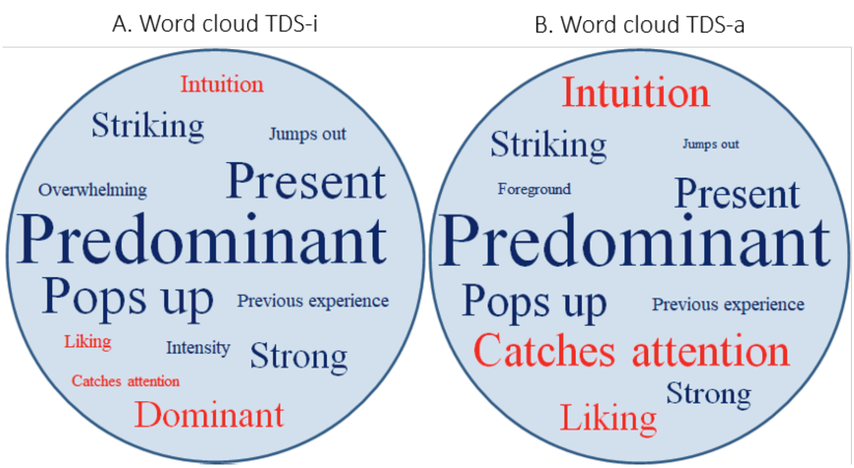

Figure 2.6. Word cloud of categories obtained from open-ended questions responses from consumers after TDS-i (A) and TDS-a (B). Words with large font sizes represent categories that were mentioned more frequently.

4. DISCUSSION

This study compared the dynamic sensory profiles obtained using TDS with different task instructions, attentional capture versus intensity, employing TDS-a and TDS-i, respectively. We hypothesized that these different task instructions would lead to different dynamic sensory profiles. We observed, however, similar dynamic sensory profiles for three out of four products when consumers were instructed to select the sensory attribute that caught most of their attention compared to the most intense sensory attribute at each moment in time. For one out of four products significant differences in dominance rates were only observed for two out of ten sensory attributes for a period longer than 10% of standardized mastication time. Together, these results imply that the definition of dominance provided to consumers using TDS hardly influences the dynamic sensory profiles.

We speculated that when consumers focussed on one aspect of the conceptualization of dominance (i.e. attentional capture or intensity), this would narrow down and simplify the sensory attribute selections for consumers and, consequently, would lead to higher dominance rates (i.e. panel agreement). Nevertheless, similar dominance rates were observed when consumers selected the sensory attribute that caught their attention compared to when they selected the most intense sensory attribute at each moment in time. Our findings indicated that consumers used similar descriptors for attentional capture and intensity, whereas the *predominant* sensation, the most *present* sensation, the sensation that *pops up* and the sensations that is most *striking* were most commonly mentioned. Varela et al. (2018) reported similar findings on the conceptualization of dominance when dominance was defined as the sensation that caught attention most. They reported that most consumers described attentional capture as the most intense sensation, followed by the most striking sensations and the sensation that popped up. Varela et al. (2018) suggested that individual differences might be reduced by focusing the assessor's attention to one dimension of dominance (e.g. intensity). Our findings do, however, not support this notion. We suggest that instructions to select the most intense sensory attribute at each moment in time does not exclude other dimensions of dominance (e.g. attentional capture) and vice versa.

We speculate that similarities and differences in dynamic sensory profiles between TDS-a and TDS-i might depend on the product that is evaluated. For other products than chocolates, focusing on attentional capture or intensity may lead to different dynamic sensory profiles. For example, for orange juice with pulp, in the beginning of consumption pulp might attract the attention of the consumer leading to dominance of pulpy/thick sensations in TDS-a although pulpy/thick sensations are not the most intense ones. The sourness intensity of orange juice might be higher than the pulpy/thick intensity at any moment in time during consumption. Therefore, sourness might become the dominant sensation at the beginning of consumption when TDS-i of orange juice is performed. We speculate that there might be products with textural contrasts and simultaneous intense taste characteristics for which the definition of dominance provided to the assessor could lead to different dynamic sensory profiles. Further research is needed to generalize the findings of this study towards other food categories.

A second aim of this study was to investigated panel repeatability by comparing dynamic sensory profiles of the same product evaluated with a 7-day interval. We expected that consumers who were instructed to select the most intense sensory attribute at each moment in time would have more homogenous attribute selection strategies, which would result in better reproducible dynamic sensory profiles. Although interindividual differences in strategies to select sensory attributes were reported, good panel agreement was observed for the same product between evaluations with a 7-day interval.

When consumers were asked how they selected sensory attributes they commented that *intuition, hedonic perceptions, previous experiences* and *expectations of the product* played an important role. These results are in agreement with the observations reported by Varela et al. (2018) who observed that consumers selected sensory attributes based on previous expectations followed by the selection of sensory attributes based on the sensation they liked or disliked. Heterogeneity in sensory attribute selection can lead to low agreement and poor panel repeatability on the dominantly perceived sensory characteristic (Ares et al., 2015). Panel repeatability provides information about the validity and reliability of the sensory profiles derived from TDS data. The current study showed that consumers reported similar dynamic sensory profiles when they performed TDS evaluations of the same product in separate sessions. Visalli et al. (2016), Jager et al. (2014) and van Bommel et al. (2019b) reported dynamic profiles of the same dark chocolates from the Lindt Excellence series as were used in the current study. All studies discriminated products similarly to our study, whereas the higher the cocoa content of the chocolate the more bitter, sour and dry and the less sweet, cocoa and crunchy the product was perceived. This indicates that independent consumer panels lead to similar product discrimination, which further strengthens the validity of the TDS method using naïve consumers as assessors.

The current study used a between subjects design with naïve consumers, who were not familiar with the TDS method, to test if task instructions (attentional capture vs. intensity) influences the obtained dynamic sensory profiles using TDS method. The advantage of using two independent naïve consumer panels is that product evaluations are not biased by previous knowledge about and experience with the evaluation procedure.

From a methodological point of view, TDS has the disadvantage that it does not allow the selection of two or more sensory attributes at the same time, but forces the consumer to choose one sensory attribute at a time. Some consumers reported that they experienced competition of two or more sensory attributes at the same time, and indicated they changed their sensory attribute selection to compensate for loss of this information. Consumers reported they clicked quickly back and forth between sensory attributes to indicate that both sensory attributes were perceived at the same time. However, TDS does not register quickly switching between attribute selections as competing sensory attributes at that moment in time. It is plausible that a characteristic from both modalities, i.e. taste and texture, dominate at the same time. The selection of a single sensory attribute might result in loss of this information. TDS by modality

(TDS-M) might help to overcome this problem, as it allows an assessor to select one dominant taste and one dominant texture attribute. This TDS-M method has been proven useful to characterize simultaneous dynamic taste and texture profiles using trained panels (Lesme et al., 2020; Nguyen et al., 2018), but warrants further investigation with consumer panels.

In conclusion, our results imply that the definition of dominance provided to consumers does not strongly influence the dynamic sensory profiles. Moreover, consumers are consistent in reporting their perceived dynamic sensory characteristics, independent of the conceptualization of dominance. It seems the TDS task at hand evokes a more intuitive selection response, which is not influenced by the definition of dominance provided to the consumer. Our results suggest that literature which uses different definitions can be compared and used interchangeably. It seems consumers use their own criteria to select sensory attributes using the TDS method, which is subjective to the consumer.

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CHAPTER 3

Dutch consumers do not hesitate:

Capturing implicit 'no dominance' durations using Hold-down Temporal Dominance methodologies for Sensations (TDS) and Emotions (TDE)

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ABSTRACT

In the 'classic' Temporal Dominance (TD) method, panellists are instructed to select a dominant attribute, which remains dominant until another attribute is selected. This procedure does not allow recording 'no dominance (ND)'. ND periods can occur because of indecisive selection behaviour due to hesitation or uncertainty about attribute selection and time needed to switch from one attribute to another. ND periods may create noise in TD data. ND can be recorded implicitly using a 'Hold-down' procedure, where panellists actively hold down the attribute button that is perceived dominant, but release it when no longer dominant. The 'Hold-down' procedure allows subjects to report indecisive behaviour simply by not holding down a button. This study compared the 'classic' and 'Hold-down' TD methodologies. One hundred and thirty-seven participants evaluated four dark chocolates in two sessions, one for sensory (TDS) and one for emotion (TDE) evaluations. Participants employed either classic (n=68) or Hold-down (n=69) TD following a between subjects design. Similar dominance rates and dynamic evolutions of attributes during consumption were observed for both methods. ND durations between attribute selections were shorter than 1s during sensory and emotion evaluations. Such short ND durations unlikely reflect periods of true hesitation, but rather reflect the time needed to switch between dominant attributes. No evidence is found for Hold-down TD outperforming classic TD in terms of sensitivity and discrimination ability. In conclusion, irrespective of the conceptual likelihood regarding the occurrence of 'no dominance' periods, the present study failed to demonstrate moments of hesitation using the 'Hold-down' procedure.

1. INTRODUCTION

Sensory perception of foods and beverages changes dynamically during consumption (Lenfant et al., 2009; Panouille et al., 2014; Saint-Eve et al., 2015; Young et al., 2013). Over the years several methodologies have been proposed to measure the temporal evolution of sensory perception of food products, such as the Time-Intensity (TI) technique (Lee & Pangborn, 1986), Dual-Attribute Time-Intensity (DATI) (Duizer et al., 1997), Temporal Dominance of Sensations (TDS) (Pineau et al., 2009), and the Temporal Check-All-That-Apply (T-CATA) method (Castura et al., 2016). Temporal Dominance of Sensations (TDS) is one of the most commonly used methodologies to measure temporal dynamics in sensory perception during consumption (Pineau et al., 2009). More recently, Temporal Dominance of Emotions (TDE) was introduced to measure the sequence of dominant food-evoked emotions perceived during consumption (Jager et al., 2014). Combining the TDS and TDE method allows to investigate relationships between dynamic sensory perception and food-evoked emotions.

In the early stages of the TDS development, trained panellists were instructed to select a dominant sensory attribute and give a corresponding intensity score (Labbe et al., 2009). However, to make TDS more suitable for untrained consumers, TDS relies on the concept of dominance without intensity scoring (Pineau et al., 2009; Visalli et al., 2016). Dominance is most commonly defined as the ‘sensation catching most of the attention at a given time’ (Bruzzone et al., 2013) or ‘the new sensation popping up’, not necessarily the most intense (Pineau et al., 2009). Different Temporal Dominance (TD) protocols have been used depending on the aims of the studies and products. In the default TD protocol, from now on here referred to as ‘classic’ TD, the assessors select the perceived dominant attribute, and dominance recording of this attribute starts from then and remains until a new attribute is selected (Pineau et al., 2009).

Varela et al. (2018) investigated the reasoning of assessors behind changing and selecting dominant attributes using TDS. They observed that assessors reported indecisive selection behaviour on dominance between two attributes (e.g. texture or flavour) and hesitations due to dumping effects (e.g. response restrictions), using a retrospective verbalization task. To engage assessors and to stimulate attribute selection, Thomas et al. (2015) used a TDS protocol that highlighted the dominant attribute for 3 s after selection. After 3 s the visual highlight disappeared, but dominance duration of that attribute was recorded until the next attribute was selected. Castura and Li (2016) investigated the effect of these 'dominance gaps' (i.e. the moment where nothing is visually highlighted as dominant), and suggested there is a need for better task instruction to actively involve assessors during TDS evaluations. Only 10% of the assessors selected a subsequent dominant attribute within 6 s after the selection highlight disappeared, and 58% of the assessors took longer than 10 s to select a subsequent dominant attribute after the selection highlight disappeared (Castura & Li, 2016). Hence, it is plausible that moments of 'no dominance (ND)' occur, defined here as the time gap between the selection of two subsequent dominant attributes. ND periods can occur because of a delayed response time, indecisive selection behaviour due to hesitation or uncertainty about attribute selection, the cognitive effort to choose a dominant attribute or time needed to select a new attribute, which may create noise in the TD data. Capturing periods of ND could reduce noise and improve sensitivity, consequently leading to better product discrimination and better reproducibility of TDS and TDE.

Recently, Rodrigues et al. (2018) included a 'no perception' button for TDS evaluations by trained panellists using a predefined consumption time protocol. They observed that 'no perception' gradually increased towards the end of the predefined consumption time. 'No perception' was defined as the absence of a sensation (Rodrigues et al., 2018), while the present study defines 'no dominance' as the absence of dominance for any of the sensations. Including a 'no dominance' button in TDS evaluations assumes to record ND explicitly. However, it seems counterintuitive and contradictory to the concept and definition of 'dominance' to include a no dominance' button in TD evaluations. Hence, the introduction of a 'Hold-down' TD method, where panellists actively hold down the button of the attribute that is perceived dominant, but release it when they no longer perceive it as dominant, allows to record ND duration implicitly (Schlich, 2017). ND is recorded when the active selection of an attribute ends until a new dominant attribute is selected. To better understand the concept of dominance, the occurrence of implicit ND duration periods in TD methods has to be explored.

To date, the question remains how dynamic sensory and emotion evaluations of foods are influenced by ND periods that occur between the selection of two subsequent dominant attributes. In addition, from a methodological perspective, it is unclear how to best capture or measure 'no dominance' or indecisive behaviour as part of panellist behaviour. Finally, it is unclear how ND periods affect sensitivity and product discrimination capability in TD methods. The aims of this study are to shed further light on the questions raised above by (i) comparing the performance of the Hold-down TD with the classic TD methodology for dynamic sensory and emotion profiling, and (ii) identification of ND duration periods in TD evaluations in an example product category (dark chocolates). This study evaluated four varieties of dark chocolates in two sessions, one for sensory (TDS) and one for emotions (TDE). Participants employed either classic TD (n = 68) or Hold-down TD (n = 69) in a between subjects design. We hypothesized that the Hold-down TD method allows to implicitly capture periods of hesitation and indecisive behaviour which leads to reduced noise in the data, resulting in higher sensitivity and better product discrimination.

2. METHODS

2.1. Participants

One hundred thirty-seven healthy (self-reported) Dutch participants, aged 18 to 65 years, were recruited for this study from a database with volunteers to participate in research of the Division of Human Nutrition of Wageningen University, the Netherlands. All participants were consumers of dark chocolate, without allergies or intolerances for milk, lactose or nuts, with normal abilities to taste and smell (self-reported), and without chocolate cravings (self-reported). None of the participants was familiar with TD methodology or had any previous training in sensory evaluation of chocolates. After inclusion, participants were randomly divided in two groups, employing either classic TD (n = 68) or Hold-down TD (n = 69) for sensory and emotion evaluation in a between subjects design. Table 3.1 shows participant demographics per group. No significant differences were observed for age, gender and BMI between the two participant groups ($p > 0.05$). Participants received a monetary incentive for their participation, and gave written informed consent before the start of the study. The study protocol was submitted to and exempted from ethical approval by the Medical Ethical Committee of Wageningen University.

Table 3.1. Participant characteristics.

		Classic TD (n=68)	Hold-down TD (n=69)
Age (years)	Mean ± SD	27.0 ± 12.1	24.2 ± 9.1
Gender [%(n)]	Male	27.9 (19)	27.5 (19)
	Female	72.1 (49)	72.5 (50)
BMI (kg/m^2)	Mean ± SD	22.0 ± 2.0	21.8 ± 1.8

2.2. Products

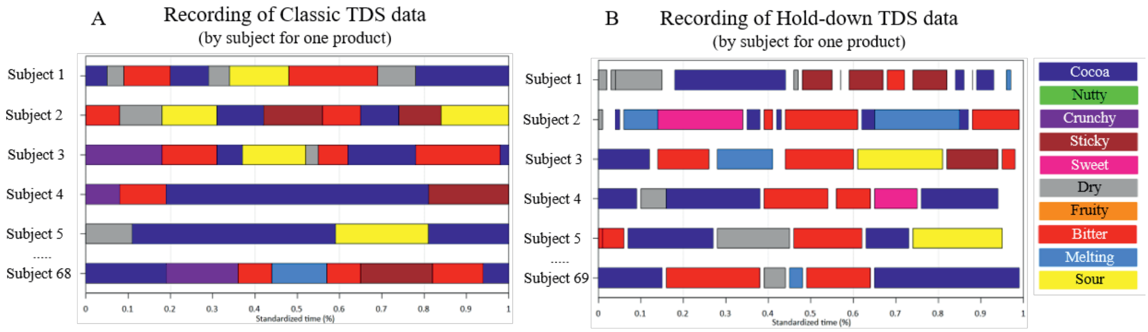
Four varieties of commercially available dark chocolates from the Lindt Excellence series (70% cocoa, Intense Orange, Grilled Sesame and Intense Cranberry) were chosen because of previously reported emotional associations with chocolate products (Cardello et al., 2012; den Uijl et al., 2016; den Uijl et al., 2016; Jager et al., 2014; Thomson et al., 2010). Clear differences in sensory characteristics between products (e.g. plain dark chocolate vs. flavoured dark chocolate with small pieces of nuts or dried fruit) were chosen to evoke different emotion responses between the dark chocolates. Participants received unbranded pieces of chocolate of approximately 3 g per sample, presented in small transparent plastic bags coded with 3-digits. Products were presented in sequential monadic order according to a Williams Latin Square design (Williams, 1949).

2.3. Attribute selection

For comparative reasons, the sensory and emotion attributes included in this study were based on the attributes and definitions used by Jager et al. (2014). Ten sensory attributes describing texture and flavour (*bitter, cocoa, crunchy, dry, fruity, melting, nutty, sour, sticky* and *sweet*) and ten emotion attributes describing valence and arousal (*aggressive, bored, calm, energetic, guilty, happy, interested, loving, nostalgic* and *whole*) were used in this study. Emotion and sensory attributes and descriptions were translated from English to Dutch and checked using back translation.

2.4. Temporal Dominance Methodologies

TimeSens (version 1.1.601.0, ChemoSens, Dijon, France) was used to collect the data for the classic TD and Hold-down TD methodologies. Participants who evaluated the four chocolates with the classic TD were instructed to put the sample into their mouth and simultaneously click the start button, allowing time recording to start. Then, they had to select the dominant attribute (e.g. the one that catches most of their attention) with a single click on the left mouse button. Dominance recording of that attribute started from then and remained selected until a new dominant attribute was chosen. When perception ended, participants had to click the stop button, allowing time recording to stop (Pineau et al., 2009). Participants could select as many dominant attributes as they liked, using the same attributes several times or never select an attribute during the consumption time. Figure 3.1a shows a typical example of how dominance duration is recorded using classic TD. Procedures for the Hold-down TD were similar to the classic TD apart from attribute selection. In the Hold-down TD participants were instructed to keep the attribute button 'actively selected' (e.g. holding down the left mouse button for as long as this attribute was perceived dominant), and release this active selection when the attribute was no longer perceived dominant. ND was recorded from the moment participants released the active selection for a dominant attribute until a new attribute was selected. See Figure 3.1b for a typical example of how dominance duration is recorded using Hold-down TD.



Gaps between dominant attributes are 'no dominance' duration periods.

Figure 3.1. Representation of typical dominance recording by classic TD method (A) and Hold-down TD method (B) by subject for one product (70% cocoa chocolate).

2.4. Procedure

Participants evaluated four dark chocolates in two separate sessions, one for sensory (TDS) and one for emotion (TDE) evaluations, employing either classic TD or Hold-down TD, using a balanced between subjects design. TDS and TDE evaluations were counterbalanced, meaning that half of the participants started with the evaluation of sensory attributes and half with the evaluation of emotions. Sessions were scheduled on separate days on the same time of day. Each session lasted for about 30 minutes. Sessions took place in the sensory facilities of the Division of Human Nutrition (Wageningen University, The Netherlands). Sensory booths were design according to ISO 8589 standards (ISO, 2007), and tests were conducted under artificial daylight and temperature control (20-22 ºC). Two days before each session participants received the definitions and examples of the sensory and emotion attributes by email. Participants were instructed to familiarize themselves with these sensory and emotion attributes. A live demonstration of TD evaluation was given before each session to inform participants about the procedures. The first sample of each session was a warm-up sample (Lindt Excellence Blueberry) so that participants could acquaint themselves with the test method. Participants were instructed to consume the whole sample at once (3 g of chocolate) for the product evaluation. After each product evaluation participants had to indicate their liking of the product on a 9-point hedonic scale with end anchors 'dislike extremely' to 'like extremely'. A neutralisation time of 1 min was included between samples, and participants were instructed to eat a piece of cracker and rinse their mouth with water.

2.5. Data analysis

All figures were plotted using TimeSens software (version 1.1.601.0, ChemoSens, Dijon, France). Statistical analyses were performed using R-studio (R version 3.4.2, RStudio team, 2016). Analyses were performed separately for classic TD and Hold-down TD. Data was pre-processed by standardizing time between 0 (first attribute selection) and 1 (click on the stop button) (Lenfant et al., 2009). Results of this study were considered significant at an alpha level of 0.05. TDS and TDE curves by product were generated for the classic TD and the Hold-down TD method. TD curves represent the proportion (%) of participants that cited an attribute as dominant at that moment in time (Lenfant et al., 2009; Pineau et al., 2009). A significance line at $p = 0.05$ was calculated according to the equation proposed by Pineau et al. (2009). The significance line in Hold-down TD is slightly lower compared to the classic TD as ND citations are considered as elicitations of an additional attribute in the analysis. For each product that was evaluated by Hold-down TD, proportions of ND duration rates in the TDS and TDE curves were compared to the significance line to determine the moments during consumption when ND duration became significantly dominant. In addition, bandplots by product were generated separately for TDS and TDE for the classic TD and Hold-down TD method. Bandplots are depicted above each TD curve, and represent the sequence and duration of dominant attributes as time-bands (Galmarini et al., 2017).

2.5.1. No dominance duration and test behaviour

Means and standard errors of the mean were calculated for total duration, latency before first citation, and total number of citations for each product for classic and Hold-down TDS and TDE. Additionally, means and standard errors of the mean were calculated for total ND duration, latency after last citation, and ND durations between citations for each product for Hold-down TDS and Hold-down TDE. To establish mean values for ND periods between attribute selections, ND periods that occurred after the first attribute selection were coded 'ND 1st switch', the ND periods after the second attribute selection were coded 'ND 2nd switch' and so forth. The switch from the last attribute selection to the stop button was coded 'ND last switch'. When assessors only had one ND period during their evaluation, this ND period was categorized in 'ND last switch'. Mean ND durations were calculated for each ND switch based on the number of assessors for each ND switch. To check if test behaviour parameters differed between methods within protocol (TDS and TDE), a three-way analysis of variance (ANOVA) was performed on each test behaviour, with product and method (classic TD and Hold-down TD) as fixed factors and subject as random factor. A three-way ANOVA was used to check for differences between TDS and TDE within method, with product and protocol (TDS and TDE) as fixed factors and subject as random factor. Differences on test behaviour parameters between products within method were tested using a two-way ANOVA, with product as fixed factor and subject as random factor. Upon significance of the ANOVA, Tukey HSD pairwise comparison was performed to indicate differences in test behaviour parameters between the four chocolate products.

2.5.2. Comparison of performance of classic TD and Hold-down TD

TDS and TDE curves and bandplots were visually inspected to identify differences and similarities in dominance sequences and dominance rates between classic TD and Hold-down TD. A two-way ANOVA was performed on the dominance duration by attribute for classic TD and Hold-down TD separately, with product as fixed factor and subject as a random factor (Galmarini et al., 2017). Product discrimination by method was evaluated with the F-product statistic. Canonical Variate Analysis (CVA) (Peltier et al., 2015b) was performed on dominance durations for classic TD and Hold-down TD separately. Attributes included in the CVA maps are significant at $p < 0.15$. CVA maps were generated separately for sensations and emotions. CVA maps included ellipses representing 90% confidence intervals (CI) for each product. Hotelling-Lawley MANOVA tests were performed for pairwise product comparison for classic TD and Hold-down TD separately (Peltier et al., 2015a). The CVA maps were visually compared on differences and similarities in product representation between classic TD and Hold-down TD.

2.5.3. Liking

Liking was evaluated immediately after the TDS and TDE evaluation. For each product, mean liking scores and standard errors were calculated for classic TD and Hold-down TD separately. To test how liking scores differed between methods, a three-way ANOVA was performed on liking, with product and method (classic TD and Hold-down TD) as fixed factors and subject as random factor. To test how liking scores observed in classic TD and Hold-down TD differed between products, a two-way ANOVA was performed on liking by method, with product as fixed factor and subject as random effect. Due to an experimental mistake, only the liking scores for the products in the last session were saved. Because a balanced design was used, half of the liking scores were saved after TDS evaluation and half after the TDE evaluation. Results based on differences in liking are therefore to be interpreted with caution due to the low sample size (n~34).

3. RESULTS

TDS and TDE curves and bandplots for the four chocolates evaluated with the classic TD (left column) and Hold-down TD methodology (right column) are depicted in Figure 3.2 and 3.3. The significance line for the classic TD is represented at a dominance rate of 16.0% and for the Hold-down TD at a dominance rate of 14.7%. The TD curves for the Hold-down TD methodology represent an attribute line characterizing the ND duration time during product evaluation. TDS and TDE curves and bandplots for the Hold-down TD methodology show that during each product evaluation ND duration time becomes significantly dominant at the last 10% of standardized consumption time. ND rates increase to approximately 100% towards the end of consumption time. Significant ND duration times in TDS for Hold-down TD methodology were observed only for the Orange-flavoured chocolate between 70-75% of standardized time. ND duration times in TDE for the Hold-down TD methodology touched significance only between 72-78% of standardized time for the 70% cocoa chocolate, and between 60-65% of standardized time for the Sesame chocolate.

3.1 No dominance duration and test behaviour

Table 3.2 shows the test behaviour at panel level by product observed with the classic and the Hold-down TD method. The number of ND periods per evaluation in the Hold-down TD is equal to the number of clicks on an attribute. The TDS protocol of the Hold-down TD had significantly more clicks, and consequently more ND periods, compared to the TDE protocol ($F(1,68) = 41.8$, $p < 0.001$). The averaged ND periods between attribute selections observed in Hold-down TD were significantly shorter for TDS compared to TDE ($F(1,68) = 11.1$, $p = 0.001$). However, the ND period between the last attribute selection and the stop button did not differ between TDS and TDE protocols in the Hold-down TD ($F(1,68) = 0.83$, $p = 0.37$). The ND period between the last attribute selection and the stop button was significantly shorter compared to the latency before first attribute selection ($F(1,68) = 74.0$, $p<0.001$). However, the latency between start and first attribute selection was significantly shorter in the Hold-down TD method ($F(1,65) = 17.1$, $p < 0.001$) compared to the classic TD method. Furthermore, participants needed significantly longer time to select the first dominant attribute in TDE compared to TDS in both methods ($F(1,65) = 19.2$, $p < 0.001$). No significant differences were observed on the overall duration of consumption for the classic and Hold-down TD in TDS and TDE ($F(3,655) = 0.7$, $p = 0.55$).

3.2 Comparison of performance of classic TD and Hold-down TD

Visual inspection of the TDS curves and bandplots (Figure 3.2) show overall very similar dominance rates and dominance durations as well as very similar sequences of dominant attributes per product for classic TD and Hold-down TD. Some minor differences, however, were observed. Compared to the Hold-down TD, *dry* was observed to be significantly dominant at the beginning of consumption in the classic TD for the 70% cocoa chocolate. For the Orange-flavoured chocolate, *melting* touched significance in the middle of consumption with the classic TD method, but not with the Hold-down TD method. In contrast to the classic TD method, *cocoa* and *sweet* were observed to be significantly dominant for the Sesame chocolate at the end of consumption with the Hold-down TD method. For the Cranberry chocolate only in the classic TD method *sticky* was observed to be significantly dominant at the middle of consumption.

TDE curves and bandplots (Figure 3.3) per chocolate evaluated with classic TD (left column) and Hold-down TD (right column) show overall similar dominance rates for the TDE evaluations, but display different dominance sequences per product. From the middle to the end of consumption lower dominance rates were observed for *calm* and *bored* for 70% cocoa chocolate in the Hold-down TD compared to the classic TD. For the Orange-flavoured chocolate longer and higher dominant rates for *nostalgic* were observed in the Hold-down TD. *Happy* only touched significance for Sesame chocolate in the classic TD, however, *happy* was observed to be significantly dominant throughout consumption in the Hold-down TD. Higher dominance rates for *calm* and *energetic* were observed in the classic TD method for the Cranberry chocolate in the beginning and middle of consumption, respectively, whereas the Hold-down TD depicted higher dominance rates for *happy* throughout consumption.

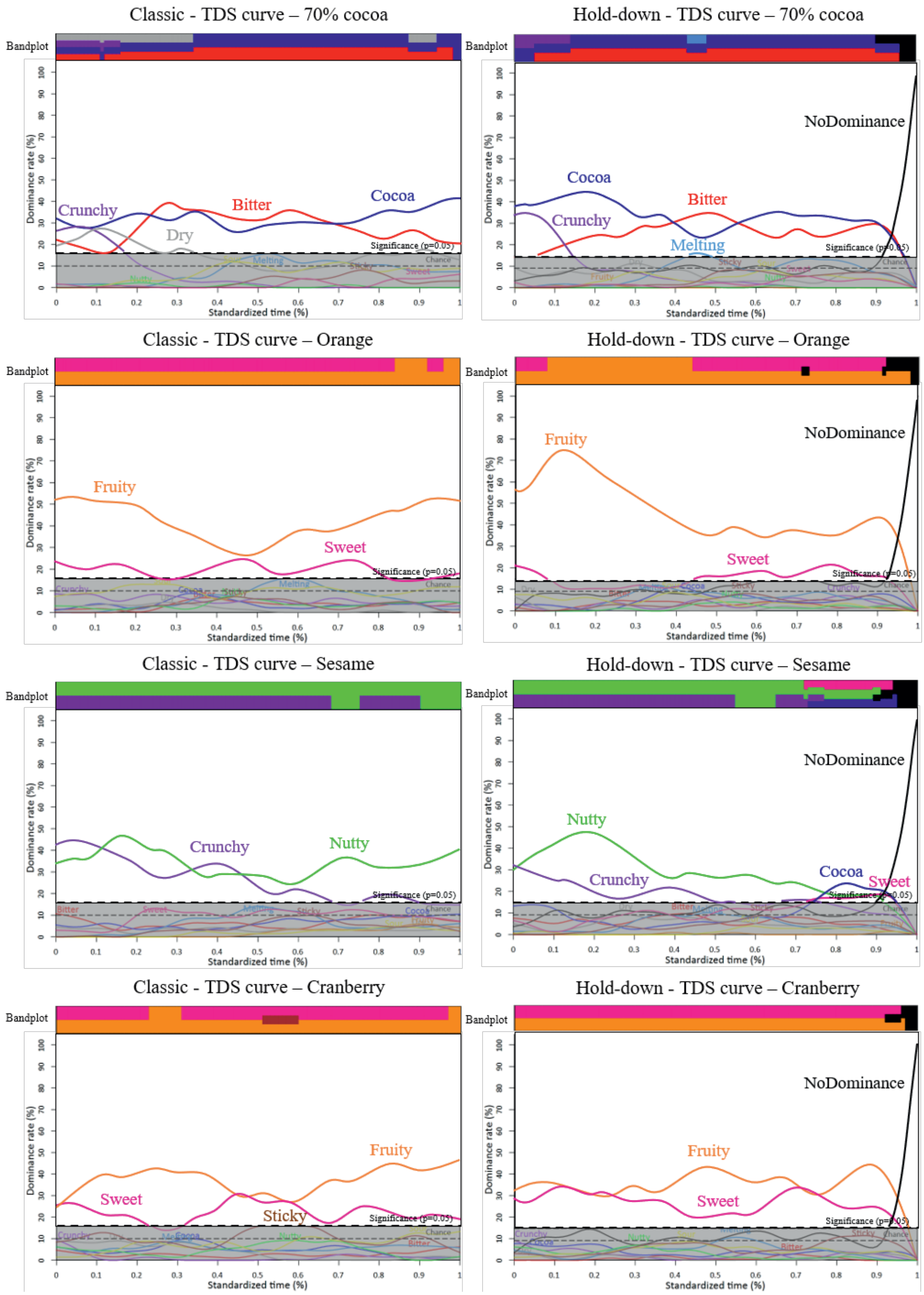


Figure 3.2. Graphic representation of the sequence of dominant sensations (TDS curves) for classic TD method (left column) and Hold-down TD method (right column) for all four chocolate products. Areas under the significance line are coloured grey.

