Beyond liking: emotional and physiological responses to food stimuli

Wei He

Thesis committee

Promotor

Prof. Dr Kees de Graaf
Professor of Sensory Science and Eating Behaviour
Wageningen University

Co-promotors

Dr Sanne Boesveldt
Assistant professor, Division of Human Nutrition
Wageningen University

Dr Rene A. de Wijk
Senior sensory scientist, Food and Biobased Research
Wageningen University & Research Centre

Other members

Prof. Dr Hans C.M. van Trijp, Wageningen University
Dr Herbert L. Meiselman, Herb Meiselman Training and Consulting Services, Rockport, USA
Dr Monique Smeets, Utrecht University / Unilever Research & Development, Utrecht
Dr Sylvain Delplanque, Swiss Center for Affective Sciences, University of Geneva, Switzerland

This research was conducted under the auspices of the Graduate School VLAG (Advanced studies in Food Technology, Agrobiotechnology, Nutrition and Health Sciences).

Beyond liking: emotional and physiological responses to food stimuli

Wei He

Thesis
submitted in fulfilment of the requirements for the degree of doctor
at Wageningen University
by the authority of the Rector Magnificus
Prof. Dr A.P.J. Mol,
in the presence of the
Thesis Committee appointed by the Academic Board
to be defended in public
on Tuesday 15 March 2016
at 4 p.m. in the Aula.

Wei He

Beyond liking: emotional and physiological responses to food stimuli,
150 pages.

PhD thesis, Wageningen University, Wageningen, NL (2016)
With references, with summary in English

ISBN 978-94-6257-650-6

Abstract

Background and aim

Traditional liking ratings are typically seen as an important determinant in eating behavior. However, in order to better understand eating behavior, we need to first better understand (the dynamic and implicit features underlying) liking appraisal. The aim of this thesis was to investigate the effects of food stimuli varying in sensory modality (smell and taste), pleasantness and intensity, on emotional and physiological responses leading up to liking appraisal.

Methods

Four studies, using healthy participants, were conducted as part of this thesis. In the first study, responses to pleasant versus unpleasant food odors varying in intensity were measured discretely using pleasantness ratings, intensity ratings and non-verbally reported emotions (PrEmo), as well as continuously using facial expressions and autonomic nervous system (ANS) responses. To further explore how explicit and implicit factors contribute to pleasantness appraisal, the same measures were assessed in response to food odors with a wider range of valence. Next, we focused on facial expressions and ANS responses elicited by single sips of breakfast drinks that were equally liked. In the last study, we investigated changes in pleasantness after consuming semi-liquid meals to (sensory-specific) satiety, combined with measures of facial expressions and ANS responses.

Results

Both non-verbal reported emotions and emotional facial expressions were demonstrated to be able to discriminate between food odors differing in pleasantness and between food odors differing in intensity. In addition to discrete emotional responses, odor valence associated best with facial expressions after 1 second of odor exposure. Furthermore, facial expressions and ANS responses measured continuously were found odor-specific in different rates over time. Results of food odors with a wider range of valence showed that non-verbally reported emotions, facial expressions and ANS responses correlated with each other best in different time windows after odor presentation: facial expressions and ANS responses correlated best with the explicit emotions of the arousal dimension in the 2nd second of odor presentation, whereas later ANS responses

correlated best with the explicit emotions of the valence dimension in the 4^{th} second. For food stimuli varying in flavor (breakfast drinks), facial expressions and ANS responses showed strongest associations with liking after 1 second of tasting, as well as with intensity after 2 seconds of tasting. Lastly, we were able to demonstrate that ANS responses, as well as facial expressions of anger and disgust were associated with satiety. Further effects of sensory-specific satiety were also reflected by skin conductance, skin temperature, as well as facial expressions of sadness and anger.

Conclusions

Both non-verbal reported emotions and emotional facial expressions were demonstrated to be able to discriminate between food odors differing in pleasantness and/or intensity. Explicit and implicit emotional responses, as well as physiological patterns are related to liking appraisals involved in smelling foods. Implicit measures such as facial expressions and ANS responses can provide more multidimensional information for both food odors and tastes than explicit measures and prove to be highly dynamic over time with specific time courses. Early implicit facial and ANS responses primarily reflect emotion arousal, whereas later ANS responses reflect emotion valence, suggesting dynamic unfolding of different appraisals of food stimuli. Furthermore, ANS responses and facial expressions can reflect pleasantness, satiety, and a combination of both: sensory-specific satiety. This suggests that implicit processes play an important role in dynamic liking appraisals with respect to eating behavior.

Contents

CHAPTER 1

General introduction

1.1 Eating behavior

Eating behavior is among the most frequent and most important human behaviors, which occurs in discrete episodes throughout the day. Blundell et al. (1) developed the satiety cascade over 20 years ago identifying overlapping processes, satiation and satiety, occurring during and after food intake until the next period of eating. Based on this satiety cascade, the current thesis also highlights the phase prior to the eating episode where thoughts and sensory properties of food also exert important influences on food intake by creating anticipation based on learned associations (2) (see Figure 1.1). Eating behavior starts with a desire to eat resulting from a combination of the internal state of hunger along with external stimulation. The mere thought of a food can elicit increased salivation, gastric acid secretion, or insulin release (3-5). Next, appearance and orthonasally detected odors identify a food's suitability for ingestion and further enhance appetite, bodily reactions and (reward) signals to the brain (6-8). When a food is placed in the mouth, its flavor (the integration of taste, retronasal olfaction and oral-somatosensation) is perceived during chewing and swallowing (9). As a food is consumed, its reward value decreases leading to termination of the meal (10,11). Further food processing and nutrient absorption initiate neural and hormones responses that are translated in the brain to suppress hunger until the next eating episode (12,13). These three phases, anticipation, satiation and satiety, can be thought of as integrated, but separate processes. The research described in this thesis investigates food cue responses before, during and after food consumption with a focus on olfactory and gustatory stimuli.

Both the smell of food before or after a meal and the experience of flavor during a meal may act to regulate appetite, to stimulate or inhibit it. The ability of olfactory cues to stimulate appetite and meal initiation under conditions of hunger is well established in humans (7,15). Ramaekers et al. (7) investigated appetite responses to palatable food odors and found that exposure to food odors increased the appetite for congruent foods, but decreased the appetite for incongruent foods, to prepare the body for intake of the cued food. An opposite phenomenon is sensory-specific satiety, the effect of food intake on subsequent pleasantness and intake of that same food (10,16).

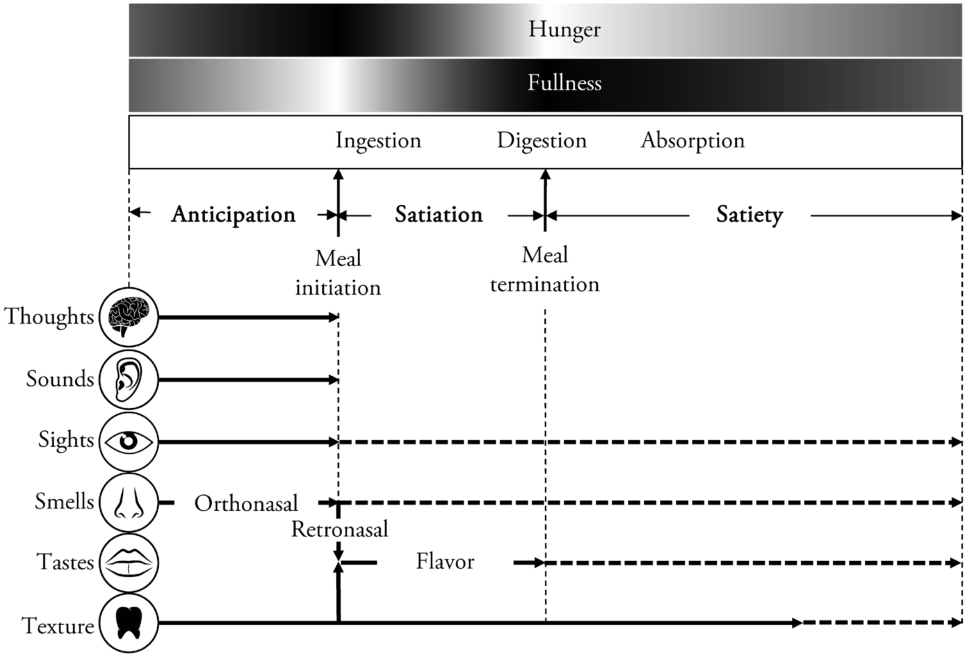


Figure 1.1 Visual representation of processes occurring before, during and after food consumption. Changes in the degree of hunger and fullness are represented by the gray value: black is a high degree; white is a low degree. The duration of influences exerted by each sensory property on eating behavior is represented by thick lines: solid lines are direct influences; dashed lines are effects of sensory-specific satiety. The figure is adapted based on (1,14).

As described above, hedonic aspects (also referred to as liking, reward, pleasure, valence or palatability) of food play an important role in mediating eating behavior. The most commonly used method to measure palatability of food is subjective ratings of sensory liking. Indeed, products with a higher liking score are chosen more often than those with a lower liking score (17). In addition, foods with a higher rating of palatability appear to make participants more hungry and consume more food subsequently (18). Nevertheless, several studies have revealed that these ratings may face limitations. It was found that liking ratings based on brief exposure may give a biased estimation of the optimal palatability of a food (19-21) and that liking ratings alone may be insufficient to predict subsequent intake (21-23). It is possible that consumers make food-related decisions less based on conscious processing and rational reasoning, but more on unarticulated and unconscious motives and associations (24).Therefore, explicit (conscious) liking ratings alone may be inadequate to reveal other aspects influencing liking appraisal as well. Combining implicit (unconscious) aspects with explicit measures may thus contribute to a better understanding of appraisal processes leading up to liking and thus a more complete picture of eating behavior.

Although seemingly simple, sensory liking in fact involves very complex appraisal processes in which sensory properties of food (e.g. appearance, taste, smell), physiological (e.g. hunger/satiety, bodily reactions, brain responses) and psychological factors (e.g. cognition, emotion, reward, motivation, decision making) constantly interact (see Figure 1.2) (25,26). These changing interactions make palatability also a dynamic process and influence ultimate behavior about whether, what, where, when, how much to eat. In contrast, results of traditional hedonic tests are like photographic stills that fixate the liking of a food at a given moment in its development (28). Therefore, underestimating the dynamic nature of eating behavior may also be one of the main causes for an inadequate predictive validity of liking ratings with respect to eating behavior (27,28). This stresses the necessity to adopt a broader perspective to explore how food-induced psychological and physiological responses and their interactions contribute to dynamic liking appraisals.

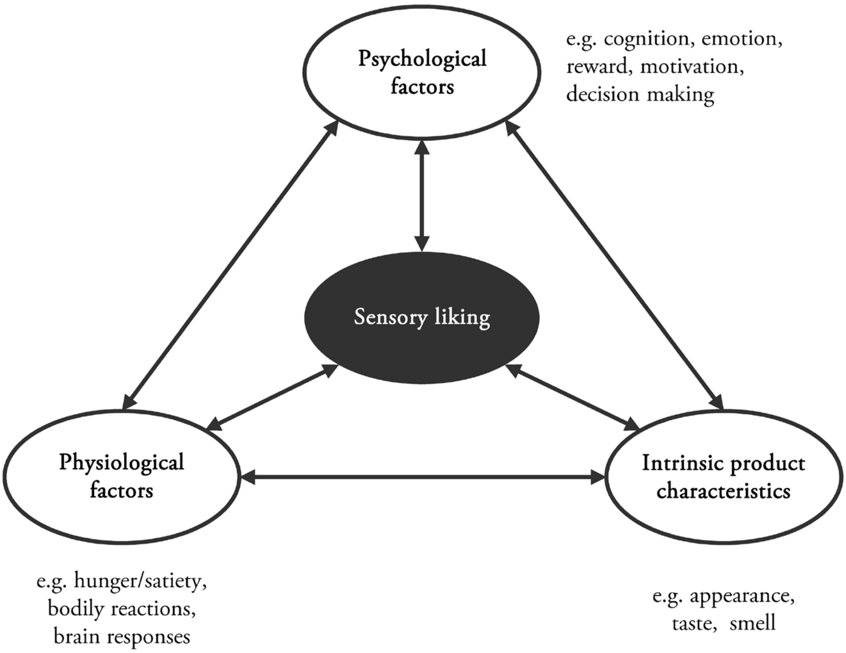


Figure 1.2 Factors influencing sensory liking (adapted from (26)).

1.2 Emotional responses

Many studies have postulated bi-directional influences between emotions and eating behavior (29-31). For example, a person may decide to eat chocolate out of sadness, and feel happier afterwards (32,33). Investigating emotional responses to food stimuli may therefore contribute to a better understanding of eating behavior.

1.2.1 Emotion theories

There are several models that have dominated emotion research. Proponents of discrete emotion theories, inspired by Darwin (34), have suggested different numbers of basic emotions by observing universal facial expressions of emotion (35-37). Ekman et al. (38) further reduced the number of these basic emotions to six, joy, sadness, fear, anger, surprise and disgust, and related each of them to specific physiological response patterns (39-42). In contrast, dimensional theories of emotions (43,44), mainly based on Russell's Circumplex Model of affect (see Figure 1.3), reduce the dimensions that organize all emotional responses to two orthogonal dimensions: valence (i.e. pleasantness versus displeasantness) and arousal (i.e. deactivation versus activation). Dimensional models have been used to relate self-reported pleasantness and arousal to physiological (45,46) and brain responses (47). Unlike both discrete emotion and dimensional theories, componential appraisal theories of emotion (48,49) explain emotion processing from a dynamic perspective. Componential appraisal theories are based on the notion that emotional processes are elicited and dynamically patterned as the individual continuously and recursively appraises objects, behaviors, events, and situations with respect to their effect on his/her values, goals, and general well-being. Such appraisals involve a few components (48-54): (a) the cognitive system responsible for appraisal of the situation, (b) the autonomic system in charge of system regulation, (c) the motor system responsible for communication of reaction and behavioral intention, (d) the motivational system responsible for preparation and direction of action, and (e) the monitor system in charge of subjective feeling.

1.2.2 Explicit emotion measurement

Due to the complexity of emotion processing, various methods have been developed to measure explicit or implicit components of food-induced emotions. Direct, explicit emotion measurement is the most frequently applied method. Participants are usually

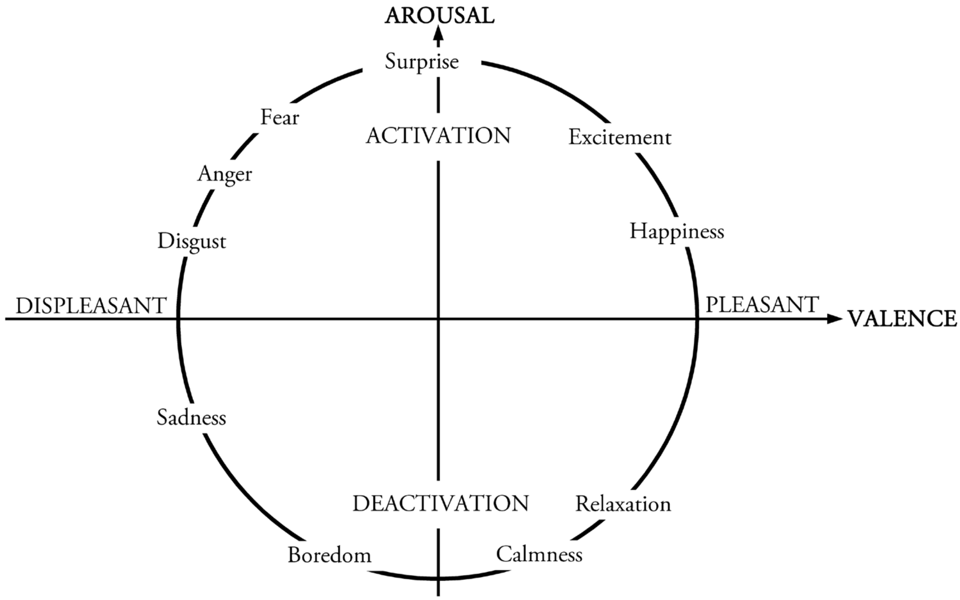


Figure 1.3 Two dimensions of emotions, valence and arousal, based on Russell's Circumplex Model of affect (44).

requested to report their feelings in response to food odors or tastants on the basis of a standardized emotion lexicon provided by the experimenters. Chrea et al. (55) developed a scale, called Geneva Emotion and Odor Scale (GEOS), for the measurement of the emotions elicited by odors. Porcherot et al. (56) and Delplanque et al. (57) subsequently used GEOS to measure the subjective affective experience (i.e., feeling) elicited by everyday odors. King & Meiselman (58) have developed the EsSense Profile, including 39 emotion descriptors (25 pleasant, 3 unpleasant and 11 non-classified) chosen on the basis of a questionnaire of 81 terms, to measure emotions relevant to tasting and eating food. Desmet & Schifferstein (59) used 22 emotion descriptors that were equally divided over pleasant and unpleasant ones to measure emotional experience during food consumption. Both groups suggest that most emotions related to food appear to be mildly positive. They demonstrated that the verbal measurement of feelings provided insight into consumer liking and improved the discrimination between products with similar liking scores (60).

A scale or word list makes people think about the meaning of the words and leads to rational thought processes, whereas in choice and purchase behavior often irrational and non-cognitive influences play a major role (60). This is why some researchers have adopted non-verbal measurements. Desmet (61) developed the Product Emotion Measuring instrument (PrEmo), using animated figures expressing different emotions. The idea was based on the fact that people from different cultures all recognize emotions in facial and vocal expressions. Six pleasant (desire, satisfaction, pride, hope, joy, and fascination) and six unpleasant (disgust, dissatisfaction, shame, fear, sadness, and boredom) are depicted. Each of these is accompanied by a five-point scale. The major advantage of the method seems to be that it avoids the translation of emotions into words (60). Gutjar et al. investigated emotions evoked by either unbranded or branded breakfast drinks using both EsSense Profile and PrEmo (62,63), and concluded that food-evoked emotions add predictive value to solely liking ratings.

1.2.3 Implicit emotion measurement

Beyond explicit scales, more implicit measures have also been used to assess food-induced emotions over the past few decades. A more natural and less intervening method of emotion measurement is the direct reading of emotional facial expressions (64,65). The link between emotions and facial expressions goes back to Darwin (34) and its strongest present day advocate is Ekman (66). In their view, facial expressions are elements of a coordinated response involving multiple response systems. Facial expressions are thought of as biologically based adaptations crucial for survival. One function may be to warn others of a potentially harmful substance or to facilitate ingestion of nutritious foods (67). Well-known are the positive facial expressions of infants toward liked and the negative expressions toward disliked tastes and odors, suggesting innate preference of certain food stimuli (68-74). In this way, facial actions support the two basic reactions to stimuli: approach or avoidance (75). This is probably the reason why facial expressions are usually interpreted as positive or negative affect (76).

Facial expressions can be measured and analyzed by the anatomically based system called Facial Action Coding System (FACS) (77), which describes visually distinguishable facial activities on the basis of 44 unique reactions (77). Many studies have used either trained observers (75,78,79) or software (6,80-83) to analyze facial expressions defined in this coding system and investigate preference of and emotional responses to food stimuli. Zeinstra et al. (79) investigated whether facial expressions are a suitable and accurate method to assess food preferences in children. They found that facial expressions were able to measure dislike, but less suited to measure various gradients of food acceptance. De Wijk et al. (6) and Danner et al. (80,84) examined facial expressions in response to food stimuli in either children or adults with an automated tool, the FaceReader technology (85). They found that neutral, angry and disgust facial expressions explained the liking ratings well and may provide more detailed information than other more explicit tests.

Another way to measure facial expressions is electromyography (EMG) recordings, where measurements are made of electric potentials from facial muscles. It has been concluded that facial EMG activity can be used as an indicator of palatability in humans (86). It has also been shown that the sensibility of facial EMG recordings to provide support for the sequential feature of the appraisal process (87-89). Delplanque et al. (50) investigated the appraisal of odor novelty, odor pleasantness and consequent emotional responses with EMG. They demonstrated that an effect of odor novelty started as early as 100 ms after odor presentation, whereas the effect of pleasantness on activity reached significance after 500 ms. However, the sequential unfolding of appraisal processes investigated by FACS-based measurement still lack of exploration due to technical challenges. Exploring the dynamic feature of emotional facial expressions in response to food stimuli in this thesis may thus bridge the knowledge gap.

1.3 Physiological responses

As a part of the peripheral nervous system, the autonomic nervous system (ANS) acts as a control system regulating bodily functions, such as the heart rate, digestion, respiratory rate, pupillary response, urination, and sexual arousal (90). Although this system is regulated by the Central Nervous System (CNS), it functions largely unconsciously and in control of approach/avoidance responses (91). Avoidance behavior is primarily activated in those situations involving threat, with the resulting behaviors aimed at withdrawal and escape. In contrast, approach behavior is mainly active in situations that promote survival including sustenance and nurturance, thus important for maintaining homeostasis (92). Emotions are an essential for appropriate reactions to specific situations. A situation where one is confronted with spoiled food can evoke disgust emotions, resulting in avoidance behavior. In contrast, an encounter with a delicious food can evoke happiness emotions resulting in approach behavior. Thus, ANS may act as a supporting system to mediate between emotional responses to external stimuli and appropriate output behavior.

Despite the large number of studies (93) on ANS responses to emotional stimuli, it is still debated in how far patterns of autonomic responses are emotion-specific. Barret (94) has claimed that patterns of ANS responses lack any emotion-specificity, whereas Cacioppo et al. (95,96) claims to have seen at least some degree of emotion-specific ANS patterns. They also note that valence-specific patterns tend to be more consistent than emotion-specific patterns (6,42). In contrast, Stemmler (97), based on a meta-analysis, has found considerable specificity between ANS patterns related to fear and anger. Moreover, Stemmler (97) states that emotions have distinct goals and therefore require differentiated autonomic activity from body protection and behavior preparation.

Measures of ANS activity can be separated in cardiovascular, respiratory and electrodermal measures. An extensive review of 134 studies by Kreibig (93) revealed the most popular measures based on these three types are heart rate, blood pressure, finger temperature, respiratory rate and skin conductance level. Patterns of such ANS responses linking to specific emotions are represented as an increase, a decrease, or no change compared to baseline of that measure in relation to a specific emotion, such as fear, sadness, anger, disgust, and happiness. Furthermore, ANS specificity is also observed between negative emotions, for example, reduced finger temperature, increased heart rate and skin conductance for the emotion of anger, whereas reduced heart rate, finger temperature and skin conductance for the emotion of sadness (42). In this thesis, these three ANS responses, heart rate, skin conductance and finger temperature, were chosen to produce such patterns for food-induced emotions.

The dynamic features over time of physiological responses have typically fallen outside of the scope of most studies, even though they play a crucial role in componential appraisal theories of emotions (49). Delplanque and colleagues (50) found evidence for temporal priority of stimulus novelty processing over pleasantness processing on cardiac activity in response to odors. Their results showed that novelty processing was observed about 2 to 4 s after stimulus onset, whereas pleasantness processing was observed only 5 s after odor presentation. Further investigation with various ANS measures (heart rate, skin conductance and finger temperature) in this thesis may add more information to dynamic affective responses.

1.4 Aim and thesis outline

Traditional liking ratings are typically seen as an important determinant in eating behavior. However, to better understand eating behavior, it is necessary to explore dynamic and implicit features underlying liking appraisal. The aim of this thesis was to investigate the effects of food stimuli varying in sensory modality (smell and taste), pleasantness and intensity, on emotional and physiological responses leading up to liking appraisal. In this thesis the following research questions are addressed:

- Can emotional and physiological responses differentiate between (and within) liked and disliked food stimuli?
- If and how are emotional and physiological responses related to liking appraisal of food stimuli?
- Do emotional and physiological responses reflect dynamic unfolding of liking appraisal of food stimuli?

To tackle these questions, the chapters of this thesis were built up based on increasing complexity of food stimuli, starting with simple and basic odorous stimuli to more complex tastants, and ending with more dynamic real-life eating foods. We first investigated emotional and physiological responses to pleasant or unpleasant food odors varying in intensity **(chapter 2 & 3)**. We explored relations either between emotional facial expressions and non-verbal emotional ratings **(chapter 2)**, as well as between emotional facial expressions and physiological responses **(chapter 3)**. Then we used food odors with a wider range of valence **(chapter 4)** to determine how explicit and implicit methods contribute to pleasantness appraisal. Next, we focused on emotional and physiological responses elicited by actual consumption of food, single sips of equally liked breakfast drinks **(chapter 5)**. In the last study, we investigated changes in pleasantness upon consuming semi-liquid meals to satiety by facial expressions and physiological responses **(chapter 6)**. Finally, the main findings are discussed and directions for future research are presented **(chapter 7)**.

CHAPTER 2

The relation between continuous and discrete emotional responses to food odors with facial expressions and non-verbal reports

Wei He
Sanne Boesveldt
Cees de Graaf
René A. de Wijk

Published in Food Quality and Preference, 2016, 48, 130-137.

Abstract

Traditional sensory and hedonic tests are often limited to predict market performance. Investigating emotional responses to food stimuli may contribute to a better understanding of consumers' eating behavior. In the present study, 26 female participants were exposed to an orange (pleasant) and a fish (unpleasant) odor presented in three different concentrations perceived as weak, medium and strong intensity in a semi-random order via an olfactometer. Emotional responses to those food odors were measured discretely using non-verbal subjective reports, and continuously using facial expressions. Non-verbal reports reflected primarily the odor's valence with positive emotions, such as joy, satisfaction and hope, related to orange and negative emotions, such as dissatisfaction, fear and disgust, related to fish. Facial expressions varied dynamically over the 4 seconds following stimulation, whereby expressions at 1250 and 2000 ms associated best with odor valence and odor intensity, respectively. The correlation between non-verbal subjective reports and facial expressions reached a maximum during the 2nd second after exposure. Pleasant odors were associated with neutral and surprised expressions, and with fewer expressions of disgust. More intense odors were associated with fewer neutral expressions and more expressions of disgust. Facial expressions reflect the dynamic sequential unfolding of different emotional responses, whereas non-verbal reports primarily reflect the end result of valence appraisal. The distinction between initial and subsequent reactions detected by facial expressions may offer a new valuable perspective for sensory and consumer research.

2.1 Introduction

The high failure rate of new food products in the market, even after extensive sensory and consumer tests, shows the limits of traditional sensory profiling and hedonic scales (26). There appears to be more to eating behavior than just sensory liking (98). Other factors that also underlie and influence eating behavior include external context, such as environmental (ambience or food varieties) (99,100) and social factors (the presence of others) (101,102), as well as internal conditions, such as nutritional state (satiation or thirst) (103) and mood (e.g. sadness or happiness) (104,105). Moreover, a number of studies have postulated a bidirectional effect between emotions and eating behavior (see (30,31) for reviews) : emotions may alter the foods that people choose, and the foods that people eat influences their emotions. For example, a person may decide to eat ice-cream to relieve sadness and feel happier afterwards. Investigating emotional responses to food stimuli may therefore contribute to a better understanding of consumer behavior.

The effect of eating behavior on emotions has been investigated with a wide variety of methods. Basically, we can distinguish between different types of measurements to assess emotions, i.e. verbal explicit tests such as the EsSense Profile (58), non-verbal explicit tests, e.g. PrEmo (61), and implicit measurements such as facial expressions (77) and physiological measures (93). Wansink (24) suggested that most of the choices that people make related to eating behavior are unarticulated and unconscious. Therefore, in the present study we focus on measuring subjective and expressional components of emotions, using non-verbal reports (PrEmo) and facial expressions (FaceReader).

Product Emotion Measurement Instrument (PrEmo, (61)) is a visual self-report tool based on expressive cartoon animations representing separate emotional states instead of relying on verbalizations or a list of emotion words. PrEmo has been applied to measure non-verbal subjective emotional responses to product design, such as cars (106), mobile telephones (107), wheelchairs (108) and office chairs (109,110). Only recently, Gutjar et al. (62) adopted PrEmo to measure non-verbal subjective emotions induced by food products, i.e. breakfast drinks. They found that liking was only partly associated with the non-verbal subjective emotional responses to food products, suggesting that food-evoked emotional profiles can provide new information not captured by liking scores.

Facial expressions, partially beyond an individual's control, have also been used to implicitly measure expressive emotional responses to food stimuli. Well-known are the positive facial expressions of newborns towards liked (sweet) and the negative expressions towards disliked (bitter) basic tastes, extensively documented by Steiner (71,74). More recently, the Facial Action Coding System (FACS) developed by Ekman and Friesen (77) was used to investigate whether facial expressions are a suitable and accurate method to assess food preferences in school-aged children (79). They found that facial expressions were able to measure dislike, but not suited to measure various gradients of food acceptance in children aged 5-13 years. As a new development, de Wijk et al. (6) analyzed facial expressions to the sight, smell, and taste of liked and disliked foods and to well-liked breakfast drinks (81) with an automatic tool, FaceReader (111). Facial expressions were found to be stronger to disliked foods than to liked foods and were already detected at the first visual encounter with the food.

Although the abovementioned studies shed light on emotional processes, they do not account for dynamic features of emotion, which play an important role in current appraisal theories of emotions (see (49) for an overview). According to these theories, emotions are the result of unfolding appraisals over time of the consumption situation. These appraisals produce cognitive, expressive, physiological, motivational and subjective changes over time in the consumer, which can be monitored with time-dependent measures, such as autonomic nervous system responses and facial expressions. For example, Delplanque et al. (50) investigated the effects of odors on appraisal processes and consequent emotional responses by measuring facial muscle activity and heart rate. They demonstrated that odors were detected as novel or familiar before being evaluated as pleasant or unpleasant. In addition, their results also argued in favor of a dynamic construction of facial expressions. The early reactions, such as raising the eyebrows and opening the eyes, were related to the detection of a novel or unexpected stimulus, which is associated with increased alertness and attention. After this novelty detection, assessment of pleasantness may lead to avoidance when the stimulus is aversive or threatening, or approach when a pleasant response is activated. Following this sequential appraisal perspective (49), the present study sought to extend the temporal dynamics of emotional facial expressions to pleasant and unpleasant food odors using FaceReader. Food odors were chosen as appropriate stimuli in this study. First, olfactory stimuli are well known for their capacity to elicit emotional responses.

Olfaction has been described as the "emotional sense" (112), since it not only elicits emotions (113,114), but can also modulate emotions (115,116). Second, odorants allow for systematic variation of stimulus' valence and intensity, two dimensions known for their ability to affect emotions. Third, as food cues, odors can have considerable effects on eating behavior via appetite (7,117), satiety (16) and evoking memories related to food previously consumed (118).

In a separate paper, we established the temporal differentiation between pleasant and unpleasant emotions for these food odors using measures of the autonomic nervous system (heart rate frequency, skin conductance response and skin temperature) as well as facial expressions (82). Facial expressions such as expressions of disgust and anger showed fast differentiation between odors in as little as 200-500 msec, whereas other expressions such as happy showed much slower differentiation. These different dynamics may reflect the results of various sequential appraisals, as was also suggested by Delplanque's findings (50).

The present study will focus on the temporal development of facial expressions and their relation with odor intensity, pleasantness, and with discretely measured emotional responses using PrEmo. The emotional profile assessed with PrEmo may result from the integration of preceding response patterns, as reflected by facial expressions (51). Following this reasoning we hypothesize that over time, dynamic emotional responses reflected by facial expressions will correlate more with the end product of the emotional response, as reflected by PrEmo.

2.2 Materials and methods

2.2.1 Participants

A total of 26 young healthy female participants (mean age: 22.6 ± 1.5 years, range: 20-25 years, 18.5 < BMI < 25) were recruited from the subject pool of Food & Biobased Research, part of Wageningen University and Research Center. Participants self-reported their BMI and if they had actual/previous history of smell or taste disorders known to affect chemosensory. Detailed information regarding the experiment was given and an informed consent form was signed by all participants prior to testing. The study was approved by the Medical Ethical Committee of the Wageningen University.

2.2.2 Odor presentation

Two food odors were selected from among those used in a previous study (119) on the basis of their relatively negative (fish odor) or positive (orange odor) valence. The orange (cold-pressed Californian orange oil, Sigma Aldrich, St. Louis, MO, USA) and fish (Fish flavor oil, Givaudan Inc., Geneva, Switzerland) odors were diluted with mineral oil (70%, v/v) and 1,2-propanediol (27%, v/v), respectively. With a dynamic olfactometer based on air-dilution (OM2s, Burghart instruments, Wedel, Germany), each odor was delivered in three different concentrations (low, middle, or high), correspondingly perceived as weak, medium and strong intensity in a pilot study. The degree of dilution for each concentration is shown in Table 2.1. The olfactometer allows the presentation of odorous stimuli within a continuous airstream of 8 L/min, which does not alter the mechanical or thermal conditions at the nasal mucosa (120). These stimuli were delivered through a nosepiece for 1 s with an inter stimulus interval of 60 s. Each block of 6 stimuli (i.e. 3 orange odors and 3 fish odors differing in concentration) was randomized and presented 5 times, for a total of 30 stimuli. Intensity and pleasantness of those odors were subsequently rated by participants after presentation (see Table 2.1). Orange odors were rated more pleasant than fish odors ($F(1, 25) = 99.86$, $p < 0.001$) by the participants. The difference between concentrations of orange odor reached significance ($F(1, 25) = 11.68$, $p < 0.001$), with low concentration judged more pleasant than middle and high concentrations, whereas different concentrations of fish odor were rated equally unpleasant. Fish odors were rated more intense than orange odors ($F(1, 25) = 17.27$, $p < 0.001$) and odor intensity increased with concentration ($F(2, 50) = 47.15$, $p < 0.001$).

2.2.3 Measurements

A visual analog scale (VAS) of 10 cm was used to rate pleasantness and intensity after each odor presentation, ranging from ‘not perceivable’ (left-hand end = 0 cm) to ‘extremely strong’ (right-hand end = 10 cm), or from ‘very unpleasant’ (left) to ‘neutral’ (middle of the scale = 5 cm) to ‘very pleasant’ (right).

Product Emotion Measurement Instrument (PrEmo) is an instrument developed by Desmet et al. (61) that measures 12 emotions in response to a stimulus. Participants have to rate on animations expressing an emotion, on a 5-point scale, to indicate to what extent their feeling elicited by the stimulus was expressed by certain animations.

Table 2.1 Average ratings (0-10, with standard deviation) of fish and orange odors diluted to different concentrations

Odor	Concentration	Air-diluted to (%)	Intensity		Pleasantness	
			Mean	SD	Mean	SD
Fish (27% v/v)	Low	10	6.2	1.9	1.5	1.3
	Middle	25	6.7	1.6	1.5	1.3
	High	50	7.1	1.7	1.3	1.1
Orange (70% v/v)	Low	50	4.8	1.7	6.4	1.1
	Middle	80	6.0	1.7	5.6	1.6
	High	100	6.6	1.7	5.4	1.3

Ratings were made on a visual analog scale of 10 cm length. For intensity, 0 indicates 'not perceivable' and 10 indicates 'extremely strong'; For pleasantness, 0 indicates 'very unpleasant', 5 indicates 'neutral', and 10 indicates 'very pleasant'.

Of these 12 emotions, six are pleasant (i.e. desire, satisfaction, pride, hope, joy, and fascination), and six are unpleasant (i.e. disgust, dissatisfaction, shame, fear, sadness, and boredom).

Facial expressions of participants were filmed with a Logitech C600 webcam, mounted on top of a computer monitor placed in front of the participant. Facial expression data were automatically analyzed by FaceReader 4 (Noldus Information Technology, Wageningen, The Netherlands) based on Active Appearance Modeling (111) in each time frame (at a frequency of 25 Hz) during 4 seconds after stimulus presentation. The face classification provides the output of six basic expressions (happy, sad, angry, surprised, scared, disgusted) and one neutral state with 89% accuracy (111) on the basis of the Facial Action Coding System developed by Ekman and Friesen (77). A more detailed description of the science behind FaceReader can be found at: http://info.noldus.com/free-white-paper-on-facereader-methodology/. Whether all possible emotional expressions can be categorized by these six emotions remains a matter of debate (e.g. (53)). For the present study, the fact that FaceReader is able to automatically monitor (changes in) expressions was more important than the exact interpretation of these expressions in underlying emotions. In a very recent development FaceReader also monitors specific action units as defined by Ekman, which would allow the opportunity to monitor more than 6 emotions. Unfortunately this addition was yet not available during the present study.