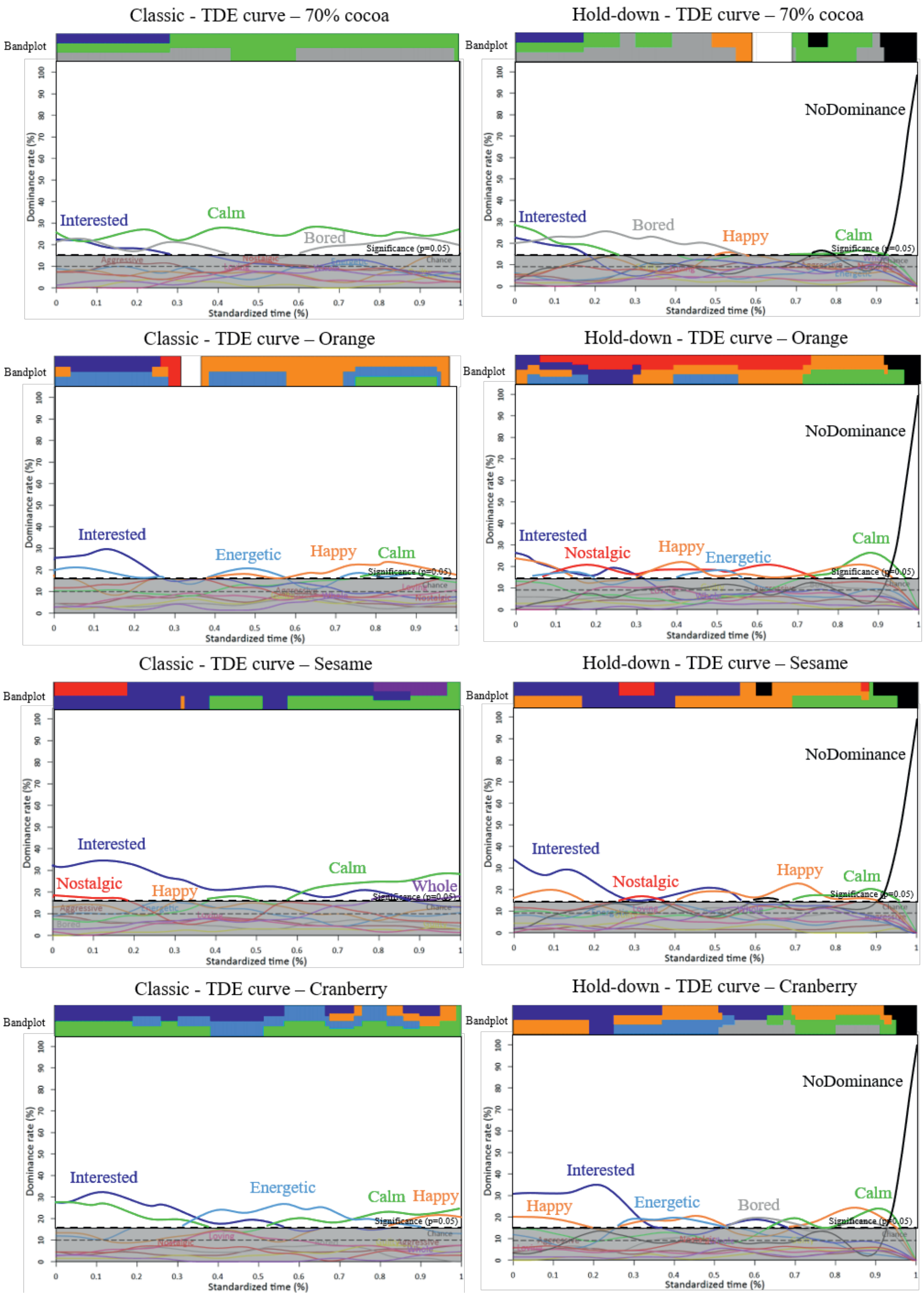


Figure 3.3. Graphic representation of the sequence of dominant emotions (TDE curves) for classic TD method (left column) and Hold-down TD method (right column) for all four chocolate products. Areas under the significance line are coloured grey.

Table 3.2. Comparison of test behaviour between products (mean values ± standard error of the mean).

	Parameter	Method	70% cocoa	Orange	Sesame	Cranberry	$F_{product}$
Temporal Dominance of Sensations	Overall duration (s)	Classic	49.7 ± 3.19[c]	43.2 ± 2.61[ab]	41.5 ± 2.29[a]	46.0 ± 2.73[bc]	**11.2*****
		Hold-down	51.3 ± 2.60[b]	46.4 ± 2.62[a]	44.8 ± 2.30[a]	48.7 ± 2.81[a]	**8.8*****
	Latency between start and first attribute selection (s)	Classic	5.26 ± 0.56	4.03 ± 0.34	4.19 ± 0.36	5.06 ± 0.44	2.65
		Hold-down	3.32 ± 0.26b	2.97 ± 0.25[a]	3.16 ± 0.27[ab]	4.17 ± 0.51[b]	**3.64***
	Total number of attribute selections	Classic	6.63 ± 0.48	6.13 ± 0.46	5.85 ± 0.40	6.47 ± 0.46	2.29
		Hold-down	6.55 ± 0.38[b]	5.49 ± 0.31[a]	6.10 ± 0.38[ab]	6.41 ± 0.43[b]	**5.17****
	Total no dominance duration per evaluation (s)	Classic	.	.	.	.	.
		Hold-down	4.63 ± 0.32	4.90 ± 0.57	5.17 ± 0.57	5.16 ± 0.51	0.54
	Latency between last attribute selection and stop (s)	Classic	.	.	.	.	.
		Hold-down	1.43 ± 0.12	1.45 ± 0.31	1.43 ± 0.14	1.17 ± 0.09	0.54
	No dominance duration between attribute selections (s)	Classic	.	.	.	.	.
		Hold-down	0.58 ± 0.04	0.77 ± 0.08	0.73 ± 0.11	0.74 ± 0.07	1.63
Temporal Dominance of Emotions	Overall duration (s)	Classic	48.2 ± 3.05[b]	42.1 ± 2.60[a]	42.4 ± 2.51[a]	44.2 ± 2.76[a]	**7.15*****
		Hold-down	51.6 ± 2.72[b]	44.6 ± 2.71[a]	43.1 ± 2.35[a]	46.0 ± 2.53[a]	**13.3*****
	Latency between start and first attribute selection (s)	Classic	6.23 ± 0.46	5.88 ± 0.65	5.42 ± 0.42	6.10 ± 0.65	0.65
		Hold-down	4.72 ± 0.48[b]	3.46 ± 0.29[a]	4.61 ± 0.46[b]	3.97 ± 0.38[ab]	**3.52***
	Total number of attribute selections	Classic	4.12 ± 0.29	3.99 ± 0.25	3.88 ± 0.29	3.87 ± 0.28	0.41
		Hold-down	4.86 ± 0.32	4.3 ± 0.29	4.42 ± 0.30	4.59 ± 0.33	2.03
	Total no dominance duration per evaluation (s)	Classic	.	.	.	.	.
		Hold-down	5.49 ± 0.59	4.08 ± 0.47	4.90 ± 0.61	4.53 ± 0.47	2.25
	Latency between last attribute selection and stop (s)	Classic	.	.	.	.	.
		Hold-down	1.61 ± 0.21	1.27 ± 0.09	1.69 ± 0.31	1.39 ± 0.19	0.91
	No dominance duration between attribute selections (s)	Classic	.	.	.	.	.
		Hold-down	1.13 ± 0.13	0.95 ±0.18	1.11 ± 0.29	0.99 ± 0.13	0.77

Significant at (*) 0.05, (**) 0.01, (***) 0.001.

[ab] Different letters in a row indicate significant differences ($p < 0.05$) between products according to Tukey's HSD at 95% confidence.

3.3 Product discrimination

Table 3.3 shows the product discrimination for each attribute for the classic TD and the Hold-down TD method for the sensory and emotion evaluations. The classic TD and the Hold-down TD both discriminated the products on *bitter, cocoa, crunchy, dry, fruity, nutty* and *sweet* sensations. The classic TD additionally discriminated the products on *sour* and *sticky*. The classic TD and the Hold-down TD both discriminated the products on the emotions *bored, interested, nostalgic* and *whole*. The classic TD additionally discriminated the products on *calm, energetic, happy* and *loving*, whereas the Hold-down TD additionally discriminated the products on *aggressive*.

Table 3.3. ANOVA of dominance durations of sensation and emotion attributes for the classic TD and the Hold-down TD methodologies.

	Attribute	Classic TD F-value	Hold-down TD F-value		Attribute	Classic TD F-value	Hold-down TD F-value
Sensations	Bitter	**37.30*** **	**59.94*** **	Emotions	Aggressive	0.95	**3.32***
	Cocoa	**56.61*** **	**83.10*** **		Bored	**8.66*** **	**4.23** **
	Crunchy	**50.50*** **	**28.40*** **		Calm	**4.17** **	1.22
	Dry	**26.84*** **	**8.04*** **		Energetic	**3.96** **	1.68
	Fruity	**118.99*** **	**149.65*** **		Guilty	1.00	0.13
	Melting	0.45	2.52		Happy	**3.60***	2.13
	Nutty	**84.11*** **	**91.95*** **		Interested	**3.34***	**2.84***
	Sour	**4.31** **	1.86		Loving	2.03	1.39
	Sticky	**10.64*** **	1.38		Nostalgic	**2.86***	**4.39** **
	Sweet	**27.71*** **	**26.04*** **		Whole	**4.6** **	**3.84***
	No dominance	.	2.44		No dominance	.	2.13

Significant at (*) 0.05, (**) 0.01, (***) 0.001.

CVA maps on dominance duration of sensations for classic TD (left map) and Hold-down TD (right map) are depicted in Figure 3.4. Each of those maps account for 98% of the explained variance. The MANOVA F-statistics are of the same magnitude (52-55) indicating the same level of discrimination of the two methods. Hotelling-Lawley test showed that all products were evaluated significantly different from each other on sensory characteristics ($p < 0.05$) in the Hold-down CVA map. In contrast, product differences observed with the classic TD method show that the Cranberry chocolate and Orange chocolate are perceived similar in terms of their sensory characteristics ($p = 0.94$).

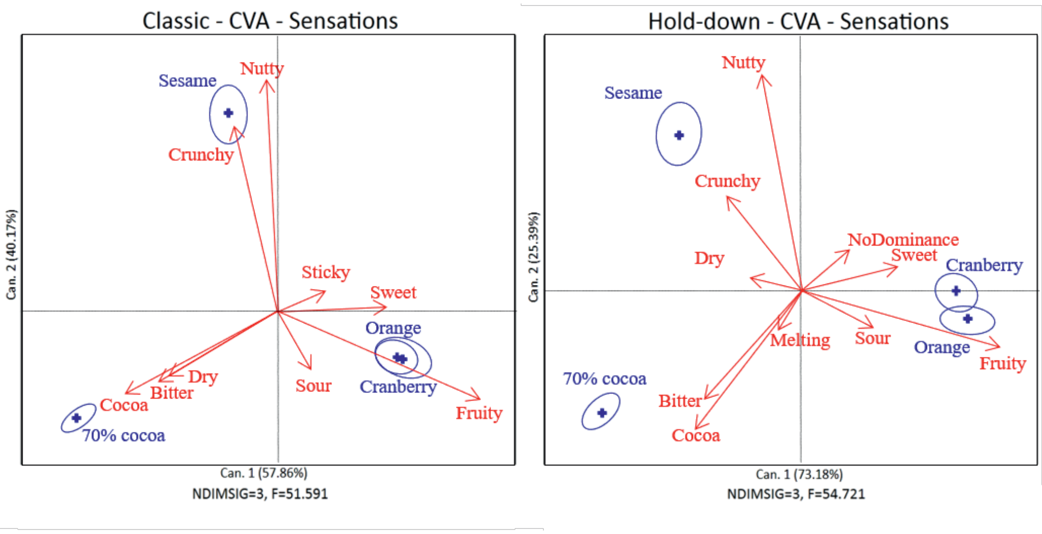


Figure 3.4. CVA maps of dominance durations of sensations by classic TD (left column) and Hold-down TD (right column) methodology. Confidence ellipses at 90% and F-values significant at p<0.001. NDIMSIG represents the number of significant dimensions.

Figure 3.5 represents the CVA maps on dominance duration of emotions for classic TD (left map) and Hold-down TD (right map) accounting for 87.7% and 79.6% of the explained variance, respectively. Overall, product discrimination is slightly better with classic TD ($F = 3.5$) versus Hold-down TD ($F = 3.0$). The Orange-flavoured chocolate and Cranberry chocolate were perceived similar in terms of their emotion profiles as observed with the classic TD method ($p = 0.13$). The CVA map for the emotions by the Hold-down TD method show no significant differences in emotion perception between the Sesame and Cranberry chocolate ($p = 0.19$). All other pairwise comparisons between products by Hotelling-Lawley test were significant ($p < 0.05$) in both methods.

Interestingly, both methods show similar product differentiation for sensations and emotions, whereas dimension 1 differentiates the fruity-flavoured chocolates from the non-fruity flavoured chocolates. Dimension 2 further distinguishes between the Sesame (nutty) chocolate and the other chocolates.

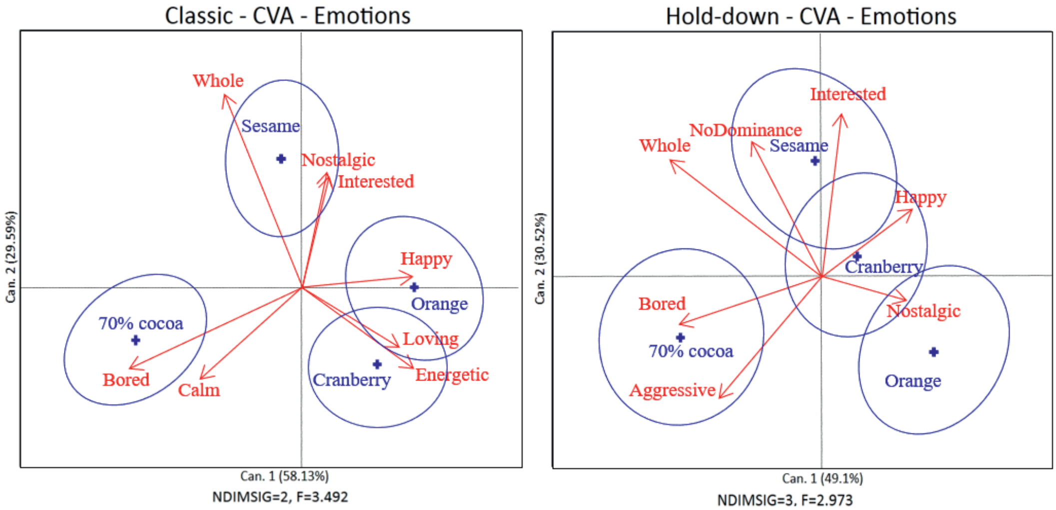


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Figure 3.5. CVA maps of dominance duration of emotions by classic TD (left column) and Hold-down TD (right column). Confidence ellipses at 90% and F-values significant at p<0.001. NDIMSIG represents the number of significant dimensions.

3.4 Liking

Mean liking scores and standard errors for the four chocolates assessed on a 9-point hedonic scale after TDS and TDE evaluations with classic TD and Hold-down TD are represented in Table 3.4. Liking results should be interpreted with caution due to the low sample size (n~34). No interactions for product by method ($F(3,405) = 0.20$, $p = 0.90$) and protocol (TDS and TDE) by method ($F(1,405) = 0.01$, $p = 0.93$) were observed. That suggests that the method (classic TD and Hold-down TD) did not influence how products were liked and that liking scores were similar between methods by protocol. However, a significant interaction for product by protocol ($F(3,405) = 5.56$, $p < 0.001$) indicates that products were scored significantly different on liking after TDS and TDE evaluations. No clear direction of difference was observed as the 70% cocoa and Sesame chocolate were less liked and the Orange flavoured and Cranberry chocolate were more liked after TDE evaluations compared to TDS evaluations. Liking scores obtained after TDE evaluations did not significantly differ among the four chocolate varieties ($p > 0.05$). In contrast, significant differences in liking between chocolates where observed when liking was rated after TDS evaluations ($p < 0.05$). Liking scores observed after TDS evaluations with classic TD and Hold-down TD report that the Sesame chocolate was most liked and Cranberry chocolate least liked.

Table 3.4. Mean liking scores (± standard error of the mean) of the four chocolates assessed on a 9-point hedonic scale (1 being dislike extremely and 9 being like extremely) after classic TD and Hold-down TD evaluations.

Method	Protocol	n	70% cocoa	Orange	Sesame	Cranberry	F-value	P-value
Classic	TDS	35	6.0 ± 0.3^{ab}	5.8 ± 0.4^{a}	6.9 ± 0.3^{b}	5.8 ± 0.3^{a}	2.8	0.04
	TDE	33	5.8 ± 0.4	6.3 ± 0.3	5.9 ± 0.3	5.9 ± 0.3	0.5	0.66
Hold-down	TDS	33	6.4 ± 0.3^{ab}	6.0 ± 0.4^{a}	7.2 ± 0.3^{a}	5.8 ± 0.3^{b}	4.0	0.01
	TDE	36	5.4 ± 0.4	6.6 ± 0.3	6.2 ± 0.4	6.5 ± 0.3	2.6	0.06

[ab] Similar letters within one row refer to statistically comparable liking scores ($p<0.05$).

4. DISCUSSION

The aims of this study were (i) to compare the performance of the Hold-down TD with the classic TD methodology for dynamic sensory and emotion profiling, and (ii) to identify ND duration periods in TD evaluations in an example product category (dark chocolates). We hypothesized that the Hold-down TD method allows to implicitly capture periods of hesitation and indecisive behaviour which leads to reduced noise in the data, resulting in higher sensitivity and better product discrimination. Our findings indicate similar performance in terms of sensitivity of the classic TD method and the Hold-down TD method. No evidence was found for the Hold-down TD method outperforming the classic TD method with regard to product discrimination ability.

ND duration periods observed between the selection of two subsequent dominant attributes in the Hold-down TD method were on average less than 1 s. It seemed plausible that periods of ND would have occurred because of a delayed response time, uncertainty about attribute selection or indecisive selection behaviour due to hesitation. In contrast, the short ND duration periods between the selection of dominant attributes observed in TDS and TDE in the Hold-down method could indicate that subjects continuously perceive dominant attributes. One could speculate that consumers already think about the next dominant attribute before letting go of the currently dominant attribute. The observed time between subsequent dominant attributes is considered too short to represent moments of ‘true’ hesitation and indecisive behaviour, such as mentally weighing the dominance of more than one attribute. Consequently, it seems far more likely the ND duration periods represent the time needed to switch between dominant attributes. Hence, despite subjects were offered the possibility to implicitly indicate indecisive behaviour, and for example think about the next attribute to select for some time, simply by not holding down any attribute button, this behaviour was not observed in this study. The question is whether this was in part related to the task paradigm at hand. We deliberately chose not to include a ND button and/or to highlight the occurrence of ND periods to participants, as this seems to be incompatible with the very nature of ND (i.e. the absence of something). Still, panellists might need clearer and more explicit instruction on the option of ND periods.

As a result of time standardization, implicit ND captured with Hold-down TD will always reach a dominance rate of 100% at the end of consumption. A dominance rate of 100% represents 100% panel agreement since all subjects release the selection of the last dominant attribute and press the stop button at the end of the TD task. ND becomes significantly dominant only in the last 10% of product evaluation, meaning that there are individual differences on the latency between last attribute selection and pressing the stop button. Consequently, panel consensus about dominance of any of the sensory and emotion attributes dropped below significance. Hence, the Hold-down TD method might possibly correcting an overestimation of significant dominance rates in the last 10% of standardized consumption time in classic TD. The present results on ND duration time in TDS evaluations were in line with previous observations from a pilot study (presented by Schlich et al., at the 2nd Asian Sensory and Consumer Research Symposium, Shanghai, May 2016). In this pilot study ND duration time was observed in TDS evaluations of dark chocolate. The results of the pilot study showed that ND duration time became significantly dominant in the last 10% of standardized consumption time. Most studies on TDS correct for the latency before first attribute selection to reduce noise in the data. However, the current study did not find indications to correct for the latency after the last attribute selection as this duration was observed to be short (approx. 1.4 s) and was significantly lower compared to the latency before first attribute selection. One could speculate that the increase in ND duration towards the end of consumption time could have been due to ambiguity on the definition ‘when perception ends’.

ND represents the absence of dominance for any of the sensations instead of an ‘active’ perception. Due to the nature of the concept ‘no dominance’ participants were not informed that periods of ND were recorded, nor were they given the option to explicitly choose for a ND period during their evaluations (e.g. by providing a button coded “no dominance”). Instead, the Hold-down TD measured ND periods in TDS and TDE implicitly, where ND reflected the period between the selection of two subsequent dominant attributes. A previous study included a ‘no perception’ button in TDS evaluations with predefined consumption times. They observed that dominance rates of 'no perception' gradually increase towards the end of the predefined consumption time and even reach significance at the end of consumption time in 2 out of 5 product profiles when texture and taste attributes are assessed simultaneously (Rodrigues et al., 2018). Although the concept and design of the current study was different, it seems plausible that at the end of consumption time it becomes more difficult to perceive and report dominant sensations. However, one could debate whether the inclusion of a 'no dominance' or 'no perception' button does justice to the conceptual nature and definition of dominance and the absence of it.

The classic and Hold-down TD method differed on the selection procedure of a dominant attribute. In the classic TD only the moment of dominance of an attribute has to be weighted by the assessors, whereas in the Hold-down TD the assessors also have to decide when dominance of an attribute ends. Although the Hold-down TD is based on the concept of dominance, the selection procedure of a dominant attribute comes closer to the selection procedure in the TCATA method, where assessors have to select and deselect attributes that are applicable at a given moment in time (Castura et al., 2016). Comparable to the aim of our study, TCATA Fading was introduced to reduce noise and to eliminate an overestimation of applicable attributes at moments of consumption in the TCATA method (Ares et al., 2016). In TCATA Fading, assessors select applicable attributes at a given moment in time and the attribute selection is gradually unselected over a period of 8 s. Similar dynamic profiles were observed between TCATA and TCATA Fading, but TCATA Fading resulted in lower citation proportions. Ares et al. (2016) suggested that selecting and un-selecting attributes might require different cognitive processes that possibly underlie differences in dynamic profiles.

As sensory characteristics of foods are thought to be related to food-evoked emotions (Gutjar et al., 2015a), one would expect that with similar dynamic sensory profiles observed between classic TD and Hold-down TD, the dominance sequences for emotions would also be similar for the different methods. However, this was not what was found in the present study. Although the type of emotions that characterized each product were similar between methods, the dynamic sequences of emotions by product deviated between classic TD and Hold-down TD. This suggests that not only the sensory characteristics of food but other factors, such as context or the task paradigm at hand, may influence food-evoked emotion profiles. It is still unknown to what extent food-evoked emotion profiles are solely elicited by the evaluated food and to which degree context and task characteristics influence the reproducibility of food-evoked emotion evaluations.

Lower dominance rates were observed for the emotion attributes compared to the sensory attributes in classic and Hold-down TD method. Consequently, better product discrimination was observed in TDS compared to TDE. The difference in dominance rates and product discrimination supports the idea that consumers show less agreement on self-reported food-evoked emotions compared to sensory characteristics (Jager et al., 2014). The evaluation of food-evoked emotions might include recalled believes and experiences of the food product, rather than the actual food-evoked emotion the product communicates during the evaluation moment (Köster & Mojet, 2015; Thomson et al., 2010). Furthermore, it could be that emotion responses evoked by food are not as strong as sensory characteristics, are more intuitive, and therefore more difficult to recognize and report compared to the sensory characteristics of food. Emotions are perceived rather unconscious, but direct self-reported emotion measurements demand consumers to verbalize these unconscious emotions (Thomson, 2016). Consequently, reporting food-evoked emotions might be a more demanding task compared to the identification of sensory characteristics which requires a more analytical mind-set.

When discussing the results of the hedonic assessment, caution should be taken with interpretation due to the low sample size (n~34). Hence, these findings should be considered as explorative and need replication. No differences in liking of products were observed between liking scores obtained after classic TD and Hold-down TD, meaning that the selection task of the different methods does not seem to influence the liking scores. However, significant differences in liking of products were observed when liking was evaluated after TDS and TDE evaluations, suggesting that reporting dominant sensations or emotions might have an effect on hedonic evaluations. The cognitive process prior to the hedonic evaluations might have influenced the liking scores. Traditionally, hedonic evaluations are decoupled from analytical assessments to put consumers more in an integrated state of mind to evaluate the product as a whole instead of breaking it down in sensory characteristics (Lawless & Heymann, 2010). Liking scores observed after TDS, which has a more analytical nature, discriminated more between products (significant differences in liking assessed after TDS between products were observed) compared to liking scores after TDE, which has a more intuitive nature (no significant differences in liking assessed after TDE between products were observed).

From a methodological point of view the Hold-down TD method has its strengths and limitations. The Hold-down TD method has the advantage that it actively involves assessors during the TD evaluations, as they have to monitor the start, duration, and the end of perceiving an attribute as dominant. The currently proposed Hold-down TD measured ND periods implicitly, that is, ND was not included as an 'active' choice option, by providing an ND 'attribute' button. Yet, ND was included as an additional descriptor in the analysis of the Hold-down TD methodology and, consequently, the TD curves of the classic and Hold-down TD methodologies are not completely comparable. Measuring ND explicitly in TDS and TDE by including a ND attribute button seems a plausible alternative. However, in our opinion this would raise a conceptual 'difficulty' as it seems counterintuitive to ask participants to actively report something that is 'not there', i.e. dominance, the central concept in TDS. In addition, the option of a ND button eliminates the forced choice in TD and might result in less attribute selections and consequently a decrease in product discrimination. These are issues that are related to similar debates in, for example, scaling and the design of scales, e.g. including a 'neutral' or 'not applicable' option or not, which affects how panellist use a scale (Lawless & Heymann, 2010).

The current study used a between subjects design to reduce learning effects on the performance of the TD methods. The advantage of using two independent consumer panels, who were not familiar with the TD methodologies, is that previous knowledge about and experience with the evaluation procedure of the classic TD method could not have influenced the Hold-down TD evaluations and vice versa. The downside of using a between subjects design is the introduction of an extra source of variation in the data related to the different subject groups. This touches upon the issues of reliability, test-retest reproducibility for TDS and TDE, topics that warrants further study. However, this is not restricted to TD methods, but clearly true for many other available methods to measure (temporal) sensory and emotion profiles in the field of sensory science.

Although currently available self-reported food-evoked emotion measures often include intensity ratings, TDE requires consumers only to select the dominant emotion at a given moment in time during consumption (King & Meiselman, 2010; Nestrud et al., 2016). The advantage of using the TDE method to generate dominant emotion profiles is that it can provide a more intuitive selection procedure compared to the analytical mind-set provoked by asking intensity scores. However, all self-report methods, either static or temporal, only reveal the subjective conscious experience of emotions (the subjective feeling one becomes aware of), whereas parts of the complex emotion process in other subsystems, both central (the brain) and peripheral (bodily and physiological signals such as changes in heart rate, and facial expressions) remain hidden (Kahneman, 2003; Köster, 2003; Köster & Mojet, 2015; Scherer, 2005, 2009). More implicit measures, such as observational measurements (e.g. facial expressions) and physiological measurements (e.g. heart rate) might provide additional information on fast changes in emotion response during food consumption (de Wijk et al., 2012; Liao et al., 2015). To get more insight on the dynamics of food-evoked emotions measured with consumers we recommend to compare the TDE method with implicit dynamic emotion measures such as facial expressions. Furthermore, monitoring panel performance has been suggested for the evaluation of sensations using TDS (Lepage et al., 2014; Meyners, 2011; Nguyen et al., 2018), but has not yet been explored in TDE. To better understand the food-evoked emotion evaluations of consumers there is a need to explore the repeatability of TDE within one consumer group by including replicates.

In conclusion, using Hold-down TD revealed ND duration times between the selection of two subsequent attributes that were too short (less than 1 s on average) to be considered moments of true hesitation or indecisive behaviour by panellists. Consequently, no evidence was found for Hold-down TD outperforming classic TD in terms of sensitivity and discrimination ability in this study. Irrespective of the conceptual likelihood of panellists experiencing 'no dominance' periods, the present study failed to demonstrate moments of hesitation using the 'Hold-down' procedure. Capturing moments of indecisive selection behaviour (both at the individual and panel level) warrants further exploration and methodological developments to be able to identify this likely characteristic of panellist behaviour.

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CHAPTER 4

From first to last bite:

Temporal dynamics of sensory and hedonic perceptions using a multiple-intake approach

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ABSTRACT

Sensory perceptions evolve over time. Evaluation of sensory and hedonic perceptions after one bite are common. However, single bite assessments do not represent normal eating behaviour as consumers eat food portions with multiple bites. We hypothesise that dynamics of sensations and hedonics not only evolve within a bite but also evolve over bites. This study aims to investigate the temporal dynamics of sensations and hedonic perceptions using multiple-intake assessment employing Temporal Dominance of Sensations (TDS) and Alternated Temporal Drivers of Liking (A-TDL). Seventy-six participants evaluated six yogurts with granola pieces varying in size, hardness and concentration. An attentional shift was observed from yogurt attributes (*creamy* and *sour*) in the beginning of each mouthful to granola attributes (*sweet, wheat* and *sticky*) at the end of each mouthful. *Sticky* sensations gradually increased in dominance duration from the first to the fifth mouthful for five of six yogurts demonstrating the built up of dominance of this attribute. *Creamy, crunchy* and *sweet* were observed to be positive drivers of liking, consequently increasing liking. *Sour* and *sticky* were negative drivers of liking, decreasing liking upon dominance of these attributes. We conclude that consumer's sensory perception of food products changes from bite to bite. Our findings indicate that multiple-intake evaluations of dynamic sensations provide additional information about food perception, such as the built up of sensations from bite to bite. These changes in sensations cannot be captured by single bite assessments.

1. INTRODUCTION

Profiling composite foods is gaining interest in sensory- and consumer science because it reflects more natural eating conditions. Composite foods, e.g. yogurts with fruit or granola pieces or breads with cheese, have increased sensory complexity as the sensory characteristics of one food product influences the sensory perceptions of the other food (van Eck et al., 2019). Moreover, composite foods with texture or flavour contrasts are generally more liked (Hyde & Witherly, 1993). Despite the fact that normal eating behaviour often involves eating full portions with multiple bites, it is still common practice in sensory- and consumer science to focus on single bite sensory evaluations (Di Monaco et al., 2014). However, single bite assessments of single food components do not do justice to the dynamics in sensory and hedonic perceptions that unfold over time during consumption of a portion of food or a meal (Castura et al., 2016; Delarue & Blumenthal, 2015; Pineau et al., 2009). Measuring the dynamics of sensory and hedonic perceptions over multiple bites of composite foods with increased sensory complexity will lead to more representative product profiles that fit better with natural eating behaviour and, consequently, to a better understanding of consumer behaviour. In addition, it seems plausible to expect differences in the dynamics of sensory and hedonic perceptions both within and between bites due to lingering and/or built up of sensations, or changes in responsiveness (adaptation) over repeated exposure (Köster, 2003; Lawless & Heymann, 2010).

Several studies investigated the dynamic changes in sensory and hedonic perceptions using multiple bite assessments. Antúnez et al. (2017) compared the sensory and hedonic evaluations of single and two bite assessments of salt reduced bread samples employing Check-All-That-Apply method and liking scores. No significant differences were observed in sensory and hedonic profiles between first and second bite, but better product discrimination was observed between samples in the second bite. Antúnez et al. (2017) suggests that multiple bite assessments might provide more accurate information on the sensory and hedonic perceptions of consumers during consumption, but acknowledged that the number of evaluations (two bites) might have been too low. Zorn et al. (2014) evaluated artificial sweetened orange juices employing Temporal Dominance of Sensations (TDS) methodology using a three-sip approach. Depending on the sweetener added to the orange juice, they observed dynamic changes in dominance duration of sour, sweet and bitter sensations from the first to the third sip. A study that used a substantial higher number of subsequent tastings was done using six oil-in-water emulsions which were evaluated by a trained panel performing descriptive analysis for 12 subsequent spoons. Results indicated that the intensity of fatty sensations built up with subsequent intakes, and that differences in sweetness between emulsions only became noticeable after first exposure (Appelqvist et al., 2016). Taken together, these findings imply that repeated measures over multiple bite/sips provide additional information on product performance beyond an assessor's first impression, i.e. the first bite/sip. A next step involves multiple bite studies with consumers (vs. trained panels) being exposed to full portions of common foods or drinks (vs. model foods like oil-in-water emulsions and vs. 2 or 3 bite/sip approaches) in order to mimic more closely natural eating behaviour.

The aim of the present study was to expose a consumer panel to a larger number of bites/sips than two or three, and to use composite foods with a higher sensory complexity, which may impact the temporal dynamics of hedonic and sensory evaluations, both within- and between bites. As composite foods we used portions of yogurt with six added granola toppings varying in size, hardness and concentration, to be evaluated on sensory (TDS) and hedonic (liking) characteristics using a multiple-intake approach of five subsequent spoonsful of yogurt with granola . We hypothesized that, in line with previous findings, results from the first spoon may stand out to some extend from the results of the subsequent spoons due to lingering and/or built up of particular sensations. In addition, it was hypothesized that within- and between mouthfuls the sensory characteristics from the yogurt influence the sensory perceptions of the granola and vice versa. This may be expressed by shifts in attention/dominance from one product component to another or from one sensory domain to another, e.g. from taste to texture. Finally, we explored how potential changes in liking across bites co-occur with changes in perceived dominance of specific sensory attributes. This could allow for identification of temporal drivers of liking (Thomas et al., 2016).

2. METHODS

As part of a larger study, participants completed two separate test sessions; one for the sensory and hedonic evaluations employing TDS and alternated-TDL, and a second session for emotion evaluations employing Temporal Dominance of Emotions (TDE). Simultaneously with these sessions participants were video recorded in order to monitor facial expressions using FaceReader™ (Noldus Information Technology, Wageningen, The Netherlands). The data and findings on food-evoked emotions (TDE and facial expressions) are outside the scope of the current paper and will be reported in a separate paper. This paper focuses on the sensory and hedonic evaluations employing TDS and alternated-TDL. All data were collected at Wageningen University (The Netherlands). The experimental protocol was submitted to and exempted from ethical approval by the Medical Ethics Committee of Wageningen University.

2.1. Participants

A sample size calculation according to Pineau et al. (2009) was done, where the minimal number of observations for a TDS test is calculated with the equation: n = number of products/(P_0 * (1- P_0)), with P_0 = 1/p, with p being the number of attributes. This resulted in n = 6/(0.1 * (1 – 0.1)) = 67. As the study does not include replicates, a minimum number of 67 participants were required.

Taking into account some drop outs, 76 healthy Dutch participants (34% male, mean age 28.8 ± 12.9 years, mean BMI 22.4 ± 2.2 kg/m^2) were recruited from a database with volunteers to participate in research of the Division of Human Nutrition of Wageningen University, the Netherlands. All participants were consumers of yogurt, without allergies or intolerances for lactose, gluten, milk or nuts and with normal abilities to taste and smell (self-reported). Participants received a monetary incentive for their participation, and gave written informed consent before the start of the study.

2.2. Products

Commercially available yogurt (Optimel Greek Style, Friesland Campina, The Netherlands) and commercially available granola (Crunchy Hazelnut Granola, Biofamilia, Switzerland) were used in this study. Product characteristics are specified in Table 4.1. To obtain granola pieces differing in size, commercially available granola was sieved using a stack of sieves differing in mesh size. By those means fractions of granola with average particle diameters of 9.5 ± 0.22 mm (small granola pieces) and 19.7 ± 0.24 mm (large granola pieces) were obtained. To obtain granola pieces differing in hardness, the commercially available granola was softened by placing 6 g granola in a sealed box with a cup of 23 g still mineral water for 19 hours at room temperature. Mineral water evaporated inside the sealed box and was taken up by the granola, causing softening of the granola. Participants received a total of 60 g per yogurt-granola combination, presented in white plastic cups coded with 3-digits. A warm-up sample, consisting of 54 g yogurt with 3 g of small granola and 3 g of large granola, was included to familiarize participants with the study procedures.