2.2.4 Experimental procedure

The experimenter explained procedures and equipment to the participant and allowed ample time for questions. Then participants were seated in a comfortable chair, fitted with the olfactometer nosepiece, and oriented towards an adjustable computer monitor set with a webcam at eye-level (1 m viewing distance). They were asked to look directly towards the camera while receiving the odor stimulus to ensure recognition by the FaceReader software. Each trial started with an auditory attention signal to remind the participant to pay attention to the upcoming odor. For the first four blocks of stimuli, the pleasantness and intensity of each odor were rated subsequently on a paper questionnaire (i.e. VAS) after stimulation. For the last block of 6 stimuli, participants rated PrEmo animations with an introduction and example at the beginning, instead of rating pleasantness and intensity. The intervals between two odors stimuli in the last block were flexible, meaning that they were dependent on the pace of PrEmo ratings by the participants. The whole experiment lasted 45 min in total and the experimental schematic is shown in the Figure 2.1. Activity of the autonomic nervous system was recorded as well but these results will be reported elsewhere.

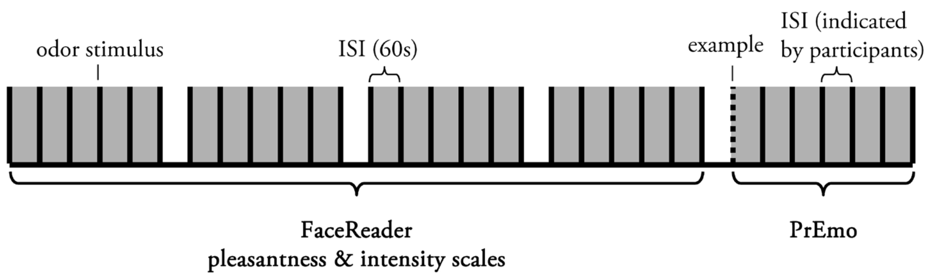


Figure 2.1 Schematic of experimental procedures. Each block of 6 randomized stimuli (i.e. 3 orange odors and 3 fish odors differing in concentration) was presented 5 times, for a total of 30 stimuli. For the first 4 blocks, each odor stimulus lasted for 1 s with an inter stimulus interval (ISI) of 60 s. Participants rated pleasantness and intensity after each stimulus with their facial expressions monitored simultaneously. For the last block, PrEmo was adopted with a flexible interval indicated by participants between odor presentations.

2.2.5 Statistical analysis

We conducted a repeated measures ANOVA (IBM SPSS Statistics 19.0, IBM Corporation, Armonk, USA) for the 2 (odors) by 3 (concentrations) within-subject design to analyse intensity, pleasantness and PrEmo ratings using the Greenhouse-Geisser correction for multiple factorial levels. A similar ANOVA was conducted for FaceReader scores with time as extra factor. FaceReader scores were calculated as post-odor change scores (40-ms bins), relative to a pre-odor baseline score, which was the average score 120 ms immediately before odor presentation. A p-value of 0.05 was considered significant. Partial Least Square analysis (Unscrambler, CAMO ASA, Oslo, Norway) was used to evaluate associations between FaceReader scores for 4 s after stimulation in 250 ms intervals with pleasantness or intensity ratings of the odors using normalized variables and random cross-validation. Correlation coefficients between observed and predicted values were used as indicator for the strength of associations, and regression coefficients were used to quantify the contribution of each facial expression to these associations. To summarize the data collected by PrEmo and FaceReader, we used the principal component analysis (PCA) in the program Unscrambler (CAMO ASA, Oslo, Norway) using non-normalized variables, centered data, and orthogonal principle components. The distances between the emotions, either measured using facial expressions or non-verbal reports, reflect their relationships, meaning that emotions that are plotted close to each other are similar, whereas those which are plotted at a distance from each other are different. PCA bi-plots were used to explore overlap and differences between PrEmo results and FaceReader scores at various intervals following the odor presentation. For this purpose, we correlated loadings of the odors on the principle components based on the PrEmo results to those based on the FaceReader scores at 1-second intervals. Correspondence between PrEmo results and FaceReader scores at specific time intervals should result in relatively high correlation coefficients between odor loadings.

2.3 Results

2.3.1 Non-verbal reports of emotions

By examining participants' subjective emotional responses to odor stimulation, a clear distinction between orange and fish odor was found. Orange odor was more associated with positive emotions, while fish was more associated with negative emotions (see

Figure 2.2). Overall analyses showed significant main effects on PrEmo scores of type of emotion ($F(4, 99) = 21.9$, $p < 0.001$) and concentration ($F(2, 38) = 4.1$, $p = 0.03$, and significant interactions between type of emotion and odor valence ($F(2, 57) = 42.8$, $p < 0.001$), and between type of emotion and concentration ($F(7, 185) = 2.6$, $p = 0.01$). Analysis per type of emotion showed that all emotions except boredom varied significantly with odor valence (all $p < 0.006$). In addition, emotions of disgust ($F(2, 38)) = 5.6$, $p < 0.01$), dissatisfaction ($F(2, 38) = 5.80$, $p < 0.01$) and fear ($F(2, 38) = 8.3$, $p < 0.001$) also varied with odor concentration. Post-hoc testing showed that the low concentration of orange odor for those three emotions was judged significantly lower than the medium and high concentrations (all $p < 0.01$), whereas the difference between three concentrations of fish odor for those three emotions did not reach significance. The statistical analysis also revealed an interaction between odor and concentration for emotion of fear ($F(1, 36) = 3.34$, $p < 0.05$): fear increased from low to high concentration for orange odor, while no difference was found between fear scores for the three concentrations of fish odor.

2.3.2 Facial expressions

Facial expressions evolved at different rates over time. Some facial expressions such as disgust (Figure 2.3A) and sad (Figure 2.3B) reached their maximum intensity relatively early (roughly between 1000 and 1500 ms after stimulation), and others such as angry, sad and happy (Figure 2.3A) reached their maximum relatively late (roughly between 3000 and 3500 ms after stimulation). In general, fish odor caused more intense facial expressions than orange odor, irrespective whether they refer to positive (e.g., happy, surprised) or negative (e.g., disgust, sad) emotions (see Figure 2.3A and 2.3B).

In addition, facial expressions to fish and orange odors differed significantly as indicated by main effects of odor valence for angry ($F(1, 25) = 7.2$, $p = 0.01$), disgust ($F(1, 25) = 11.1$, $p < 0.01$), neutral ($F(1, 25) = 15.4$, $p < 0.001$), scared ($F(1, 25) = 4.6$, $p < 0.05$) and surprise ($F(1, 25) = 4.1$, $p < 0.05$) and by interactions between odor valence and time for angry ($F(2, 50) = 4.0$, $p < 0.05$), disgust ($F(2, 55) = 3.6$, $p < 0.05$ and neutral ($F(3, 83) = 5.4$, $p < 0.001$). Moreover, expressions intensified at higher concentrations resulting in weaker neutral expressions ($F(2, 47) = 3.25$, $p < 0.05$, see Figure 2.4) and stronger scared expressions ($F(2, 50)=3.51$, $p < 0.05$).

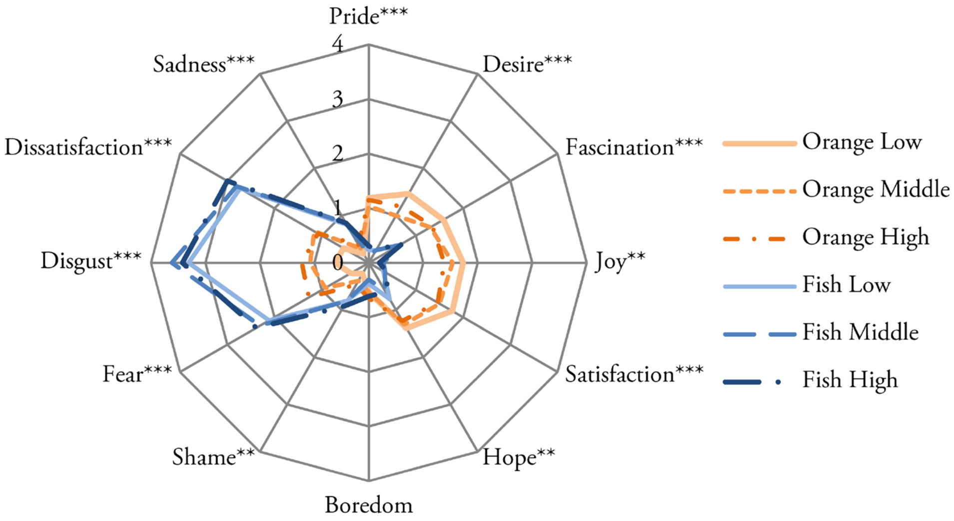


Figure 2.2 Average PrEmo scores (0 - 4) for all emotions for the two odors in three concentrations. The * indicates that certain emotions induced by fish and orange odors are significantly different (*: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$).

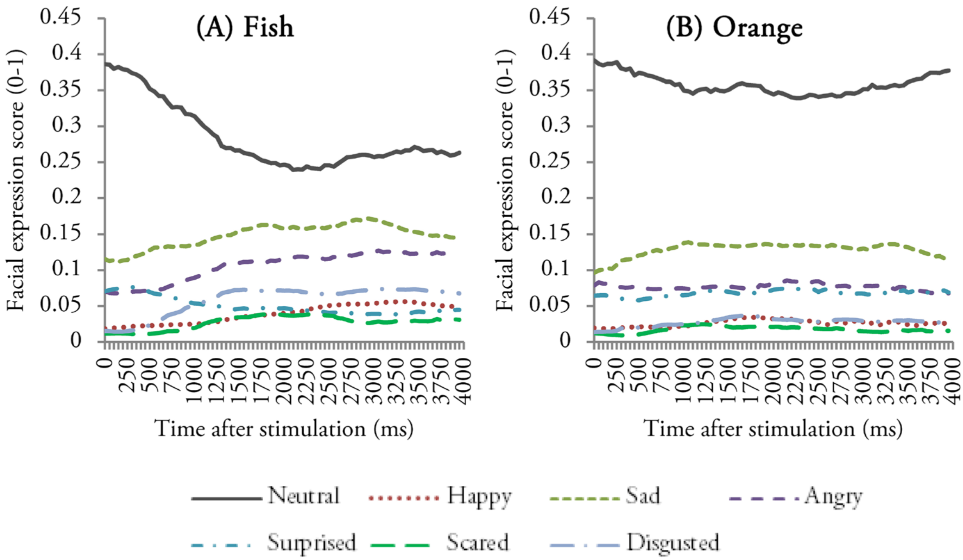


Figure 2.3 Sequential unfolding of seven emotional facial expressions over time (every 40 ms over 4 s) in response to both odors. (A) Responses to fish odor (averaged across all 3 concentrations and 4 replications); (B) Responses to orange odor (averaged across all 3 concentrations and 4 replications).

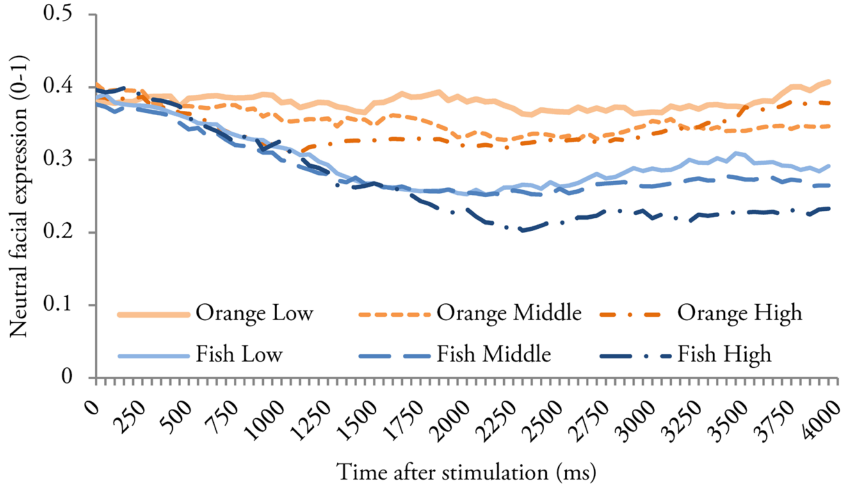


Figure 2.4 Sequential unfolding of neutral facial expression over time (every 40 ms over 4 s) in response to the different odors and concentrations (averaged across 4 replications).

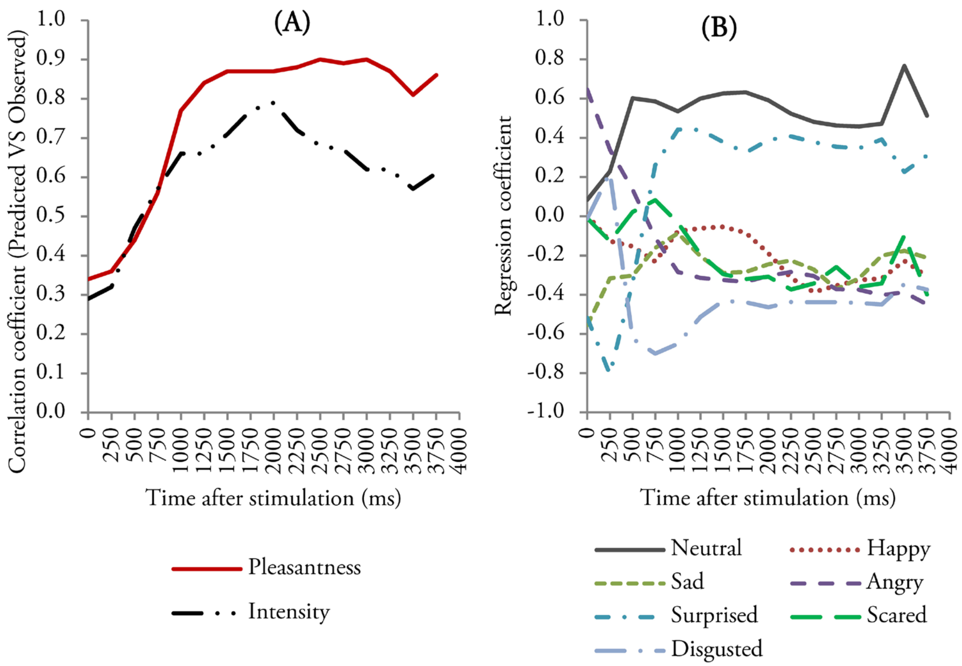


Figure 2.5 (A) Partial Least Square analysis correlating facial expressions with pleasantness and intensity across all odors; (B) Regression coefficients between pleasantness and each facial expression across all odors.

Partial Least Square analysis related FaceReader scores over time with pleasantness ratings. Figure 2.5A shows that pleasantness ratings were best predicted from 1250 ms onwards after stimulation reflected by the correlation coefficients between predicted and actual ratings ($r = 0.84$, $n = 24$) that became asymptotic after 1250 ms. Pleasantness ratings at 1250 ms were positively associated with neutral (regression coefficient = +0.60) and surprised (regression coefficient = +0.44) FaceReader scores and negatively associated with disgusted (regression coefficient = -0.51, Figure 2.5B) FacerReader scores. Intensity ratings were best predicted ($r = 0.79$, $n = 24$) around approximately 2000 ms.

2.3.3 Comparison between non-verbal reports of emotions and facial expressions

The PCA bi-plot (see Figure 2.6A) of the PrEmo results shows two main dimensions. The first dimension, which explains 99% of the response variance primarily reflects valence with the pleasant orange odors on the left, together with non-verbally reported positive emotions such as fascination and joy, and the unpleasant fish odors on the right, together with non-verbally reported negative emotions such as disgust and dissatisfaction. In addition, the second dimension explains only 1% of the variance. To verify the overlap between non-verbally reported emotions and the facial expressions at various times, we compared the odor loadings (as shown in Figure 2.6A) with the odor loadings based on facial expressions for 1-4 seconds following the odor presentation using the PC1 odor loadings. The correlation coefficient between the PC1 odor loadings based on non-verbally reported emotions and on the facial expressions during the first second equaled 0.65 and reached a maximum of 0.97 during the second sec, after which it remained relatively constant. The PCA bi-plot of facial expressions during the second sec shown in Figure 2.6B shows a similar distribution of the odors along PC1 as found for the non-verbally reported emotions with neutral, surprised and happy expressions associated with the pleasant orange odor and with disgusted and angry expressions associated with the unpleasant fish odor.

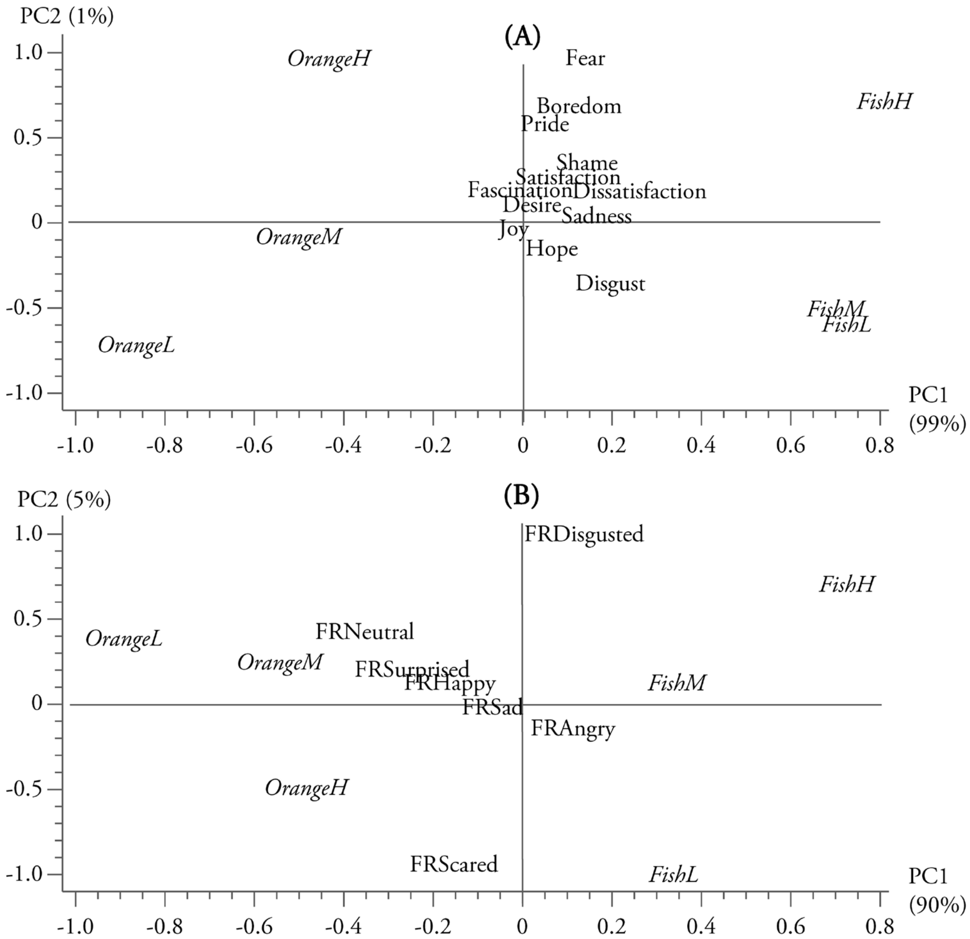


Figure 2.6 (A) PCA bi-plot of PrEmo scores and pleasant (Orange) and unpleasant (Fish) odors presented in low (L), medium (M) and high (H) intensities; (B) PCA bi-plot of FaceReader (FR) scores between 1 and 2 seconds after presentation of pleasant (Orange) and unpleasant (Fish) odors presented in low (L), middle (M) and high (H) concentrations.

2.4 Discussion

Emotional responses to a pleasant and an unpleasant food odor presented in varying concentrations were assessed continuously using facial expressions, and discretely using non-verbally reported emotions.

The results demonstrated that individual facial expressions develop at specific rates over time resulting in continuously changing profiles of emotional expressions. Different profiles seem to associate to different aspects of the odors: From 1250 ms onwards after the onset of the odor the profile relates most strongly to the rated pleasantness scores of the odors, and around 2000 ms the profile relates most strongly to the rated intensity scores. Possibly, profiles at other times relate more strongly to other aspects of the odor such as novelty - or to the appraisal of these aspects by the perceiver - which would be congruent with the component appraisal model that predicts different appraisal stages resulting in different emotions (48). A direct test of this model with the present results is not possible because a key appraisal in this model, novelty, was not assessed in the present study. Intensity was assessed instead, and the results suggest that intensity and pleasantness were associated to facial expressions at different intervals, which is consistent with the component appraisal model. Studies by others suggest that novelty is appraised immediately after stimulation during which the stimulus is evaluated in terms of unpredictability and unfamiliarity, aspects of stimuli that may signal danger to the perceiver (121). In the present study expression profiles during the initial stages of odor stimulation were dominated by expressions of surprised and scared emotions, suggesting that the initial stages of processing of our familiar odor stimuli also involved the appraisal of novelty and predictability. Future studies should include pleasantness ratings as well as familiarity ratings or more unfamiliar stimuli to verify the sequential appraisal of emotions.

Understandably, results based on two selected odors with opposing valences are too limited to warrant conclusions regarding odor valence in general, but some interesting observations can still be made. Facial expressions in response to orange and fish odor dynamically vary in a different way. Disgust and scared expressions in response to fish odor reach maximum values faster than other expressions, such as happy, whereas scared and sad expressions in response to orange odor reach maximum values faster, followed by happy and disgust expressions. In addition, fish odors also elicited larger variations in facial expressions than orange odor, an issue also addressed by Weiland et al. (122). This may be explained from an evolutionary perspective. Unpleasant stimuli typically signal danger. Thus, greater facial reactions to unpleasant odors versus pleasant odors may serve as an important social role to communicate the negative emotion to others in the group (34,79,123). However, future studies could explore a plethora of odors with a wider range of valence, in order to generalize these conclusions.

Facial expressions are in general congruent with odor valence, with neutral and surprised expressions associated with positive valence, and disgusted, scared, and angry expressions associated with negative valence. The exception, however, is expression of happiness which is actually associated with negative expressions after 3 seconds. The reason for this unexpected finding is unclear. Possibly, the happy expressions in our study served multiple purposes; the 'early' happy response may reflect the valence of the odor, whereas the 'late' happy response may serve a communicative purpose towards the other people present during the study (124) for example in an attempt to counteract the negative expressions displayed earlier. This supports the findings of Danner et al. (80) and Zeinstra et al. (79) that happy expression cannot discriminate liked or disliked foods implicitly. Moreover, FaceReader's identification of facial expressions may not always be perfect, as indicated in the method section, and certain expressions may be incorrectly interpreted as happy. Finally, the number of possible facial expressions in response to our stimuli may exceed the six expressions identified by FaceReader, which could result in incorrect identification of some facial expressions.

The results showed that PrEmo responses reflected primarily the odor's valence with non-verbally reported positive emotions related to the pleasant orange odor and negative emotions related to the unpleasant fish odor. Facial expressions were also strongly associated with odor valence but, depending on their timing, also with odor intensity. In addition, facial expressions varied dynamically over seconds following odor presentation and reflected the sequential unfolding of emotions. The facial expressions give a more dynamic and richer picture about the response to the odors than the single pleasantness rating.

PrEmo successfully distinguishes between liked and disliked concentrations and between liked and disliked food odors, e.g. joy, satisfaction and hope were associated with orange odor, and dissatisfaction, fear, disgust with fish odor. This correspondence between non-verbally reported emotions and rated pleasantness suggest that both measures reflect similar cognitive evaluations or appraisals. The only exception is the non-verbally reported emotion of boredom, which is unrelated to pleasantness. This supports the suggestion of (62) that PrEmo can provide extra information beyond liking for specific food products. In particular, the emotion of boredom might be relevant when assessing repeated exposure, an important feature in consumer and eating behavior.

Even though a direct comparison of FaceReader and PrEmo results is difficult because the methods assess a limited number of emotional responses that are only partly overlapping, some conclusions can still be drawn. The strong (r = 0.97) correlations between the PCA odor space based on PrEmo and the facial expressions after 1-2 seconds demonstrate that at this time, emotional responses from both measures are primarily organized according to the odors' valence. The fact that implicit facial expressions during these stages correspond well to the subsequent odor pleasantness and PrEmo ratings suggests that they reflect the pleasantness appraisal process that ultimately produces the obtained pleasantness ratings and non-verbally reported emotions.

The corresponding results of facial expressions and PrEmo during the later stages of processing may question the added value of facial expressions. Facial expressions are technically challenging to score, even with an automated system as used in this study, whereas explicit responses are relatively easy to capture, for example with the PrEmo tool (125). However, PrEmo has to be rated subsequently after each stimulus, whereas FaceReader can monitor facial expressions simultaneously without extra effort put in by participants. Therefore, prolonged experiments and repeated rating procedures due to PrEmo may trigger negative emotions like boredom. Therefore, in the present study, we chose to have participants rate PrEmo for only one block, whereas facial expressions were measured for 4 blocks of stimuli. Moreover, primary emotional responses when a stimulus is first encountered may determine approach or avoidance behavior, i.e. whether a product on the supermarket shelf is further inspected or ignored. These initial reactions may be based on the novelty of the product. As currently shown, facial expressions may prove to be valuable to detect these initial reactions despite the technical challenges.

Most studies on facial expressions investigate frequency of visible facial muscle movement (122) or average intensity of facial expressions across a certain time period (80). The findings of our study draw particular importance of choosing certain time period to increase accuracy of analyzing emotional facial expressions. Future research should clarify the role of initial reactions in eating behavior, especially for those expressions that may change immediately after a food cue is presented, such as surprised or scared expressions. Moreover, measurements of the autonomic nervous system (ANS) which monitor physiological responses simultaneously can perhaps create a more complete picture on the dynamic of emotional responses. ANS patterns during the various phases following stimulus presentation may be associated to specific emotional states, such as the stages in which relevance and pleasantness of the stimuli are appraised (126).

In conclusion, non-verbally self-reported emotions are relatively uni-dimensional reflecting primarily the odor's valence whereas facial expressions reflect not only the odor's valence but also other aspects such as its intensity. In addition, facial expressions provide support for the sequential appraisal of emotions. This study offers a new perspective on the distinction between initial and subsequent reactions to food products for consumer research. Future studies will have to relate each of the reactions to specific consumer behaviors, such as purchasing behavior.

CHAPTER 3

Dynamics of autonomic nervous system responses and facial expressions to odors

Wei He
Sanne Boesveldt
Cees de Graaf
René A. de Wijk

Published in Frontiers in Psychology, 2014, 5, 110.

Abstract

Why we like or dislike certain products may be better captured by physiological and behavioral measures of the autonomic nervous system than by conscious or classical sensory tests. Responses to pleasant and unpleasant food odors presented in varying concentrations were assessed continuously using facial expressions and responses of the autonomic nervous system (ANS). Results of 26 young and healthy female participants showed that the unpleasant fish odor triggered higher heart rates and skin conductance responses, lower skin temperature, fewer neutral facial expressions and more disgusted and angry expressions ($p < 0.05$). Neutral facial expressions differentiated between odors within 100 ms, after the start of the odor presentation followed by expressions of disgust (180 ms), anger (500 ms), surprised (580 ms), sadness (820 ms), scared (1020 ms), and happy (1780 ms) (all p values < 0.05). Heart rate differentiated between odors after 400 ms, whereas skin conductance responses differentiated between odors after 3920 ms. At shorter intervals (between 520 and 1000 ms and between 2690 and 3880 ms) skin temperature for fish was higher than that for orange, but became considerable lower after 5440 ms. This temporal unfolding of emotions in reactions to odors, as seen in facial expressions and physiological measurements supports sequential appraisal theories.

3.1 Introduction

Up to 80% of all new food products fail in the marketplace, despite the fact that they are typically subjected to a large number of sensory and consumer tests before their market introduction (127). This suggests that the 'standard' sensory and consumer tests, which typically include sensory analytical profiling and liking tests, have a low predictive validity with respect to general product performance. Possibly, consumer food choice outside the laboratory may be less based on cognitive information processing and rational reasoning, and more on unarticulated/unconscious motives and associations (24). Reasons for likes or dislikes of specific foods are typically difficult to articulate but may determine much of our food choice. Unarticulated/unconscious motives and associations are not very well captured by traditional tests based on conscious cognitive processes, and may be better captured by physiological and behavioral measures (e.g. facial expressions) of the autonomic nervous system (ANS) which do not require conscious processes (128).

Physiological measures have been used extensively to capture responses of the autonomic nervous system (ANS) to various types of stimuli such as film clips, personalized recall of specific situations, and odors. In a previous study, Alaoui-Ismaïli et al. (41) related various autonomic parameters to the pleasantness of five odorants, and found that unpleasant odors were associated with increased heart rate and longer skin conductance responses compared to pleasant odors. Bensafi et al. (45) related ANS measures to rated pleasantness, arousal, intensity and familiarity for a set of six odorants and found that their results could be explained by two main factors: pleasantness, inversely related to heart rate (similar to (39)) and arousal, positively related to skin conductance and rated intensity. Delplanque et al. (50) found stronger skin conductance responses and higher heart rate for unpleasant compared to pleasant odors. They also established that heart rate differences between pleasant and unpleasant odors occurred relatively late in the deceleration phase, approximately 5 to 8 seconds after odor presentation. Considerable faster odor-specific responses were found for facial expressions; facial muscle activity associated with positive and negative facial expressions showed different activities for pleasant and unpleasant odors as soon as 400-500 ms after odor presentation (50).

Facial expressions have also been used extensively by others to measure emotional responses to food-related stimuli. Well-known are the positive facial expressions of new-borns towards liked (sweet) and the negative expressions towards disliked (bitter) basic tastes, extensively documented by Steiner (71,74). More recently, an automated tool, FaceReader, has been developed and used to analyze more diverse, universal facial expressions. Using different food stimuli, it was found that happy expressions were not systematically related to liking scores, in contrast to neutral, angry, and disgusted expressions (80), and that stronger facial expressions to disliked foods compared to liked foods were already detected at the first visual encounter with the food (6).

The dynamic features over time of physiological responses and facial expressions have typical been outside the scope of most studies, even though they play a key role in several modern theories on emotion, the so-called componential appraisal models (see (49) for an overview). The models assume that the elicitation and the differentiation of emotions are determined by appraisals, the continuous, recursive evaluations of events, Delplanque et al. (50) investigated the appraisal of odor novelty and pleasantness and consequent emotional responses by measuring facial muscle activity and heart rate. They demonstrated that odors were detected as novel or familiar before being evaluated as pleasant or unpleasant (129,130). In addition, their results also argued in favor of a dynamic construction of facial expressions providing support for sequential appraisal theories (49). For example, early reactions, such as raising the eyebrows and opening the eyes, were related to the detection of a novel or unexpected stimulus, which is associated with increased alertness and attention. After this novelty detection, assessment of pleasantness may lead to avoidance when the stimulus is aversive or threatening, or approach when a pleasant response is activated.

The present study will expand on previous studies by using (food) odors delivered by an olfactometer, offering a high degree of control over timing and concentrations, and by incorporating additional ANS measures (skin temperature) and other types of facial expressions. Similar to Delplanque et al. (50) the present study will also focus on the temporal development of each measure instead of the more commonly used time-averaged means (e.g. (6,80)). Physiological responses and facial expressions will be measured continuously and analyses will be based on time-averaged means (similar to most of the previous studies) as well as on their temporal development.

It is hypothesized that the results based on time-averaged means will replicate the findings of similar studies by others, i.e. higher heart rate and skin conductance, lower skin temperature and more negative facial expressions after exposure to the unpleasant odor compared to exposure to the pleasant odor. It is further hypothesized that ANS responses are slower than facial expressions, but that both follow sequential appraisal processes of evaluating the stimuli.

3.2 Material and Methods

3.2.1 Participants

26 young healthy female participants (mean age: 22.6 ± 1.5 years, range: 20-25 years, 18.5 < BMI < 25 kg/m^2) were recruited from the subject pool of Food & Biobased Research, part of Wageningen University and Research Center. Participants self-reported their BMI and if they had actual/previous history of smell or taste disorders known to affect chemosensory function. Detailed information regarding the experiment was given and an informed consent form was signed by all participants prior to testing. The study was approved by the Medical Ethical Committee of the Wageningen University.

3.2.2 Odor stimuli and presentation

As described elsewhere (83), two food odors were selected on the basis of their relatively negative (fish odor) or positive (orange odor) valence (119). The orange (cold-pressed Californian orange oil, Sigma Aldrich, St. Louis, MO, USA) and fish (Fish flavor oil, Givaudan Inc., Geneva, Switzerland) odors were diluted with mineral oil (to 70%, v/v) and 1,2-propanediol (to 27%, v/v), respectively. With a dynamic olfactometer based on air-dilution (OM2s, Burghart instruments, Wedel, Germany), each odor was delivered in three different concentrations (low, medium, or high), correspondingly perceived at different intensities in a pilot study. The olfactometer allows the presentation of odorous stimuli within a continuous humidified (80%) and warmed (37 °C) airstream of 8 L/min, which does not alter the mechanical or thermal conditions at the nasal mucosa (131). These stimuli were delivered through a nosepiece for 1 s with an inter stimulus interval of 60 s. Each block of 6 stimuli (i.e. orange odor in 3 concentrations and fish odor in 3 concentrations) was randomized and presented 5 times, for a total of 30 stimuli.

3.2.3 Procedure

The experimental sessions took place in the physiological laboratory of the Restaurant of the Future located in Wageningen, the Netherlands. The experiment leader explained the experiment to the participant, allowed ample time for questions and asked the participant to sign the inform consent form (which they had received by e-mail prior to the experimental session) after which the electrodes were placed. Participants were seated in a comfortable chair, fitted with the olfactometer nosepiece, and oriented towards an adjustable computer monitor set with a webcam at eye-level (1 m viewing distance). They were asked to look directly towards the camera while receiving the odor stimulus to ensure recognition by the FaceReader software. Each trial started with an auditory attention signal to remind the participant to pay attention to the upcoming odor. The pleasantness and intensity of each odor was rated subsequently on a paper questionnaire 10 seconds after stimulation. The procedure is also shown schematically in Figure 3.1. The whole experiment lasted 45 min in total. Photograph 1 shows the set-up as used in this study.

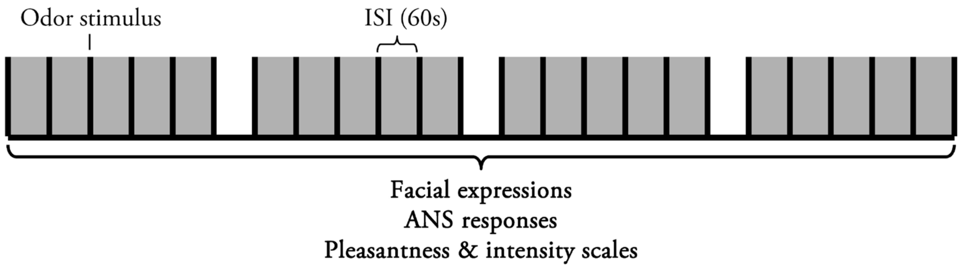


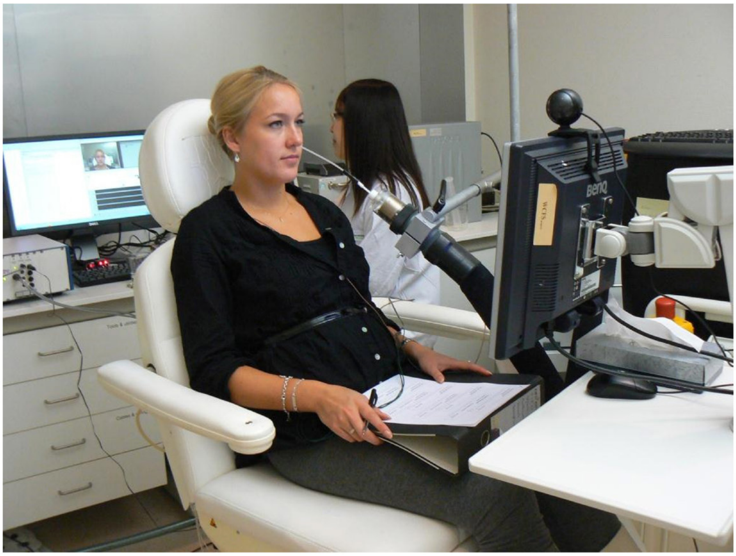
Figure 3.1 Schematical representation of the experimental procedure followed during one experimental session.

3.2.4 Measurements

3.2.4.1 Physiological ANS measures

Physiological measures included:

1. Skin conductance response (SCR) measured in μSiemens with electrodes placed on the palm of the non-dominant hand of the participant.
2. Heart rate (HR) measured in beats per minute with electrodes placed on the chest.
3. Skin temperature (ST) measured in degrees Celsius with an electrode placed on the palm of the non-dominant hand of the participant.



Photograph 3.1 Set-up used in this study showing the participant and the experimenter, the arm of the olfactometer for odor presentation, and the monitor used for instructions with a camera used for facial expressions.