Table 4.1. Product specifications.

Product	Granulation (mm)	Hardness	Concentration		kcal
			Yogurt (g)	Granola (g)	
Hard:Large:10%	23	Hard	54	6	57
Hard:Small:10%	10	Hard	54	6	57
Soft:Large:10%	23	Soft	54	6	57
Soft:Small:10%	10	Soft	54	6	57
Hard:Small:20%	10	Hard	48	12	84
Hard:Small:3%	10	Hard	58	2	38

Granulation: size of the breaking grids that were used to define particle sizes.

2.3. Attribute selection

Twenty sensory attributes were preselected based on literature (Bouteille et al., 2013; Bruzzone et al., 2013). A Check-All-That-Apply was performed by 10 consumers (not participating in real experiment) to identify the 10 most frequently cited sensory attributes, that were used for TDS evaluations. Table 4.2 shows the sensory attributes with descriptions as provided to the participants during TDS instructions.

Table 4.2. Sensory attributes and descriptions.

Sensation	Modality	Description
Sour	Taste	Taste associated with citric acid
Sweet	Taste	Taste associated with sugar
Wheat	Flavour	Taste associated with grains (all kind of grains)
Nutty	Flavour	Taste associated with nuts (all kind of nuts)
Crunchy	Texture	Perception of the crushing sound transmitted through the jaws while chewing
Hard	Texture	High force required to compress the sample with the molars
Stale	Texture	Air-exposed, tough structure when chewing the product
Creamy	Texture/ mouth feel	Sensation related to a full, soft and smooth texture
Dry	Texture/ mouth feel	Sensation related to a dry and rough feeling on the tongue and oral cavity
Sticky	Texture/ mouth feel	Adhesion of the product to the palate and teeth

2.4. Procedure

Participants completed two test sessions for the sensory evaluations. Participants evaluated one warm-up sample and three test samples per test session. Total amount of product evaluated per session was 240 g, which approximately corresponds to the amount of a full portion. Sessions took place in sensory booths (Restaurant of the Future, Wageningen, The Netherlands), had a duration of 45 minutes and were scheduled on separate days between 08.00 and 10.00 h. Sensory booths were designed according to ISO 8589 standards (ISO, 2007), and tests were conducted under artificial daylight and temperature control (20-22 ºC). One day before each session participants received the attribute list with definitions by email to familiarize themselves with the terminology. A live demonstration of the study procedures was given at the start of the first session. Participants were instructed to consume the whole sample (60 g) in five small portions using a table spoon, and to always consume yogurt and granola within one spoonful. Participants were not instructed about the number of chews within one mouthful. Participants were video recorded during all bites, and performed TDS ratings during the first, third and fifth spoonful, after which they were also instructed to rate liking on a continuous scale with end anchors 'dislike extremely' to 'like extremely'. During the second and fourth spoonful ('no task') participants ate the product without performing TDS or liking ratings. To determine the bite duration of the second and fourth spoonful, participants were instructed to put the sample in their mouth and simultaneously click the start button, allowing time recording to start. When perception ended, participants had to click the stop button, allowing time recording to stop. A 3 min neutralisation period was included between samples where participants ate a piece of cracker and rinsed their mouth with water.

2.5. Temporal Dominance of Sensations (TDS)

At the first, third and fifth spoonful participants were instructed to put a full spoon with yogurt and granola into their mouth and simultaneously click the start button, allowing time recording to start. Then, they had to select the dominant attribute, defined as the attribute that catches most of their attention at each moment in time. Dominance recording of that attribute started from then and continued until a new dominant attribute was selected. When perception ended, participants had to click the stop button, allowing time recording to stop (Pineau et al., 2009). Participants could select as many dominant attributes as they liked, using the same attributes several times or never select an attribute during the consumption time.

2.6. Data analysis

All figures were plotted using TimeSens software (version 1.1.601.0, ChemoSens, Dijon, France). Statistical analyses were performed using R (R version 3.4.2, RStudio team, 2016). Data was pre-processed by standardizing time between 0 (first attribute selection) and 1 (click on the stop button) (Lenfant et al., 2009). Bandplots were computed by product for the first, third and fifth spoonful. Bandplots represent the sequence and duration of dominant attributes as time-bands (Galmarini et al., 2017). Dominant attributes visualised in the bandplots are significant at $p < 0.05$.

2.6.1. Multivariate product discrimination

Canonical Variance Analysis (CVA) was performed on non-standardized data of the dominance durations. Attributes included in the CVA plots are significant at $p < 0.15$. CVA plots include ellipses representing 90% confidence intervals (CI) for each product. Hotelling-Lawley MANOVA tests were performed for pairwise product comparison (Peltier et al., 2015a).

2.6.2. Product discrimination

To check for order effects of serving position, mean liking scores and mean dominance durations of the sensory descriptors per response order were calculated and included in a mixed model ANOVA. No significant order effects of serving position were observed for liking or any of the sensory attributes (data not reported). Therefore, the product's evaluation order was not included in follow-up mixed model ANOVA's. Mean liking scores and mean dominance durations per sensory descriptor and standard errors of the mean (SEM) were calculated for each spoonful per product. A three-way ANOVA was performed with product and spoonful as fixed effects, and subject and its interactions with all fixed factors as random effects. Upon significance of the ANOVA, Tukey's HSD pairwise comparison was performed.

2.6.3. Temporal Drivers of Liking

Temporal drivers of liking were computed according to Thomas et al. (2016). In short, dominance durations per attribute by product were obtained from non-standardized data. For each sensory descriptor, an individual Liking While Dominant (LWD) score was calculated by weighing the average liking score to the descriptor's dominance duration for each product. Centred Liking While Dominant (CLWD) scores were calculated by subtracting the average liking scores weighed by the bite durations from the LWDs per attribute by product. CLWDs for each sensory descriptor were averaged for the number of consumers who cited the attribute as dominant, and tested for equality to the theoretical mean of 0 using a one-sample t-test. An attribute was considered a significant driver of liking at $p < 0.05$. When an attribute's CLWD score is significantly higher than 0 it identifies as a positive driver of liking and with a score significantly lower than 0 it represents a negative driver of liking (Thomas et al., 2016).

2.6.4. Bite duration

Mean durations (± SEM) of each bite by product were calculated for TDS (first, third and fifth spoonful) and 'no task' (second and fourth spoonful). A mixed model ANOVA was performed on bite duration, with product, task (TDS and 'no task') and spoonful as fixed factors, and subject and its interactions with all fixed factors as random effects. Because the tasks include multiple intakes, spoonful was nested within task. Upon significance of the ANOVA, Tukey HSD pairwise comparison was performed.

3. RESULTS

3.1. Temporal dominance of sensations

Figure 4.1 depicts the dominance bandplots for sensations for all yogurts with granola for the first, third and fifth spoonful. The *hard:large:10%* and *hard:small:10%* yogurt-granola samples were mainly dominated by yogurt characteristics (*sour* and *creamy*) in the first half of each mouthful and shifted towards dominance of granola characteristics (*sweet, wheat* and *sticky*) in the second half of each mouthful. From the first to the fifth spoonful, the dominance durations of *sticky* sensations increased for both samples.

The *soft:large:10%* and *soft:small:10%* yogurt-granola samples were dominated by *stale* and *sour* sensations in the beginning of each mouthful and *sticky* and *sweet* sensations at the end of each mouthful. For both samples the dominance duration of *stale* decreased and *sticky* sensations gradually increased in dominance duration from the first to the fifth spoonful of consumption.

The *hard:small:20%* yogurt-granola sample was mainly dominated by granola characteristics (*crunchy, sweet, wheat* and *sticky*). A decrease in dominance duration of *wheat* sensations and an increase in dominance duration of *sticky* sensations was observed towards the last spoonful of consumption. The yogurt characteristics *sour, creamy* and *dry* were significantly dominant for the *hard:small:3%* yogurt-granola sample. A slight decrease in dominance duration for *crunchy* sensations and increase in dominance duration for *sweet* sensations was observed from the first to the last spoonful of consumption for the *hard:small:3%* yogurt-granola sample.

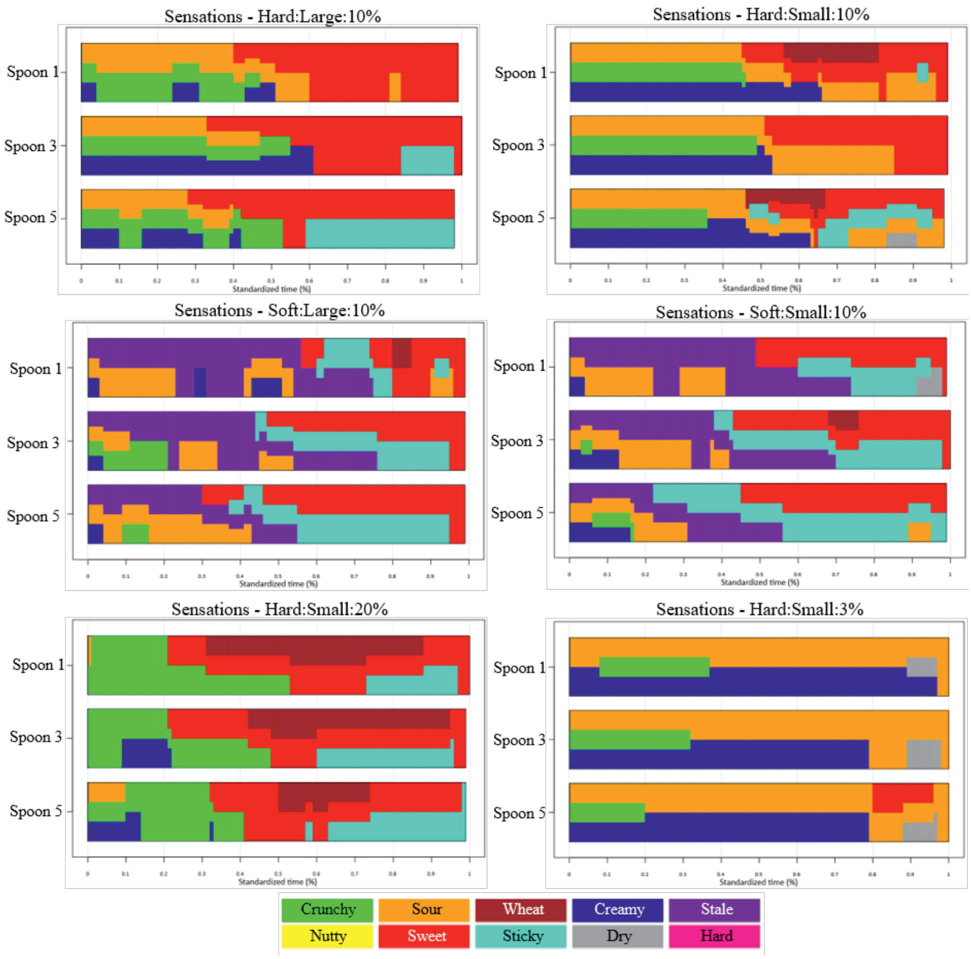

Figure 4.1. TDS bandplots. A yes/no graph per product, showing all attributes that are significantly dominant for the 1st, 3rd and 5th spoonful. Coloured rectangles represent the dominant attributes and are stacked at each moment, displaying multiple dominances (without taking into account dominance rates) at a given time point. Represented attributes are significant at $p < 0.05$.

3.2. Product discrimination

The CVA plot (Figure 4.2) indicates product differentiation based on the dominance duration of sensations, accounting for 98.3% of explained variance. The magnitude of the MANOVA for product discrimination at a multidimensional level equalled an F-statistic of 22.6 at $p < 0.001$. Hotelling-Lawley test showed that consumers did not report differences in sensory perception based on the size of the particles added to the yogurt, as similar sensory profiles were observed for *hard:large:10%* and *hard:small:10%* ($p = 0.27$); and *soft:large:10%* and *soft:small:10%* (p = 0.80). The first dimension of the CVA map discriminates products with different yogurt-granola concentrations on taste attributes. The *hard:small:20%* had longer dominance durations for *sweet, nutty* and *wheat* compared to the *hard:small:3%* which had longer dominance durations for *sour* and *creamy*. The second dimension differentiates the soft yogurt-granola samples from the hard yogurt-granola samples on texture attributes. The *soft:large:10%* and *soft:small:10%* had longer dominance durations for *stale* and *sticky* compared to the *hard:large:10%* and *hard:small:10%* which had longer dominance durations for *creamy* and *crunchy*. Hotelling-Lawley test showed significant differences between spoonful 1 and 5 (p = 0.004), and 3 and 5 (p = 0.035) for the *hard:small:20%.* Moreover, the *hard:small:3%* differed significantly in terms of sensory perception between spoonful 1 and 3 (p = 0.012), and spoonful 1 and 5 (p < 0.001). Furthermore, Hotelling-Lawley test showed that spoonful 1 and 5 of the *hard:small:10%* were perceived significantly different from each other in terms of their sensory perception (p = 0.004). All other pairwise comparisons between spoons by Hotelling-Lawley test were not significant (all p > 0.05).

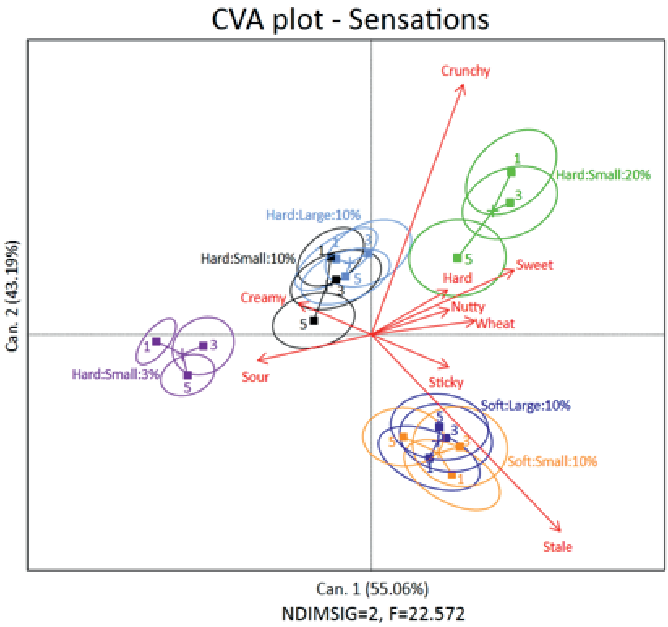

Figure 4.2. CVA maps of dominance durations of sensations. Numbers represent the first (1), third (3) and fifth (5) spoonful of consumption. Confidence ellipses at 90% and F-values significant at p < 0.001. NDIMSIG represents the number of significant dimensions.

Table 4.3 shows the ANOVA results and mean dominance durations (in % of standardized time) for each attribute per product and spoonful. A significant product by spoonful interaction effect was observed for *hard* ($F(10,750) = 2.1$, $p = 0.02$) and *stale* ($F(10,750) = 3.1$, $p = 0.001$), meaning that these two sensations do not evolve the same way over mouthfuls between products. The dominance duration of *hard* was similar between mouthfuls for *soft:large:10%, soft:small:10%* and *hard:small:3%,* while the dominance duration of *hard* significantly decreased from the first to the fifth mouthful for *hard:large:10%, hard:small:10%* and *hard:small:20%.* Furthermore, dominance durations of *stale* significantly decreased towards the fifth mouthful for *soft:small:10%,* while dominance durations of *stale* significantly increased towards the fifth mouthful for *hard:small:20%.* Significant spoonful effects were observed for *crunchy, sour,* and *sticky* ($p < 0.05$). Dominance durations for *crunchy* significantly decreased and dominance durations for *sticky* significantly increased from the first to the fifth mouthful, while dominance durations for *sour* significantly increased from the first to the third mouthful of consumption.

Table 4.3. Mean dominance durations (in % of standardized time) and standard errors of the mean for each attribute by product and spoonful. ANOVA results for product, spoonful and their interaction.

Descriptor	Fproduct	Hard: Large: 10%	Hard: Small: 10%	Soft: Large: 10%	Soft: Small: 10%	Hard: Small: 20%	Hard: Small: 3%	Fspoon	Spoonful 1	Spoonful 3	Spoonful 5	Fprod*spoon
Creamy	**19.0*** **	15 ± 1^{b}	16 ± 1^{b}	9 ± 1^{a}	10 ± 1^{a}	10 ± 1^{a}	24 ± 2^{c}	0.4	14 ± 1	15 ± 1	14 ± 1	1.1
Crunchy	**52.0*** **	20 ± 1^{cd}	18 ± 1^{c}	6 ± 1^{ab}	4 ± 1^{a}	$24 \pm 1d$	10 ± 1^{b}	**4.5* **	15 ± 1^{b}	14 ± 1^{b}	12 ± 1^{a}	1.4
Dry	2.0	4 ± 1	5 ± 1	5 ± 1	6 ± 1	3 ± 1	6 ± 1	3.0	5 ± 1	4 ± 1	6 ± 1	1.2
Hard	2.1	2 ± 0	2 ± 0	2 ± 0	1 ± 0	3 ± 1	1 ± 0	**3.7* **	2 ± 0^{b}	2 ± 0^{ab}	1 ± 0^{a}	**2.1* **
Nutty	**3.5** **	3 ± 1^{ab}	3 ± 1^{ab}	3 ± 1^{ab}	3 ± 1^{ab}	5 ± 1^{b}	1 ± 0^{a}	0.5	3 ± 0	3 ± 0	3 ± 0	1.2
Sour	**57.1*** **	18 ± 1^{bc}	21 ± 1^{c}	16 ± 1^{bc}	15 ± 1^{b}	8 ± 1^{a}	$41 \pm 2d$	**5.4** **	21 ± 1^{b}	18 ± 1^{a}	20 ± 1^{ab}	1.4
Stale	**70.2*** **	1 ± 0^{a}	2 ± 1^{a}	22 ± 1^{b}	22 ± 1^{b}	4 ± 1^{a}	2 ± 1^{a}	2.0	9 ± 1	9 ± 1	8 ± 1	**3.1*** **
Sticky	**7.6*** **	9 ± 1^{ab}	9 ± 1^{ab}	14 ± 2^{bc}	17 ± 2^{c}	10 ± 1^{ab}	7 ± 1^{a}	**11.1*** **	9 ± 1^{a}	11 ± 1^{a}	13 ± 1^{b}	0.5
Sweet	**21.6*** **	19 ± 1^{bc}	15 ± 1^{b}	15 ± 1^{b}	14 ± 1^{b}	22 ± 1^{c}	6 ± 1^{a}	4.3	14 ± 1	16 ± 1	15 ± 1	1.3
Wheat	**9.8*** **	8 ± 1^{c}	10 ± 1^{bc}	8 ± 1^{c}	8 ± 1^{c}	13 ± 1^{c}	3 ± 1^{a}	0.3	8 ± 1	8 ± 1	8 ± 1	1.2

Significant at (*) 0.05, (**) 0.01, (***) 0.001.

^{ab} Means with different letters indicate significant differences ($p < 0.05$) between products according to Tukey's HSD at 95% confidence.

4

3.3. Dynamic liking

No product by spoonful interaction effect ($F(10,750) = 0.9$, $p = 0.51$) was observed for liking scores after TDS evaluations, meaning that the liking scores developed similarly over mouthfuls for each product. A borderline significant spoonful effect ($F(2,150) = 3.1$, $p = 0.05$) was observed. However, pairwise comparison test showed no significant differences between liking scores over mouthfuls. Since liking scores did not change significantly over mouthful and no product by spoonful interaction effect was observed, the liking scores were averaged over spoons for each product (see Figure 4.3). Products significantly differed in terms of liking ($F(5,363) = 43.0$, $p < 0.001$). The *hard:small:20%* was liked most followed by *hard:large:10%* and *hard:small:10%,* whereas the *soft:large:10%, soft:small:10%* and *hard:small:3%* were liked least.

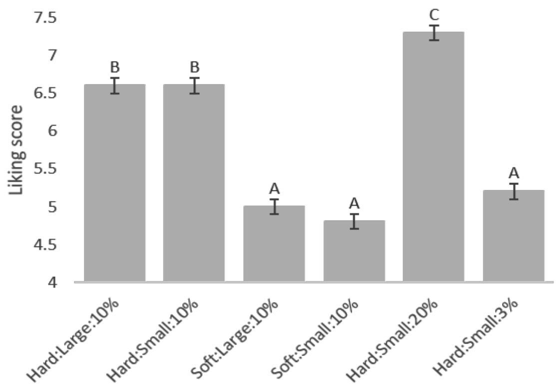

Figure 4.3. Mean liking scores and standard errors of the mean by product after TDS evaluations. Means with different letters indicate significant differences ($p < 0.05$) between products according to Tukey's HSD at 95% confidence.

3.4. Temporal Drivers of Liking

Temporal Drivers of Liking (TDL) of the six yogurt with granola samples are depicted in Table 4.4. *Creamy, crunchy* and *sweet* were significant positive temporal drivers of liking, and *sour* and *sticky* were significant negative temporal drivers of liking for at least 50% of the consumers. For more than 65% of the consumers the dominance of *creamy* increased liking by 0.05 and 0.10, and the dominance of *sour* decreased liking by 0.09 and 0.10 in the *soft:small:10%, soft:large:10%* and *hard:small:3%. Sweet* was a significant driver of liking in *hard:small:10%, soft:small:10%* and *hard:small:3%,* and for more than 40% of the consumers dominance of sweet increased liking by 0.11, 0.13 and 0.21, respectively. Furthermore, for 53% of the consumers, dominance of *sticky* decreased liking by 0.11 in *hard:small:20%.*

Table 4.4. Temporal drivers of liking.

Attribute	Hard:Large:10%		Hard:Small:10%		Soft:Large:10%		Soft:Small:10%		Hard:Small:20%		Hard:Small:3%	
	n	CLWD	n	CLWD	n	CLWD	n	CLWD	n	CLWD	n	CLWD
Creamy	59	-0.03	64	0.06	**50**	**0.10***	**54**	**0.05***	55	0.00	**67**	**0.07****
Crunchy	74	0.06	73	0.06	41	0.02	35	0.03	74	0.03	**61**	**0.15*****
Dry	21	-0.16	23	-0.16	25	0.04	29	-0.13	16	0.00	26	0.00
Hard	20	0.06	20	-0.03	17	0.13	17	0.00	16	0.09	7	0.00
Nutty	21	0.05	22	0.06	16	0.04	20	0.09	28	0.07	10	-0.01
Sour	60	-0.03	69	-0.09	**65**	**-0.10****	**64**	**-0.09****	55	-0.05	**71**	**-0.09****
Stale	14	-0.15	14	-0.21	65	-0.01	62	-0.01	23	-0.07	18	-0.27
Sticky	40	-0.06	41	0.01	44	0.04	48	-0.01	**40**	**-0.11***	35	0.01
Sweet	57	0.06	**52**	**0.11***	48	0.06	**47**	**0.13****	62	0.02	**33**	**0.21****
Wheat	39	0.04	40	0.06	34	0.10	38	0.02	48	0.03	20	0.07

Significance at (*) 0.05, (**) 0.01, (***) 0.001.

CLWD: Average of individual Centred Liking While Dominant scores.

n: number of consumers that cited the corresponding descriptor during product evaluation.

4

3.5. Bite duration

Figure 4.4 depicts the average bite durations by product during TDS evaluations compared to the bite durations when no task was performed. No interaction effect of product by spoonful was observed ($F(15,1500) = 1.3$, $p = 0.19$), meaning that the duration of the bites were similar for each spoonful by product within a task (TDS and no task). The average bite duration observed for TDS evaluations (25.9 s) was significantly longer ($F(1,300) = 92.0$, $p < 0.001$) compared to the average bite duration when no task (22.1 s) was performed. Nevertheless, the bite durations by product for TDS and no task followed similar patterns, with the *hard:small:20%* having a significantly higher average bite duration (27.8 s), and the *hard:small:3%* having a significantly lower average bite duration (19.5 s) compared to the other samples.

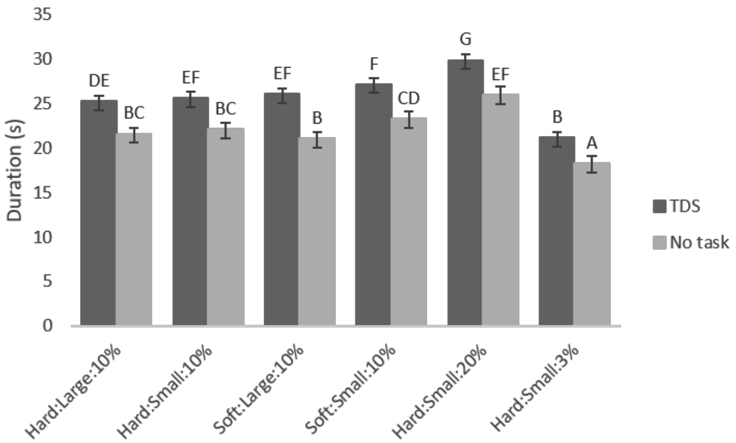

Figure 4.4. Average bite duration by product during Temporal Dominance of Sensations (TDS) evaluations and ‘no task’. Means with different letters indicate significant differences ($p < 0.05$) between products according to Tukey’s HSD at 95% confidence.

4. DISCUSSION

This study investigated the temporal dynamics of sensory (TDS) and hedonic (A-TDL) perceptions, reported by a consumer panel, both within- and between multiple-intake evaluations, using a composite food (yogurt with granola pieces varying in size, hardness and concentration) with higher sensory complexity as compared to single food products. We hypothesized that dynamic perception of the first mouthful would be different from dynamic perception of the consecutive mouthfuls due to lingering and/or built up of particular sensations. We also hypothesized that for composite foods, within- and between mouthfuls, sensory characteristics from one food component may influence sensations of the other component(s), in this case the yogurt may influence perception of the granola and vice versa, which could influence dominance patterns. Finally, this study aimed to identify temporal drivers of liking in an example composite food (yogurt with granola pieces varying in size, hardness and concentration). Our findings indicate that for five out of six yogurts with granola, indeed a specific texture attribute (*sticky*) builds up in dominance from the first to the last spoonful. This built up in dominance duration of *sticky* occurred gradually, which is not in line with the notion that the first bite stands out from the subsequent bites, but more with an even and gradual built up of this sensation over bites. These dynamics in sensory perception over bites would not have been captured with a single bite evaluation, nor with two bites evaluations. In addition, the findings indicate that for this particular composite food, dominant attributes reported during the first half of each mouthful were related to yogurt characteristics (e.g. *sour, creamy*), whereas during the second half of each mouthful attention seemed to shift to granola characteristics (e.g. *sweet, sticky*). This is in line with our expectation of one food component affecting sensory perceptions of another food component. With regard to liking, our findings suggest that dominance of *creamy, crunchy* and *sweet* sensations positively affect liking, while dominance of *sour* and *stale* sensations play a negative temporal role in liking in yogurt with granola.

The observation that *sticky* sensory perceptions become dominant at the end of a mouthful is congruent with previous studies reporting that sticky and cohesive texture perceptions are related to texture requirements to swallow the bolus, especially for cereal products (Fiszman & Tarrega, 2018; Rosenthal & Pang, 2018). Similar to our findings, Lenfant et al. (2009), Rodrigues et al. (2014) and Young et al. (2013) reported that sticky texture perceptions become dominant at the end of mastication of a single bite of biscuits and dry breakfast cereals. Additionally to the built up of sticky sensations at the end of a single bite, our study observed a gradual increase of sticky texture perceptions from spoon to spoon and the perceptual changes in dominance duration for *sticky* were larger between spoons compared to the perceptual differences between samples. *Sticky* sensations might become noticeable after repeated tasting due to sensory adaptation (Lawless & Heymann, 2010) accompanied by an 'attentional' shift from taste to texture perceptions. Moreover, the observed increase in dominance durations of *sticky* sensations from spoon to spoon might be caused by an accumulation of granola residuals in the oral cavity. Several studies have shown that fatty sensory perceptions built up in the mouth due to fat lingering on the oral surfaces (tongue and palate) (Appelqvist et al., 2016; Camacho et al., 2014). Consequently, fat deposits remain on the oral surfaces which might increase from sip to sip or bite to bite and might be sensed as a more intense fatty sensation. Hence, certain sensory characteristics may reflect fat or oil residuals remaining in the oral cavity after swallowing, which increases the intensity of the sensory perception upon repeated ingestion (Adams et al., 2007; Appelqvist et al., 2016).

Although consumers discriminated the six yogurt samples on liking, liking scores did not change from spoon to spoon. In contrast to our results, Thomas et al. (2016) did observe a significant decline in liking towards the end of consumption of a full portion of oral nutritional supplements (ONS). Moreover, Galmarini et al. (2015) reported significant decreases in liking for three chewing gum samples over a period of 10 minutes. These discrepancies in findings could be explained by the differences in type of product and consumption time between these studies and the present study. Yogurt with granola is not an outspoken food with strong taste profiles, whereas ONS are known for the built up of off flavours and 'metallic' taste due to the high protein content (Thomas et al., 2016), and chewing gum for the decrease in release of its (mint) flavours during consumption (Galmarini et al., 2015). An alternative explanation for the lack of changes in liking scores in our study, is that consumers may be prone to consistency bias, i.e. they avoid reporting changes in liking and persist in their scores over consecutive ratings (Delarue & Blumenthal, 2015). This may have well been the case in the present study, but we cannot draw firm conclusions based on our data as it is also possible that the observed similarities in liking scores between spoons are a true effect.

With regard to temporal drivers of liking, it is important to note that the sample size influences the magnitude of significant changes in liking while certain attributes are dominant. According to the procedure by Thomas and colleagues (2015; 2016), data from participants who cited the attribute as being dominant in at least one of the three tasting periods, are included in the statistical analysis. Therefore, the sample size varies per product and attribute, which affects the effect size of the temporal drivers of liking. A sensory attribute that causes a relatively large change in liking reflects a strong driver of liking, which seems more relevant and meaningful from the perspective of product development. However, when cited by just a small percentage of consumers this change might not be indicative of the preferences of a majority of consumers. Vice versa, a small change in liking while a specific attribute is dominant, may seem less relevant (weak driver of liking) but if the majority of the consumers agrees on it, it may still be worthwhile in terms of improving product performance.

The TDS task influenced the bite duration significantly, by prolonging bite durations when TDS evaluations were performed compared to the bite durations when no task was performed. This finding is in line with previous research which observed longer chew durations when consumers performed TDS compared to the actual mastication duration (Devezeaux de Lavergne et al., 2015a; Tang et al., 2017). The task at hand seems to slow down oral processing, which is something to consider when interpreting results from sensory studies where participants sample foods/drinks and at the same time perform an evaluation task. Moreover, the consumption time increased with increasing granola concentration. This implies that oral processing behaviour was changed by varying the concentration of added granola. We speculate that the addition of more granola requires more chewing and increases consumption time. Consequently, eating rate might have been reduced by the addition of particles which is a means to induce earlier meal termination (Bolhuis et al., 2014). Previous studies suggest that slower eating rates are associated with lower energy intake (Robinson et al., 2014). In the current study, samples with highest concentration of granola added to the yogurt had longest bite durations but were also most energy dense. Robinson et al. (2014) suggests that slower eating rates are associated with reduced food intake independent of the approach to manipulate eating rate. Hence, the addition of low calorie particles to yogurt might elongate consumption duration, slow down eating rates and consequently reduce food intake and lower energy intakes.

A multiple-intake approach employing TDS has the advantage that it does not only capture dynamic changes in sensory perceptions within a bite but also between bites, and our findings indicate that dynamic changes of sensory characteristics continue even after the first couple of intakes. This raises the question of the 'ideal' number of bites. In the present study, consumers evaluated small portions of 60 g of yogurt with added granola particles to shed light on the dynamic evolvement of sensory and hedonic perceptions at the beginning of consumption. This amount seemed sufficient to observe a built up of *sticky* sensations during the consumption of five subsequent spoonsful of the same product. Still, multiple bite evaluations of full portions or ad libitum intake should be explored to investigate the effect of sensory specific satiety, which characterizes a decrease in perception for a specific food upon repeated exposure (Hetherington & Havermans, 2013). It is plausible that the built up of certain sensory characteristics will be even more pronounced upon consumption of a full portion or *ad libitum* intake.

From a methodological point of view, however, multiple-intake protocols have the disadvantage that the evaluation of several products in one session might stretch the sensory space which might drive differences in sensory perceptions within a product closer together. On the other hand, with separate sessions for each product evaluation there is a risk to miss differences between products. Multiple-intake protocols require sequential sensory assessments which make results more prone to consistency bias (Delarue & Blumenthal, 2015). Hence, the ideal number of evaluation moments per serving needs further exploration. Different approaches could be explored, such as reducing the number of assessments per serving or evaluating the first, middle and last bite of the same product in separate sessions. Moreover, the added value of multiple-intake assessments and interactions of composite foods could be further explored, also using products with strong differences in sensory characteristics between bites (e.g. ice cream on a cone).

In conclusion, the present results imply that a consumer's sensory perception of food products changes over the course of consumption, and that for composite foods, the different food components dynamically interact with one another during consumption. This is of relevance for sensory and consumer science, where the common practice still focuses on single bite evaluations, which can be described as 'tastings'. Based on this, product development is steered and products are tailored to consumer preferences. However, 'tasting' is likely very different from 'eating' in the sense of finishing a portion of commonly composite foods or multiple dishes, which also plays a role in the consumer's long term acceptation and market success of a food product. Hence, to better understand a consumer's perception and food preferences we should move towards more natural and realistic test conditions, that reflect real consumption behaviours, including multiple bite evaluations.

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CHAPTER 5

Beyond the first bite and sip:

Temporal dynamics of foods using multiple bite/sip evaluations employing TDS and TCATA

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Submitted for publication.