The physiological data were collected at 200 Hz via a MindWare Acquisition data acquisition system (MindWare Technologies, Inc.) with separate filter settings for the electrocardiogram, finger temperature and electrodermal (skin conductance response) activity. Filter settings were low-pass 0.5 Hz, high-pass 45 Hz for heart rate frequency, low-pass 1 Hz, high-pass 45 Hz for SCR and low-pass 10 Hz, high-pass 45 Hz for skin temperature. Electrodes were used with a surface of 4.1 cm^2 and filled with 1% Chloride wet gel. Signals were transferred to the Acquisition Unit (16-bit A/D conversion) and stored on computer hard disk (sampling rate 500 Hz/s). Electrocardiographic R waves were detected offline, and intervals between heartbeats were converted to heart rate, expressed in beats per minute (BPM). SCR activity was recorded (high-pass filter: 0.025 Hz) by the constant voltage method (0.5 V). The signal was amplified by 1,000 and low-pass filtered (30 Hz).

3.2.4.2 Facial expressions

Facial expressions were automatically analyzed using FaceReader software version 4.0 (Noldus Information Technology B.V.). FaceReader works in three steps: (1) face finding, (2) face modeling, and (3) face classification. During face finding an accurate position of the face is found using the Active Template Method. During modeling, the

Active Appearance Model is used to synthesize an artificial face model, which describes the location of 491 key points as well as the texture of the face. The actual classification of the facial expressions is done by training an artificial neural network as training material nearly 2000 manually annotated images were used. The network was trained to classify the six basic or universal emotions described by Ekman (132): happy, sad, angry, surprised, scared, and disgusted and a neutral state. FaceReader analyzed the facial expressions on a frame-by-frame basis, i.e. at 25 Hz. Previous studies showed that FaceReader results corresponded between 71% (angry) to 99% (neutral) of all cases, with an average of 87%, with results from human observers (133). FaceReader happiness scores correlated significantly (r = 0.79) with objectively measured activity in the *ygomaticus supercilli* or cheek muscle, a muscle that is activated during expressions of happiness (134). A more detailed description of the science behind FaceReader can be found at: http://info.noldus.com/free-white-paper-on-facereader-methodology/.

3.2.5 Ratings of pleasantness and intensity

A visual analog scale of 10 cm was used to rate pleasantness and intensity after each odor presentation, ranging from 'not perceivable' (left-hand end = 0 cm) to 'extremely strong' (right-hand end = 10 cm), or from 'very unpleasant' (left) to 'neutral' (middle of the scale = 5 cm) to 'very pleasant' (right). In this study, orange odors were rated more pleasant ($F(1, 25) = 99.86$, $p < 0.001$) and less intense ($F(1, 25) = 17.27$, $p < 0.001$) than fish odors by the participants (see Table 3.1). Furthermore, odor intensity increased with concentration ($F(2, 50) = 47.15$, $p < 0.001$).

Table 3.1 Average ratings (0-10, with standard deviation) of fish and orange odors diluted to different concentrations

Odor	Concentration	Air-diluted to (%)	Intensity		Pleasantness	
			Mean	SD	Mean	SD
Fish (27% v/v)	Low	10	6.2	1.9	1.5	1.3
	Middle	25	6.7	1.6	1.5	1.3
	High	50	7.1	1.7	1.3	1.1
Orange (70% v/v)	Low	50	4.8	1.7	6.4	1.1
	Middle	80	6.0	1.7	5.6	1.6
	High	100	6.6	1.7	5.4	1.3

Ratings were made on a visual analog scale of 10 cm length. For intensity, 0 indicates 'not perceivable' and 10 indicates 'extremely strong'; For pleasantness, 0 indicates 'very unpleasant', 5 indicates 'neutral', and 10 indicates 'very pleasant'.

3.2.6 Data analysis

The processed images with the facial expressions were combined with raw physiological data in Observer XT 10.5 software (Noldus Information Technology) for further analyses. The moments that odors were presented to the participants were marked automatically using the 'trigger-out' signal from the olfactometer that signals the start of each odor presentation. The physiological measures skin conductance response (SCR), heart rate (HR) and skin temperature (ST) were analyzed per odor presentation. The video images of the facial expressions were processed per odor presentation with FaceReader 4.0 software (Noldus Information Technology). Due to a technical malfunction, absolute skin temperature values were not recorded, but the results can still be used to assess changes over time in skin temperature per odor presentation. Results from some participants had to be removed from the analysis due to a large number of artifacts. The number of participants that is included in the analysis is 21 (heart rate), 22 (skin conductance and skin temperature) and 24 (facial expressions)

Two types of statistical analyses were used: one based on post-odor time-averaged responses to verify systematic effects of odor and concentration, and one based on pre- and post-odor time-series of responses to verify the post-odor time at which responses become odor-specific. Details of each type of analysis are given below. In addition, correlational analysis was used to verify systematic associations between measures.

1. Repeated measures ANOVAs (IBM SPSS Statistics 19.0, IBM Corporation, Armonk, USA) were conducted on post-odor time-averaged facial expressions, ANS responses with odor and concentration as within-subject variables. A p-value of 0.05 was considered significant.
2. To verify the time at which time-series ANS responses and facial expressions become odor-specific (i.e. differ significantly between odors), absolute deltas between orange and fish odors were calculated together with the standard deviations for the 2.5 s interval preceding odor presentation to establish a pre-odor baseline. Subsequently, post-odor times were identified at which the absolute delta between the odors exceeded the pre-odor average plus 3 times the pre-odor standard deviation.

3.3 Results

3.3.1 Effects of odor and concentration

3.3.1.1 Physiological measures

Time-averaged means for heart rate $F(1, 20) = 18.7$, $p < 0.001$) and skin conductance ($F(1, 21) = 6.3$, $p < 0.05$) were significantly higher for the unpleasant fish odor compared to the pleasant orange odor (Figures 3.2A & 3.2B). Skin temperature did not vary systematically with odor ($F(1, 21) = 2.0$, n.s.; Figure 3.2C). Heart rate also increased systematically with concentration ($F(2, 40) = 5.3$, $p < 0.01$). Concentration did not affect skin conductance ($F(1, 21) = 0.6$, n.s.) or skin temperature $F(1, 21) = 0.9$, n.s.).

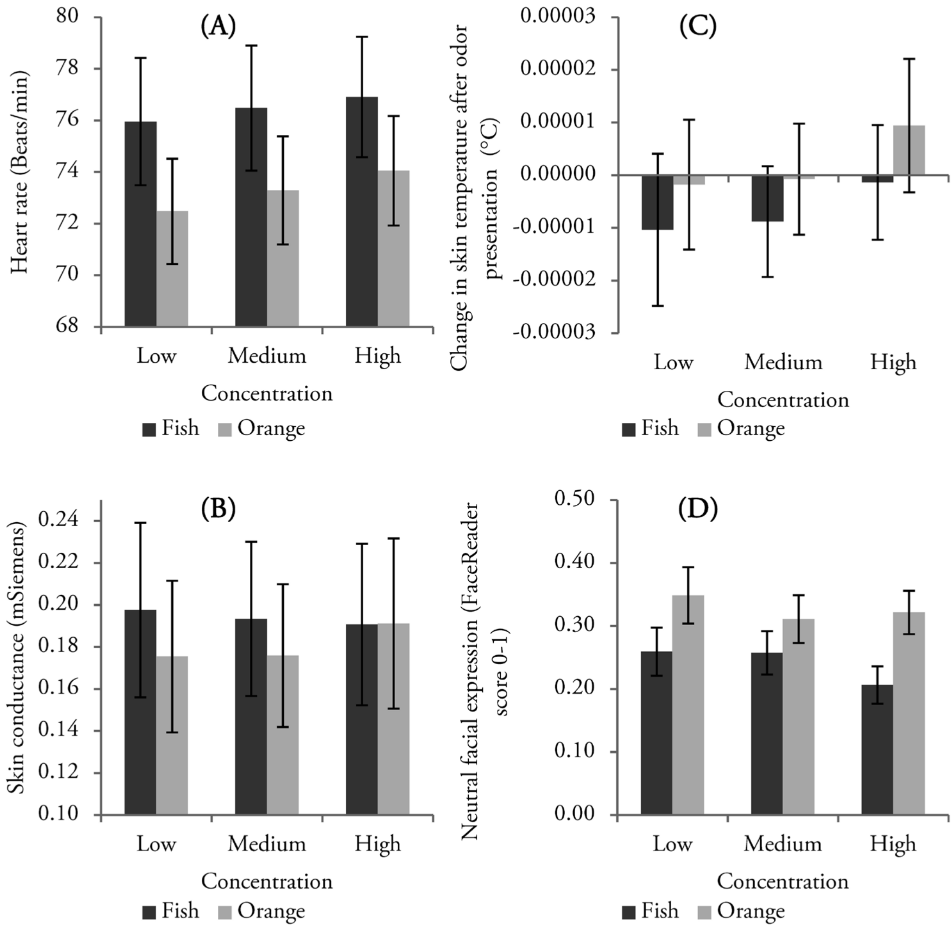


Figure 3.2 Effects of odor and concentration on (A) skin conductance responses, (B) heart rate, (C) skin temperature, and (D) neutral facial expressions (averaged across time and bars indicate standard errors).

3.3.1.2 Facial expressions

Time-averaged means of facial expressions to the fish compared to the orange odor were significantly less neutral ($F(1, 23) = 21.25$, $p < 0.001$; Figure 3.2D) and more disgusted ($F(1, 23) = 9.63$, $p < 0.01$), and angry ($F(1, 23) = 4.00$, $p < 0.05$). Moreover, facial expressions intensified at higher concentrations resulting, depending on the odor, in weaker neutral expressions (odor by concentration effect: $F(2, 46) = 3.25$, $p < 0.05$) and stronger scared expressions (odor by concentration effect: $F(2, 46) = 3.51$, $p < 0.05$).

Associations between physiological measures, facial expressions and ratings are summarized by correlational analysis based on 24 stimuli (2 odors × 3 concentrations × 4 replicates) averaged across participants (Table 3.2).

3.3.2 Time-series responses: when do responses become odor specific?

3.3.2.1 Physiological measures

Prior to the odor presentation, but after the warning signal is given, ANS measures show gradual changes that are independent of the odor valence whereby skin conductance and heart rate gradually increase and skin temperature gradually decreases (Figures 3.3). Skin conductance continues to increase for seconds after odor presentation independent of the specific odor. After approximately three seconds, SCR for orange decreases whereas that for fish continues to increase. The difference in SCR becomes significant after 3920 ms (Figure 3.3B and Table 3.3). Heart rate for the unpleasant fish odor increases almost instantaneously after the odor is presented whereas heart rate for the pleasant orange odor shows much smaller effects (Figure 3.3A and Table 3.3). The difference in heart rate response between the odors becomes significant after 400 ms. Skin temperature follows a different, irregular pattern with higher temperatures for fish odor at shorter intervals (between 520 and 1000 ms and between 2690 and 3880 ms) and lower temperature at longer intervals (after 5440 ms) (Figure 3.3C and Table 3.3) compared to orange odor.

Table 3.2 Pearson correlation coefficients between facial expressions. ratings and physiological measures for 24 stimuli averaged across participants.

		Facial expressions							Ratings		Physiological measures		
		Angry	Disgusted	Happy	Neutral	Sad	Scared	Surprised	Pleasantness	Intensity	HR	SCR	ST
Facial expressions	Angry	1	.49	.61*	-.65*	.07	.50	-.36	-.71*	.49	.61*	-.09	.02
	Disgusted		1	.40	-.78*	.48	.57*	-.59*	-.71*	.56*	.61*	.04	-.02
	Happy			1	-.52*	-.04	.31	-.18	-.55*	.57*	.50	-.21	.12
	Neutral				1	-.43	-.58*	.48	.83*	-.55*	-.73*	.15	.19
	Sad					1	.43	-.33	-.41	.41	.45	.56*	-.23
	Scared						1	-.23	-.61*	.52*	.50	.06	-.10
	Surprised							1	.65*	-.35	-.62*	-.22	-.03
Ratings	Pleasantness								1	-.61*	-.93*	-.08	.21
	Intensity									1	.67*	.07	.17
Physiological measures	HR										1	.23	-.16
	SCR											1	.11
	ST												1

*: Correlation is significant at the 0.005 level (2-tailed).

3.3.2.2 Facial expressions

Neutral expressions become odor-specific after less than 100 ms. Disgusted expressions take approximately another 100 ms to become odor-specific. Angry, surprised, sad and scared become after 500-1000 ms odor-specific, whereas happy expression become odor-specific after more than 1700 ms (Figure 3.4 and Table 3.3). Table 3.3 summarizes the times at which ANS responses and facial expressions significantly differentiate between the unpleasant fish and pleasant orange odor.

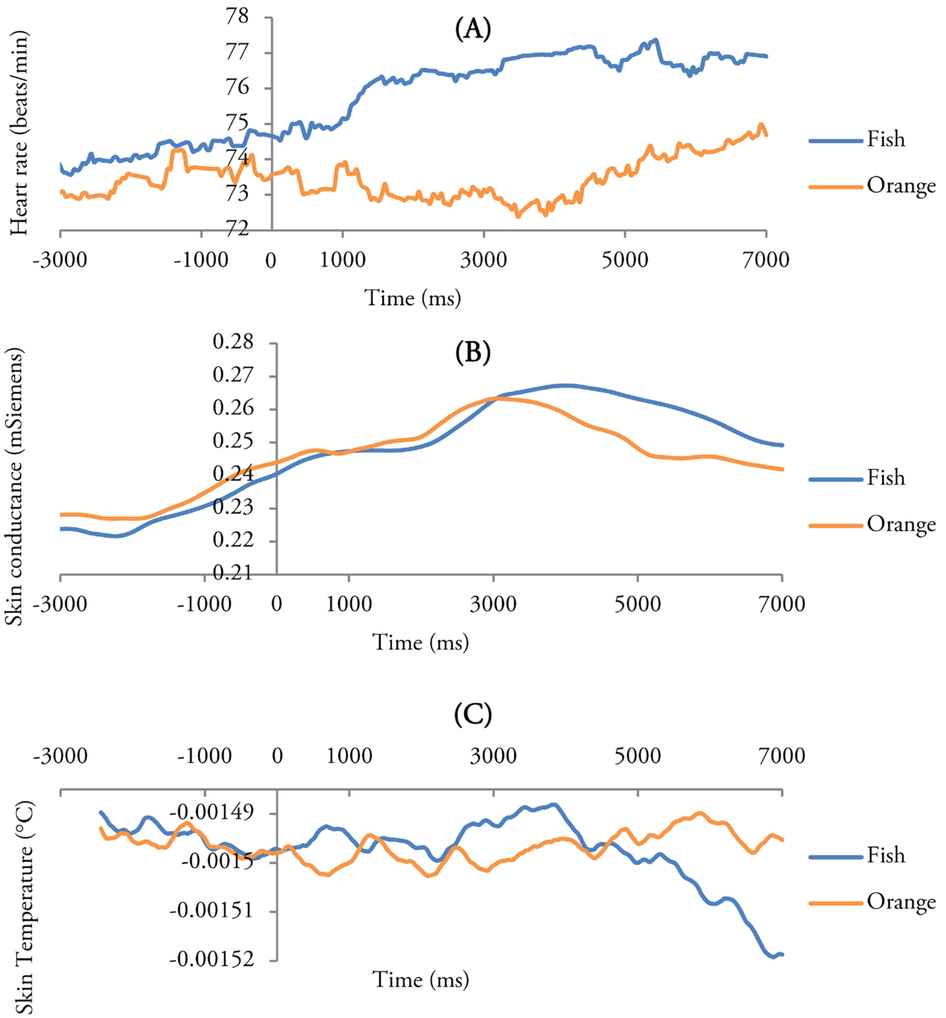


Figure 3.3 Effects of odor (averaged across concentrations) on (A) heart rate, (B) skin conductance and (C) skin temperature. Absolute skin temperatures are incorrect due to a technical malfunction.

Table 3.3 Intervals in ms following odor presentation at which responses become odor-specific.

Measures		Odor-specific time (ms)
Facial expressions	Neutral	<100-end
	Happy	1780 end
	Sad	820-end
	Angry	500-end
	Surprised	580-end
	Scared	1020-end
	Disgusted	180-end
ANS responses	HR	400-end
	SCR	3920-end
	ST	520-1000
		2640-3880
		5440-end

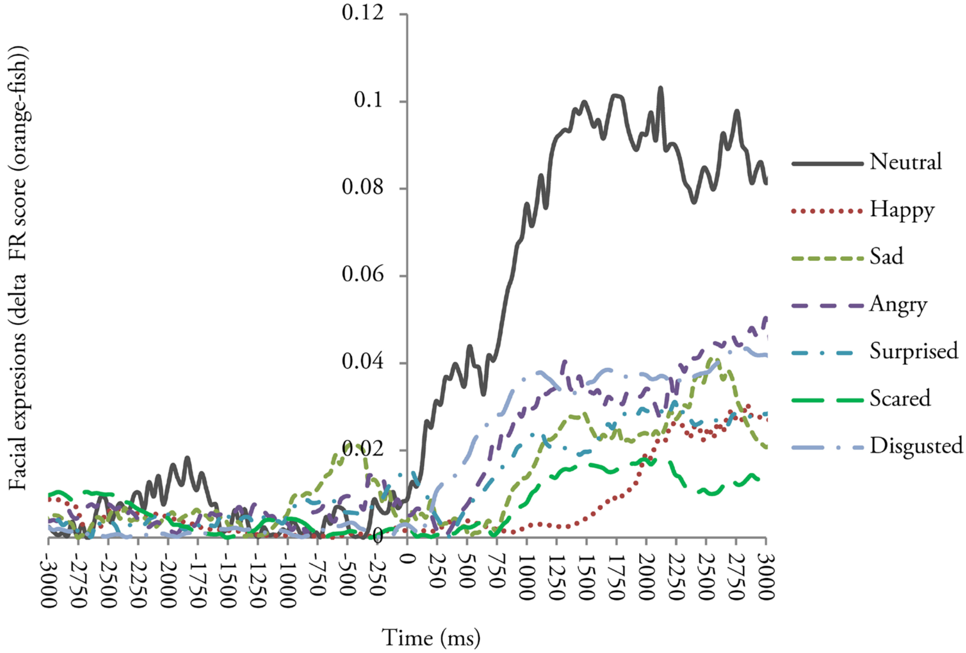


Figure 3.4 Sequential unfolding of differences in facial expressions between the unpleasant fish odor and the pleasant orange odors for seven emotional facial expressions over time following the odor presentation.

3.4 Discussion

Human responses to pleasant and unpleasant food odors presented in varying concentrations were assessed with facial expressions and responses of the autonomic nervous system. Analysis were carried out on results with and without averaging over time, and showed partly overlapping and partly different results.