ABSTRACT

Built ups of sensory perceptions over multiple bites/sips have been reported for oil-in-water emulsions, yogurts with granola and artificial sweetened orange juices. Oil containing liquids and artificial sweeteners might facilitate built ups of sensory perceptions due to lingering or the formation of oral residues in the mouth. It is unclear if changes in sensory perceptions from first to last bite can be generalized to a broader category of foods. This study aims to (i) investigate built ups or changes in sensory and hedonic perceptions over multiple bites in four foods belonging to different product categories, and (ii) compare dynamic sequences and product discrimination in TDS (n=71) and TCATA (n=71), using a between subjects design. Consumers evaluated the first, middle and last bite/sip of full portions of cheese (26g), bread (32g), drink yogurt (200ml) and sausage (70g). Sensory perceptions changed from first to last bite of consumption for all four products. Three out of thirteen dynamic changes in sensory perceptions from first to last bite were similar between TDS and TCATA: *dry* sensations increased for bread, *fruity* sensations decreased for drink yogurt and *juicy* sensations increased for sausage. Liking significantly decreased from first to last bite/sip for cheese, drink yogurt and sausage. To conclude, sensory perceptions change during consumption of full portions for a broad variety of foods, including solid foods without fat and foods without artificial sweeteners. The decline of desired and built-up of undesired sensory perceptions over multiple bites/sips can contribute to the decline in liking from first to last bite/sip, and can only be determined using multiple bite/sip evaluations. Moreover, TDS and TCATA were able to capture dynamic changes in sensory perceptions over multiple bites/sips and provide complementary information.

1. INTRODUCTION

Dynamic changes of sensory perceptions of single bite evaluations have been extensively reported in literature (Di Monaco et al., 2014). However, consumers usually eat full portions with multiple bites, and it is likely that sensory perceptions not only change within a bite but also between bites due to built-ups of perception or changes in responsiveness (adaptation) (Köster, 2003; Lawless & Heymann, 2010). Zorn et al. (2014) observed dynamic changes in sweetness, sourness and bitterness from first to third sip of orange juices with artificial sweeteners employing TDS with consumers. Appelqvist et al. (2016) reported that fatty sensations built-up from first to twelfth spoon of oil-in-water emulsions employing descriptive analysis using trained panelists. Previously we (van Bommel et al., 2019a) evaluated sensory perceptions from first to fifth spoon of yogurts with granola employing TDS. From first to fifth bite, a built-up of sticky sensations for all yogurts with granola was observed. These three studies demonstrate that multiple bite/sip evaluations identify changes in sensory perceptions that could not have been captured by single bite assessments. These studies suggest that multiple bite/sip evaluations can provide additional information about food perception beyond a consumer's first impression. The above mentioned studies focused on multiple bite/sip assessments of liquid (oil-in-water emulsions, orange juices) and soft semi-solid foods (yogurts with granola). Built-ups and changes in sensory perceptions from first to subsequent bites/sips in these studies are expected due to lingering of sweetness caused by artificial sweeteners or the formation of fatty mouth-coatings in the oral cavity. Liquids and soft semi-solid foods might facilitate the built-up of residues in the mouth from first to last sip due to their mouthcoating properties which can lead to the lingering of oil residues on the tongue (Camacho et al., 2015; Camacho et al., 2014). Multiple bite/sip assessments have not yet been performed with solid foods and foods without fat and artificial sweeteners. It is unclear if built-ups and changes in sensory perceptions from first to subsequent bites can be generalized to a broader group of products from different product categories. We speculate that built-ups are product specific and that liquid products, products rich in fat or containing artificial sweeteners are more prone to dynamic changes in sensory perceptions over multiple bites compared to solid foods with relatively plain and bland tastes and without fat and sweeteners, such as bread, potatoes and rice (i.e. staple foods that are common part of our diet and are often consumed on a daily basis). We hypothesize that if built-ups are perceived, these built-ups become more pronounced with increasing number of bites.

Several studies have shown that liking changes over time during consumption (Galmarini et al., 2015; Sudre et al., 2012; Thomas et al., 2016; Thomas et al., 2015; Veldhuizen et al., 2006). Consumption of full portions of a food might induce Sensory Specific Satiety (SSS), which is the decrease in liking of a food just eaten to satiation in contrast to uneaten foods (Rolls et al., 1981). It is plausible that SSS is reinforced by built-ups of undesired sensory perceptions or decline of desired sensory perceptions possibly due to adaptation or decline in responsiveness. Evaluating liking over multiple bites of a portion might provide a more realistic measure of food acceptance, future food choices and behaviour beyond a consumer's first impression.

Rapid dynamic sensory methods, such as Temporal Dominance of Sensations (TDS) and Temporal Check-All-That-Apply (TCATA), allow the identification of dynamic sensory perceptions during consumption. Temporal Dominance of Sensations (TDS) relies on the concept of dominance. Assessors select the perceived dominant attribute, and dominance recording of this attribute starts from then and remains until a new attribute is selected (Pineau et al., 2009). Weighing the dominance of taste and texture attributes allows the consumer to indicate the most salient sensory attribute perceived at each moment in time during consumption. Nevertheless, the selection of a single attribute at a time might give rise to halo or dumping effects when consumers have to choose between dominance of simultaneously perceived attributes (Varela et al., 2018). In contrast, TCATA allows assessors to select multiple sensory attributes, from multiple modalities (e.g. taste and texture), at the same time. TCATA relies on the concept of applicability and assessors are instructed to check all sensory attributes that apply at each moment in time and uncheck these sensations when they no longer apply during consumption (Castura et al., 2016).

Studies that have compared TDS and TCATA suggest that TCATA provides better sensory discrimination between samples (Ares et al., 2015; Nguyen et al., 2018). Differences in the ability to discriminate samples might be related to product characteristics (i.e. complexity and dynamics in sensory profiles during consumption), which may fit better with either the TDS or the TCATA approach. Antúnez et al. (2017) compared first and second bite evaluations of salt reduced bread samples employing TCATA and suggests consumers discriminate products better in the second bite. It is plausible that when assessors evaluate multiple bites of the same product, they become familiar with the dynamic product characteristics which makes it easier to select and deselect sensory attributes in subsequent bite evaluations using TCATA. To our knowledge, Antúnez et al. (2017) is the only study that investigated the ability of TCATA to capture dynamic changes in sensory perceptions beyond the first bite/sip of consumption. More evidence is needed to explore the potential of TCATA to capture dynamic sensory perceptions using multiple bite evaluations.

This study aims to (i) investigate built-ups or changes in sensory and hedonic perceptions over multiple bites in four foods belonging to different product categories, and (ii) compare dynamic sequences and product discrimination in TDS and TCATA using multiple bite assessments, using a between subjects design. We hypothesize that sensory perceptions change from bite to bite due to built-ups of particular sensory perceptions and that these changes are product specific. Moreover, we expect that if desired or undesired sensations built-up this would lead to an increase or decrease in liking from first to last bite. If built-ups of sensory characteristics from bite to bite are generalizable to a broader product space, this emphasizes the relevance of extending product evaluations beyond the first bite of consumption. Findings in this study will provide insights in consumer's attribute selection behaviour and the dynamic properties of TDS and TCATA evaluations within and between bites of the same product. We hypothesize that TCATA provides better discrimination in changes between bites since consumers can select multiple sensory attributes from multiple sensory dimensions (taste and texture), at the same time. The selection of a single sensory attribute at a time in TDS might be an easier task to perform compared to TCATA where consumers have to actively select and deselect multiple sensory attribute at the same time. These insights can be used to select the appropriate dynamic sensory method to capture dynamic changes for multiple bite assessments.

2. METHODS

2.1. Participants

One hundred forty-two healthy (self-reported) consumers, aged 18-65 years, were recruited for this study from a database with volunteers to participate in research of the Division of Human Nutrition and Health of Wageningen University, The Netherlands, and via posts on social media. All participants were consumers of cheese, bread, drink yogurt and sausage, without allergies or intolerances and with normal abilities to taste and smell (self-reported). None of the participants was familiar with TDS or TCATA methodology or had any previous training in sensory evaluation of cheese, bread, yogurt or sausage. After inclusion, participants were randomly divided in two groups and performed sensory evaluation of cheese, bread, drink yogurt and sausage employing either TDS (n = 71, 24 male, mean age 25.7 ± SD 10.2 years, mean BMI 22.4 ± SD 2.6 kg/m^2) or TCATA (n = 71, 20 male, mean age 27.6 ± SD 11.1 years, mean BMI 22.4 ± SD 2.3 kg/m^2). No significant differences were observed for age, gender and BMI between the two participant groups ($p > 0.05$). Participants received a monetary incentive for their participation, and gave written informed consent before the start of the study. The experimental protocol was submitted to and exempted from ethical approval by the medical ethics committee of Wageningen University.

2.2. Products

A wide range of products, with and without artificial sweetener, varying in fat contents and consistency (liquid, semi-solid and solid state) were included in this study. Commercially available cheese (La Vache qui rit® mini cubes plain flavour, Fromageries Bel), whole wheat bread (Zaans whole wheat bread, Albert Heijn), drink yogurt (Optimel® Drink Yogurt Raspberry 0% fat, FrieslandCampina) and vegetarian sausage (Roockworst, Vegetarische Slager) were evaluated in this study. Cheese and sausage were included because they are both fat containing products varying in consistency (semi-solid vs. solid), and will provide information on the built-up of sensory perceptions of (semi)solid fat containing foods. Bread was chosen because it is a fat free solid product without artificial sweeteners. We expect that the bread, with its bland sensory profile, will not lead to built-ups in sensory perceptions from first to last bite of consumption. The drink yogurt was an artificial sweetened (sucralose), fat free liquid product, and was included as a positive control similar to the study performed by Zorn et al. (2015). Product characteristics are specified in Table 5.1. Participants evaluated full portions of cheese (25 g), bread (32 g), drink yogurt (200 ml) and sausage (70 g) as defined on the package of the product. Bite and sip sizes were standardized to avoid individual variation in number and size of the bites/sips. Bite and sip sizes of bread, drink yogurt and sausage were defined by 8 consumers (not participating in this study). Consumers received the full portion of the product and were instructed to eat and drink the product freely as they normally would. Number of bites/sips of each full portion were counted and averaged per product (data not reported). Each consumer received 5 cubes of cheese (cube dimension: 17 x 17 x 17 mm), 8 pieces of bread (dimension of a bite: 35 x 35 x 8 mm), 10 sips of drink yogurt (20 ml per sip) and 13 bites of sausage (dimensions of a sliced, round disk: 10 x Ø20 mm). The edges of the sausage and crusts of the bread were excluded from tasting and evaluations. Wrappings were removed before serving. Each bite of cheese, bread and sausage was presented individually on aluminium plates, and sips of drink yogurt were presented in small transparent cups. A warm-up sample, consisting of one piece of plain cracker, was included to familiarize participants with the TDS and TCATA method.

Table 5.1. Product characteristics per portion size and list of sensory attributes in TDS and TCATA.

Product	Portion size	Number of bites/sips	kcal	Protein (g)	fat (g)	Carbohydrates (g)	Sugar (g)	Artificial sugar	Sensory descriptors
Cheese	25 g	5	64	3	4.9	1.3	1.3	.	Butter, creamy, dairy, dry, melting, mouth coating, salty, sour, sticky, sweet
Bread	32 g	8	68	3.5	0.6	12.2	0.5	.	Doughy, dry, grainy, salty, soft, sour, spongy, sticky, sweet, wheat
Yogurt	200 ml	10	62	6.4	0	7.4	6.6	Sucralose	Bitter, chalky, creamy, dairy, dry, fruity, mouth coating, smooth, sour, sweet
Sausage	70 g	13	160	8.2	16	1.9	0.4	.	Bitter, dry, fatty, grainy, juicy, salty, savoury, sour, sticky, sweet

Portion size as indicated on the package of the product.

2.3. Attribute selection

Sensory attributes for each product were selected from literature reporting dynamic characteristics of cheese (Galmarini et al., 2017; Santagiuliana et al., 2019; Thomas et al., 2017), bread (Antúnez et al., 2017; Jourdren et al., 2016), yogurt (Ares et al., 2015; Esmerino et al., 2017) and sausage (Devezeaux de Lavergne et al., 2015b). A Check-All-That-Apply was performed by 10 consumers (not participating in real experiment) to identify the 10 most relevant and most cited sensory attributes for the cheese, bread, yogurt and vegetarian sausage used in this study (data not reported). Table 5.1 shows the sensory attributes that were included in the TDS and TCATA evaluations per product.

2.4. Procedure

Consumers evaluated a full portion (as indicated on the package of the product) of cheese, bread, drink yogurt and sausage in four separate sessions. One product was evaluated per session, and the evaluation order of products was randomized across participants, using a balanced randomization design. Test sessions lasted about 30 minutes and were scheduled on the same time of day between 13.00 and 17.00 h. Test sessions took place in sensory booths (Restaurant of the Future, Wageningen, The Netherlands), and tests were conducted under artificial daylight and temperature control (20-22 °C). A live demonstration of the test procedures was given at the start of the first session. Consumers were instructed to consume the whole portion of a product with a fixed and standardized amount of bites/sips (5 bites of cheese, 8 bites of bread, 10 sips of drink yogurt and 13 bites of vegetarian sausage). A schematic overview of the product's evaluation procedure is presented in Figure 5.1. Before and after consumption of the portions of the four test products consumers rated hunger on a continuous VAS scale [0-10] with end anchors 'not at all' to 'extremely'. Consumers evaluated the first, middle and last bite of each product with TDS or TCATA. After TDS and TCATA evaluations, consumers indicated liking of the first, middle and last bite/sip using a continuous VAS scale [0-10] with end anchors 'dislike extremely' to 'like extremely'. For the bites/sips between the first, middle and last bite/sip consumers ate the product without performing TDS/TCATA or liking ratings. For each bite between the first, middle and last bite/sip consumers were instructed to indicate the bite duration by pressing the start button when they put the sample into their mouth, allowing time recording to start, and press the stop button when they did not perceive anything anymore, allowing time recording to stop. No neutralization periods were included between bite/sip evaluations of the same product.

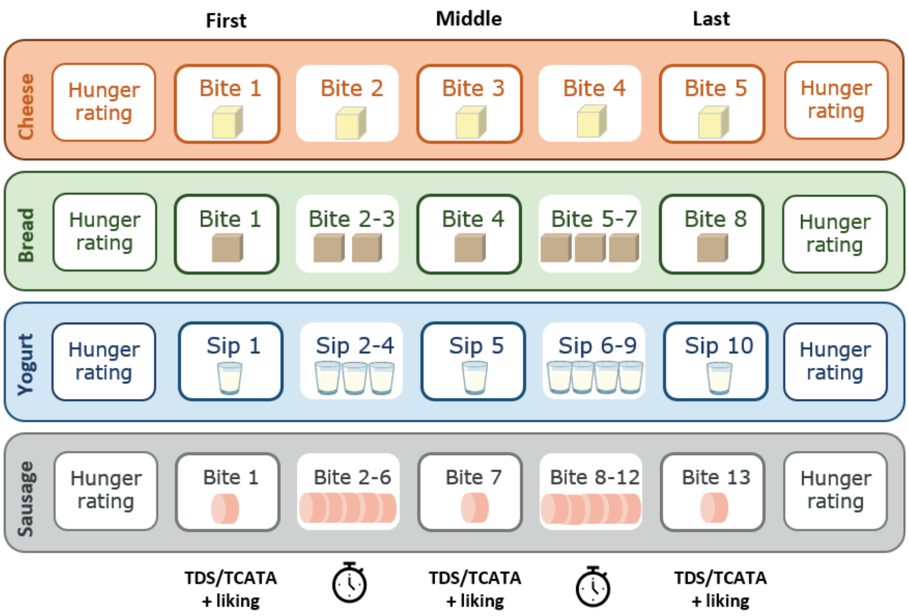


Figure 5.1. Schematic overview of study design.

2.5. Temporal Dominance of Sensations and Temporal Check-All-That-Apply

TimeSens (version 1.1.601.0, ChemoSens, Dijon, France) was used to collect TDS and TCATA data. Consumers were instructed to put the bite or sip into their mouth and simultaneously press the start button, allowing time recording to start. Consumers who evaluated the products with TDS were instructed to select the dominant attribute defined as the attribute that caught most of their attention at each moment in time. Dominance recording of that attribute started from then and remained until a new dominant sensory attribute was selected (Pineau et al., 2009). Consumers who evaluated the products with TCATA were instructed to select the sensory attributes that were applicable at each moment in time and to uncheck selected sensory attributes when they no longer applied during consumption (Castura et al., 2016). Time recording of the applicable sensory attribute started from then and remained until this attribute was unchecked. When perception of the bite or sip ended, consumers were instructed to click the stop button, allowing time recording in TDS and TCATA to stop. Consumers could select as many attributes as they liked, using the same attributes several times or never select an attribute during the evaluation time.

2.6. Data analysis

All figures were plotted using TimeSens (version 1.1.601.0, ChemoSens, Dijon, France). Statistical analyses were performed using R (R version, 3.4.2., RStudio Team, 2016). Data was pre-processed by standardizing time between 0 (first attribute selection) and 1 (click on the stop button) (Lenfant et al., 2009). Results were considered significant at $p < 0.05$.

2.6.1. TDS and TCATA curves

TDS and TCATA curves were generated for the first, middle and last bite of bread, cheese, drink yogurt and sausage. TDS curves represent the proportion (%) of participants that cited a sensory attribute as dominant at each moment in time (Lenfant et al., 2009; Pineau et al., 2009). A significance line was calculated at $p = 0.05$ and added to the TDS curve (Pineau et al., 2009). TCATA curves represent the proportion (%) of participants that cited a sensory attribute as applicable at each moment in time (Castura et al., 2016). The proportions of dominance rates in TDS and applicability rates in TCATA of the first bite were statistically compared to the dominance and applicability rates of the middle and last bite of consumption. Dominance rate differences and proportion rate differences were considered significant when they were significantly different from 0 according to a classical test of comparison of binomial proportions (Pineau et al., 2009). Dotted lines in TDS and TCATA curves represent significant differences ($p < 0.05$) in dominance rates and proportion rates at each moment of mastication time for each attribute.

2.6.3. Comparison of sensory profiles between TDS and TCATA

A Multiple Factor Analysis (MFA) (Escofier & Pages, 1994) was performed on the average dominance durations observed with TDS and average citation durations observed with TCATA for each product separately. Product spaces and correlation plots were constructed to visualize differences and similarities in the characterization of the first, middle and last bite of each product between TDS and TCATA. RV coefficients were calculated from MFA analysis to investigate the correlation between TDS and TCATA. Mean dominance durations (TDS) and citation durations (TCATA) per sensory attribute and standard errors of the mean (SEM) were calculated for each bite/sip per product. A mixed model ANOVA was performed for TDS and TCATA separately, with bite (first, middle and last bite/sip) as fixed factor, and subject and its interaction with bite as random effects. Tukey's HSD pairwise comparison was performed upon significance of the ANOVA.

2.6.4. Bite/sip duration

Mean durations (± SEM) of each bite/sip by product were calculated for TDS and TCATA (first, middle and last bite/sip) and 'no task' (each bite/sip between TDS and TCATA evaluations, where consumers did not perform a product evaluation task). A mixed model ANOVA was performed on bite duration for each product separately, with task (TDS/TCATA and 'no task') and bite as fixed factors, and subject and its interaction with all fixed factors as random effects. Because tasks include multiple intakes, bite was nested within task. Upon significance of the ANOVA, Tukey's HSD pairwise comparison was performed.

2.6.5. Attribute selections and deselections

Standardized mastication times of each bite evaluated with TDS and TCATA were divided into tertiles representing the beginning (0-33% standardized time), middle (34-66% standardized time) and last (67-100% standardized time) part of the mastication time of a bite/sip. Consumer's attribute selections (TDS and TCATA) and deselections (TCATA) were counted for each tertile and converted into percentages of attribute selections and deselections per product and bite/sip.

2.6.6. Liking and hunger ratings

For each product, mean liking scores (± SEM) were calculated for the first, middle and last bite/sip for TDS and TCATA. To test how liking scores differed between methods, a mixed model ANOVA was performed on liking, with bite nested in method (TDS and TCATA) as fixed factors and subject as random factor. To test how liking scores and test parameters differed between bites by product a mixed model ANOVA was performed on the liking scores obtained after TDS and TCATA separately, with bite as fixed factor and subject and its interaction with bite as random factor. Mean hunger ratings (± SEM) were calculated before and after consumption of the four products for TDS and TCATA. For comparison between methods, a mixed model ANOVA was performed on hunger ratings, with method (TDS and TCATA), product and time (before and after consumption) as fixed factors, and subject as random factor. Differences in hunger ratings between start and finish of the product were tested with a mixed model ANOVA with time (before and after consumption) as fixed factor and subject as random factor. Upon significance of the ANOVA, Tukey's HSD pairwise comparison was performed.

2.6.7. Temporal drivers of liking

Temporal drivers of liking were computed according to Thomas et al. (2016) on temporal sensory data obtained with TDS and TCATA. Dominance and citation durations were obtained from non-standardized TDS and TCATA data, respectively. For each sensory attribute per product, an individual Liking While Dominant (LWD) score was calculated by weighing the average liking score to the attribute's dominance or citation duration. Centred Liking While Dominance (CLWD) scores were calculated by subtracting the average liking scores weighed by the bite/sip durations from the LWD scores per sensory attribute and product. CLWD scores for each sensory descriptor were averaged for the number of consumers who cited the sensory attribute as dominant or applicable, and tested for equality to the theoretical mean of 0 using a one-sample t-test. An attribute was considered a significant driver of liking at $p < 0.05$. Sensory attributes with CLWD scores higher than 0 are considered positive drivers of liking and sensory attributes with a CLWD score lower than 0 are considered negative drivers of liking (Thomas et al., 2016).

3. RESULTS

3.1. Changes in dynamic sensory perceptions within and between bites/sips observed with TDS

Figure 5.2 depicts the Temporal Dominance curves for the first, middle and last bite of cheese, bread, drink yogurt and sausage. Dotted lines in Figure 5.2 represent significant differences ($p < 0.05$) in dominance rates per product for the middle and last bite compared to the first bite of consumption. Differences in sensory characterization over bites are described for sensory attributes that were above the significance line in the TDS curves for at least one out of the three bite evaluations.

Cheese was characterized by *creamy* and *melting* sensations at the first half of the bite and *mouthcoating* sensations at the last half of the bite. From first to last bite, *sticky* sensations significantly increased between 40-60% of standardized mastication time. TDS curves show that bread was characterized by *spongy* and *soft* sensations at the beginning of the first bite, *wheat* and *doughy* sensations at the middle of the first bite and *soft* and *wheat* sensations at the end of the first bite. Dominance rates of *dry* (between 10-35% of standardized mastication time) and *sticky* sensations (between 70-100% of standardized mastication time) gradually built up from first to last bite of bread consumption. Drink yogurt was perceived as *fruity* and *sweet* during the whole course of the first sip. *Fruity* sensations significantly decreased towards the middle and last sip between 0-20% and 50-90% of standardized mastication time. Dominance rates of dairy sensations were significantly higher in the middle sip at 35-45% and 60-80% of mastication time compared to the first sip of consumption. Dominance rates of *smooth* (between 0-10% and 35-65% of standardized mastication time) and *mouthcoating* (between 65-75% of standardized mastication time) significantly increased from first to last sip. The first bite of sausage was characterized by *fatty, juicy* and *savoury* sensations at the first half of the bite, and *sour* and *fatty* towards the last half of the bite. From first to last bite, *salty* and *juicy* sensations significantly decreased in the last bite between 0-10% and 10-20% of standardized mastication time, respectively.

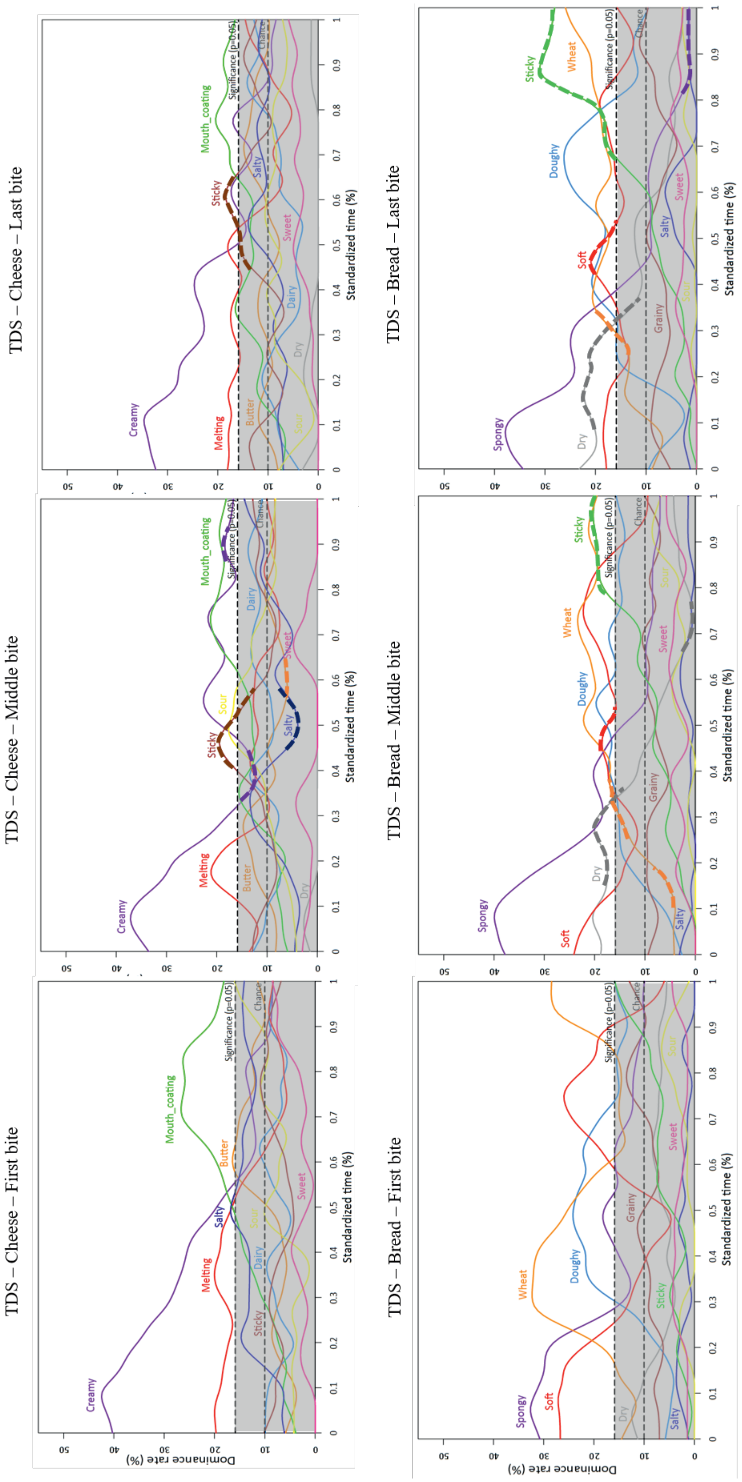
To summarize, consumers who evaluated the products with TDS mainly report a built up of texture sensations, such as *sticky* in cheese and bread, and a decrease of *fruity* sensations in drink yogurt from first to last bite/sip of consumption.

3.2. Changes in dynamic sensory perceptions within and between bites/sips observed with TCATA

Figure 5.3 depicts the Temporal Check-All-That-Apply curves for the first, middle and last bite of cheese, bread, drink yogurt and sausage. Dotted lines in Figure 5.3 represent significant differences ($p < 0.05$) in the citation proportion of an attribute per product for the middle and last bite compared to the first bite of consumption.

Highest citation proportions for cheese were observed for *creamy*, followed by *melting, dairy, sticky* and *butter*. Applicability of *mouthcoating* gradually increased in the last half of mastication time. From first to last bite, citation proportions of *mouthcoating* gradually increased between 20-60% of standardized mastication time. Moreover, citation proportions of *salty* significantly decreased in the last bite between 50-60%, 65-75% and 80-90% of standardized mastication time compared to the first bite. Bread was characterized by *spongy* and *dry* sensations at the beginning of mastication time and *soft, wheat* and *doughy* sensations at the middle and end of mastication time. Citation proportions of *spongy* significantly increased between 0-10% and 20-40% in the middle bite compared to the first bite of consumption. Significantly higher citation proportions were observed in the last bite for *dry* between 5-15% of standardized mastication time compared to the first bite. Citation proportions of *spongy* significantly decreased in the last bite compared to the first bite of consumption between 70-100% of standardized mastication time. Drink yogurt was mainly perceived as *fruity* and *sweet*, followed by *creamy*, *dairy* and *smooth*. Perception of *dairy* (between 0-50% of mastication time), *creamy* (0-30% of mastication time) and *dry* (between 20-50%, 60-70% and 75-85%) gradually increased from first to last sip. Citation proportions of *sweet* (between 55-65% of standardized mastication time) and *fruity* (between 60-95% of standardized mastication time) significantly decreased in the last sip compared to the first sip of consumption. Sausage was characterized by *fatty, salty, juicy* and *savoury* sensations throughout the course of a bite. Citation proportions of *sour* increased towards the last half of the first bite. Significantly higher citation proportions were observed in the last bite compared to the first bite for *sour* sensations (between 10-30% of mastication time), *dry* sensation (between 0-25% and 65-100% of mastication time) and *bitter* sensations (between 10-25% and 90-100% of mastication time). Perception of *juicy* sensations gradually decreased from first to last bite between 35-100% of mastication time.

To summarize, consumers who evaluated the products with TCATA report built ups of *mouthcoating* sensations for cheese, and increase of *dairy* sensations and decrease of *fruity* sensations for drink yogurt, a decrease of *spongy* sensations for bread and a decrease of *juicy* sensations for sausage from first to last bite/sip of consumption.



TDS – Cheese – First bite
TDS – Cheese – Middle bite
TDS – Cheese – Last bite
TDS – Bread – First bite
TDS – Bread – Middle bite
TDS – Bread – Last bite
Dominance rate (%)
Standardized time (%)
Significance (p=0.05)
Chance
Creamy
Melting
Mouth_coating
Butter
Salty
Sour
Dairy
Sticky
Sweet
Dry
Spongy
Soft
Wheat
Doughy
Grainy

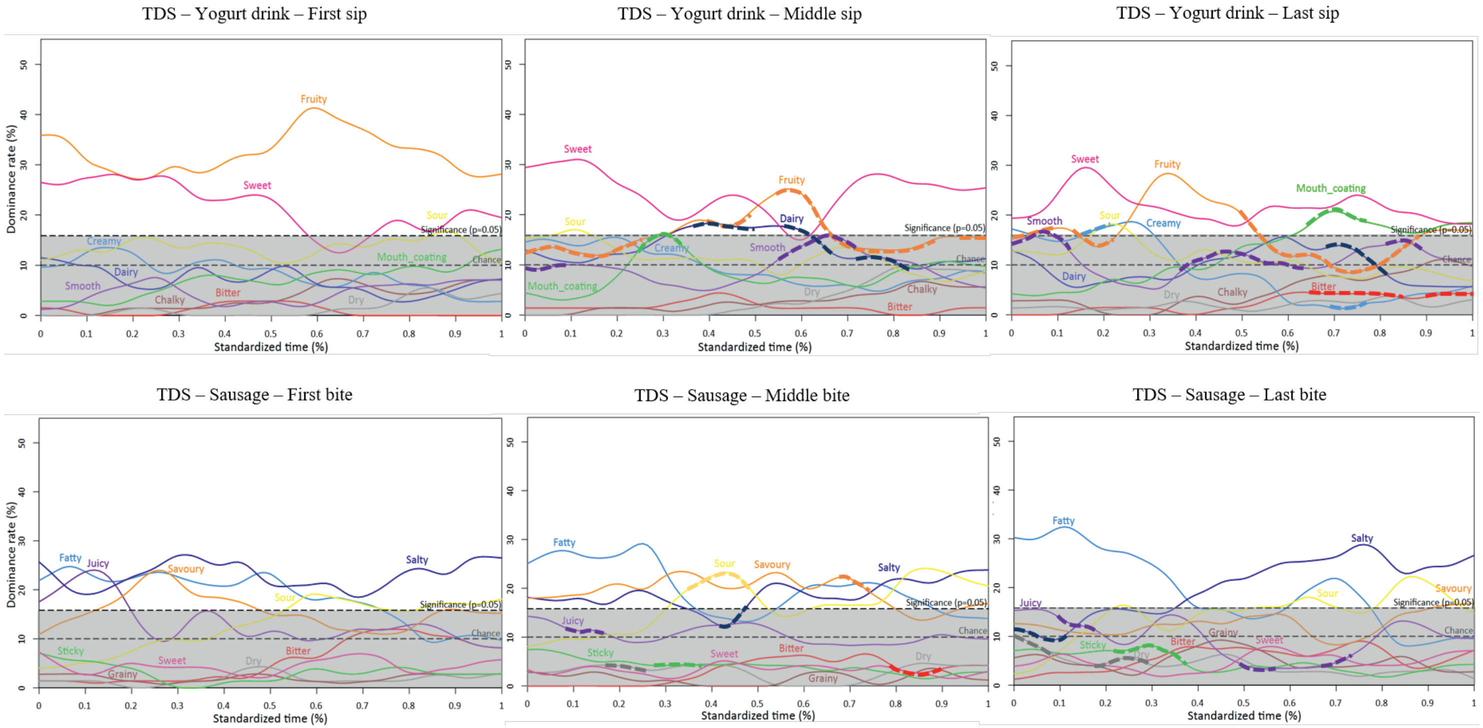
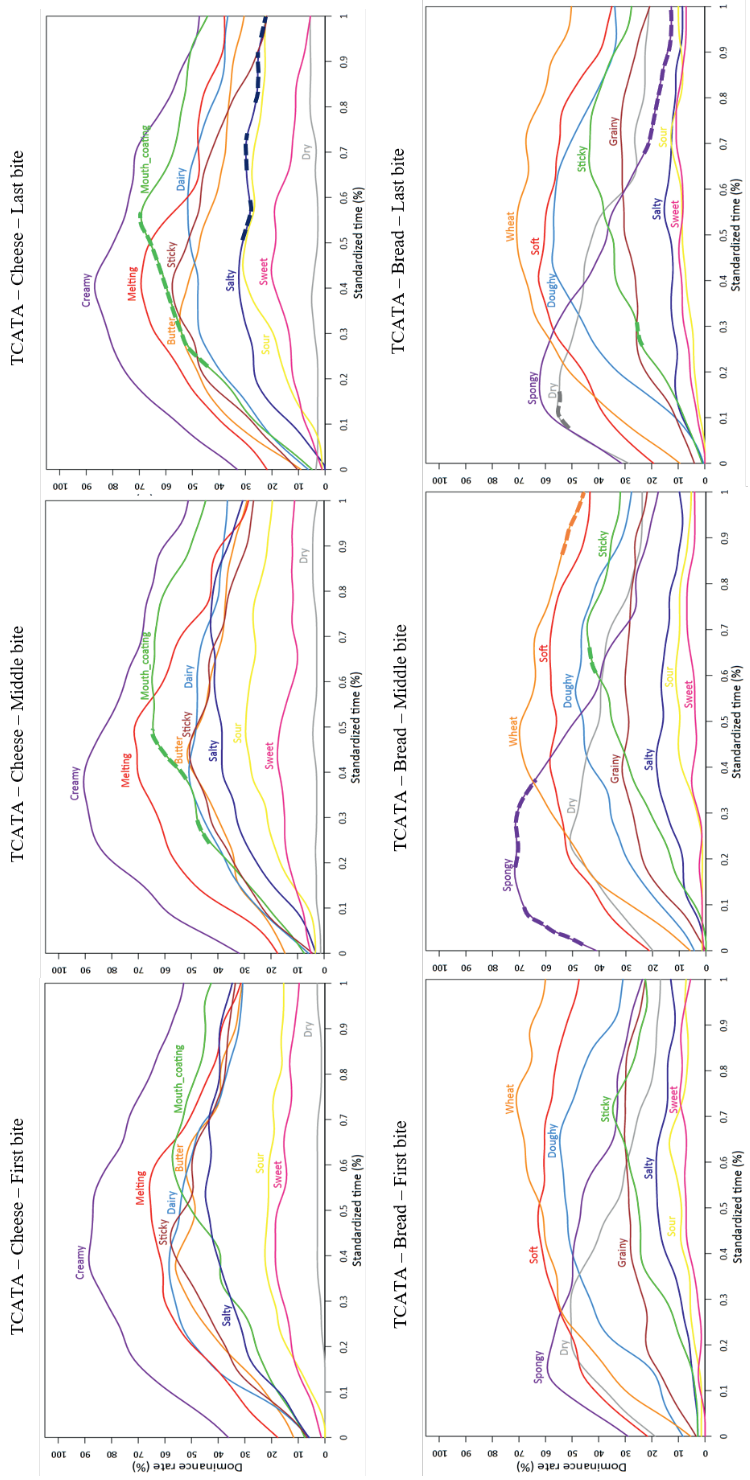


Figure 5.2. Graphical representation of the sequence of dominant sensations obtained with TDS for cheese, bread, drink yogurt and sausage. Areas under the significance line are coloured grey. Dotted lines represent significant differences ($p < 0.05$) in dynamic sensory profiles for each product between first and last bite.


TCATA – Cheese – First bite
TCATA – Cheese – Middle bite
TCATA – Cheese – Last bite
TCATA – Bread – First bite
TCATA – Bread – Middle bite
TCATA – Bread – Last bite
Dominance rate (%)
Standardized time (%)
Creamy
Melting
Sticky
Dairy
Butter
Mouth_coating
Salty
Sour
Sweet
Dry
Spongy
Soft
Wheat
Doughy
Grainy
Sticky

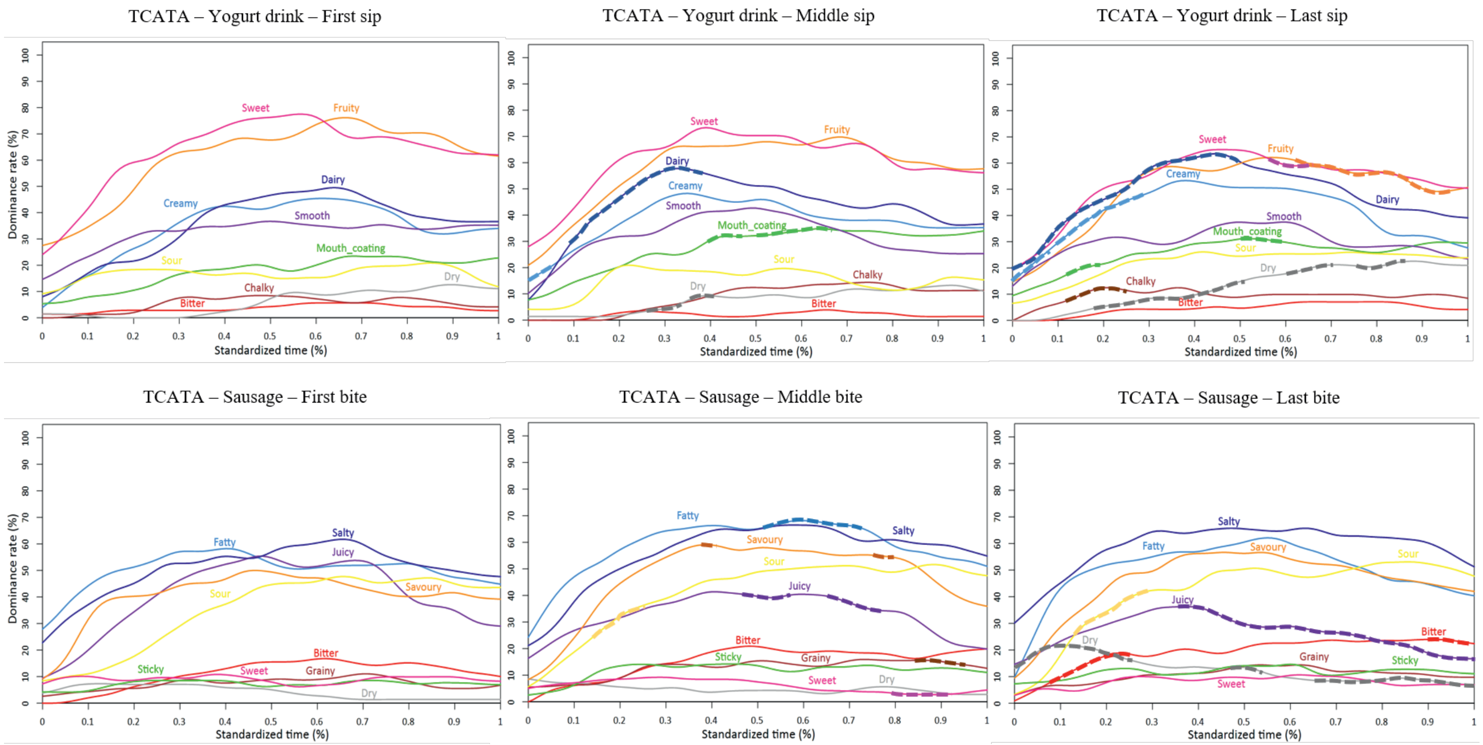


Figure 5.3. Graphical representation of the sequence of citation proportions obtained with TCATA. Dotted lines represent significant differences ($p < 0.05$) in dynamic sensory profiles for each product between first and last bite.

3.3. Liking and hunger ratings from first to last bite

Table 5.2 represents the liking scores for the first, middle and last bite per product after TDS and TCATA evaluations and the difference in hunger ratings from start to finish of a full portion of cheese, bread, drink yogurt and sausage. Similar trends were observed for liking scores obtained after TDS and TCATA evaluations. Liking scores of cheese, drink yogurt and sausage significantly decreased ($p < 0.05$) from first to last bite/sip of consumption, whereas liking scores of bread remained the same ($p > 0.05$) from first to last bite after TDS and TCATA evaluations. Overall liking scores of bread were significantly higher after TDS compared to TCATA evaluations ($F(1,204) = 5.7$, $p = 0.02$). However, no significant differences ($F(2,280) = 1.0$, $p = 0.42$) were observed when comparing liking scores per bite of bread after TDS and TCATA evaluations. No significant differences ($p > 0.05$) between liking scores after TDS and TCATA evaluations were observed for any of the other products.

Hunger ratings significantly decreased from start to finish for all full portions of cheese, bread, drink yogurt and sausage before and after TDS and TCATA evaluations (Table 5.2). No significant test by product interaction effect was observed, meaning that the differences in hunger ratings between products were similar between consumers who evaluated the products with TDS or TCATA ($F(1,140) = 1.4$, $p = 0.24$). Significant differences in hunger ratings were observed between products, where cheese had significantly least satiating effects and sausage had significantly most satiating effects ($F(3,420) = 13.0$, $p < 0.001$).

3.4. Temporal drivers of liking

Table 5.3 depicts the Temporal Drivers of Liking (TDL) of the four products. *Sweet* was a significant positive temporal driver of liking in cheese, and increased liking by 0.33 and 0.40 for 36.6% and 42.3% of the consumers using TDS and TCATA, respectively. The presence of *fruity* sensations in drink yogurt significantly increased liking with 0.36 and 0.08 for 91.5% and 94.4% of the consumers using TDS and TCATA, respectively. For 83.1% of the consumers using TCATA, *creamy* sensations significantly increased the liking of yogurt with 0.15 and liking significantly decreased with 0.22 for 70.4% of the consumers upon the presence of *mouthcoating* sensations. Upon the perception of *juicy* sensations in sausage, liking significantly increased with 0.22 for 85.9% of the consumers using TCATA. Moreover, *dry* was a significant negative driver of liking, decreasing liking with 0.41 for 33.8% of the consumers using TCATA. No significant drivers of liking were observed for bread.

Table 5.2. Mean liking scores and standard errors of the mean by product after first, middle and last bite evaluation with TDS and TCATA and mean differences in hunger ratings from start to finish for cheese, bread, drink yogurt and sausage.

		Liking scores					Hunger ratings			
Test	Product	Fbite	First bite	Middle bite	Last bite	Difference last-first bite	Fbite	Before consumption	After consumption	Difference last-first bite
TDS	Cheese	**12.6*****	6.1 ± 0.3^{a}	5.6 ± 0.3^{b}	5.3 ± 0.3^{b}	-0.8	**22.0*****	5.2 ± 0.2^{b}	4.3 ± 0.2^{a}	-0.9
	Bread	1.4	5.0 ± 0.2	4.9 ± 0.2	4.7 ± 0.2	-0.3	**51.1*****	5.1 ± 0.2^{b}	3.5 ± 0.2^{a}	-1.6
	Yogurt	**7.5*****	6.6 ± 0.2^{a}	6.1 ± 0.2^{b}	6.0 ± 0.2^{b}	-0.6	**53.1*****	5.2 ± 0.2^{b}	3.8 ± 0.2^{a}	-1.4
	Sausage	**11.3*****	4.9 ± 0.3^{a}	4.7 ± 0.3^{a}	4.1 ± 0.3^{b}	-0.7	**98.4*****	5.4 ± 0.2^{b}	3.5 ± 0.2^{a}	-1.9
TCATA	Cheese	**7.6*****	6.2 ± 0.3^{a}	5.9 ± 0.3^{ab}	5.5 ± 0.3^{b}	-0.7	**27.2*****	5.0 ± 0.2^{b}	4.1 ± 0.2^{a}	-0.9
	Bread	0.28	4.3 ± 0.2	4.3 ± 0.2	4.2 ± 0.2	-0.1	**53.4*****	5.4 ± 0.2^{b}	3.8 ± 0.2^{a}	-1.6
	Yogurt	**7.1****	7.0 ± 0.2^{a}	6.7 ± 0.2^{ab}	6.4 ± 0.2^{b}	-0.6	**53.9*****	5.3 ± 0.2^{b}	3.5 ± 0.2^{a}	-1.8
	Sausage	**13.9*****	4.8 ± 0.3^{a}	4.6 ± 0.3^{a}	3.9 ± 0.3^{b}	-0.9	**103.7*****	5.2 ± 0.2^{b}	3.2 ± 0.2^{a}	-2.0

Significant at (*) 0.05, (**) 0.01, (***) 0.001.

[ab] Mean with different letters indicate significant differences ($p < 0.05$) between bites according to Tukey's HSD at 95% confidence.

Table 5.3. Temporal drivers of liking

Attribute	Cheese				Bread				Drink yogurt				Sausage			
	TDS		TCATA		TDS		TCATA		TDS		TCATA		TDS		TCATA	
	n	CLWD	n	CLWD	n	CLWD	n	CLWD	n	CLWD	n	CLWD	n	CLWD	n	CLWD
Bitter	.	.	.	.	.	.	.	.	10	-0.28	10	-0.67	24	-0.16	31	-0.21
Butter	42	0.07	60	0.05	.	.	.	.	.	.	.	.	.	.	.	.
Chalky	.	.	.	.	.	.	.	.	21	-0.22	27	-0.01	.	.	.	.
Creamy	67	0.06	70	0.01	.	.	.	.	46	0.03	**59**	**0.15***	.	.	.	.
Dairy	52	0.1	60	0.14	.	.	.	.	47	0.1	63	-0.01	.	.	.	.
Doughy	.	.	.	.	56	-0.07	64	-0.06	.	.	.	.	.	.	.	.
Dry	5	-1.06	13	-0.3	53	-0.12	64	0.02	17	-0.12	24	-0.05	18	-0.21	**24**	**-0.41****
Fatty	.	.	.	.	.	.	.	.	.	.	.	.	64	0.02	66	-0.07
Fruity	.	.	.	.	.	.	.	.	**65**	**0.36*****	**67**	**0.08***	.	.	.	.
Grainy	.	.	.	.	45	0.01	52	0.01	.	.	.	.	21	-0.33	27	-0.12
Juicy	.	.	.	.	.	.	.	.	.	.	.	.	48	0.16	**61**	**0.22****
Melting	62	0.12	70	-0.05	.	.	.	.	.	.	.	.	.	.	.	.
Mouth coating	54	0.02	65	0.02	.	.	.	.	48	0.06	**50**	**-0.22***	.	.	.	.
Salty	42	0.05	51	0.04	18	-0.03	28	-0.02	.	.	.	.	64	0.02	65	-0.02
Savoury	.	.	.	.	.	.	.	.	.	.	.	.	49	0.1	56	0.1
Smooth	.	.	.	.	.	.	.	.	46	-0.12	56	0.05	.	.	.	.
Soft	.	.	.	.	59	0.03	69	0.03	.	.	.	.	.	.	.	.
Sour	36	-0.08	36	-0.1	16	-0.12	19	-0.08	43	-0.11	40	-0.04	44	0.09	57	-0.05
Spongy	.	.	.	.	64	0.08	69	0.01	.	.	.	.	.	.	.	.
Sticky	51	-0.13	65	0.09	45	-0.05	55	-0.06	.	.	.	.	24	-0.23	27	-0.06
Sweet	**26**	**0.33****	**30**	**0.40***	16	0	18	0.11	62	0.03	70	0.09	**21**	**0.36***	21	0.24
Wheat	.	.	.	.	67	0	64	-0.01	.	.	.	.	.	.	.	.

Significant at (*) 0.05, (**) 0.01, (***) 0.001.

3.5. Comparison between multiple bite/sip evaluations using TDS and TCATA

Figure 5.4 shows the MFA plot which indicates differences in sensory characterization between TDS (green font) and TCATA (red font) for the first, middle and last bite of cheese (A), bread (B), drink yogurt (C) and sausage (D). The correlation circle visualizes the sensory attributes in TDS and TCATA, and the MFA individual factor map represents the three evaluation moments as mean points, i.e. first bite, middle bite and last bite, and the variation between TDS and TCATA in colour. A RV coefficient of 0.82, 0.81, 0.79 and 0.83 was observed for cheese, bread, drink yogurt and sausage, respectively, representing good correlation between TDS and TCATA measures. Visual inspection of the MFA plots reveals that the first dimension differentiates the first bite from the middle and the last bite. The second dimension of the MFA plot further differentiates the middle bite from the last bite. Although TDS and TCATA identify similar sensory attributes to describe the products, a difference in dynamic sensory characterization over bites is observed between TDS and TCATA.

Sensory attributes in the MFA plot that are highlighted in yellow represent sensory attributes that change significantly over bites, as obtained from F-values of the ANOVA for bite (first, middle and last) based on the mean durations of attribute selection (in % of standardized time) obtained from TDS and TCATA (Table 5.4). TDS detected a significant built up in dominance durations of *sticky* from the first to the last bite of cheese. Contrarily, TCATA captured a significant increase in citation durations for *mouthcoating* from the first to the middle and last bite, and a significant decrease in citation durations for *salty* from the first to the last bite.

TDS and TCATA both report a significant built up of *sticky* sensations from the first to the last bite for the consumption of bread. Additionally, TDS detected a significant increase in dominance durations from first to last bite for *dry*, while consumers who evaluated the bread with TCATA reported an increased perception of *spongy* from the first to the middle bite.

TDS and TCATA similarly detected a significant decrease of *fruity* sensations from first to last sip in drink yogurt. Moreover, TCATA captured a significant increase in citation durations of *dry, dairy* and *mouthcoating* sensations from first to last sip. TDS, on the other hand, reported a significant increase in dominance durations of *smooth* sensations from first to last sip and a significant increase in dominance durations of *dairy* perceptions from first to middle sip.

From first to last bite, TCATA detected a significant increase in citation durations of *bitter* and a significant decrease in citation durations of *juicy* sensations from the first to the last bite of sausage. TDS did not find these changes, but reported a significant increase in dominance durations of *grainy* perceptions from the first to last bite, and a significant increase in dominance durations of *savoury* sensations from the first to the middle bite of consumption.

Table 5.4. F-values from ANOVA results for bite (first, middle and last) based on the mean durations of attribute selections (in % of standardized time).

Attribute	Cheese		Bread		Drink yogurt		Sausage	
	TDS	TCATA	TDS	TCATA	TDS	TCATA	TDS	TCATA
Bitter	-	-	-	-	0.7	1.2	2.3	**3.6***
Butter	0.3	0.6	-	-	-	-	-	-
Chalky	-	-	-	-	0.8	1.8	-	-
Creamy	0.4	1	-	-	0.2	1.6	-	-
Dairy	1.4	0.3	-	-	**4.5***	**3.8***	-	-
Doughy	-	-	0.3	1.1	-	-	-	-
Dry	2.4	0.7	**3.5***	0.9	1.6	**4.9***	1.7	**6.3****
Fatty	-	-	-	-	-	-	0.1	2.5
Fruity	-	-	-	-	**14.9*****	**3.2***	-	-
Grainy	-	-	0.4	0	-	-	**4.2***	2
Juicy	-	-	-	-	-	-	3	**6.1****
Melting	0.4	0.3	-	-	-	-	-	-
Mouth-coating	0.5	**6.3****	-	-	3.1	**5.4****	-	-
Salty	2.7	**4.1***	0.5	0.2	-	-	1.1	3
Savoury	-	-	-	-	-	-	**5.9****	1.5
Smooth	-	-	-	-	**5.7****	0.1	-	-
Soft	-	-	0.1	0.5	-	-	-	-
Sour	2.2	1.5	2.7	0.02	0.5	1.5	1.7	2.6
Spongy	-	-	1	**3.8***	-	-	-	-
Sticky	**3.5***	0.8	**8.1*****	**4.0***	-	-	0.7	1.6
Sweet	1.3	0.02	0.3	1.1	0.5	2.3	1.1	0.8
Wheat	-	-	1.8	0.4	-	-	-	-

Significant at (*) 0.05, (**) 0.01, (***) 0.001.

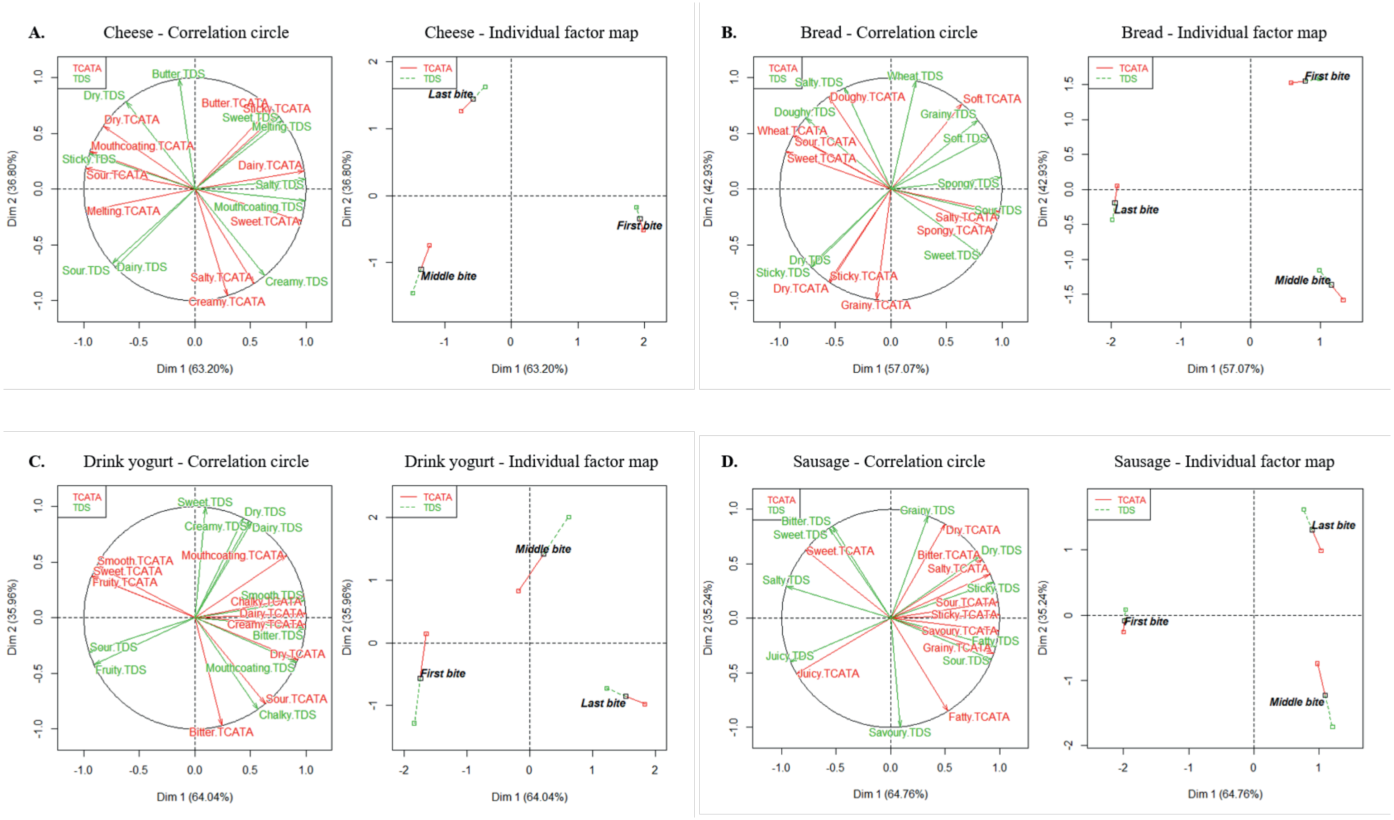


Figure 5.4. Representation of the first two dimensions of the MFA space showing correlation circle for sensory descriptors based on mean dominance durations observed with TDS (green font) and mean citation durations observed with TCATA (red font), and the first bite, middle bite and last bite as partial individuals representing the sensory configurations of the bites of TDS and TCATA for cheese (A), bread (B), drink yogurt (C) and sausage (D). Sensory attributes highlighted in yellow are significantly different from one bite to another.

3.6. Bite/sip durations

Table 5.5 shows the bite/sip durations per product of the first, middle and last bite/sip evaluations with TDS and TCATA and all bites between without performing a task. Bite durations were significantly longer in TCATA compared to TDS for bread ($F(1,140) = 7.9$, $p = 0.01$) and sausage ($F(1,140) = 7.2$, $p = 0.01$). Bite/sip durations for cheese and yogurt were not significantly different when consumers used TCATA compared to TDS (cheese $F(1,140) = 3.4$, $p = 0.07$; yogurt $F(1,140) = 2.9$, $p = 0.08$). For all products, the bite/sip durations between the first, middle and last bite/sip of consumption (i.e. when no task was performed) were significantly shorter ($p > 0.05$) compared to the bite/sip durations when TDS or TCATA was performed. Bite durations significantly increased from first to last bite of bread evaluations using TDS and TCATA. Additionally, bite durations of cheese significantly increased from first to fifth evaluation when consumers evaluated the product with TDS. Although a trend could be observed where bite/sip durations gradually increased from first to last bite/sip, no other significant differences in bite/sip durations from first to last bite of consumption were observed for yogurt and sausage.

3.7. Attribute selections and deselections

Table 5.6 shows the average number of selections (TDS and TCATA) and deselections (TCATA) of sensory attributes during product evaluation. The number of attribute selections increased significantly ($p < 0.05$) from first to last bite for all four products in TDS, and attribute selections and deselections significantly increased from first to last bite for yogurt and sausage evaluations with TCATA. Table 5.6 depicts the number of attribute selections and deselections for the first tertile (0-33% mastication time), second tertile (34-66% mastication time) and third tertile (67-100% mastication time) of the first, middle and last bite of consumption employing TDS and TCATA evaluations. Between 46-51% of the sensory attributes in TDS were selected in the first tertile, followed by 27-35% in the second tertile and 17-23% in the third tertile of a bite/sip evaluation. A majority of 64-76% of the attribute selections in TCATA took place in the first tertile of the evaluation of a bite/sip, followed by 18-24% in the second tertile, and 5-11% of the attributes were selected in the third tertile of a bite/sip evaluation. On average about 40-61% of the total selected sensory attributes in TCATA were deselected during each bite/sip evaluation. About 3-13% of these deselections took place in the first tertile of the evaluation of a bite/sip (0-33% mastication time), followed by 16-26% of attribute deselections in the second tertile (34-66% mastication time), and 17-27% of attribute deselections in the third tertile (67-100% mastication time) of the evaluation of a bite/sip.

Table 5.5. ANOVA results and average (± SEM) of the bite/sip durations for each bite of cheese (5 bites), bread (8 bites), drink yogurt (10 sips) and sausage (13 bites).

Test	Product	F_{task}	$F_{task*bite}$	Bite 1	Bite 2	Bite 3	Bite 4	Bite 5	Bite 6	Bite 7	Bite 8	Bite 9	Bite 10	Bite 11	Bite 12	Bite 13
TDS	Cheese	**16.6*****	**4.9****	27.9±1.1^{b}	22.8±1.4^{a}	29.2±1.2^{bc}	24.6±1.2^{a}	30.5±1.2^{c}	.	.	.	.	.	.	.	.
	Bread	**9.4****	**7.9*****	31.6±1.1^{c}	25.6±1.0^{a}	25.5±1.1^{a}	31.9±1.2^{c}	26.2±1.3^{ab}	27.0±1.2^{ab}	28.8±1.5^{b}	36.2± 1.5^{d}	.	.	.	.	.
	Yogurt	**54.6*****	1.7	19.2±1.2^{b}	13.2±1.2^{a}	13.0±1.0^{a}	12.8±1.2^{a}	19.1±1.5^{b}	12.6±1.3^{a}	12.0±1.0^{a}	13.3±1.2^{a}	13.7±1.3^{a}	20.8±1.5^{b}	.	.	.
	Sausage	**40.3*****	**4.0*****	26.9±1.3^{c}	18.9±1.0^{a}	18.8±0.9^{a}	18.8±1.0^{a}	20.8±1.2^{ab}	21.4±1.3^{ab}	27.2±1.2^{c}	19.4±1.1^{ab}	21.1±1.2^{ab}	20.1±1.2^{ab}	21.1±1.3^{ab}	21.8±1.4^{b}	28.7±1.4^{c}
TCATA	Cheese	**20.7*****	2.4	32.7±1.8^{b}	25.6±1.7^{a}	32.5±1.9^{b}	27.4±1.9^{a}	34.7± 2.1^{b}	.	.	.	.	.	.	.	.
	Bread	**27.0*****	**5.1*****	38.3±1.8^{c}	29.3±1.9^{a}	29.8±1.6^{a}	38.5±2.1^{c}	30.5±1.6^{ab}	31.1±1.7^{ab}	33.0±1.9^{b}	41.8±2.1^{d}	.	.	.	.	.
	Yogurt	**43.0*****	1.0	22.9±1.7^{b}	15.6±1.5^{a}	14.8±1.3^{a}	15.2±1.4^{a}	22.9±1.8^{b}	15.1±1.3^{a}	15.8±1.6^{a}	16.5±1.6^{a}	16.0±1.5^{a}	24.6±2.0^{b}	.	.	.
	Sausage	**31.2*****	**2.1***	33.5±2.3^{b}	25.2±2.1^{a}	27.2±2.5^{a}	26.3±2.1^{a}	27.1±2.2^{a}	28.0±2.5^{a}	35.2±2.9^{b}	25.2±2.0^{a}	26.4±2.3^{a}	25.5±1.9^{a}	26.0±1.9^{a}	27.1±1.9^{a}	37.1±2.6^{b}

Significant at (*) 0.05, (**) 0.01, (***) 0.001.
Bite/sip durations highlighted in grey are bites/sips for which consumers performed a task (TDS or TCATA).

Table 5.6. Average number of sensory attribute selections (TDS and TCATA) and deselections (TCATA) (± SEM) per bite and average attribute selections and deselections in percentage of total attribute selections per tertile (first tertile: 0-33%; second tertile: 34-66% and third tertile: 67-100% of mastication time) for cheese, bread, drink yogurt and sausage.

Test	Product	Parameter	F_{bite}	First (mean ± SEM)	Middle (mean ± SEM)	Last (mean ± SEM)	$F_{tertile}$	$F_{bite*tertile}$	First bite/sip (%)			Middle bite/sip (%)			Last bite/sip (%)		
									0-33%	34-66%	67-100%	0-33%	34-66%	67-100%	0-33%	34-66%	67-100%
TDS	Cheese	Selection	**6.0****	5.8 ± 0.3^{a}	5.7 ± 0.3^{a}	6.3 ± 0.3^{b}	**243.1*****	0.6	50.1^{c}	33.3^{b}	22.2^{a}	51.2^{c}	34.6^{b}	23.5^{a}	51.4^{c}	35.2^{b}	23.6^{a}
	Bread	Selection	**5.4****	5.4 ± 0.3^{a}	5.5 ± 0.3^{a}	6.1 ± 0.3^{b}	**181.4*****	1.8	48.5^{c}	30.9^{b}	21.0^{a}	49.2^{c}	32.2^{b}	21.6^{a}	49.3^{c}	33.2^{b}	21.9^{a}
	Yogurt	Selection	**8.5*****	4.0 ± 0.3^{a}	4.3 ± 0.3^{a}	4.7 ± 0.3^{b}	**149.2*****	**3.6****	46.6^{c}	26.9^{ab}	16.9^{a}	46.7^{c}	27.6^{b}	17.4^{a}	46.8^{c}	29.6^{b}	18.1^{a}
	Sausage	Selection	**11.6*****	4.3 ± 0.3^{a}	4.8 ± 0.3^{b}	5.2 ± 0.3^{b}	**158.5*****	1.4	47.5^{d}	29.8^{bc}	18.3^{a}	48.4^{d}	29.8^{bc}	18.4^{a}	48.5^{d}	30.2^{c}	19.3^{ab}
TCATA	Cheese	Selection	0.1	6.2 ± 0.2	6.2 ± 0.2	6.2 ± 0.2	**314.4*****	**2.4***	71.0^{c}	21.0^{b}	8.1^{a}	69.8^{c}	22.2^{b}	7.9^{a}	75.8^{c}	19.4^{b}	4.8^{a}
		Deselection	1.1	3.3 ± 0.3	3.4 ± 0.2	3.6 ± 0.2	**51.4*****	1.1	6.1^{a}	42.4^{b}	51.5^{b}	11.4^{a}	42.9^{b}	45.7^{b}	11.4^{a}	45.7^{b}	42.9^{b}
	Bread	Selection	2.3	5.6 ± 0.2	5.8 ± 0.2	5.9 ± 0.2	**626.2*****	2.2	64.9^{c}	24.6^{b}	10.5^{a}	67.3^{c}	25.5^{b}	7.3^{a}	71.2^{c}	22.0^{b}	6.8^{a}
		Deselection	**3.8***	3.1 ± 0.2^{a}	3.5 ± 0.2^{ab}	3.6 ± 0.2^{b}	**51.7*****	0.7	16.1^{a}	35.5^{b}	48.4^{b}	14.7^{a}	41.2^{b}	44.1^{b}	19.4^{a}	38.9^{b}	41.7^{b}
	Yogurt	Selection	**5.4****	4.7 ± 0.2^{a}	5.1 ± 0.2^{ab}	5.2 ± 0.2^{b}	**471.3*****	**3.8****	65.2^{c}	23.9^{b}	10.9^{a}	72.5^{d}	19.6^{b}	7.8^{a}	69.8^{d}	20.8^{b}	9.4^{a}
		Deselection	**3.1***	1.9 ± 0.2^{a}	2.3 ± 0.2^{ab}	2.4 ± 0.2^{b}	**61.7*****	1.9	5.0^{a}	40.0^{b}	55.0^{b}	13.0^{a}	47.8^{b}	39.1^{b}	16.0^{a}	40.0^{b}	44.0^{b}
	Sausage	Selection	**7.9*****	4.7 ± 0.3^{a}	5.1 ± 0.2^{b}	5.3 ± 0.2^{b}	**526.2*****	**3.4****	68.1^{c}	23.4^{b}	8.5^{a}	72.0^{d}	18.0^{ab}	10.0^{a}	72.2^{d}	18.5^{ab}	9.3^{a}
		Deselection	**4.7***	2.3 ± 0.3^{a}	2.6 ± 0.2^{ab}	2.8 ± 0.2^{b}	**22.7*****	1.0	16.7^{a}	37.5^{b}	45.8^{b}	19.2^{a}	34.6^{b}	46.2^{b}	25.9^{a}	37.0^{b}	37.0^{b}

Significant at (*) 0.05, (**) 0.01, (***) 0.001.

4. DISCUSSION

This study investigated dynamic changes in sensory and hedonic perceptions using multiple bite evaluations of cheese, bread, drink yogurt and vegetarian sausage employing TDS and TCATA. We hypothesized that sensory and hedonic perceptions change dynamically over bites/sips due to lingering and/or built ups of specific sensory perceptions. Moreover, we expected that plain products, such as bread, would have less lingering properties which would result in less dynamic changes in sensory perceptions over bites. Nevertheless, our results indicate dynamic changes in sensory profiles from first to last bite/sip of consumption for all four products, and emphasize the relevance of extending product evaluations beyond the first bite/sip of consumption.