ANOVAs on time-averaged results showed that the unpleasant fish odor triggered higher heart rates and skin conductance responses, lower skin temperature, fewer neutral facial expressions and more disgusted and angry expressions compared to the pleasant orange odor. Overall, our results were similar to the ones found in studies by others for heart rate (39,45,50), skin conductance (39,50), and skin temperature (see (26)), indicating that these averaged physiological measurements are mainly responsive to the valence of a stimulus, and less to intensity, whereas facial expressions appear to demonstrate more concentration-specific effects.

Correlational analyses based on time-averaged results shows positive associations between odor liking and neutral/surprised facial expressions, and negative associations between odor liking and all other facial expressions, including happiness. Negative associations between odor liking and happy facial expressions have also been reported previously by others (79,80) suggesting that happy expressions cannot discriminate liked or disliked foods implicitly. Facial expressions of happiness are rarely displayed when one is alone and social interactions are absent suggesting that these expressions serve a social function (see also (67,135)). The fact that they did occur in this study in the presence of experimental staff suggests that the happy facial expressions may serve some kind of social signaling function, e.g., to signal the staff that one is OK despite the previous display of negative expressions associated with disliked odors.

When results are not averaged across time, analyses demonstrate that facial expressions and physiological responses become rapidly odor-specific and are dynamic in nature. Responses such as skin conductance already start before the actual odor presentation These responses are obviously odor non-specific and probably reflect anticipatory processes, Almost immediately after the onset of the odor presentation, neutral facial expressions decrease followed after 100 ms by an increase in facial expressions of disgust. Within 400 ms heart rate for the unpleasant odor increase (similar to rapid acceleration in heart rate observed for negative emotions by Levenson (136)), skin temperature briefly increases, followed between 500 and 1000 ms by facial expressions of angry, surprised, sad and scared, and after 1700 ms by happy expressions. During all this time, skin conductance gradually increases for both odors until approximately 3 seconds when skin conductance for the pleasant odor starts to decrease whereas that for the unpleasant odor continues to increase. Finally, after more than 4 seconds, skin conductance for the unpleasant odor decreases together with skin temperature for the unpleasant odor. Combined these time-related results show that most facial expressions and physiological responses are fast reacting and odor-specific.

Our results correspond well with those found in previous studies; Delplanque et al. (50) found odor-specific activities in two types of facial muscle activities 400-500 ms after odor presentation, which coincides approximately with sad, angry, and surprised expressions in the present study. These values also concur with the values found for other stimulus modalities such as vision; Dimberg et al. (137) found facial responses to positive or negative visual stimuli after approximately 400-500 ms. In addition, we found other expressions that were triggered even faster, such as disgust, or slower, such as happy.

Response times for heart rate and for most of the facial expressions are well within one second after the odor is presented, and are often shorter than for example response time for odor detection (approx. 800 ms, (138)) or response time to decide whether or not an odor is more pleasant than a previous one (approx. 850 ms, (139)), where conscious action is needed. These differences in timing are possibly related to automated versus conscious processes in the central nervous system. Facial expressions and ANS responses probably reflect automated processing of the central nervous system (see (137)) for automated processes and facial expressions), whereas decisions regarding detection and pleasantness/unpleasantness require also time-consuming conscious processing. The fact that automated emotional odor-response times may be as fast as response times in the visual domain despite the relatively slow peripheral and peri-peripheral processing of odors may reflect the anatomical overlap between CNS structures involved in olfaction and emotions; the peripheral and central olfactory system are only separated by one relay (glomerulus of the olfactory bulb) after the odor interacts with the primary olfactory neurons. Next, olfactory information is conducted to other olfactory structures, some of which are also involved in emotions (hippocampus, anterior cingulate cortex, orbitofrontal cortex and parts of the amygdala and insula (140,141). Given the close correspondence of CNS structures involved in olfaction and emotions and the fact that these structures are activated simultaneously to when information becomes available for conscious, higher order cognitive processing in the cortex, it is no longer surprising that automated emotional odor response times are often faster than odor response times that involve conscious processing.

Combined the time-series responses found in this study show that most facial expressions and physiological responses are fast reacting and odor-specific. Moreover, different facial expressions and physiological measures develop at their own specific rate over time. Consequently, responses to the same stimulus may produce very different patterns of results depending on the time at which they are assessed. For example, fast responses around 500 ms, may be dominated by negative facial expressions such as disgust, increased heart rate and increased skin temperature, whereas slower responses may be dominated by positive facial expressions, lower heart rate and decreased skin temperature. The fast responses may be automated reflexes to novel and potentially dangerous stimuli, as observed by Delplanque et al. (50), whereas the later responses may reflect a conscious processing of a sequence of different emotions, each resulting from a different appraisal of the stimulus by the observer (e.g. (49)). Results from the same laboratory indicate that conscious evaluative ratings of participants are associated with ANS responses and facial expressions between one and three seconds after stimulation (83). This supports the notion that the fast responses, with response times of less than one second, are automated and relatively independent of evaluative ratings, whereas slower responses reflect conscious processing that form the basis for evaluative ratings and facial expressions of happiness for communicative purposes.

The present study has its obvious limitations; only a small number of odors were investigated, and their effects were investigated under controlled laboratory conditions with female participants. Nevertheless, the results may have some implications for consumer behavior in the real world. For example, visitors to supermarkets may have approximately 45 minutes to select their weekly groceries from up to 30000 products. This task becomes even more daunting considering the fact that many of these selections are not planned but made in the supermarket. Given this abundance of choices consumers need a fast and partly automated selection mechanism that combines affect, appraisal, action readiness and autonomic arousal. This fast selection mechanism may be based on fast and probably automated ANS responses and facial expressions similar to the ones found in the present study. These fast responses may not only be triggered by odors, but also product packages and brand names. To explore real-life applications, future studies will measure ANS responses and facial expressions in relation to consumer choice behavior. Initially, consumer behavior will be assessed in the semi-real-life test environment of a virtual supermarket, followed by real-life assessment in an actual supermarket. Such studies will allow a proper evaluation of ANS measures and facial expressions as tools for marketing (research) because their associations with consumer product interactions and purchasing behaviors will be tested directly.

In summary, physiological and facial responses to odors prove to be fast and dynamic and the balance between these responses is continuously changing depending on their timing. This changing balance may reflect different sequential appraisals of emotions. This study along with other recent studies (e.g. (50)) shows the necessity of taking the time dimension into account and future studies should further explore the relation between dynamic responses and appraisals.

CHAPTER 4

Implicit and explicit measurements of affective responses to food odors

Wei He
René A. de Wijk
Cees de Graaf
Sanne Boesveldt

Submitted for publication

Abstract

One of the main functions of olfaction is to activate approach/avoidance behavior, towards or away from people, foods, or other odor sources. These behaviors are partly automated and therefore poorly accessible via introspection. Explicit tests need therefore be complemented by implicit tests to provide additional insights into the underlying processes of these behaviors. Affective responses to seven food odors plus one control non-odor were assessed in 28 female participants (18-30 years) using explicit tests (pleasantness, intensity, and non-verbal emotional ratings (PrEmo)) as well as implicit tests that reflect dynamic expressive emotional reactions (facial expressions) as well as behavioral-preparation responses (autonomic nervous system responses: heart rate, skin conductance and skin temperature). Explicit tests showed significant differences in pleasantness ($p < 0.05$), and all PrEmo emotions ($p < 0.05$) except shame. Explicit emotional responses were summarized by valence (explaining 83% of the responses variance) and arousal (14%) as principal components. Early implicit facial and ANS responses (after 1 second) seem to reflect the odors' arousal, whereas later ANS responses (after 3-4 seconds) reflected the odors' valence. The results suggest that explicit measures primarily reflect the odors' valence, as result of from relatively long (conscious) processing, which may be less relevant for odor acceptance in the real world where fast and automated processes based on arousal may play a larger role.

4.1 Introduction

Olfaction may be the most underrated of the five senses, although it is vital for identifying potential environmental hazards, for social communication, and, not the least, for ingestive behavior (142). Its main function is thus to activate approach/avoidance behavior, towards or away from people, foods, or other odor sources. It is not surprising then, that the primary axis of odor perception is pleasantness (143,144). Pleasant odors eliciting positive feelings lead to approach behavior, such as a safe environment or an edible food, whereas unpleasant odors evoking negative feelings lead to avoidance behavior, such as shying away from poison or a predator. The different appraisal processes between pleasant and unpleasant odors are supported by reaction time (145,146), physiological response patterns (46,147-149) and functional neuroimaging studies (47,150-152). Additionally, there is evidence that edibility is also an important factor in classification of odors (153), and Boesveldt et al. (119) have demonstrated that an unpleasant food odor (fish) is detected faster and more accurately than either pleasant (orange) or non-edible odors (dirty socks, rose).

Odors are thus a powerful tool in eliciting affective responses, emotions and memories, that may be explained by the close neuroanatomical connections between olfactory areas and the limbic system (e.g. amygdala) (140). However, measuring affective responses to odors can be challenging. Beyond liking, we can distinguish between different types of measurements to assess emotions, i.e. verbal explicit tests such as the EsSense Profile (58), non-verbal explicit tests, e.g. PrEmo (61), and implicit measurements such as facial expressions (77) and physiological measures (93).

Bensafi et al. (45) investigated the relation between explicit odour ratings (intensity, arousal, pleasantness and familiarity) and activation of the autonomic nervous system (ANS) with six pure chemicals as odorants. Results indicated that a pleasantness factor correlated with heart rate variations, whereas skin conductance variations and odor intensity correlated with an arousal factor. As current theories on emotions suggest a dynamic unfolding over time (49,50), or continuous repeated appraisals in our own previous studies (82,83), we investigated ANS responses to odors differing in valence and intensity, and expanded this into the time domain to asses these dynamic changes in emotional response patterns. In addition, we assessed PrEmo (self-report emotional ratings) and implicitly recorded emotional facial expressions. Facial expressions and ANS appeared to reflect different stages of the same processes: Facial expressions provided emotional information on the results of each of the appraisals, whereas ANS responses were indicative of resulting behavioral actions. The results showed that while PrEmo responses primarily reflected the odors' valence, facial expressions were not only strongly associated with odor valence but, depending on their timing, also with odor intensity. In addition, facial expressions and ANS responses varied dynamically over time following odor presentation. This temporal unfolding of emotions in reactions to odors, as seen in facial expressions and physiological measurements, supports sequential appraisal theories. A limitation of that study is that we only used two food odors (orange, fish) at opposite sides of the pleasantness spectrum (highly liked, highly disliked), which may not be sufficient induce various emotional patterns. Furthermore, the relation between self-reported non-verbal ratings of, and autonomic nervous system responses to food odors has not been investigated yet, either by us or by others.

Therefore, the present study continued to explore how explicit and implicit factors contribute to dynamic pleasantness appraisal, using iso-intense food odors varying in a wider range of valence and using similar measurements (i.e. liking scores, PrEmo, facial expressions and ANS responses) as in the previous study. We hypothesize that all three types of measurement contribute to the pleasantness appraisal of food odors and may correlate to each other differentially at the different time windows of odor exposure. The emotional profile assessed with PrEmo may result from the integration of preceding response patterns, as reflected by facial expressions and ANS responses. Following this reasoning we hypothesize that over time, dynamic emotional responses correlate more with the end product of the emotional response, as reflected by PrEmo and liking scores.

4.2 Materials and methods

4.2.1 Participants

A total of 28 female participants were recruited from the subject pool of Food & Biobased Research, part of Wageningen University and Research Center. Participants had a normal weight (BMI 18.5-25 kg/m^2, mean ± SD 21.7 kg/m2 ± 1.7) and were aged between 18 and 30 years (mean ± SD 23.1 years ± 2.7). Participants were healthy, based on self-report, and had no current or history of smell disorders known to affect chemosensory functioning. Detailed information regarding the experiment was given and an informed consent form was signed by all participants in an information meeting prior to the test session. The study was approved by the Medical Ethical Committee of the Wageningen University (NL52249.081.15) and conducted according to the principles of the Declaration of Helsinki for Medical Research involving Human Subjects (version 2013).

4.2.2 Experimental procedure

Participants came for one session, in which they were presented with 8 odors including an odorless control, repeated 5 times each, for a total duration of 45 minutes. In the beginning of the test session, electrodes were placed on participant's body to get stable baseline data of autonomic nervous system responses. Participants were seated in a comfortable chair, fitted with a nosepiece for odor presentations, and oriented towards an adjustable computer monitor set with a webcam at eye-level (1 m viewing distance). They were asked to look directly towards the camera while receiving the odor stimulus to ensure recognition by FaceReader software. Each trial started with a red fixation cross on the screen to remind the participant to pay attention to the upcoming odor. Odors were presented in 5 blocks, in each of which the order of 8 odors was randomized. For the first four blocks of stimuli, the pleasantness and intensity of each odor were rated 10 s after odor presentation on a digital VAS. Facial expressions and ANS responses were recorded continuously. For the last block of stimuli, participants rated PrEmo animations, instead of pleasantness and intensity. The intervals between two odors stimuli in the last block were not fixed, but dependent on the pace of PrEmo ratings by the participants. The experimental schematic is shown in Figure 4.1.

4.2.3 Odor presentation

Seven food odors (mushroom, fish, chocolate, caramel, cucumber, orange and apple), plus one odorless control were used in this study. The odors were selected so that they would include pleasant as well as unpleasant odors, but were similar with respect to intensity and familiarity, as determined in a pilot session prior to the test session. Odors were presented with a computer-controlled, 8-channel olfactometer to ensure accurate odor onset (154), for 3 s with a flow of 3 liter per minute (lpm). To prevent possible discomfort by a continuous (high) airflow, the airflow was switched to a low stream in between odor presentations (0.5 lpm). The air flow was switched to a similar (3 lpm), odorless airflow ~2 s before onset of the stimulus, to prevent any tactile cues that might alert the subject to the odor delivery. The stimulus presentation program E-Prime 2.0 Professional (Psychology Software Tools Inc., Pittsburgh, PA) was used to trigger the olfactometer.

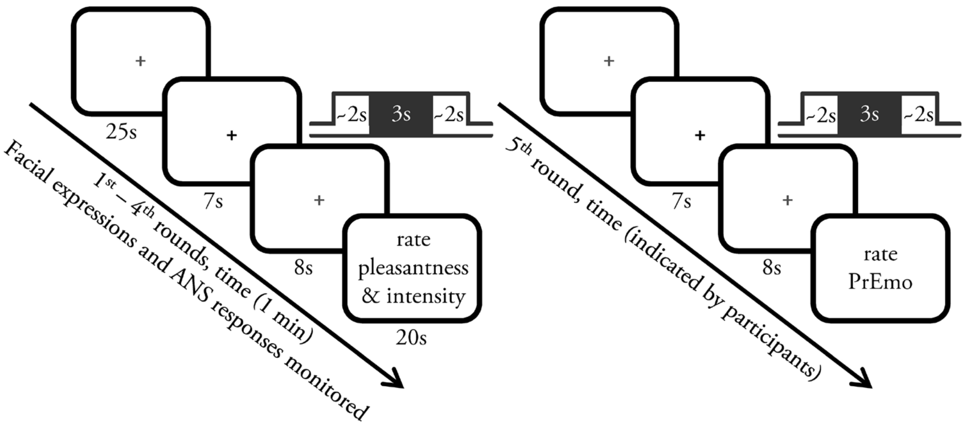


Figure 4.1 Scheme of experimental design.

4.2.4 Measurements

A digital visual analog scale (VAS) of 100 mm was used to rate pleasantness and intensity after each odor presentation, ranging from ‘not perceivable’ (left-hand end = 0 mm) to ‘extremely strong’ (right-hand end = 100 mm), or from ‘very unpleasant’ (left) to ‘neutral’ (middle of the scale = 50 mm) to ‘very pleasant’ (right).

Product Emotion Measurement Instrument (PrEmo) developed by Desmet et al. (61) was used to measure 12 emotions in response to odors. Participants have to rate animated figures expressing an emotion, on a 5-point scale, to indicate to what extent their feeling elicited by the stimulus was expressed by the animations. Of these 12 emotions, six are pleasant (i.e. desire, satisfaction, pride, hope, joy, and fascination), and six are unpleasant (i.e. disgust, dissatisfaction, shame, fear, sadness, and boredom).

Facial expressions of participants were filmed with a Logitech C600 webcam, mounted on top of a computer monitor placed in front of the participant. Facial expression data were automatically analyzed by FaceReader 5.0 (Noldus Information Technology, Wageningen, The Netherlands) based on Active Appearance Modeling (111) in each time frame (at a frequency of 25 Hz) during 5 seconds after stimulus presentation. The face classification provides the output of six basic expressions (happy, sad, angry, surprised, scared, disgusted) and one neutral state with 89% accuracy (111) on the basis of the Facial Action Coding System developed by Ekman and Friesen (77).

The physiological data were collected at 200 Hz via a Biolab data acquisition system (MindWare Technologies, Gahanna, US) for heart rate, skin conductance level and skin temperature. Heart rate (HR) was measured using electrodes placed on the shoulder and the waist of the participant; skin conductance level (SCL) was measured in µSiemens via surface electrodes covered with electrode gel and placed on in the palm of the left hand; skin temperature (ST) was measured in degrees Celsius using a surface sensor placed on the subject's middle finger of the left hand. Electrodes were used with a surface of 4.1 cm^2 and filled with 1% Chloride wet gel. Signals were transferred to the Acquisition Unit (16-bit A/D conversion) and stored on computer hard disk (sampling rate 500 Hz). Electrocardiographic R waves were detected offline, and intervals between heartbeats were converted to HR, expressed in beats per minute (BPM). SCL was recorded by the constant voltage method (0.5 V).

4.2.5 Statistical analysis

The video images of the facial expressions were processed per odor presentation with FaceReader 5.0 software. The raw physiological data of the skin conductance level (SCL), heart rate (HR), and skin temperature (ST) were analyzed per odor presentation with MindWare software. The processed facial expressions scores and physiological data were combined with in ObserverXT 12.5 software (Noldus Information Technology) for further analyses. The moments that odors were presented to the participants were marked automatically using the 'trigger-out' signal from the E-Prime software that signaled the start of each odor presentation.

Univariate ANOVA tests (IBM SPSS Statistics 19.0, IBM Corporation, Armonk, USA) were used to analyze the odors' intensity, pleasantness and PrEmo ratings. ANS results were averaged per 1-second bins, for 4 s upon start of odor presentation.