To date, only a few studies explored multiple bite/sip sensory evaluations for small portions of food, such as three sips of artificially sweetened orange juices (Zorn et al., 2014), 12 sips of oil-in-water emulsions (Appelqvist et al., 2016) and 5 spoons of yogurt with granola (van Bommel et al., 2019a). Our results suggest that sensory adaptations or built-ups of sensory perceptions can be observed in a broad range of products and are not limited to liquid or soft-semi solid products that contain fat or artificial sweeteners. The current study used naïve consumers, who were not trained in performing sensory evaluations. The question that arises here is whether multiple bite evaluations represent 'true' changes in sensory perceptions or whether these changes are mere variations in consumers' test performance from bite to bite. In a previous study, we investigated consumer's repeatability and observed similar dynamic sensory profiles for dark chocolates with a 7-day interval between first and second sensory evaluation using TDS. We, therefore, speculate that if consumers can repeat the sensory evaluation of the same product with a 7-day interval, consumers are likely to repeat themselves for sensory evaluations of subsequent bites/sips of the same product within a single session. Hence, we suggest that the multiple bite/sip evaluations of the same product do not indicate replicate measures, but reveal dynamic changes in sensory perceptions that are possibly caused by changes in responsiveness, sensory adaptation or lingering of sensory characteristics over subsequent bite/sip intake (Lawless & Heymann, 2010).

Hunger ratings significantly decreased from first to last bite for all four products, and liking ratings decreased significantly from first to last bite for three out of four products. We speculated that Sensory Specific Satiety (SSS) is reinforced by built-ups of undesired sensory perceptions or decline of desired sensory perceptions. SSS might indeed have played a role in the decrease in liking from first to last bite. SSS characterizes a decrease in liking of a food eaten to satiation in contrast to uneaten foods (Rolls et al., 1981). Our results indicate that the magnitudes of changes in liking from first to last bite were largest for cheese and sausage and liking scores for bread did not change from first to last bite. It has been observed that savoury products have a stronger effect on SSS compared to sweet or plain tasting foods such as bread (Griffioen-Roose et al., 2010). Liking of plain staple foods such as bread, rice or potatoes, declines less due to SSS compared of savoury foods (Hetherington et al., 2002; Meiselman et al., 2000). It is possible that staple foods are resistant to monotony because they are repeatedly eaten in combination with a variety of other foods. The observed decrease in liking from first to last bite for cheese, drink yogurt and vegetarian sausage seems to align with SSS. Changes in sensory perceptions from first to last bite might provide an additional contribution to SSS. *Fruity* was a positive driver of liking, increasing liking upon the presence of *fruity* sensations, while *mouthcoating* sensations negatively influenced liking in the drink yogurt sample. TDS and TCATA curves show that *fruity* sensations declined and *mouthcoating* sensations increased towards the last bite of consumption. Similarly, *juicy* sensations increased liking in vegetarian sausage, and the perception of *juicy* sensations significantly decreased from first to last bite of consumption. Hence, our findings suggest that a decrease of desired sensory attributes and a built-up of undesired sensory attributes from first to last bite may cause a decline in liking.

A second aim of this study was to compare the performance of TDS and TCATA using multiple bite/sip assessments, using a between subjects design. We hypothesized that TCATA provides better discriminative product profiles and that TDS reveals better dynamic changes in sensory perceptions within and between bites, due to the conceptual differences in sensory attribute selections between TDS and TCATA. Highest citation proportions observed with TCATA were also the significantly dominant sensory attributes reported with TDS, indicating that TDS and TCATA characterize products similar. Mainly texture attributes were significantly dominant in TDS and reached highest citation proportions in TCATA. A second layer of citation proportions reveals the taste characteristics of the products, which would indicate that TCATA provides a more detailed product description compared to TDS. It seems, however, that TDS provides a better description of the dynamic changes in sensory perceptions over the course of a single bite, as we see sensory attributes appear and disappear above the significance line at different moments in time during consumption. With TCATA only a few sensory attributes (*mouthcoating, spongy, dry* and *sour*) appear to show clear peaks in citation proportions at specific moments in time during evaluations, while all other sensory attributes reach maximum citation proportions at the same moment in time during consumption, i.e. in the middle (34-66% of mastication time) of mastication. The bell-shaped curve for the applicability of sensations is seen for the majority of the sensory attributes in TCATA peaking in the second tertile of mastication time. It seems that consumers struggle with keeping track of the applicability of 10 sensory attributes at each moment in time when using TCATA.

TDS and TCATA results both showed changes and built-ups in sensory perceptions from first to last bite/sip of consumption. Some similarities in changes in sensory perceptions were observed from first to last bite/sip, such as the increase of *dry* sensations in bread, the decrease of *fruity* sensations in drink yogurt and the decrease of *juicy* sensations in sausage. All other observed dynamic changes from first to last bite/sip were different in nature between TDS and TCATA. Differences in discrimination ability between bites/sips might be due to different cognitive processes that underlie the selection of a dominant attribute or the selection and deselection of applicable attributes in TDS and TCATA, respectively (Ares et al., 2015; Nguyen et al., 2018). Coupling this to the average deselections per product and bite, we observed that consumers only deselect about half of the selected sensory attributes during an evaluation. Our findings are supported by a study of Alcaire et al. (2017), who compared CATA with TCATA. They reported that the average citation proportions observed with TCATA increased from the first to the second quarter of consumption and then reached a plateau up to the fourth quarter of the evaluation. They suggested that the maximum citation proportions of any of the attributes in the second, third and fourth quarter of TCATA were largely similar to the static citation proportions with CATA, suggesting a lack of temporality in TCATA (Alcaire et al., 2017).

TCATA Fading and TDS by modality (M-TDS) might overcome current drawbacks of TDS and TCATA, and might simplify the tasks, reduce noise in data and increase the sensitivity of TDS and TCATA measurements. TCATA Fading, where applicable sensory attributes gradually deselect over a predefined period, could assist and simplify attribute selections in TCATA and induce better dynamic characterization of the multisensory experience of a consumer (Ares et al., 2016; Rizo, Vidák, Fiszman, & Tarrega, 2020). M-TDS allows simultaneous selection of a dominant sensory attribute from different modalities (taste and texture), and might provide a more detailed description of sensory perceptions during consumption compared to TDS.

The current study observed that bite/sip durations were significantly longer when consumers performed a sensory task (TDS or TCATA) compared to when they only had to indicate the beginning and start of the bite/sip (i.e. no task). These findings are in line with previous studies, which indicated that the performance of a task prolongs the actual mastication time (Devezeaux de Lavergne et al., 2015a; Tang et al., 2017; van Bommel et al., 2019a). In TDS and TCATA, consumers are instructed to evaluate sensory perceptions till perception ends. It is plausible that consumers elongate their evaluation durations due to ambiguity of the concept 'till perception ends', which might have caused longer bite/sip durations in TDS and TCATA. Furthermore, longer bite/sip durations were observed when consumers performed TCATA compared to TDS. It could be that the multiple attribute selection and deselection procedure in TCATA might make it more difficult for assessors to properly follow applicable sensory attributes over time, resulting in longer bite/sip durations compared to TDS, where consumers only have to focus on the dominant sensory attribute at each moment in time. When interested in investigating more realistic consumption contexts, TDS might be more suitable as bite/sip durations are closer to actual mastication durations compared to TCATA.

From a methodological point of view, multiple bite evaluations have the advantage that they better reflect natural eating behaviour and increase the external validity of classic sensory tests. Multiple bite evaluations have the disadvantage that they increase the number of test sessions needed to profile a set of products and increase costs and time needed to perform these sensory tests. However, multiple bite evaluations of more than one product in the same session could broaden the sensory space and push the perceptual differences between bites of the same product closer together. It is possible that consumers do not notice small differences between bites of the same product when the perceptual differences between products are large. Monadically testing product in separate sessions provides a wash-out period between product evaluations and the comparison between products might be less dependent on the sample set under investigation. Moreover, it is still unknown how portion size (i.e. several bites vs. full portions) influences the magnitude of changes in sensory perceptions and liking. It is plausible that dynamic changes in sensory and hedonic perceptions become more pronounced with increasing number of bites.

To conclude, sensory perceptions change dynamically from first to last bite of consumption of a full portion. Multiple bite evaluations provide additional information and reveal built-ups of sensory perceptions which could not have been captured by single bite assessments. The findings of sensory perceptions changing from first to last bite during consumption of full portions and built-ups of specific sensory properties for different products suggests this is a phenomenon that can be generalized to a broader scope of product categories, including plain staple foods. We suggest that built-ups of undesired sensations and reduction of desired sensations reinforces the decline in liking of consumed foods in addition to sensory specific satiety. TDS and TCATA both resulted in discrimination between multiple bites/sips of the same product and revealed differences in sensory perceptions that built up during consumption. However, TDS seems to provide better temporal discrimination of dynamic changes within bites/sips compared to TCATA.

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CHAPTER 6

Does the face show what the mind tells?

A comparison between dynamic emotions obtained from facial expressions and Temporal Dominance of Emotions (TDE)

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ABSTRACT

Measuring food-evoked emotions dynamically during consumption can be done using explicit self-report methods such as Temporal Dominance of Emotions (TDE), and implicit methods such as recording facial expressions. It is not known whether or how dynamic explicit and implicit emotion measures correspond. This study investigated how explicit self-reported food-evoked emotions evaluated with TDE are related to implicit food-evoked emotions determined from facial expressions. Fifty-six participants evaluated six yogurts with granola pieces varying in size, hardness and concentration, using multiple bite assessment employing TDE for the first, third and fifth bite of consumption. Consumers were video recorded during each bite of consumption and facial expressions were analysed using FaceReader™. *Happy, interested, disgusted* and *bored* were similar descriptors measured explicitly and implicitly. Little overlap was observed regarding the type of emotion characterization by FaceReader™ and TDE. Products were mainly discriminated along the valence dimension (positive – negative), and directly reflected product discrimination in terms of liking. FaceReader™ further differentiated the least liked products from each other on arousal and negative facial expressions. Our results indicated little dynamics in food-evoked emotions within and between bites. Facial expressions seemed more dynamic within bites, while explicit food-evoked emotion responses seemed more dynamic between bites. We conclude that FaceReader™ intensities of emotions and dominance durations observed in TDE are not directly comparable and show little overlap. Moreover, food-evoked emotion responses were fairly stable from first to last bite and only very limited changes were observed using implicit and explicit emotions measures.

1. INTRODUCTION

Sensory perceptions of foods and beverages change dynamically during consumption due to mastication and salivation (Castura et al., 2016; Delarue & Blumenthal, 2015; Pineau et al., 2009). Consequently, changes in appraisal of these dynamic sensory perceptions might lead to an unfold of different food-evoked emotions during consumption. The Component Process Model (CPM) by Scherer (2005, 2009) describes emotions as dynamic events that change upon the cognitive appraisal of a stimulus (e.g. food) (Figure 6.1). The CMP defines emotions as dynamic episodes, with an onset (event, stimulus) followed by a complex process of continuous changes both centrally in the brain, and peripherally via the co-occurring bodily symptoms and expressions (e.g. heart rate, blood pressure, and facial and vocal expressions), and eventually the subjective, conscious experience, the feeling one becomes aware of (Jager, 2016; Scherer, 2005, 2009).

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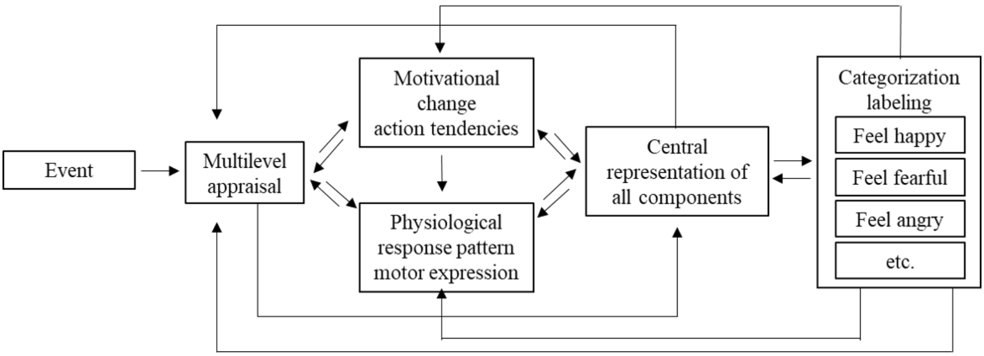

Figure 6.1. Component Process Model (CMP). Source: Scherer (2009).

It is suggested that self-report measures only reveal the emotion one becomes aware of, whereas parts of the complex emotion process in other subsystems remain hidden (Kahneman, 2003; Köster, 2003; Köster & Mojet, 2015; Scherer, 2005, 2009). More implicit measures, such as facial expressions might provide additional information on fast changing emotions during food consumption. Few studies compared the performance of facial expressions and self-reported food-evoked emotion measurements (He et al., 2016; Leitch et al., 2015). Leitch et al. (2015) compared product profiles of natural and artificial sweeteners in tea obtained with a self-reported emotion questionnaire (Check-All-That-Apply) and facial expressions (FaceReader™, version 5.0). They observed product differentiation using the emotion questionnaire, but they did not find significant differences in facial expression profiles between products (Leitch et al., 2015). He et al. (2016) compared an explicit non-verbal emotion method (PrEmo®) with facial expressions (FaceReader™, version 4.0). They concluded that the self-reported food-evoked emotions are relatively unidimensional, whereas facial expressions report multidimensional aspects such as intensity and the sequential unfolding of emotions during food consumption.

An explicit method that allows consumers to self-report dynamic changes in emotion perception during tasting is the Temporal Dominance of Emotions (TDE) methodology (Jager et al., 2014; Mahieu et al., 2019). TDE originates from the Temporal Dominance of Sensations (TDS) technique, and is based on the concept of dominance (e.g. defined as the emotion catching most of the attention at each time) (Jager et al., 2014; Pineau et al., 2009). TDE might provide a better dynamic understanding of a consumer's subjective product experience because it allows the sequential evaluation of the perceived food-evoked emotions that dominate during consumption.

Different components of the emotion process are complementary, and linking implicit to explicit emotion measurements over time will generate novel insights on how to interpret consumers' affective responses in relation to food and eating behaviour. Previous findings on dynamic changes of sensory perceptions using multiple bite assessments, indicate that different food components dynamically interact with one another during consumption and evoke a perceptual change in sensory characteristics from bite to bite (van Bommel et al., 2019a). Hence, exposure to multiple bite intakes impacts the temporal dynamics of sensory perceptions, and consequently, may elicit a change in hedonic and emotion evaluations, both within- and between bites. To investigate this, we recorded facial expressions during the subjective evaluation of six yogurts with added granola varying in hardness, size and concentration employing TDE and TDS using a five bite evaluation approach. Sensory profiles of the yogurt with added granola, presented in a separate paper, revealed product differentiation between samples on hardness of the granola particle and on the concentration of granola added to the yogurt (van Bommel et al., 2019a). The different sensory characteristics of these yogurts with added granola would lead to differential emotion profiles. This study aims to compare dynamic changes in emotion profiles and product discrimination employing implicit (facial expressions) and explicit (TDE) emotion measures. Although the type of information obtained with monitoring facial expressions and TDE is very different and, therefore, not directly comparable, we hypothesized a certain extent of correspondence between both emotion components. We hypothesized that results (i.e. dynamic changes) measured by both methods correspond at the level of a two-dimensional framework of valence (positive – negative) and arousal (high activation – low activation) within and between bites (Russell, 1980).

2. METHODS

As part of a larger study, participants completed two separate test sessions; one for the sensory and hedonic evaluations employing Temporal Dominance of Sensations (TDS) and alternated-Temporal Drivers of Liking (a-TDL), and a second session for emotion evaluations employing Temporal Dominance of Emotions (TDE). Simultaneously with these sessions participants were video recorded in order to monitor facial expressions using FaceReader™ (version 7.0, Noldus Information Technology, Wageningen, The Netherlands). The data and findings on sensory perceptions and drivers of liking (TDS and alternated-TDL) are outside the scope of the current paper and have been reported elsewhere (van Bommel et al., 2019a). This paper focuses on food-evoked emotion evaluations employing TDE and FaceReader™ (version 7.0). All data were collected at Wageningen University (The Netherlands). The experimental protocol was submitted to and exempted from ethical approval by the medical ethics committee of Wageningen University.

2.1. Participants

Seventy-six healthy Dutch participants, between 18 and 65 years old, participated in this study. After data collection, participants with more than 5% missing data frames were removed from data analysis. Consequently, twenty participants were excluded from data analysis resulting in a total of fifty-six participants (17 male, 39 female, mean age 27.7 ± SD 11.9 years, mean BMI 22.1 ± SD 2.1 kg/m^2) included in the data analysis of this study. Incomplete FaceReader™ data frames were caused by a loss of eye contact with the camera; inappropriate lighting that caused shadows in the face which made it impossible for FaceReader™ to quantify the facial expression; people wearing glasses; and, people with facial hair, such as beards and moustaches. Participants were recruited from a database with volunteers to participate in research of the Division of Human Nutrition of Wageningen University, the Netherlands. All participants were consumers of yogurt, without allergies or intolerances for lactose, gluten, milk or nuts and with normal abilities to taste and smell (self-reported). Participants received a monetary incentive for their participation, and gave written informed consent before the start of the study.

2.2. Products

Commercially available yogurt (Optimel Greek Style, Friesland Campina, The Netherlands) with commercially available granola (Crunchy Hazelnut Granola, Biofamilia, Switzerland) were used. Composite food (i.e. combination of two or more foods) were chosen because of their increased sensory complexity as the sensory characteristics of one food product includes the sensory perceptions of the other food. Product characteristics are specified in Table 6.1. Yogurt with granola samples differed in hardness (hard vs. soft), particle size (9.5 ± 0.22 mm vs. 19.7 ± 0.24 mm) and concentration (3%, 10% and 20%) added to the yogurt. For more details on the product characteristics, see van Bommel et al. (2019a). Participants received a total of 60 g per yogurt-granola combination, presented in white plastic cups coded with 3-digits. A warm-up sample, consisting of 54 g yogurt with 3 g of small granola and 3 g of large granola, was included to familiarize participants with the study procedures.

Table 6.1. Product specifications.

Product	Granulation (mm)	Hardness	Concentration		kcal
			Yogurt (g)	Granola (g)	
Hard:Large:10%	23	Hard	54	6	57
Hard:Small:10%	10	Hard	54	6	57
Soft:Large:10%	23	Soft	54	6	57
Soft:Small:10%	10	Soft	54	6	57
Hard:Small:20%	10	Hard	48	12	84
Hard:Small:3%	10	Hard	58	2	38

Granulation: size of the breaking grids that were used to define particle sizes.

2.3. Attribute selection

FaceReader™ is able to detect 6 basic emotions (*angry, contempt, disgusted, happy, scared* and *surprised*), a neutral state (*neutral*) and 3 affective attitudes (*interest, bored* and *confused).* To allow comparison with facial expression analysis by FaceReader™ the emotions *bored, disgusted, interested* and *happy* were included in the TDE evaluations. Twenty emotion attributes were preselected based on literature (Gutjar et al., 2015a; King & Meiselman, 2010; Schouteten et al., 2017). A Check-All-That-Apply was performed by 10 consumers (not participating in real experiment). The 6 most frequently cited emotion attributes were used in this study together with the four preselected emotion terms mentioned above. Table 6.2 shows the emotion attributes with descriptions as provided to the participants during TDE instructions.

Table 6.2. Emotion attributes and descriptions/examples.

Emotion	Dimension	Description	Example
Aggressive	Arousal	Destructive behaviour mostly caused by frustration	Losing a game makes me feel aggressive
Bored	Arousal	Finding something uninteresting.	Doing the same thing every day makes me feel bored
Calm	Arousal	A state of freedom from excitement or disturbance	Yoga and meditation make me feel calm
Disgusted	Valence	A strong aversion to something or someone.	Closing a full garbage bag makes me feel disgusted
Energetic	Arousal	Having or showing energy	I feel energetic after a good night sleep
Enthusiastic	Arousal	Excited or exuberant feeling	I feel enthusiastic when I score a goal
Good	Valence	Pleasant or good feeling	Helping someone makes me feel good
Happy	Valence	To be pleased or glad	After passing my exam I felt very happy
Interested	Valence	To arouse or hold an interest in someone or something	The claim on the package label made me interested in the product
Whole	Valence	Seemingly complete or total	Being with family makes me feel whole

2.4. Procedure

Participants completed two test sessions for the emotion evaluations. Each session, participants evaluated one warm-up sample and three test samples. The total amount of product evaluated per session was 240 g, which approximately corresponds to the amount of a full portion. Sessions lasted about 45 minutes and were scheduled on separate days between 08.00 and 10.00 hours. Participants conducted the emotion evaluations on the same time of day. Sessions took place in sensory booths (Restaurant of the Future, Wageningen, The Netherlands). Sensory booths were designed according to ISO 8589 standards (ISO, 2007), and tests were conducted under artificial daylight and temperature control (20-22 ºC). One day before each session participants received the attribute list with definitions by email to familiarize themselves with the terminology. A live demonstration of the study procedures was given at the start of the first session. Participants were instructed to consume the whole sample (60 g) in five bites, and to always consume yogurt and granola within one bite. All bites were video recorded, and participants performed TDE for the first, third and fifth bite using TimeSens software (version 1.1.601.0, ChemoSens, Dijon, France). During the second and fourth bite ('no task') participants just ate the bite without performing TDE or liking ratings. When perception ended, participants had to click the stop button, allowing time and video recording to stop. After the first, third and fifth bite participants were instructed to rate liking on a continuous scale with end anchors 'dislike extremely' and 'like extremely'. A 3 min neutralisation period was included between samples where participants ate a piece of cracker and rinsed their mouth with water.

2.5. Dynamic emotion measurements

2.5.1. Temporal Dominance of Emotions

Participants were instructed to put a full spoon with yogurt and granola into their mouth and simultaneously click the start button, allowing time recording to start. Then, they had to select the dominant attribute (e.g. the attribute that catches most of their attention), and dominance recording of that attribute started from then and remained selected until a new dominant attribute was selected. When perception ended, participants had to click the stop button, allowing time recording to stop (Pineau et al., 2009). Participants could select as many dominant attributes as they liked, using the same attributes several times or never select an attribute during the consumption time.

2.5.2. FaceReader™

Participants were video recorded using a Logitech C270 webcam with a resolution of 720p mounted on top of the computer screen. FaceReader™ (version 7.0, Noldus Information Technology, Wageningen, The Netherlands) was used to automatically classify facial expressions from the video recordings at a time frame of 0.02 s. Upon facial recognition, an artificial 3D face model is obtained based on the Active Appearance Modelling (AAM) (Cootes et al., 2001) using 500 key points in the face. For each data frame, facial expressions are classified based on a database of 10.000 facial expression images that were manually classified by trained experts. Deep Face classification method was used to allow facial expression recognition when their eyes were still identifiable but when the lower part of the face is hidden (e.g. when they cover the mouth with a spoon). Detailed information on how facial expressions are identified with FaceReader™ is described in the FaceReader™ Methodology Note by Loijens and Krips (https://info.noldus.com/free-white-paper-on-FaceReader-methodology). Emotions and attitudes are given a score between 0 (absent) and 1 (fully present) depending of the intensity of the facial expression. Furthermore, FaceReader™ calculates *valence* (i.e. positive or negative emotion state) and *arousal* (i.e. level of activation). Valence is scored between -1 (negative emotions) and 1 (positive emotions), and arousal is scored between 0 (not active) and 1 (active).

2.7. Data analysis

Statistical analysis was performed using R (R version 3.4.2, RStudio team, 2016). Results were considered significant at $p < 0.05$, unless stated otherwise. Dominance durations, maximum intensities of facial expressions and liking scores were checked for first order effect across serving positions. No significant order effects of serving position was observed (data not reported). Therefore, product order was no longer included in the mixed model ANOVA for dominance durations, maximum facial expressions and liking.

2.7.1. Temporal Dominance of Emotions

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TDE bandplots were plotted using TimeSens software (version 1.1.601.0, ChemoSens, Dijon, France). Bandplots represent the sequence and duration of significant dominant attributes as time-bands (Galmarini et al., 2017), and were computed by product for the first, third and fifth bite. Coloured rectangles represent the dominant attributes and are stacked at each moment, displaying multiple dominances (without taking into account dominance rates at a given time point). The total height of the band is a constant and the number of colours at each moment depends on the number of significantly dominant attributes at the same time, providing a characteristic 'patchwork' effect. TDE bandplots were visually inspected to identify differences and similarities in dominance sequences between products.

The first, third and fifth bites were divided into three periods (i.e. beginning, middle and end of a bite). Mean dominance durations and standard errors of the mean were calculated per tertile, bite and product for each emotion attribute. A mixed model ANOVA was performed with product, bite and tertile as fixed factors and subject and its interaction effects with all fixed factors as random effects. Tukey HSD pairwise comparison was performed upon significance of the ANOVA.

2.7.2. Facial expressions

Facial expression data was quantified using FaceReader™ (version 7.0) at a frequency of 5Hz (i.e. 5 data frames per second) using the 'general face. Individual calibration was not used since the study followed a within-subject design. All subjects evaluated all samples in all conditions. This allows to directly quantify changes in facial expressions caused by samples in all conditions without calibration. Calibration of individual facial expression responses to a neutral stimulus to correct for potential biases in an individual's facial response were therefore not employed. Data was standardized by dividing each bite into three periods (i.e. beginning, middle and end of a bite). Maximum intensities and standard errors of the mean were calculated per tertile, bite and product for each facial expression. A mixed model ANOVA was performed with product, bite and tertile as fixed factors and subject and its interaction effects with all fixed factors as random effects. Upon significance of the ANOVA, a Tukey HSD pairwise comparison was performed.

2.7.3. Comparison between Temporal Dominance of Emotions and FaceReader™

A Multiple Factor Analysis (MFA) (Escofier & Pages, 1994) was performed on the average dominance durations observed with TDE and average maximum facial intensities over tertiles observed with FaceReader™. Product spaces and correlation plots were constructed to visualize sample differences and similarities in emotion characteristics. RV coefficient was calculated from MFA analysis to investigate the correlation between FaceReader™ and TDE.

2.7.4. Liking scores

Mean liking scores and standard errors of the mean were calculated for the first, third and fifth bite per product. A three-way ANOVA was performed with product and bite as fixed factors and subject and its interaction effects with all fixed factors as random effects. A Tukey HSD pairwise comparison was performed upon significance of the ANOVA.

3. RESULTS

3.1. Temporal Dominance of Emotions

Figure 6.2 depicts the dominance bandplots for emotions per product for the first, third and fifth bite of consumption. All yogurt-granola samples were characterized by a dominance of *interested* feelings at the beginning of the first bite. The *hard:large:10%, hard:small:10%* and *hard:small:20%* were mainly characterized by *calm* and *good* feelings. Additionally, *hard:small:20%* was dominated by *enthusiastic* feelings at the beginning of the first bite and *happy* feelings at the beginning of the third bite. The *soft:large:10%, soft:small:10%* and *hard:small:3%* were mainly characterized by *calm* and *bored* feelings. The dominance duration of *interested* disappeared towards the fifth bite of consumption. Hardly any other dynamic changes could be identified for any of the other emotion descriptors between and within bites.

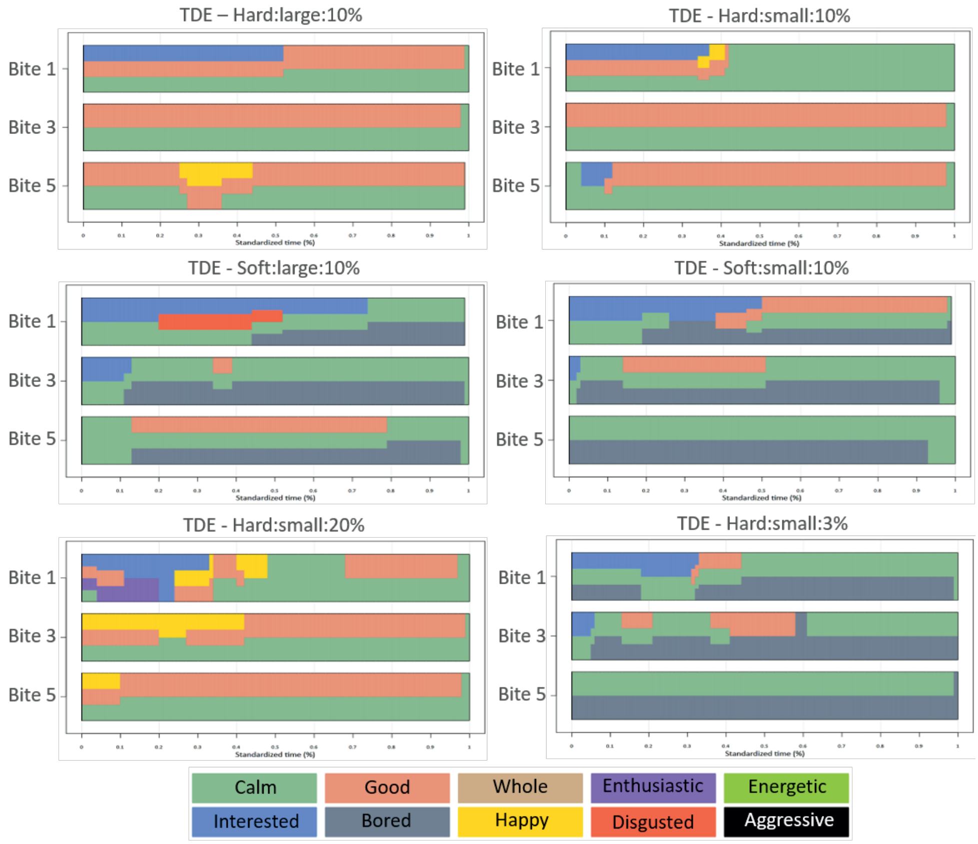

Figure 6.2. TDE bandplots of the sequence of dominant emotions by product for the first, third and fifth bite for all six yogurt-granola products. Coloured rectangles represent the dominant emotions and are stacked at each moment, displaying multiple dominances (without taking into account dominance rates) at a given time point. Represented emotions are significant at $p < 0.05$.

Table 6.3 shows the F-values of the ANOVA on dominance durations in % of standardized time for each attribute by product, bite and tertile obtained with TDE. The significant interaction effect of bite by tertile ($F(4,2420) = 4.8$, $p < 0.001$) indicates that the dominance durations of *interested* feelings significantly decreased from the beginning to the end of a bite, but that these dynamic changes were specific for the first and third bite. A main bite effect was observed for *interested* ($F(2,110) = 19.0$, $p < 0.001$), which shows that dominance durations of *interested* feelings significantly decreased from the first to the fifth bite for all products. Significant interaction effects for product by tertile were observed for *bored* ($F(10,2420) = 2.8$, $p = 0.002$), *energetic* ($F(10,2420) = 2.1$, $p = 0.02$) and *happy* ($F(10,2420) = 1.9$, $p = 0.04$), meaning that the dominance durations of these attributes did not develop the same way over tertiles between products. *Bored* feelings significantly increased in dominance duration from the first to the third tertile for the *hard:small:3%,* but no significant effect between products and tertiles were observed for *energetic* and *happy* when performing Tukey HSD pairwise comparison. Significant product by bite interaction effects were observed for *calm* ($F(10,2420) = 3.7$, $p < 0.001$), *disgusted* ($F(10,2420) = 3.5$, $p < 0.001$), *enthusiastic* ($F(10,2420) = 2.9$, $p = 0.001$), *good* ($F(10,2420) = 2.6$, $p = 0.004$) and *whole* ($F(10,2420) = 1.9$, $p = 0.04$), which indicates that the dynamic changes in dominance durations between bites were product specific. From first to fifth bite, *calm* feelings significantly increased in *soft:small:10%, disgusted* feelings significantly decreased in *soft:big:10%* and *enthusiastic* feelings significantly decreased in *hard:small:20%.* No significant effects between products and bites were observed for *good* and *whole* after pairwise comparison using Tukey HSD.

Table 6.3. ANOVA of dominance durations (in % of standardized time) by product, bite, tertile and its interactions observed in Temporal Dominance of Emotions.

Descriptor	F_{prod}	F_{bite}	$F_{tertile}$	$F_{prod*bite}$	$F_{prod*tertile}$	$F_{bite*tertile}$
Aggressive	**2.5***	1.2	0.8	0.8	0.5	0.3
Bored	**15.2*****	2.1	**5.7****	1.5	**2.8****	0.7
Calm	0.7	**5.0****	**3.3***	**3.7*****	0.2	0.1
Disgusted	**5.5*****	1.7	2.9	**3.5*****	1.2	0.1
Energetic	**5.0*****	0.7	0.1	1.1	**2.1***	0.3
Enthusiastic	**12.2*****	**4.9****	2.5	**2.9****	1.3	1
Good	**5.8*****	**3.6***	0.6	**2.6****	0.6	0.9
Happy	**7.3*****	1.2	2.4	1.3	**1.9***	1
Interested	0.6	**19.0*****	**12.6*****	1.7	0.3	**4.8*****
Whole	0.9	2.2	2.3	**1.9***	1.7	2.1

Significant at (*) 0.05, (**) 0.01, (***) 0.001.

3.2. Dynamic facial expressions

Table 6.4 shows the ANOVA results of the maximum facial expression intensities by product, bite and tertile observed with FaceReader™. Products could be differentiated based *neutral* ($F(5,275) = 3.8$, $p = 0.002$), *angry* ($F(5,275) = 3.5$, 0.004), *sad* ($F(5,275) = 3.2$, $p = 0.009$), *surprised* ($F(5,275) = 2.6$, $p = 0.03$) and *bored* ($F(5,275) = 5.0$, $p < 0.001$) facial expressions. Significant differences in facial expressions between products are visualized in Figure 6.3. *Hard:large:10%* was characterized by highest *neutral* facial expression intensities and lowest *sad* facial expressions. *Soft:large:10%* and *soft:small:10%* were characterized by highest *angry* and *sad* facial expression intensities, and had significantly lowest *neutral* facial expressions. *Hard:small:20%* had significantly highest *neutral* and *bored* facial expression intensities and lowest *angry* facial expressions.

Table 6.4. ANOVA of maximum facial expression intensities by product, bite, tertile and its interactions.

Facial expression	$F_{product}$	F_{bite}	$F_{tertile}$	$F_{prod*bite}$	$F_{prod*tertile}$	$F_{bite*tertile}$
Neutral	**3.8****	**7.8*****	**14.2*****	1.8	**2.5****	0.5
Angry	**3.5****	**8.6*****	**16.9*****	1.7	0.8	0.5
Contempt	1.8	2.1	1.2	**3.5*****	1.6	0.8
Disgusted	0.6	1.9	**24.6*****	1.4	0.8	0.4
Happy	0.8	0.9	2.7	**1.9***	0.7	0.2
Sad	**3.2****	1.7	**26.8*****	**2.0***	1.2	1.5
Scared	1	1.6	**44.5*****	1.4	0.9	0.3
Surprised	**2.6***	0.1	**14.6*****	1.5	**2.2***	0.6
Interest	0.6	0.7	1.8	1.2	0.6	2.3
Bored	**5.0*****	**3.8***	**28.8*****	**2.5****	1.3	1.4
Confused	1.8	2.6	0.1	**2.2***	0.9	0.3
Arousal	0.9	1.7	**184.8*****	0.5	1.2	0.7
Valence	1.8	0.7	**6.4****	**2.1***	1	0.4

Significant at (*) 0.05, (**) 0.01, (***) 0.001.

Looking at dynamic changes between bites, we observed that *neutral* ($F(2,110) = 7.8$, $p < 0.001$) facial expressions significantly increased, and *angry* ($F(2,110) = 8.6$, $p < 0.001$) facial expressions significantly decreased from the first to the fifth bite of consumption for all products (Table 6.4). However, these significant main effects for the dynamic changes between bites for *neutral* and *angry* facial expressions were driven by changes in facial expressions for *neutral* and *angry* for *soft:large:10%* and *hard:small:3%*. Product by bite interaction effects indicated that product specific changes in facial expressions which were observed for *contempt* ($F(10,2415) = 3.5$, $p < 0.001$), *happy* ($F(10,2415) = 1.9$, $p = 0.04$), *sad* ($F(10,2415) = 2.0$, $p = 0.03$), *bored* ($F(10,2415) = 2.5$, $p = 0.005$), *confused* ($F(10,2415) = 2.2$, $p = 0.01$) and *valence* ($F(10,2415) = 2.1$, $p = 0.03$). Figure 6.4 shows the significant changes in facial expressions per product for the first, third and fifth bite of consumption. No significant change between bites for any of the facial expressions observed with FaceReader™ were seen for *hard:large:10%, hard:small:10%* and *hard:small:20%. Soft:small:10%* revealed most dynamic changes in facial expressions over bites, such as the significant increase of *neutral, angry*, *contempt* and *bored* facial expressions and a significant decrease in *angry* facial expressions from the first to the fifth bite. Moreover, *angry* facial expressions decreased from the first to the fifth bite for *hard:small:3%* and *confused* facial expressions decreased from the third to the fifth bite for the *soft:small:10%*. Posthoc analysis did not reveal significant differences between within products for *happy* facial expressions and *valance*.

Main tertile effects indicate the dynamic change of facial expressions within bites. Significant main tertile effects were observed for *angry* (F(2,110) = 16.9, p < 0.001), *disgusted* (F(2,110) = 24.6, p < 0.001), *scared* (F(2,110) = 44.5, p < 0.001) and *arousal* (F(2,110) = 184.8, p < 0.001), indicating that these facial expressions significantly decreased from the beginning to the end of each bite for all products. Interaction effects for product by tertile showed that the dynamic changes from beginning to the end of a bite for *neutral* (F(10,2414) = 2.5, p = 0.006) and *surprised* (F(10,2525) = 2.2, p = 0.02) facial expressions were product specific. *Neutral* facial expressions decreased from beginning to end of each bite for *hard:small:10%, soft:large:10%, soft:small:10%* and *hard:small:20%,* and *surprised* facial expressions decreased from beginning to end of each bite for *hard:large:10%, hard:small:10%* and *hard:small:20%.*

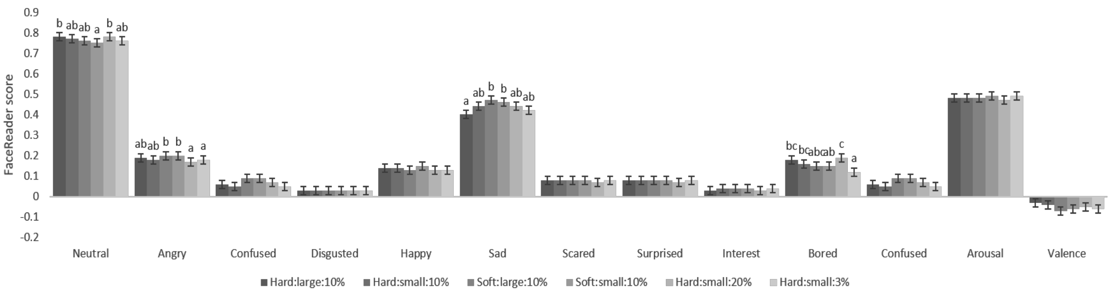

Figure 6.3. Graphic representation of the FaceReader™ scores for each facial expression per product. Means with different letters indicate significant differences between products (p < 0.05).

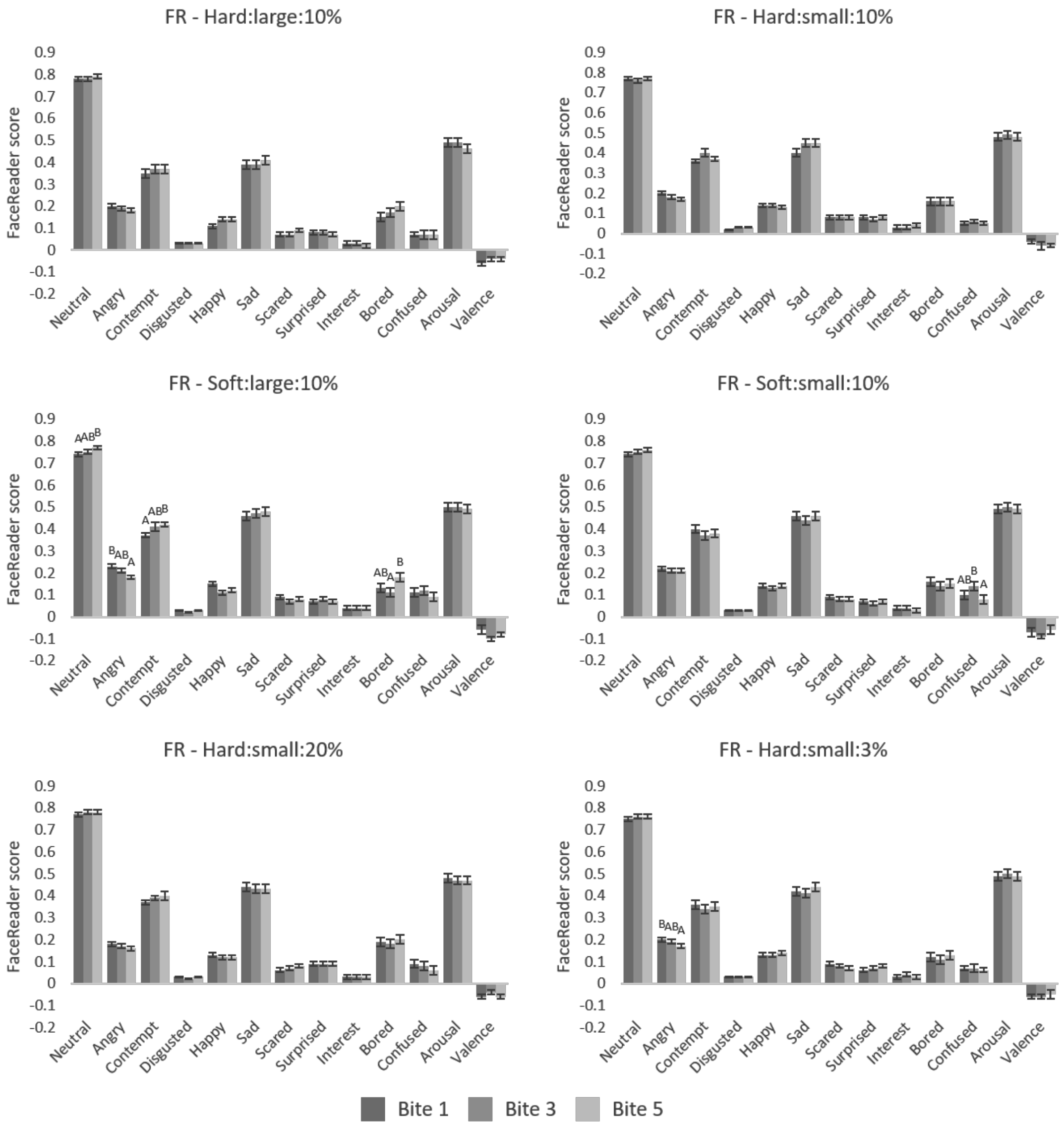

Figure 6.4. Graphic representation of the FaceReader™ scores of the facial expressions for the first, third and fifth bite for all six yogurt-granola products. Means with different letters indicate significant differences between bites within a product ($p < 0.05$).

3.3. Multivariate comparison of Temporal Dominance of Emotions and facial expressions

Figure 6.5 shows the MFA plot which indicates product differentiation for the first, third and fifth bite based on an attribute's dominance durations observed with TDE (green font) and maximum facial expression intensities observed with FaceReader™ (red font). The MFA correlation circle (Figure 6.5a) visualizes the emotion attributes in TDE and FaceReader™. The MFA individual factor map (Figure 6.5b) represents the six products in black as mean points and the emotion configurations of the emotion measures in colour. The first two dimensions account for 57% of the variance (42.2% and 14.9% respectively). Products are discriminated along the first dimension, which reflects both valence and arousal, and differentiates the products from least liked (*soft:small:10%, soft:large:10%* and *hard:small:3%*), to moderately liked (*hard:small:10%* and *hard:large:10%*) to most liked (*hard:small:20%*). The horizontal reflection of TDE and FaceReader™ emotions limits product differentiation of the products along a single dimension. Consumers self-reported mainly high arousal (*energetic* and *enthusiastic*) and positive (*happy, whole* and *good*) emotions and expressed *surprised, bored* and *neutral* facial expressions for the *hard:large:10%, hard:small:10%* and *hard:small:20%*. Least liked products were mainly characterized by low arousal (*bored* and *calm*) and negative (*disgusted* and *aggressive*) emotions using TDE. FaceReader™ further discriminates the least liked products by separating the soft:large:10% from the soft:small:10% along the second dimension. The *soft:large:10%* was mainly characterized by *sad, confused* and *interested* facial expressions, whereas *soft:small:10%* and *hard:small:3%* were characterized by negative (*angry, disgusted* and *scared*) and *happy* facial expressions.

A significant RV coefficient of 0.545 ($p < 0.001$) was observed, representing a moderate correlation between the product configurations defined by the implicit (FaceReader™) and explicit (TDE) emotion measures. Overlapping emotion terms in both methods such as *happy* and *bored* seem negatively correlated, indicating that they are likely to have different meanings in TDE and FaceReader™. *Bored* observed with FaceReader™ seems positively correlated to positive (*happy* and *good*) and high arousal (*energetic* and *enthusiastic*) emotion terms in TDE. There seems to be more robustness on the agreement on negative emotion terms between TDE (disgusted, bored and aggressive) and FaceReader™ (disgusted, angry, confused and sad).

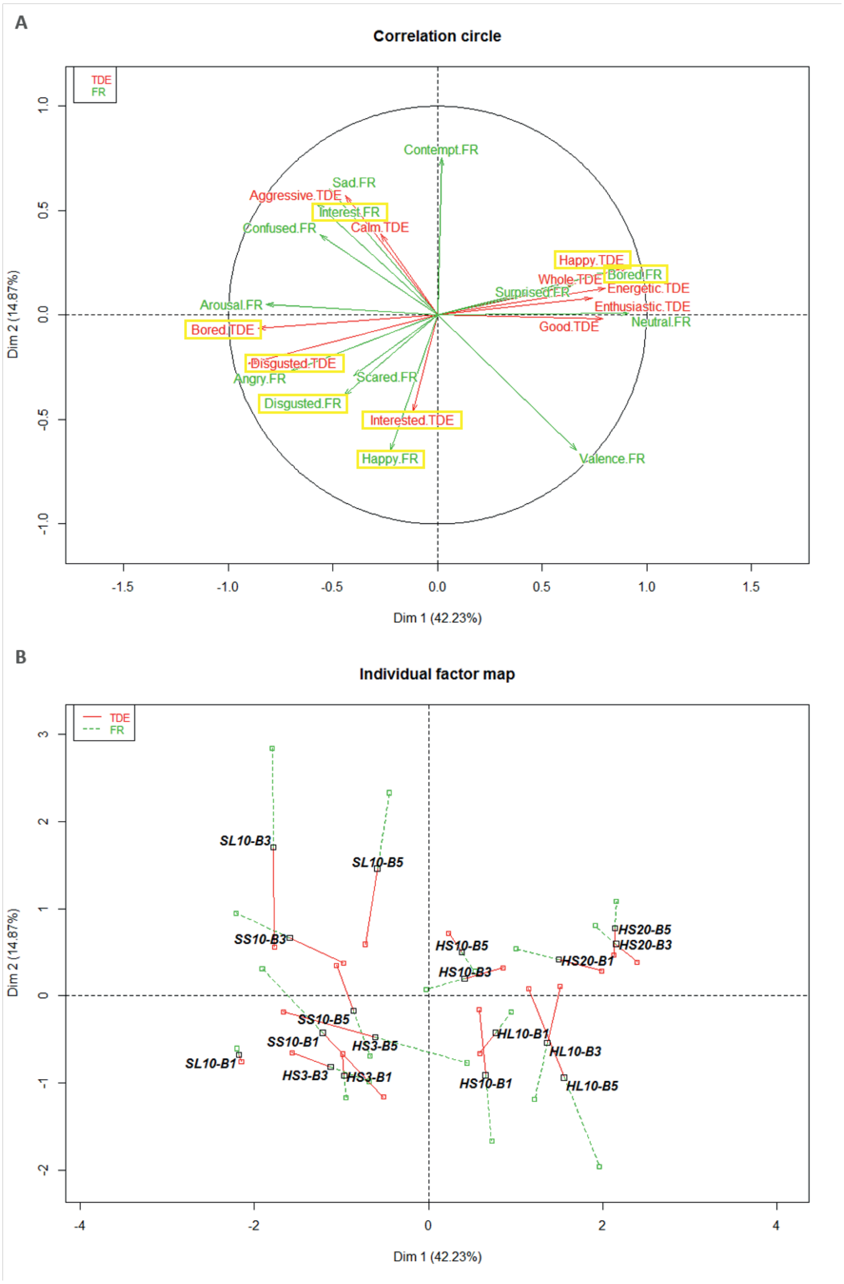

Figure 6.5. Representation of the first two dimensions of the MFA space showing (a) emotion descriptors based on mean dominance durations observed with TDE (green font) and mean maximum facial expression intensities observed with FaceReader™ (red font), and (b) the first (B1), third (B3) and fifth (B5) bite of the six products as mean points, the partial individuals representing the emotion configurations of the products of the two emotion measurements. HS10 (hard:small:10%), HL10 (hard:large:10%), SS (soft:small:10%), SL10 (soft:large:10%), HS20 (hard:small:20%), HS3 (hard:small:3%).

3.4. Dynamic liking

Figure 6.6 shows the mean liking scores of the first, third and fifth bite of each product after TDE evaluations. Products could be differentiated based on their liking, whereas the *hard:small:20%* was significantly most liked followed by *hard:large:10%* and *hard:small:10%,* and the *soft:large:10%, soft:small:10%* and *hard:small:3%* were significantly least liked. A significant product by bite interaction effect $(F10,550) = 3.4$, $p < 0.001$) was observed for the liking scores after TDE evaluations, suggesting that liking scores did not evolve the same way for the six yogurt with granola samples of the three bites. The liking scores after TDE evaluations of the *hard:large:10%* significantly increased ($p < 0.05$) from the first to the fifth bite with 0.4. No other significant increase or decrease over bites was observed for any of the other products.

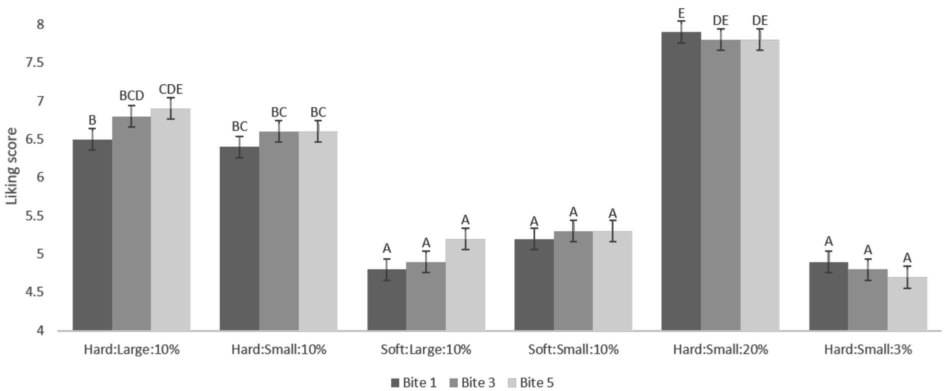

Figure 6.6. Mean liking scores and standard errors of the mean by product and bite after TDE evaluations. Means with different letters indicate significant differences between products and bites ($p < 0.05$).

4. DISCUSSION

This study compared the temporal evolvement of food-evoked emotions using a five-bite evaluation approach employing FaceReader™ and TDE. We hypothesized that the emotions obtained from facial expressions reflect the self-reported food-evoked emotion responses. Although FaceReader™ and TDE provide different type of information, we expected correspondence between FaceReader™ and TDE in terms of product discrimination and characterization (i.e. valence and arousal) within and between bites. Our findings indicate that FaceReader™ and TDE differentiate products differently and both methods show little overlap regarding type of emotion characterization. FaceReader™ and TDE discriminated products mainly along the valence dimension (positive – negative), which directly reflected product discrimination in terms of liking. Furthermore, food-evoked emotion profiles obtained with FaceReader™ and TDE show little dynamics within and between bites.

Consumers mainly self-reported positive (*good*) and low arousal (*calm* and *bored*) feelings using TDE, while highest intensities for *neutral*, *arousal* and negative (*sad* and *contempt*) facial expressions were observed using FaceReader™. Similar emotion terms in TDE and FaceReader™, such as *happy, bored, interested* and *disgusted*, do not seem to have similar meanings in both methods. We observed that *happy* facial expressions are negatively correlated to subjective *happy* feelings reported with TDE. Moreover, *happy* facial expressions are correlated to negative emotion terms, such as *angry, scared* and *disgusted*. Danner, Haindl, Joechl, and Duerrschmid (2014) reported similar findings and suggests that the detection of *happy* facial expressions by FaceReader™ needs more expressive facial movements (e.g. smiling), which could be hampered by the individual assessments of foods in laboratory settings and lack of social interactions that invites people to be more articulating and expressive of their facial movements.

Least liked products (*hard:small:3%, soft:small:10%* and *soft:large:10%*) were associated with negative emotions and most liked products (*hard:small:20%, hard:small:10%* and *hard:large:10%*) were characterized by positive emotions. FaceReader™ further differentiated the least liked products from each other on arousal and negative facial expressions. These findings are in line with previous research that suggests that facial expressions are more suitable to characterize and differentiate disliked products compared to liked products (Danner et al., 2014a; Zeinstra et al., 2009).

In line with previous research, we observed that negative facial expressions were more intense than positive facial expressions (Danner et al., 2014; de Wijk et al., 2012; Rocha-Parra et al., 2016). Zeinstra et al. (2009) suggested that facial expressions are more suitable to measure dislikes than likes because negative facial expressions are quicker to appear and less influenced by other factors compared to positive facial expressions. FaceReader™ was originally developed for consumer products other than foods, hence the type of facial expression terms in FaceReader™ are skewed towards negative emotions. To steer product development and to tailor products to consumer's preferences, food-evoked emotion research targets regular product consumers. Regular product consumers mainly have positive emotion responses to products (so-called hedonic asymmetry), compared to non-users who have more negative or no emotion responses (King & Meiselman, 2010; Schifferstein & Desmet, 2010). This raises the question whether facial expression analysis will provide the desirable product information needed to steer product development.

Consumers self-reported *interested* feelings upon the first encounter of the product (e.g. beginning of the first bite). Previous intrinsic and extrinsic product experiences of the same or similar products cause sensory and hedonic expectations (Fernqvist & Ekelund, 2014; Piqueras-Fiszman & Spence, 2015). It is plausible that taste perceptions in the first bite define taste expectations for the following bites of the same product, causing self-reported *interested* feelings to wear off towards to third and fifth bite of consumption.

Our results indicated that facial expressions were more dynamic within bites than between bites. Arousal and negative (*sad*, *scared* and *angry*) facial expressions significantly decreased from the beginning to the end of each bite and neutral facial expressions increased from beginning to end of each bite. Although FaceReader™ corrects for partial occlusion of the lower part of the face (e.g. when subjects put a spoon to their mouth) by Deep Face Classification method, we cannot exclude the possibility that changes in oral processing behaviour affect the observed changes in facial expressions. Consumers might have displayed different muscle activities during consumption due to oral processing behaviour. Consumers might have used different chewing motions during the initial processing while granola is still hard and change chewing motions towards swallowing at the end of a bite. More chewing movements are likely to display higher muscle activity or tension which could be recognized by FaceReader™ as higher intensities of negative facial expressions, whereas swallowing a bite might reflect more relaxed facial muscles which could be interpreted as neutral facial expressions by FaceReader™. Consequently, products that require intense mastication or products with 'big' changes in oral processing from beginning to end of mastication might hamper the (correct) identification of facial expressions.

The present study observed some dynamic changes in facial expressions over bites, but the direction of change was inconsistent between products. In contrast to our results, Rocha-Parra et al. (2016) observed a significant decrease of negative facial expressions accompanied by a significant increase in liking from the first to the third sip for two red wines. We speculate that the difference in observed dynamics of food-evoked emotion responses over multiple bites is caused by a difference in reward value between yogurt with added granola and red wine. Red wine is considered a highly emotional product which is likely to provide high reward value compared to yogurt with added granola which is a more basic food product and is likely to provide low reward value. Consequently, the emotion response to yogurt with added granola remains more stable during consumption. Moreover, consumers appreciated the red wines more upon increasing number of sip (Rocha-Parra et al., 2016), whereas liking scores of our yogurt with added granola samples did not change from bite to bite. The type of product and hedonic changes during consumption might have driven dynamic differences in emotion response over multiple bite assessments.

The current study used multiple bite assessments, which has the advantage that it mimics more natural eating behaviours as consumers eat food portions with multiple bites. FaceReader™ identified more negative emotions, while TDE identified more positive emotions. Hence, implicit and explicit measurements seem to be a complementary option when it comes to profiling food-evoked emotions (Leitch et al., 2015; Rocha et al., 2019). From a methodological point of view, FaceReader™ and TDE have the advantage that they allow to record changes in a consumer's food-evoked emotion response over time. TDE allows descriptive profiling of consumers' subjective experience of food products, but is limited by the number of emotion terms that can be assessed at the same time. TDE includes a minimum of 8 and a maximum of 12 emotion terms (Jager et al., 2014). The balance in emotion terms (positive, negative, high arousal and low arousal) is of utmost importance. The limited number of descriptors included in TDE could have led to dumping effects. Moreover, TDE is based on the concept of dominance, allowing the selection of only one emotion term at a time compared which could lead to relevant loss of information on the dynamic food-evoked emotion perception of a consumer.

Recording facial expressions has the advantage that it captures fast changing emotions and targets the subconscious part of the emotion experience. The downside of recording facial expressions is that it is prone to data loss due to technical failures (i.e. shadows in the face due to bad lightening or loss of eye contact with the camera) and coverage of the face (i.e. wearing glasses or having facial hair such as a beard or moustache). Recording facial expressions leads to a large data set, and screening, filtering and analysing the data is time consuming. Moreover, it is still unknown how oral processing affects the identification of facial expressions by

FaceReader™. FaceReader™ technology uses a Deep Face Classification method which allows analysis of facial expressions when the lower part of the face is hidden. It is unclear how this potentially biases or limits the facial expressions when for example the recognition of a specific expression requires opening of the mouth. Moreover, type of product seems to have important implications and could enhance bias due to oral processing behaviour. Yogurt with granola varying in hardness, size and concentration could have hampered the identification of facial expressions due to the potentially different oral processing behaviours (e.g. yogurt with hard granola vs. yogurt with soft granola). To better understand how oral processing behaviour influences the identification of facial expressions, future research should be done with products from the same product category that evoke different oral processing behaviours (e.g. peach cubes vs. peach smoothie).

To conclude, the emotion profiles obtained with implicit measures (facial expressions) show little overlap with the emotion profiles obtained with explicit measures (TDE) due to different type and nature in descriptors. Food-evoked emotions were mainly mild and positive and emotion responses did not seem product specific, but rather relate to the product category. Food-evoked emotion responses were fairly stable from first to last bite and only very limited changes were observed using implicit and explicit emotion measures. Both methods discriminated products mainly on the valence dimension (positive – negative) which directly reflected product discrimination in terms of liking.

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CHAPTER 7

General discussion

7. GENERAL DISCUSSION

This thesis aimed to investigate dynamic changes in food-evoked emotions, sensory and hedonic perceptions within and between multiple bites of consumption as perceived by consumers. Moreover, we investigated test behaviours of consumers using rapid dynamic sensory methods and compared the performance of dynamic implicit and explicit emotion measurements. This research provides insights onto best practices of using rapid temporal methods in more realistic eating conditions, such as multiple bite assessments.

7.1. Main findings

This thesis investigated the conceptualization of dominance and repeatability of consumers using TDS. The definition of dominance provided to consumers using TDS hardly influences the dynamic sensory profiles. The conceptualization of dominance is subjective to the consumer (chapter 2). Consumers defined dominance as the predominant sensation, the most striking sensation and the sensation that pops up. Consumers used different strategies to select sensory attributes, such as intuition, hedonic perceptions and previous experiences and expectations of the product. Panel repeatability was not compromised by the subjective conceptualization of dominance in TDS (chapter 2). Moreover, consumers might need some processing time to select dominant attributes. Implicit no dominance durations could capture hesitations or indecisive selection behaviours. However, no dominance durations between sensory attribute selections were shorter than 1s (chapter 3), so too short to reflect periods of true hesitation, but rather reflect the time needed to switch between dominant attributes. Capturing implicit no dominance did not reduce noise and did not lead to better sensitivity and discrimination in TDS data.

To move to more realistic eating conditions, multiple bite evaluations were performed. This thesis explored dynamic changes in sensory perceptions using multiple bite assessments. Specific sensory attributes built up in dominance from the first to the last bite of consumption for a broad range of food products. Upon consumption of a full portion of a food hedonic perceptions (liking) decline, which was related to increases of desired sensory perceptions and decreases of undesired sensory perceptions from first to last bite of consumption (chapter 4 & chapter 5).

Food-evoked emotions may add to the understanding of food choice behaviour. This thesis explored implicit (facial expressions) and explicit (Temporal Dominance of Emotions, TDE) food-evoked emotion measurements employing multiple bite evaluations. Food-evoked emotion responses were fairly stable from first to last bite. Only very limited changes were observed using implicit and explicit emotion measures. Furthermore, facial expression intensities of emotions and dominance durations observed in TDE are not directly comparable and show little overlap (chapter 6).

7.2. Methodological considerations

Most studies measure sensory and hedonic perceptions immediately after tasting a single bite of a food product (Kaneko et al., 2018; Lawless & Heymann, 2010). Static measurement methods provide an average score of the dynamic sensory perceptions during a single bite of a food product, while many studies have proven that taste and texture perceptions are dynamic and change over time due to mastication and salivation (Di Monaco et al., 2014). This thesis used rapid dynamic measurements, such as Temporal Dominance of Sensations (TDS), Temporal Check-All-That-Apply (TCATA), alternated Temporal Drivers of Liking (a-TDL), Temporal Dominance of Emotions (TDE) and facial expressions to measure a consumer's dynamic food-evoked emotions, sensory and liking perceptions.

Consumption contexts under which products are evaluated influence consumers' food-evoked emotion, sensory and hedonic responses (Piqueras-Fiszman & Jaeger, 2014a, 2014b). Appropriate consumption contexts are associated with more positive emotions and higher acceptance ratings as opposed to inappropriate consumption contexts which are associated with more negative emotions and lower acceptance ratings (Cardello & Schutz, 1996; Piqueras-Fiszman & Jaeger, 2014a, 2014b). For example, products that are evaluated outside the appropriate consumption context (e.g. the evaluation of beer or wine early in the morning) lead to an increase of negative emotions and a decrease in liking ratings. Studies included in this thesis carefully considered the appropriate consumption time of foods (i.e. evaluation of a breakfast product in the morning and evaluation of a snack products in the afternoon) and tested consumers on the same time of day when multiple sessions were employed to reduce inter-individual variability.

When comparing methods (chapter 2-3 & chapter 5), a between subjects design was used to reduce learning effects of consumers. When one is interested in panel performance of consumers a between subjects design is recommended to avoid carry over effects, while when interested in panel performance of trained assessors a within subjects design might be more suitable, which allows for direct comparison between methods (Ares et al., 2015). A between subjects design uses two independent groups of assessors and avoids carry-over effects. The advantage of a between subjects design is that previous knowledge about and experience with the evaluation procedure does not influence a consumer's performance. The downside of using a between subjects design is that it is not as powerful as a within subject design, and the introduction of an extra source of variation in the data related to the different subject groups.

This thesis performed product evaluations with regular users of the product. Previous research points out that non-users or rare users of a food product do not have subjective evaluations of a product. Non-users do not report highly negative emotions, most emotion scores are close to zero and the product does not appeal to them affectively (King & Meiselman, 2010). Hence, it is important to not recruit a random sample, but to include regular users of a food product of product category.

Research described in this thesis is performed with untrained consumers, largely consisting of undergraduate students. It is not uncommon that undergraduate students are used in academic research. However, undergraduate students are often younger, healthier and higher educated than the general population. The majority of research described in this thesis investigates the performance of consumers using rapid dynamic sensory methods. Younger participants are often more used to working with computers and might be better in performing computer tasks compared to older and less educated consumers. Hence, the results of this thesis cannot be generalized to the general population.

7.3. Discussion of the main results and implications for future research

7.3.1. Consumer based sensory evaluations

In sensory and consumer research, 'naïve' consumers provide descriptive information about the sensory properties of food products. However, consumers are not trained on the descriptive evaluation of food products, which leads to high inter-individual variability in the data (Lawless & Heymann, 2010; Schutz, 1999). Literature suggests that training assessors on the performance of Temporal Dominance of Sensations (TDS) does not improve the quality of the data (Albert et al., 2012; Meillon et al., 2009). Yet, large variation in individual performances is a well-known phenomenon in TDS data (Laguna et al., 2013; Pineau et al., 2012; Pineau et al., 2009; Saint-Eve et al., 2011). Currently, individual differences in panel performances are corrected for using data standardization (Lenfant et al., 2009; Pineau et al., 2009). However, behavioural factors, such as conceptual ideas and processes behind attribute selections, must be carefully considered when exploring consumer's behaviour when performing rapid dynamic sensory techniques. Figure 7.1 provides an overview of methodological considerations of rapid temporal sensory methods and the questions answered in this thesis.

Consumers use different concepts for dominance and different sensory attribute selection strategies when performing TDS (chapter 2). Our results are supported by findings by Varela et al. (2018) who found heterogeneity on how trained assessors and consumers select dominant attributes in TDS. Hence, the concept of dominance covers many dimensions, such as attentional capture, 'big' changes in sensory perceptions and sensory intensity. Varela et al. (2018) observed that intensity was the main dimension used by consumers to select sensory attributes in TDS and Meyners (2010) suggests that dominance and intensity are two different concepts. This thesis demonstrated that when consumers focus on different dimensions of dominance (attentional capture versus intensity) similar dynamic sensory profiles are obtained (chapter 2). Consumers selected sensory attributes based on intuition, hedonic perceptions (liking of specific sensory attributes) and previous experiences and expectations of the product (chapter 2). It seems that consumers use an intuitive approach to select sensory attributes almost independent of the instructions provided to them when performing TDS. This implies that the instructions regarding the definition of dominance provided by the researcher do not influence the obtained dynamic sensory profiles, and literature that uses different definitions for dominance can be compared and used interchangeably. Moreover, it shows that while dominance and intensity are different concepts (Meyners, 2010), the discrimination between

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these (theoretical) concepts seems to have no practical relevance or implications when TDS is considered.