Changes in ANS responses were calculated by subtracting the value at the start of the odor presentation (t = 0) from each of the post odor averages. These results were analyzed with a linear mixed model with odor (8, including the odorless control) and time (4 seconds) as fixed factors and subject as random factor. FaceReader expressions were also averaged per second over a 4-second post-odor period, but these averages were not adjusted for baseline values. Linear mixed model analyses with odor, time and subject as factors were also used to analyze each of the facial expressions. Results from participants who did not respond differentially between the odors were excluded from further analysis. Out of twenty-eight participants, results from sixteen participants were included in the skin conductance analysis, twenty-four in the skin temperature, analysis, eighteen in the heart rate analysis, and twenty-one in the facial expression analysis. A p-value of 0.05 was considered significant.

To summarize the data collected from PrEmo, FaceReader, and ANS responses per 1-second bin, principal component analysis (PCA) (Unscrambler CAMO ASA, Oslo, Norway) was used with non-normalized variables, centered data, and orthogonal principle components. Similarities in processes between these measures should reveal themselves in similarities between the factor loadings of the odors between measures. For example, if ANS responses and facial expressions share underlying processes, then the distributions of the odors in the ANS bi-plot should be similar to the distribution of the same odors in the facial expression bi-plot. Correlation coefficients between measures were calculated based on the odor loadings on the first two principle components.

4.3 Results

4.3.1 Explicit measures

The odors (excluding the odorless control) differed significantly in pleasantness ($p < 0.05$) but were similar with regard to intensity (Table 4.1).

Emotional PrEmo responses varied significantly with odor ($p < 0.05$), with the exception of shame (Figure 4.2). The associations between odors and PrEmo emotions are summarized in the bi-plot shown in Figure 4.3. Two principle components explain virtually all response variance (98%). The first PC explains 83% and seems to reflect valence because it runs from positive emotions such as joy and pride to negative emotions such as disgust and dissatisfaction and reflects valence. The second PC explains an additional 14% and seems to reflect arousal because it runs from low arousing emotions such as boredom to high arousing emotions such as joy and fear.

Table 4.1 Detailed information on food odors used in this study.

Odor	Concentration (%)	Solvent	Producer	Pleasantness		Intensity	
				Mean	SD	Mean	SD
Mushroom	0.1	DW	Givaudan	27.03	16.55	57.51	12.67
Fish	0.1	PG	Givaudan	35.64	24.79	61.72	14.85
Chocolate	0.1	DW	Givaudan	38.05	16.92	56.02	15.54
Control	0.1	DW	-	49.86	1.03	0.96	1.29
Caramel	0.1	DW	Givaudan	60.90	21.47	53.31	12.89
Cucumber	10	DW	Givaudan	61.89	16.01	59.53	15.29
Orange	0.1	PG	Sigma Aldrich	63.20	16.48	62.90	13.56
Apple	0.1	DW	Givaudan	71.35	12.04	46.73	12.45

DW: Demineralized Water; PG: Propylene Glycol.

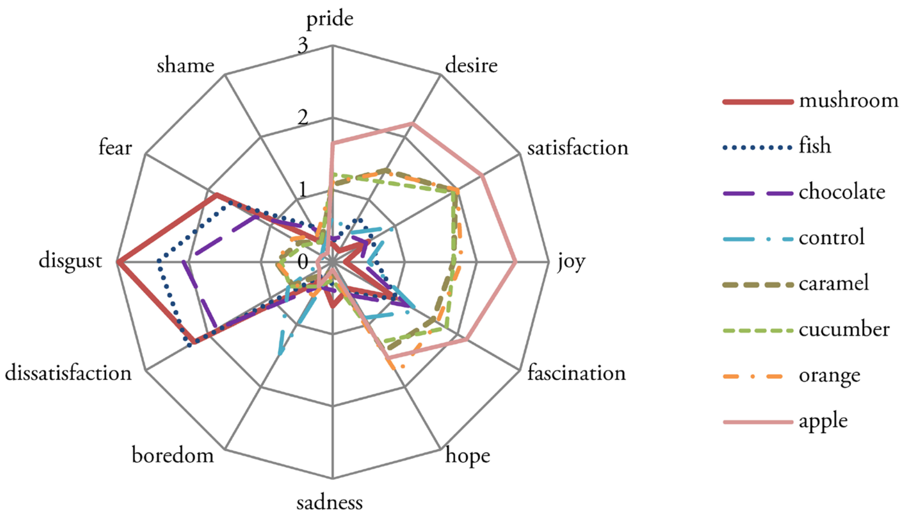


Figure 4.2 PrEmo ratings of 7 odors plus one control odor.

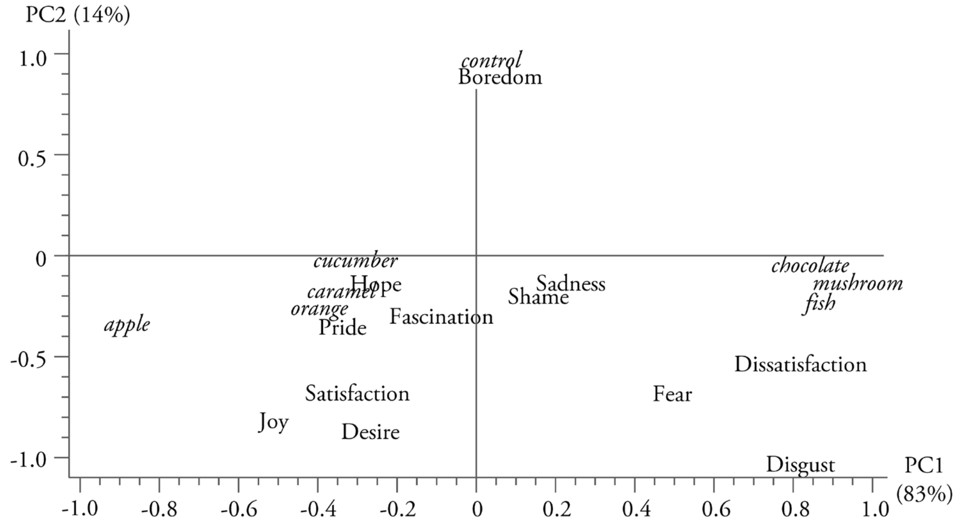


Figure 4.3 Principle component bi-plot of food odors (in italic) and facial expressions. PC1 explains 83% of the response variance, PC2 14%.

4.3.2 Implicit measures: autonomic nervous system responses.

Changes in skin conductance responses varied significantly between odors ($F(6, 717) = 4.3$, $p < 0.01$) with largest increases for the unpleasant fish and mushroom odors, as well as for caramel, and smallest increases for the pleasant orange, cucumber and apple odors (Figure 4.4A).

Changes in heart rates showed a bi-phasic response whereby an initial increase in heart rate (maximum during second 2) is followed by a decrease (minimum in second 4). Neither the positive peak nor the negative peak varied significantly with odor ($F(7, 123) = 0.8$, n.s. and $F(7, 123) = 1.8$, $p = 0.1$). In contrast, the difference between the two peaks did vary with odor ($F(7, 123) = 2.3$, $p = 0.03$) (Figure 4.4B).

Changes in skin temperature varied significantly between odors ($F(7, 713) = 3.80$, $p < 0.01$) (Figure 4.4C) with relatively large increases for the pleasant apple, cucumber and orange odors, and small or no increases for the other odors.

4.3.3 Implicit measures: facial expressions.

Facial expressions of happiness ($F(7, 619) = 2.3$, $p = 0.03$), sadness $(7, 619) = 4.3$, $p < 0.01$), surprise ($F (7, 619) = 3.4$, $p < 0.01$), scared $(7, 619) = 15.0$, $p < 0.01$)

and disgust ($F(7, 619) = 2.4$, $p = 0.02$) varied significantly between odors. Neutral expressions ($F(7, 619) = 1.7$, $p = 0.1$) and expressions of anger ($F(7, 619) = 1.8$, $p = 0.07$) did not vary significantly with odor (Figure 4.4D). In general, more pleasant odors were associated with fewer expressions of disgust, scared, surprise, anger, sad, but also happy and somewhat more neutral expressions (see also Figure 4.7).

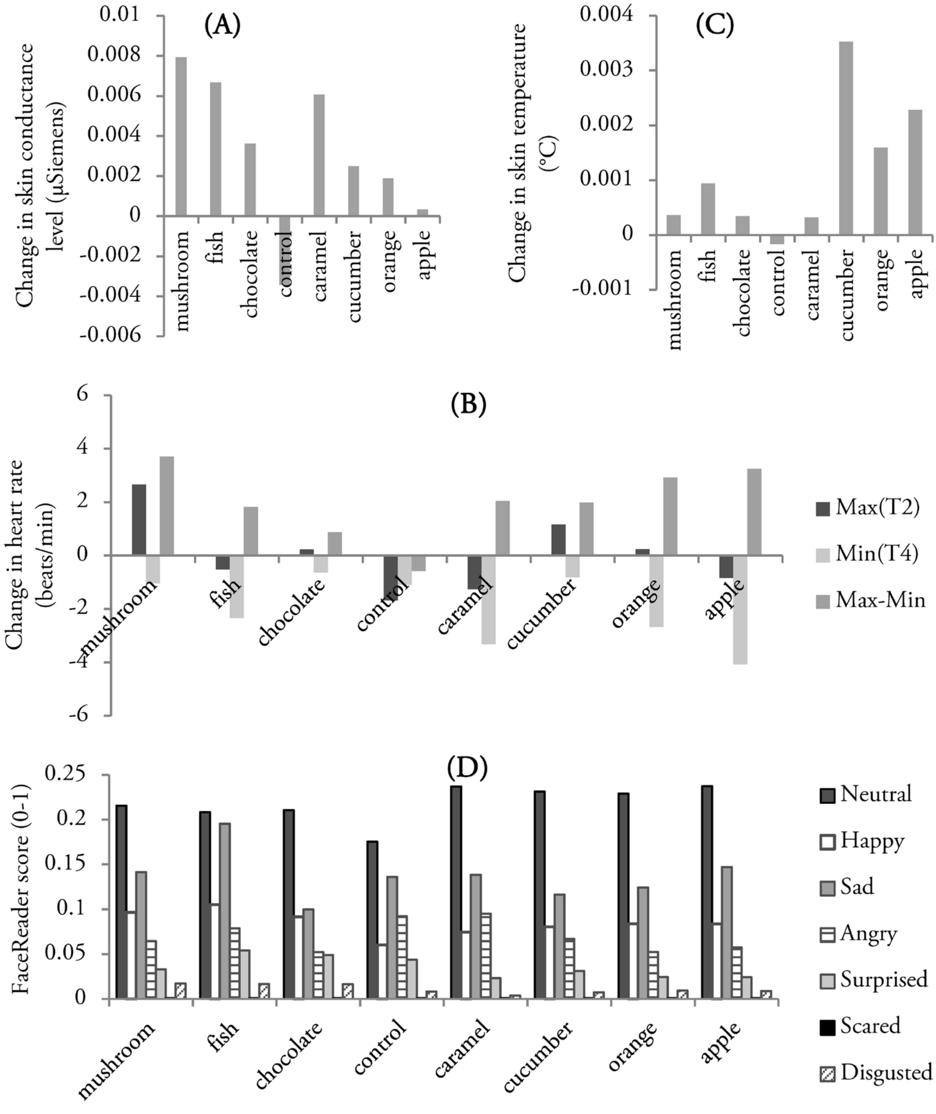


Figure 4.4 Changes compared to baseline in (A) skin conductance, (B) heart rate, (C) skin temperature, and (D) FaceReader scores for 7 odors plus one control odor ("water"). Results are averaged across 4 seconds.

4.3.4 Temporal development of facial expressions and ANS responses

Principle component bi-plots show the associations per 1-second bin between ANS responses or facial expressions and the odors. These associations change over time (Figures 4.5). Similarities between the processes captured by the temporal results at T1, T2, T3 and T4, as well as by the results of the explicit ratings made afterwards, should lead to similar distributions of the odors along PrEmo's valence and arousal dimensions as shown in Figure 4.3. Similarities were quantified by (absolute) correlation coefficients between the odor loadings (either PC1 or PC2) for each 1-second bin based on facial expressions or ANS responses and the odor loadings on the valence (PC1) and arousal (PC2) dimensions based on the PrEmo results. The correlation coefficients (Figures 4.6) show stronger associations between facial expressions and the PrEmo arousal dimension than with the valence dimension, especially in the 2^{nd} second of odor presentation. Similarly, ANS responses show stronger associations with the PrEmo arousal dimension in the 2^{nd} second. In contrast, ANS responses in the 3^{rd} and 4^{th} seconds show stronger associations with the PrEmo valence dimension.

Valence was also measured directly via rated pleasantness. Figure 4.7 shows the correlation coefficients between pleasantness and the PrEmo emotions, facial expressions for the 3^{rd} second and ANS results for the 4^{th} second (strongest association at those time points). Not surprisingly, most of the negative PrEmo emotions with the exception of boredom and shame showed significant negative correlations with pleasantness, whereas all positive PrEmo emotions showed significant positive correlations ($p < 0.05$). Pleasantness was associated with increased skin temperature, and reduced heart rate and skin conductance. Only the (negative) correlation coefficient between pleasantness and skin conductance reached significance ($p < 0.05$). All facial expressions with the exception of neutral showed negative associations with pleasantness, but only the correlation with happiness and disgust reached significance ($p < 0.05$).

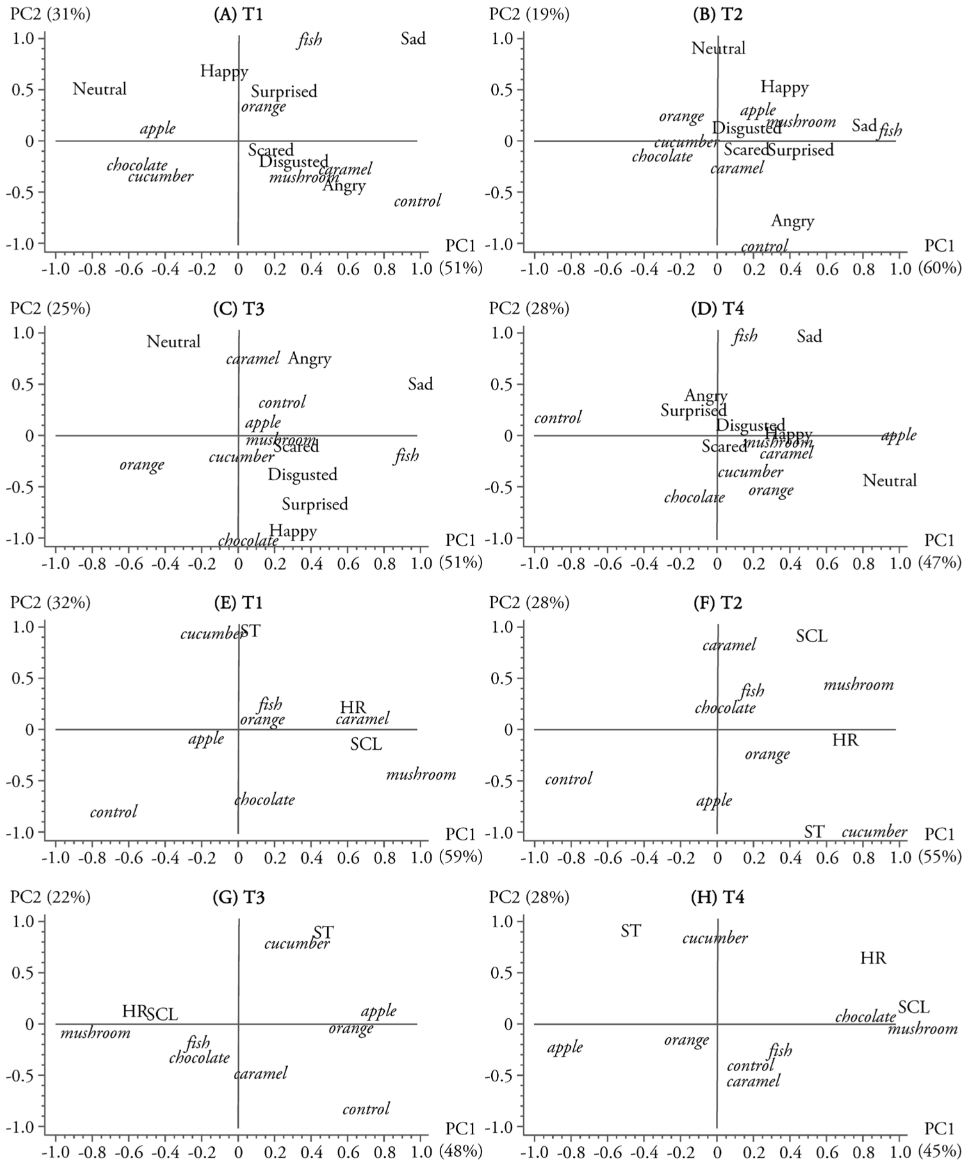


Figure 4.5 Principle component bi-plots per 1-second post-odor bin (T1-T4) of food odors (in italic) and facial expressions (A-D) and ANS responses (E-H).

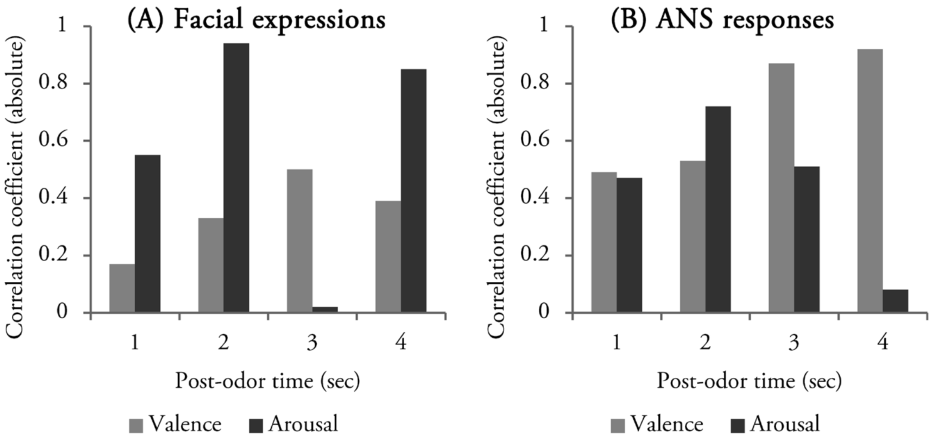


Figure 4.6 Correlation coefficients between PCA odor loadings of (A) facial expressions or (B) ANS responses and PCA odor loadings of PrEmo scores. Critical correlation coefficient is 0.62, p = 0.05 (n = 7).