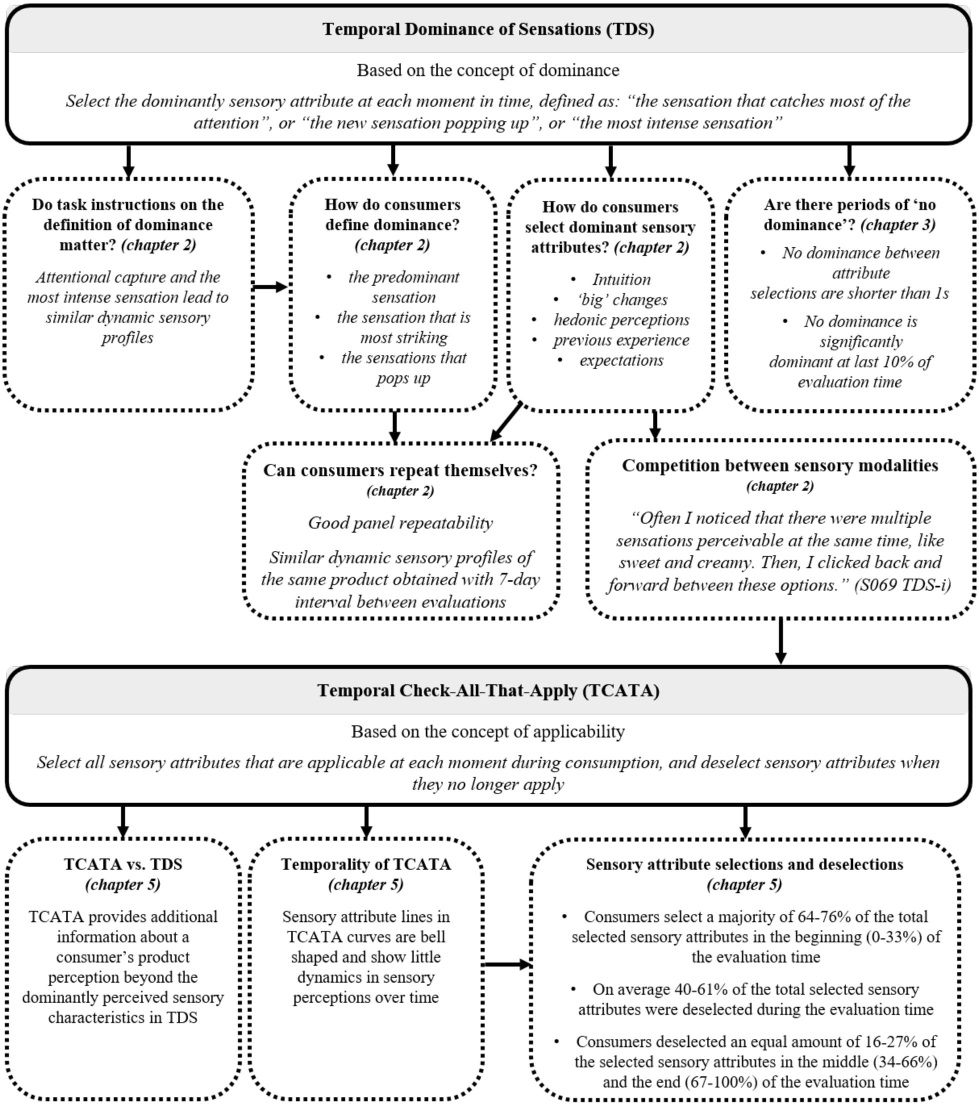

Figure 7.1. Methodological considerations of rapid temporal sensory methods and questions answered in this thesis.

The broad and vague definition of dominance is suggested to lead to heterogeneity in consumers' attribute selection strategies, which could lead to low panel agreement and poor panel repeatability in TDS data (Ares et al., 2016; Varela et al., 2018). This thesis shows that consumer panels are repeatable, as similar dynamic sensory profiles were observed between test sessions of the same product with a 7-day interval (chapter 2). It cannot be excluded that consumers use different sensory attribute selection strategies within and between product evaluations. It is well known that there is more variation in consumer data compared to descriptive sensory data obtained with a trained panel. Consumers are untrained, and to account for the variability in the use of scales or the selection of sensory attributes high number of assessors is recommended in consumer studies (Lawless & Heymann, 2010). In consumer research, it is important to measure sensory perceptions and liking in conditions and contexts that are as close as possible to realistic eating conditions. Controlling and standardizing a consumer's sensory attribute selection strategy might interfere with the interest to measure how consumers perceive a product and what is important for a consumer in a product.

Response restrictions in TDS, due to the single dominant attribute selection at each moment in time, can lead to hesitations and delays in response time. This thesis investigated implicit moments of no dominance in TDS. Despite the fact that moments of no dominance indicating hesitation were not captured in TDS, it is still possible that assessors experience moments of hesitation or delays in response times for the selection of a dominant attribute (chapter 3). Explicitly, moments of no dominance could be measured using a 'no dominance' button in addition to the buttons to select sensory attributes. Consumers can then select this no dominance button when nothing is perceived as dominant at that moment in time or when they hesitate which attribute to select. However, TDS is a forced choice task and consumers have to select an attribute at each moment in time. Including a no dominance button might give consumers an easy way out when they are in doubt about the dominant sensory attribute and decreases dominance rates in TDS curves, possibly leading to poor resolution and decreased discrimination between products (Galmarini et al., 2018; Peltier et al., 2019; Rodrigues et al., 2018). Main reasons for hesitations or delayed response times on the selection of a dominant sensory attribute might be the competition for dominance between taste and texture attributes (Varela at el., 2018). Sensory attributes from different modalities (taste and texture) or sensory attributes from the same modality could be dominant at the same moment in time during consumption and could, therefore, compete with each other.

TCATA allows consumers to select all sensory attributes that are perceived at each moment in time. In TCATA, consumers can select sensory attributes from multiple modalities (i.e. taste and texture) and the method might therefore give better descriptive sensory profiles (Ares et al., 2015; Nguyen et al., 2018). However, in TCATA consumers have to select and deselect sensory attributes, which requires different cognitive processes compared to TDS where consumers only have to focus on the selection of a dominant sensory attribute (Ares et al., 2016). This thesis shows that consumers mainly select applicable sensory attributes (64-76%) in the beginning of the evaluation time using TCATA. Only half of the selected sensory attributes in TCATA are deselected, leading to poor discrimination of temporality of different sensory attributes as curves tend to be bell shaped and sensory attributes peak at the same time (chapter 5). These findings are supported by Alcaire et al. (2017) who reported that the maximum citation proportions of any of the sensory attributes in TCATA were largely similar to the static citation proportions observed with CATA. Hence, the high cognitive load of the task may render the consumer incapable of keeping track of the selection and simultaneous deselection of applicable sensory attributes over time, which results in a lack of temporality and dynamic resolution in TCATA. TDS, on the other hand, provides better description of dynamic changes in sensory perceptions over the course of a single bite compared to TCATA, as sensory attributes appear and disappear above the significance line at different moments in time during consumption (chapter 2-5). Nevertheless, consumers also select the majority of sensory attributes (46-51%) in the beginning of the evaluation time (chapter 5). When consumers perform TDS and TCATA, they are instructed to end the evaluation of a bite when perception ends. It is plausible that sensory attribute selections decrease towards the end of the evaluation time due to vagueness of the concept ‘till perception ends’. Linking this to the observed significantly dominant no dominance durations at the last 10% of the standardized evaluation time (chapter 3), it could be that there is a latency at the end of the evaluation time where consumers re-evaluate their sensory perceptions or hesitate about the presence or absence of sensory perceptions of the food. Including a swallow button in TDS and TCATA evaluations would provide additional information about the sensory perceptions that are perceived during tasting vs. sensory perceptions that are perceived as after-taste, and could provide more insights in when consumers terminate the sensory evaluation of a single bite.

Taken together, the choice of the rapid dynamic sensory method depends on the research question at hand. TDS provides better dynamic sensory characterization, but only represents the dominantly perceived sensory attributes at each moment in time, while TCATA provides better multimodality product descriptions but lacks temporal resolution (chapter 5). New variations on TDS and TCATA have recently been introduced, such as TDS by modality (M-TDS) and TCATA Fading. These adaptions of the original TDS and TCATA methods resolve some of the drawbacks mentioned above, and seem more promising for the dynamic characterization of sensory perceptions. TDS almost only discriminates products on texture attributes (chapter 2-5). M-TDS might add a second differentiating modality to the evaluations. M-TDS allows consumers to select one dominant sensory attribute from each modality (taste and texture), which offers new opportunities to provide more detailed dynamic product profiles and reduces competition on the dominantly perceived sensory attribute between taste and texture characteristics in TDS. M-TDS is suggested to provide more robust and richer product descriptions compared to TDS (Nguyen et al., 2018). Current practice is to perform M-TDS for taste and texture attribute separately. Texture attributes are evaluated on the first screen and taste attributes in a second screen, and data is then aggregated in one TDS curve (Meyners, 2020; Nguyen et al., 2018; Agudelo et al., 2015). This has the advantage that the number of attributes presented on a screen are reduced (e.g. 10 sensory attributes divided over two screens), which might make it easier for consumers to indicate their dynamic perceptions over time. On the other hand, the number of attributes per modality could be increased when taste and texture are evaluated on separate screens, as the optimal number of attributes presented on a screen lies between 8-10 (Pineau et al., 2012). However, when aggregating the data of the separate taste and texture evaluations, the total number of attributes influences the height of significance line in TDS curves. Upon increased number of attributes the significance line drops, possibly leading to an overestimation of significant sensory attributes in aggregated M-TDS curves. Alternatively, a dual-TDS task can be performed, where consumers select one dominant sensory attribute from each modality at the same time on the same screen (Schlich, 2017). However, this might be a more complicated task to perform compared to TDS due to the dual attribute selection at each moment in time, and might overestimate dominance durations of sensory attributes due to the attentional shifts from taste to texture. Future research has to point out whether M-TDS or a dual-TDS task lead to increased sensitivity and discrimination capability compared to TDS.

TCATA in its current form does not seem to add temporal information on sensory perceptions during consumption compared to static CATA measurements (chapter 5). However, TCATA Fading allows the consumer to focus more on the selection of applicable sensory attributes, as sensory attributes automatically fade (i.e. become deselected) after a predefined time. Once a sensory attribute fades the consumer can choose to reselect the sensory attribute when it is still applicable at that moment in time, reducing 'fake' applicability ratings in TCATA (Ares et al., 2016; Rizo et al., 2020). Lower peaks in citation proportions of sensory attributes have been observed in TCATA Fading compared to TCATA, suggesting that there is an overestimation of sensory attribute citation durations in TCATA (Rizo et al., 2020). TCATA Fading seems to increase the temporal discrimination and the dynamic resolution of sensory attributes over time (Ares et al., 2016). Future research should investigate the optimal fading duration as it is still unknown whether the fading duration is attribute specific or if it can be generalized for all sensory attributes included in the evaluation. Moreover, the fading duration might depend on the average bite/sip size and the product under evaluation, as it is plausible that liquids with short sip sizes might need shorter fading durations compared to solids which have longer bite sizes.

7.3.2. Multiple bite evaluations

Single bite sensory evaluations are common. However, single bite assessments do not reflect realistic eating conditions as consumers eat full portions with multiple bites. Besides, sensory perceptions do not only change within a single bite, but also change between bites. This thesis demonstrated that food perceptions of a broad range of product categories do not only change within a bite but also between bites of the same product. Specific sensory attributes gradually built up from first to middle to last bite, depending on the sensory characteristics of different products. This indicates that not only the first bite is different from subsequent bites, but specific sensory attributes change during the course of consumption (chapter 4 & chapter 5). These results cannot be captured with single bite assessments, and stresses the importance of testing multiple bites of the same product to steer product development.

Figure 7.2 provides an overview of possible factors that may underlie dynamic changes in sensory perceptions during consumption. Oral processing behaviour, such as mastication and salivation, breaks the food down and changes the structure and flavour release of the food causing dynamic changes in sensory perceptions within each bite (Doyennette et al., 2014; Mesurolle et al., 2013). In this thesis mainly a built up of texture perceptions over multiple bites was observed (chapter 4 & chapter 5). It is plausible that specific sensory characteristics are no longer noticed or no longer perceived due to sensory adaptions (Lawless & Heymann, 2010), accompanied by an 'attentional' shift from one product component to another or from one sensory domain to another, e.g. from taste to texture. It could be that when sensations are no longer perceived due to adaptation, 'mental space' is created to notice another sensory characteristic which is, so far, less dominant. Moreover, lingering or accumulations of product residuals in the oral cavity may cause a change in perception or built up of specific sensory attributes. Several studies have shown that sensory perceptions built up in the mouth due to lingering of sweetness caused by artificial sweeteners or the formation of fatty mouth-coatings on oral surfaces (tongue and palate) (Appelqvist et al., 2016; Camacho et al., 2014; Zorn et al., 2014). We hypothesized that dynamic changes for plain and bland products, such as bread, would lead to less or no dynamic changes in sensory perceptions over bite. However, this thesis observed that, even for plain breads, sensory perceptions (such as sticky and dry sensations) built up from beginning to end of consumption (chapter 5). This further strengthens the importance of multiple bite evaluations to not miss out on important information about the evolution of a consumer's dynamic product perception.

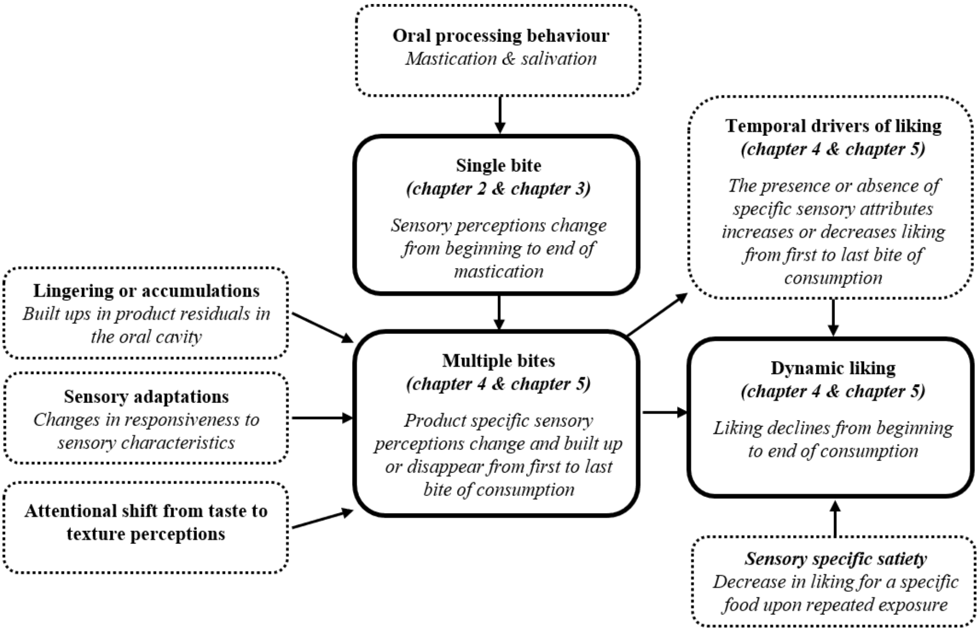

Figure 7.2. Factors affecting changes in sensory and hedonic perceptions in single and multiple bite evaluations.

Liking is liable to change as a result of the physiological changes in the perception of food over multiple bites. Eating in comparison to tasting induces another phenomenon, which is satiation. Satiation is the decrease in hunger ratings, and may affect the way a product is perceived and appreciated. Satiation may be accompanied by Sensory Specific Satiety (SSS), which refers to a decline in liking for a specific food upon repeated exposure (Rolls et al., 1981). Hence, products with even minor changes in sensory perceptions could still decline in liking upon repeated exposure due to a sense of boredom of the taste accompanied by feelings of satiety. Changes in sensory perceptions from first to last bite might contribute to SSS. Results described in this thesis reported positive and negative drivers of liking obtained with the alternated Temporal Drivers of Liking (A-TDL) method, which could have been responsible for the observed decline in liking from first to last bite (chapter 4 & chapter 5). A-TDL allows to calculate the temporal drivers of liking and disliking during consumption and gives an outcome measure for the increase or decrease in liking caused by a change in sensory perceptions over multiple bites (Thomas et al., 2016). The decrease in liking caused by the built-up of undesired sensory perceptions or the decline of desired sensory perceptions from first to last bite seems to align with SSS (chapter 5).

Multiple bite evaluations have the advantage that they better reflect natural eating conditions and increase the external validity of classic sensory tests. One of the important factors for repeated consumption of a food product is how the product is remembered and appraised (Robinson et al., 2012). It is plausible that the sensory perceptions of the last bite of a food product are key characteristics that determine whether or not a consumer repurchases a product. It could be that because product development mainly relies on the sensory characterization of a single and first bite, they may miss important information about the dynamic changes of the product towards the end of consumption of a full portion, which might further explain failures or successes on the commercial market. On the other hand, multiple bite evaluations have the disadvantage that they increase the number of test sessions needed to profile the whole product set and increase the costs and time needed to perform these sensory tests. It is still unknown if the portion size (several bites vs. full portions) might influence the magnitude of the change in sensory perceptions and liking. It could be that dynamic changes in sensory and hedonic perceptions become more pronounced with increasing number of bites. Nevertheless, it is recommended to test only one product with multiple bites per test session. When employing multiple bite evaluations one is interested in small differences or changes in sensory perceptions between bites of the same product. When including other products in the same test session, this could broaden the sensory space pushing the perceptual differences between bites of the same product closer together. Consumers may not notice small differences between bites of the same product when the perceptual differences between products are large. Moreover, when monadically testing products in separate sessions, the comparison between products might be less dependent on the sample set under investigation because there is a wash-out period between product evaluations.

Future research should focus on increasing the external validity of sensory studies. To increase the external validity of consumer tests it is recommended to test under circumstances that are as close to natural eating behaviour as possible (Köster, 1981; Meiselman, 1993; Schutz, 1988; van Trijp & Schifferstein, 1995). In this thesis, bite sizes were standardized (chapter 4 & chapter 5). Moving to free eating conditions, without the standardization of bite sizes would further increase the external validity of multiple bite evaluations. However, free eating conditions comes with increased inter-individual variations. Thomas et al. (2017) investigated full portions of oral nutritional supplements using free number of sips. Consumers performed TDS and rated liking for each sip until either the bottle was finished, consumers preferred to end consumption because they did not like the taste of the beverage, or when they felt satiated. Hence, different number of sips and portion sizes were included in this study. They divided the total number of sips per individual into three tertiles, i.e. beginning, middle and end of consumption. This study is an example of free eating conditions, but has the drawback that consumers evaluated every sip with TDS and liking. It is important to not include too many evaluation moments. Repeated sensory evaluations are prone to carry-over effects and consistency bias, i.e. consumers avoid reporting changes in sensory perceptions or liking and persist in their scores over consecutive ratings (Delarue & Blumenthal, 2015; Delarue & Loescher, 2004).

7.2.3. Food-evoked emotion research

Measuring food-evoked emotions with Temporal Dominance of Emotions (TDE) resulted in low panel agreement and poor resolution of the temporality of the self-reported emotions (chapter 3 & chapter 6). The large inter-individual differences in the formation of food-evoked emotions and subjective awareness of an emotion may hamper to achieve homogeneity in food-evoked emotion research. Food-evoked emotions are formed upon repeated experiences and recalled beliefs of food products, rather than the actual food-evoked emotions that the product communicates during the evaluation moment (Köster & Mojet, 2015; Thomson et al., 2010; Thomson, 2016). However, one would expect that certain changes in desired and undesired sensory perceptions would lead to changes in emotion perceptions (i.e. a shift from positive to negative food-evoked emotions). The notion that changes in food-evoked emotions occur in response to changes in sensory perceptions seems plausible. Yet, consumers may not be able to consciously verbalize these food-evoked emotions in the short time frames of a bite. Moreover, food-evoked emotions may not change within a single consumption moment, as the formation of food-evoked emotions might take longer and could be the result of a gradual process upon repeated exposure to the food product.

Implicit measures, such as facial expression analysis, are suggested to provide information about the dynamic subconscious part of the emotion experiences (Kaneko et al., 2018). This thesis reveals that facial expression analysis characterizes and discriminates better between the least liked products in the product set (chapter 6). Regular consumers of a food product mainly associate positive emotions with food products (so-called hedonic asymmetry), compared to non-users who have more negative or no emotion responses (Desmet & Schifferstein, 2008; King & Meiselman, 2010; Schifferstein & Desmet, 2010). However, detecting positive facial expressions is difficult, as the identification of positive facial expressions requires expressive facial movements (e.g. smiling). Consumers are less likely to show full-blown facial expressions when they evaluate a food product in laboratory settings, due to the lack of social interactions that invite people to be more articulating and expressive of their facial movements.

The challenge in understanding food-evoked emotions of consumers is not about the comparison of products from different product categories, but about the comparison between products from the same product category with small differences in sensory characteristics. However, food evoked emotions are mainly mild and positive and emotion responses do not seem product specific, but rather relate to the product category (chapter 6). Food-evoked emotion profiles directly reflected liking (chapter 3 & chapter 6), which does not add to our understanding of a food product beyond liking. Food-evoked emotion measurements are not yet able to provide detailed enough information that can lead to concrete advises and guidelines for product development. Future research should move away from food-evoked emotion research using self-reports and facial expression analysis, but rather focus on context appropriate emotion research or measuring conceptualizations and functionalities of products to get better insight into motivational drivers of food choice. More specifically, emotion research should be conducted in real life situations, such as at home, in restaurants or bars, to induce testing in more realistic eating contexts. However, it is not unlikely that the measured emotion responses then solely reflect food-evoked emotions but they might also include context-evoked emotions. A control condition could be included where consumers indicate the emotions they experience without consuming a food product. This control condition can then be compared to the condition where consumers indicate the emotions while eating the food product to filter out the emotions that are evoked by the context. Additionally, research should look towards product meaning, e.g. how are products conceptualized by the consumer (Thomson et al., 2010). Sensory characteristics across packaging and product generate meaning, and the unique set of sensory characteristics enhances a brand's promise to the consumer. Future research should look at whether these characteristics communicated by the packaging of a food product matches with the experience of the consumer. Combining external factors, such as marketing or packaging, and internal experiences, such as the constructions created in the mind that assign meaning to what we experience, will more likely allow us to steer product development to match a consumer's expectations of a food product.

7.4. Main conclusions

Consumer's sensory perception of food products changes during the course of consumption. Multiple bite evaluations provide additional information and reveal built ups of sensory perceptions which cannot be captured by single bite assessments alone. The appearance of undesired or disappearance of desired sensory perceptions contribute to the decline in liking from beginning to end of consumption of a portion of food. Multiple bite evaluations performed by consumers increases the external validity of sensory testing, as they provide better discriminative product profiles, capture the changes in sensory and hedonic perceptions over bites and better reflect realistic consumption contexts compared to classic sensory tests.

The definition of dominance provided by the researcher hardly influences the performance of a consumer and the obtained dynamic sensory profiles for TDS. The definition of dominance is subjective to the consumer, and panel performance at group level is consistent in reporting perceived dynamic sensory perceptions. No moments of hesitation or delays in response time were observed between sensory attribute selections, suggesting that consumers continuously report the perception of a dominant sensory attribute during TDS evaluations.

Food-evoked emotions were mainly mild and positive, and directly reflected product discrimination in terms of liking. Temporal Dominance of Emotions (TDE) resulted in low panel agreement and poor resolution of the temporality of the self-reported emotions. Emotion responses do not seem to be product specific but rather relate to the product category.

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SUMMARY

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Sensory perceptions evolve over time due to mastication, oral structural breakdown of food and salivation. Single bite assessments are common in sensory and consumer science, however, may not reflect a consumer's food perception of full portions. In natural eating conditions, consumers eat full portions of food products with multiple bites. Multiple bite evaluations can increase the external validity of classic sensory tests and might better reflect a consumer's full experience of food products. It is likely that sensory perceptions change during consumption due to adaptations, lingering and/or built-ups of sensory characteristics. Consequently, dynamic changes in sensory perceptions might underlie changes in food-evoked emotions and hedonic perceptions. The research described in this thesis aimed to investigate dynamic changes in food-evoked emotions, sensory and hedonic perceptions within and between multiple bites of consumption perceived by consumers.

The first part of this thesis (chapter 2 & chapter 3) investigated conceptual ideas and processes underlying the selection of sensory attributes during Temporal Dominance of Sensations (TDS). In chapter 2, we investigated how consumers conceptualize dominance using TDS and compared dynamic sensory profiles obtained with different definitions for dominance (attentional capture vs. intensity), using a between subjects design. Different task instructions on the selection of a sensory attribute (attentional capture vs. intensity) resulted in similar dynamic sensory profiles. Heterogeneity in the conceptualization of dominance and sensory attribute selection strategies was observed between consumers. Consumers defined dominance as the predominant sensation, the sensation that pops up and the sensation that strikes most. Consumers selected sensory attributes based on intuition, hedonic perceptions and previous experiences and expectations of the food product. We expected that this wide range of interpretations of dominance and variety in sensory attribute strategies would lead to poor panel agreement and poor panel repeatability. However, when investigating panel repeatability by comparing dynamic sensory profiles of the same product obtained with a 7-day interval, panel repeatability was not compromised by the subjective conceptualization of dominance in TDS (chapter 2). TDS assumes that there can only be one dominant sensory attribute at each moment in time, while multiple sensory characteristics are perceived at the same time. We hypothesized that competing sensory perceptions or response restrictions in TDS can lead to hesitation and delays in sensory attribute selections. In chapter 3, we investigated implicit 'no dominance' durations and introduced a Hold-down TDS procedure where consumers actively hold down

the attribute button that is perceived dominant, and release it when no longer dominant. This 'hold-down' procedure allows consumers to report indecisive behaviour, simply by not holding down a button. However, no dominance durations between attribute selections were shorter than 1s and were unlikely to reflect periods of true hesitation, but rather reflected the time needed to switch between dominant attributes.

The second part of this thesis focussed on investigating the dynamics of sensory and hedonic perceptions within and between multiple bites of food consumption. In chapter 4, we investigated dynamic changes in sensory perceptions for five bites of yogurt with granola varying in hardness, size and concentration. For five out of six samples, sticky sensations built-up from first to fifth bite of consumption. However, it was unclear if changes in sensory perceptions are product specific or whether these findings could be generalized to a broader range of product categories. We hypothesized that if built-ups are perceived, these built-ups would become more pronounced with increasing number of bites. In chapter 5, we investigated dynamic sensory perceptions of full portions of cheese, bread, drink yogurt and vegetarian sausage. Sensory perceptions changed from first to last bite for all four products, strengthening the evidence that multiple bite assessments provide additional information about a consumer's food experience beyond first perception. Moreover, liking declined from first to last bite/sip for three out of four products, and temporal drivers of liking were identified. We observed that the decline of desired and built-up of undesired sensory perceptions contributed to the decline in liking from first to last bite/sip.

Food-evoked emotions are suggested to add to the understanding of food choice. In chapter 6, we compared implicit (facial expressions) and explicit (Temporal Dominance of Emotions, TDE) emotion measures using multiple bite assessments. We hypothesized that that there would be a certain extent of correspondence between both methods and that they would discriminate products similarly. However, we observed that dominance durations observed in TDE and facial expression intensities showed little overlap and were not directly comparable. Moreover, limited changes in food-evoked emotions were observed from first to last bite, and food-evoked emotion profiles directly reflected liking.

To conclude, the conceptualization of dominance in TDS is subjective to the consumer, and is hardly influenced by the definition provided by the researcher. Sensory and hedonic perceptions change from first to last bite of consumption. Multiple bite evaluations provide additional information about a consumer's perception of food products which cannot be captured by single bite assessments alone. However, food-evoked emotions did not change from first to last bite of consumption and did not provide additional information beyond liking.

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I achieved something today that my future self will be thankful for!

Roelien

ABOUT THE AUTHOR

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Roelien van Bommel was born on 16th of April 1989 in Nijmegen, The Netherlands. In 2008 she enrolled in the BSc program Nutrition and Dietetics at Hogeschool van Arnhem en Nijmegen. As part of her BSc program, she worked as a clinical dietician in Hospital Rivierenland in Tiel and traveled to Nicaragua to set up an intervention program to promote healthy eating behaviour among Nicaraguan women. In 2012, Roelien enrolled in the MSc specialization Nutritional Physiology & Health Status at Wageningen University. As part of her MSc program, she followed additional courses on Sensory Science. For her MSc thesis, she performed qualitative research to investigate how Portuguese and Dutch consumers conceptualize beer, wine and non-alcoholic beer. She wrote a second MSc thesis at Food & Biobased Research where she compared food-evoked emotion profiles of younger adults, older normosmic adults (normal ability to smell), and older hyposmic adults (impaired ability to smell). In 2014, Roelien worked as a Sensory Panel Leader at KraftHeinz company and managed the external sensory panel and sensory technicians. At the beginning of 2016, Roelien was appointed as a PhD candidate at TiFN and Sensory Science & Eating Behaviour groups at Wageningen University. Her PhD project was part of the public-private project called ‘Smooth Bite For All’. Her research focused on the dynamic measurement of sensory characteristics, hedonic perceptions and food-evoked emotions from first to last bite of consumption. During her PhD project, Roelien attended various courses and presented her work at several international conferences. Furthermore, she was involved in teaching and supervising MSc students. Currently, Roelien is working as a Sensory Specialist at Nestlé Product and Technology Centre in Singen, Germany.

Roelien can be contacted by email: roelienvanbommel@gmail.com.

OVERVIEW OF COMPLETED TRAINING ACTIVITIES

Discipline specific courses and conferences	Organizer and location	Year
Sensory Perception and Food Choice	VLAG, Wageningen, NL	2016
Good Clinical Practice	Wageningen UR, NL	2016
EuroSense conference	Elsevier, Dijon, FR	2017
British Feeding and Drinking Group (BFDG)	University of Reading, Reading, UK	2017
Sensory Science has to move on	Utrecht, NL	2017
Pangborn sensory science conference	Elsevier, Rhode Island, US	2017
British Feeding and Drinking Group (BFDG)	Institute Paul Bocuse, Lyon, FR	2018
AgriFoodTop symposium	TiFN, Zwolle, NL	2018
The Quantified Consumer	VLAG, Wageningen, NL	2018
Food Oral Processing (FOP) conference	University of Nottingham, Nottingham, UK	2018
EuroSense conference	Elsevier, Verona, IT	2018
Pangborn sensory science conference	Elsevier, Edinbrough, UK	2019
General courses and activities	**Organizer and location**	**Year**
Multivariate analysis for food data	VLAG, Wageningen, NL	2016
Project and time management	WGS, Wageningen, NL	2017
Brain training	WGS, Wageningen, NL	2017
Competence assessment	WGS, Wageningen, NL	2017
Mixed model analysis	VLAG, Wageningen, NL	2017
Scientific writing	WGS, Wageningen, NL	2017
Temporal Methods	Elsevier tutorial, Verona, IT	2018
Career perspectives	WGS, Wageningen, NL	2019
Optional courses and activities	**Organizer and location**	**Year**
Preparation of research proposal	Wageningen, NL	2016
Advanced Sensory Methods and Sensometrics	Wageningen UR, NL	2016
PhD study tour to UK	Wageningen UR, NL	2017
Meetings Sensory Science & Eating Behaviour group	Wageningen UR, NL	2016-2020
Annual project meetings ‘Smooth Bite For All’	TiFN, Wageningen, NL	2016-2020

LIST OF PUBLICATIONS

Publications in peer-reviewed journals

van Bommel, R., Stieger, M., Visalli, M., de Wijk, R., Jager, G. (2020). Does the face show what the mind tells? A comparison between dynamic emotions obtained from facial expressions and Temporal Dominance of Emotions (TDE). *Food Quality and Preference,* 85, 103976.

van Bommel, R., Stieger, M., Boelee, N., Schlich, P., Jager, G. (2019). From first to last bite: Temporal dynamics of sensory and hedonic perceptions using a multiple-intake approach. *Food Quality and Preference,* 78, 103748.

van Bommel, R., Stieger, M., Schlich, P., Jager, G. (2019). Dutch consumers do not hesitate: Capturing implicit 'no dominance' durations using Hold-down Temporal Dominance methodologies for Sensations (TDS) and Emotions (TDE). *Food Quality and Preference,* 71, 332-342.

Silva, A., Jager, G., **van Bommel, R.,** van Zyl, H., Voss, H-P., Hogg, T., Pintado, M., de Graaf, C. (2016). Functional or emotional? How Dutch and Portuguese conceptualise beer, wine and non-alcoholic beer consumption. *Food Quality and Preference,* 49, 54-65.

Submitted for publication

van Bommel, R., Stieger, M., Jager, G. Instructions do not matter much: Definition of dominance (attentional capture vs. intensity) provided to consumers in Temporal Dominance of Sensations (TDS) does not influence dynamic sensory profiles.

van Bommel, R., Stieger, M., Jager, G. Beyond the first bite and sip: Temporal dynamics of foods using multiple bite/sip evaluations employing Temporal Dominance of Sensations (TDS) and Temporal Check-All-That-Apply (TCATA).

Conference presentations

Van Bommel, R., Stieger, M., Jager, G. The definition of dominance: Do consumers differentiate between attentional capture and intensity in Temporal Dominance of Sensations (TDS)? Pangborn, Edinbrough UK, July 2019. *Poster presentation.*

Van Bommel, R., Stieger, M., Boelee, N., Schlich, P., Jager, G. From first to last bite: Emotions change from high to low arousal and dominant sensations built-up during multiple bite assessment of yogurt with granola. EuroSense, Verona Italy, September 2018. *Oral presentation.*

van Bommel, R., Visalli, M., Stieger, M., de Wijk, R., Jager, G. A comparison between dynamic self-reported food-evoked emotions and facial expressions. EuroSense, Verona Italy, September 2018. *Poster presentation.*

Van Bommel, R., Stieger, M., Boelee, N., Schlich, P., Jager, G. From first to last bite: Emotions change from high to low arousal and dominant sensations built-up during multiple bite assessment of yogurt with granola. Food Oral Processing, Nottingham UK, July 2018. *Oral presentation.*

Van Bommel, R., Stieger, M., Jager, G. Measuring Temporal Dynamics of food-evoked emotions. Agri&Food Symposium, Zwolle NL, June 2018. *Oral presentation.*

van Bommel, R., Stieger, M., Boelee, N., Schlich, P., Jager, G. Temporal dynamics of sensations and emotions during multiple bite assessment of yogurt with granola. British Feeding and Drinking Group meeting, Lyon France, April 2018. *Poster presentation.*

van Bommel, R., Schlich, P., Stieger, M., de Graaf, C., Jager, G. Does recording `no dominance` during dynamic sensory and emotional profiling (TDS/TDE) increase sensitivity? Pangborn, Rhode Island USA, August 2017. *Poster presentation.*

van Bommel, R., Schlich, P., Stieger, M., de Graaf, C., Jager, G. Does recording `no dominance`during dynamic senosry and emotional profiling (TDS/TDE) increase sensitivity? British Feeding and Drinking Group meeting, Reading UK, April 2017. *Oral presentation.*

van Bommel, R., Li, J., Schlich, P., Visalli, M., Stieger, M., Jager, G. Temporal Dominance of sensations (TDS) and Emotions (TDE) method for multiple bite evaluation of dark chocolate. EuroSense, Dijon France, September 2016. *Workshop presentation.*

COLOPHON

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