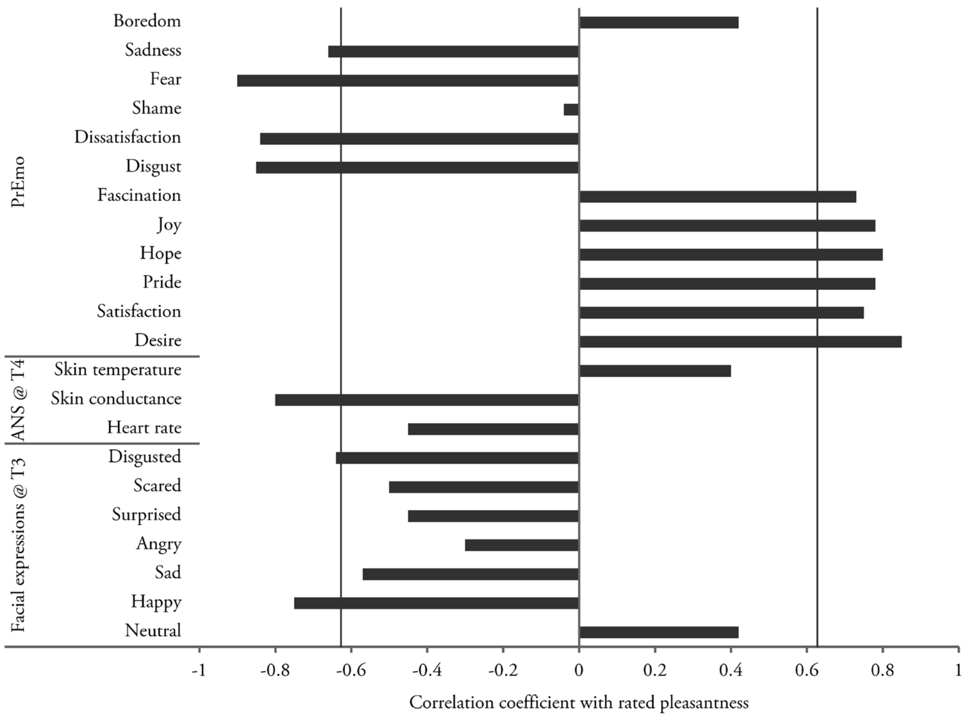


Figure 4.7 Correlation coefficients between changes in ANS responses (during the 4th second), facial expressions (during the 3rd second, PrEmo scores and rated pleasantness of the odors. Critical correlation coefficient is 0.62, p = 0.05 (n = 7).

4.4 Discussion

Affective responses triggered by food odors were measured with continuous, implicit (facial expressions and autonomic nervous system responses) and discrete, explicit (pleasantness and non-verbally reported PrEmo emotions) measures. The explicit PrEmo test results indicated that the non-verbal emotions could be summarized by two dimensions: a dimension corresponding to the odors' valence (explaining 83% of the response variance) and another independent dimension corresponding to the degree of arousal of the emotion triggered by the odors (explaining an additional 14%). This is a well-known finding that has been reported frequently by others (see for example Russell's circumplex model of affect (44) and probably also reflects the importance of valence (liking, pleasantness) for the development of food and non-food products. The market place is however flooded with products of which the majority will ultimately fail despite that they are generally well liked according to sensory and consumer tests. The results of the implicit ANS responses and facial expressions suggest that arousal may be more relevant for consumer behavior and appreciation than indicated by the more traditional explicit tests.

Facial expressions and ANS responses in the 2nd second of odor presentation related to the explicit emotions of the arousal dimension. Later ANS responses (in the 4th second) also related to the explicit emotions of the valence dimension. These findings are in line with current appraisal theories of emotions (see (49) for an overview) that state that emotions are the result of unfolding appraisals over time. These appraisals produce cognitive, expressive, physiological, motivational and subjective changes over time, which can be monitored with time-dependent measures such as autonomic nervous system responses and facial expressions. In addition, the results of this study suggest that arousal-related emotions precede valence-related emotions in time.

The separation in time of responses associated with arousal and those associated with valence is lost when explicit tests such as the PrEmo are used but may still be important in our daily life decision making. Relatively fast bodily (ANS) and expressive (facial expressions) processes primarily reflect the arousal caused by the stimulus rather than its valence. From an evolutionary point of view this makes sense: a new stimulus first needs evaluation regarding its novelty and thus its potential threat (50). A novel and potentially dangerous odor needs fast reactions to reduce the risks of exposure. These evaluative processes may drive the relatively fast arousal effects, and the odors' valence may only become relevant at a later stage (139). From an ecological point of view one may wonder what type of responses is more relevant for processes such as food choice in supermarkets or food intake behavior. If one has a choice between numerous (food) products, as in the case in a supermarket with 30,000 or more products, a fast choice mechanism based on arousal may be very practical (and useful to marketers who already know how to make dull products more exciting via packaging cues such as colors, images, and shapes). On the other hand, if limited number of foods are available, one may have time for more careful evaluation and valence may determine in this case food choice and intake behavior.

Previously, we observed strong associations between facial expressions in the 2nd second and the PrEmo valence dimension, instead of the PrEmo arousal dimension observed in this study. In that study (82,83), the arousal dimension was virtually lacking probably due to the limited number of odors tested (two) that differed strongly in valence (pleasant versus unpleasant). The present study suggests that when a more complex set of test odors is used, temporal separation takes place in the processes that result in emotions related to arousal and valence, in line with previous findings of Bensafi et al. (45).

The fact that facial expressions reflect the food odors' arousal rather than their valence is probably driven by the fact that facial expressions to food stimuli tend to reflect only negative and not positive emotions, and as a result cover only part of the full valence spectrum. in other words, facial expressions discriminate between negative food stimuli and not between positive ones. This study, as well as previous studies (82,83) demonstrate that this is not a problem related to the use of facial expressions themselves or the way they are measured expressions, but probably is an accurate reflection of consumer reactions to these type of stimuli. Facial expressions normally associated with positive emotions such as happiness are rarely used in response to foods. Instead, positive food emotions are associated with neutral expressions, resulting from the absence of negative expressions. In fact, happy expressions in this study correlate with negative valence. This seemingly contradictory finding, however, does replicate earlier findings by others (79,80,83). Moreover, FaceReader's identification of facial expressions may not always be perfect, as indicated in the method section, and certain expressions may be incorrectly interpreted as happy. Finally, the number of possible facial expressions or emotional responses to our stimuli may exceed the six expressions identified by FaceReader, which could result in incorrect identification of some facial expressions.

Combined heart rate, skin conductance and skin temperature responses of the autonomic nervous system showed strong associations to valence in the 3rd and especially in the 4th second. Individually, only skin conductance showed a significant negative correlation which supports the notion that the patterns across ANS indices are more relevant for valence/arousal/emotions than any of the single indices. This is in line with previous research that was summarized by Kreibig (93) and shows that emotions are associated with specific patterns across ANS responses rather than with individual responses. For example, an increased skin conductance response reflects arousal than can be caused by positive as well as negative emotions. It is only when skin conductance responses are combined with other responses that the valence of emotions becomes apparent.

In conclusion, explicit non-verbal reported emotions (PrEmo) to food odors can be summarized by the odors' arousal and valence. Results from implicit measures of autonomic nervous system responses and facial expressions are associated with arousal emotions which are relatively fast (1-2 secs), while ANS responses are also associated with slower (3-4 secs) valence emotions.

CHAPTER 5

ANS responses and facial expressions differentiate between the taste of commercial breakfast drinks

René A. de Wijk
Wei He
Manon G. J. Mensink
Rob H. G. Verhoeven
Cees de Graaf

Published in PLOS ONE, 2014, 9, e93823.

Abstract

The high failure rate of new market introductions, despite initial successful testing with traditional sensory and consumer tests, necessitates the development of other tests. This study explored the ability of selected physiological and behavioral measures of the autonomic nervous system (ANS) to distinguish between repeated exposures to foods from a single category (breakfast drinks) and with similar liking ratings. In this within-subject study 19 healthy young adults sipped from five breakfast drinks, each presented five times, while ANS responses (heart rate, skin conductance response and skin temperature), facial expressions, liking, and intensities were recorded. The results showed that liking was associated with increased heart rate and skin temperature, and more neutral facial expressions. Intensity was associated with reduced heart rate and skin temperature, more neutral expressions and more negative expressions of sadness, anger and surprise. Strongest associations with liking were found after 1 second of tasting, whereas strongest associations with intensity were found after 2 seconds of tasting. Future studies should verify the contribution of the additional information to the prediction of market success.

5.1 Introduction

The high failure rate of new market introductions, despite initial successful testing with traditional sensory and consumer tests, necessitates the development of other tests. The low predictive validity of traditional sensory and consumer tests, which include sensory analytical profiling and liking tests, may be due to the fact that these tests require cognitive information processing and rational reasoning whereas consumer behavior may be more based on unarticulated/unconscious motives and associations. Reasons for food choice include sensory affective reasons (dislike/like of the food), but also anticipated consequences of ingestion (satiation, illness) and ideational reasons (knowledge of the nature or origin of the food) (155). In addition, food pleasure and food choice also depends on the simultaneous internal context (food choice in a hungry state will be different from that in a satiated state), simultaneous external factors (food choice will be affected when informed that the food may be spoiled), and successive external context (pleasure of food decreases during consumption whereas pleasure of non-consumed food is unaffected, a phenomenon also known as sensory-specific satiety (10)).

The combined effect of these factors on food choice is mediated by emotional responses, such as disgust when one is informed that the consumed food was spoiled. Frijda (156) distinguishes the following elements of emotions: affect, or the hedonic pleasure of foods, appraisal of foods in terms of good/bad or pleasant/unpleasant, action readiness (whether or not the food is consumed), and autonomic arousal reflecting the degree of motor preparation for the action. Affect and appraisal are typically assessed explicitly via questionnaires (e.g. (58,59) or implicitly via facial expressions (e.g. (71,73,79,80,157)). Action readiness and autonomic arousal are typically assessed implicitly with physiological measures of the autonomic nervous system (ANS, see also (93)). More recently, the notion was introduced that various aspects of stimuli are appraised sequentially (49) whereby each type of appraisal is associated with specific physiological, expressive and motivational changes. For example, Aue and colleagues (88) presented participants with pictures that displayed biological and cultural threats or neutral stimuli, and demonstrated with EEG and facial muscle activity that relevance appraisal preceded goal conduciveness appraisal. Similarly, Delplanque and colleagues (50), using facial muscle activity and electrodermal activity and olfactory stimuli, demonstrated that novelty reactions precede pleasantness reactions. In one of the few food studies in which responses from the autonomic nervous system (ANS) were recorded, De Wijk et al (6) demonstrated that ANS responses differentiated between the sight of foods that were liked and disliked. Moreover, ANS responses to the sight of a food varied with the instruction to either view, smell or taste the food. ANS responses to the taste of the foods were not measured in that study.

ANS responses and facial expressions to the taste of foods were recorded in the present study. Unlike the previous study, foods with a single product category (breakfast drinks) with similar valence were used in this study. Moreover, responses were monitored continuously during tasting to allow testing of sequential appraisals. The study tested whether:

- ANS responses and facial expressions discriminated between foods with similar valence.
- Liking and intensity are associated with different response patterns and with different response times.

5.2 Methods

5.2.1 Participants

Nineteen adults (10 females; mean age 30.1 ± 11.7 years and 9 males, mean age 36.2 ± 12.7 years) were tested. The study was approved by the Medical Ethical Committee of the Wageningen University. Participants were recruited from the subject pool of the Consumer Science and Intelligent Systems department of the Wageningen University. All participants signed an informed consent form and received an incentive for their participation.

5.2.2 Breakfast drinks

Five commercially available breakfast drinks were used for the study. The breakfast drinks included three drink yoghurts (Royal Friesland Campina), Goede Morgen fruit Aardbei-kiwi-banaan (GM-Str), Goede Morgen original Perzik-abrikoos (GM-Pea) and Goede Morgen fruit Sinaasappel-mango-banaan (GM-Sin), and two fruit drinks (Hero): Fruit Ontbijt original Bosvruchten (FO-BV) and Fruit Ontbijt original Sinaasappel-banaan (FO-Sin). A sixth commercial breakfast drink was used once as a warm-up sample at the beginning of a session. The drinks were presented to the participants in 250 ml glasses. Drinking straws were used by participants to sample from each drink because normal drinking would cause severe visual artefacts in the facial expressions and motor artefacts for the ANS responses. Participants took a single sip from each drink. Based on an estimated sip size of 10 ml, participants consumed on average a total of 250 ml during a session.

5.2.3 Design

In the experimental session the five breakfast drinks were presented in five blocks of five food presentations. Each drink was presented once per block in a randomized order. The presentations were separated by an interval of 60 seconds. Within-subjects designs with five outcome measures (skin conductance response (SCR), heart rate frequency (HR), skin temperature (ST), facial expressions, and ratings) were used. A sixth presentation was included in the study where participants rated their emotional responses to each of the drinks. These results will be reported separately.

5.2.4 Physiological ANS measures

Physiological measures included:

- Skin conductance response or SCR measured in µSiemens with electrodes placed on the palm of the non-dominant hand of the participant;
- Heart rate or HR measured in beats per minute with electrodes placed on the chest;
- Skin temperature or ST measured in Celsius degrees with an electrode placed on the palm of the non-dominant hand of the participant.

The physiological data were collected via a Mindware Acquisition data acquisition system (Mindware Technologies, Inc.) with separate filter settings for the electrocardiogram, skin temperature and electrodermal (skin conductance response) activity. Filter settings were low-pass 0.5 Hz, high-pass 45 Hz for heart rate frequency, low-pass 1 Hz, high-pass 45 Hz for SCR and low-pass 10 Hz, high-pass 45 Hz for skin temperature. Electrodes were used with a surface of 4.1 cm^2 and filled with 1% Chloride wet gel. Signals were transferred to the Acquisition Unit (16 bit A/D conversion) and stored on computer hard disk (sampling rate 500 Hz). Electrocardiographic R waves were detected offline, and intervals between heartbeats were converted to heart rate, expressed in beats per minute (BPM). SCR activity was recorded (high-pass filter: 0.025 Hz) by the constant voltage method (0.5 V). The signal was amplified by 1,000 and low-pass filtered (30 Hz). SCRs were analyzed off-line after correction for baseline.

5.2.5 Behavioral measures

Facial expressions were automatically analyzed using FaceReader software version 4.0 (Noldus Information Technology, Wageningen, The Netherlands). FaceReader works in three steps: (1) face finding, (2) face modelling, and (3) face classification. During face finding an accurate position of the face is found using the Active Template Method. During modelling, the Active Appearance Model is used to synthesize an artificial face model, which describes the location of 491 key points as well as the texture of the face. The actual classification of the facial expressions is done by training an artificial neural network as training material nearly 2000 manually annotated images were used. The network was trained to classify the six basic or universal emotions described by Ekman (66): happy, sad, angry, surprised, scared, and disgusted and a neutral state. FaceReader analyzed the facial expressions on a frame by frame basis, i.e. at 25 Hz.

5.2.6 Liking and intensity scores

Liking and overall intensity was rated on visual analog scales of 10 cm length. The liking scale was anchored 'absolutely unpleasant' on the left side and 'absolutely pleasant' on the right side. The intensity scale was anchored 'very low intensity' on the left side and 'very high intensity' on the right side.

5.2.7 Procedure

5.2.7.1 Instruction and set-up

The experimental sessions took place in the physiological laboratory of the Restaurant of the Future located in Wageningen, the Netherlands. The experiment leader explained the experiment to the participant, allowed ample time for questions and asked the participant to sign the inform consent form (which they had received by e-mail prior to the experimental session) after which the electrodes were placed. A camera placed about one meter in front of the participant to measure the facial expressions was adjusted in height to get a clear view of the face of the participant. The camera was placed just above a computer monitor that was used to instruct the participant. A second camera was placed on the right side of the participant to identify the exact moment of tasting.

The seat of the participant was also adjusted if necessary. The breakfast drinks were prepared in transparent 250-ml drinking glasses with a drinking straw normally placed outside the viewing area of the participant. The participants were instructed to look straight in the direction of the camera. Oral instructions were given by the experiment leader. The instructions were manually timed by a researcher to allow the participants enough time to taste the presented food product. After the instruction, participants received a practice trial with a breakfast drink that was not used in the rest of the study. Next, the experimental measurements started where participants received a number of trials. Per trial, one breakfast drink was presented.

5.2.7.2 Trial

A session consists of a series of trials. During each trial, participants sipped from one of the breakfast drinks. The trial procedure was developed to minimize unwanted motor artefact that may affect the physiological measurements and to provide optimal conditions for the FaceReader automated expression analysis. Each trial started with an auditory attention signal to indicate that the participant had to look in the direction of the camera and the computer monitor, and that the trial was about to start. For 10 seconds a photograph of the breakfast drink in a glass cup was shown on the monitor to mimic the normal situation where one sees the drink before tasting. Simultaneously, a glass with the same breakfast drink plus straw was put near the participants head. After 10 seconds the photo was replaced by the instruction to take the straw in the mouth but not drink, which was replaced after 6 seconds by the instruction to take a sip and to leave the straw in the mouth. After 10 seconds the participant was instructed to remove the straw and to enter the liking and intensity of the breakfast drink using 10 point rating scales (see also Figure 5.1). Before the next trial the researcher removed the cup. The physiological and behavioral measures were continuously recorded.

5.2.8 Data analysis

The processed images with the facial expressions were combined with the images from the other camera, and with raw physiological data combined in Observer XT 10.5 software (Noldus Information Technology, Wageningen, The Netherlands) for further analyses. Markers were placed manually to identify the moments of the participant's first visual contact with the drink and of the first sip. Only the results for the first sip will be reported here.

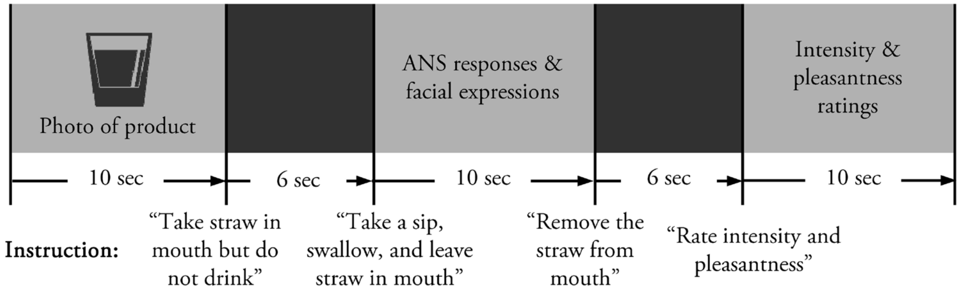


Figure 5.1 Scheme of experiment procedures.

5.2.8.1 Physiological measures

The physiological measures skin conductance response (SCR), heart rate (HR) and skin temperature (ST) were analyzed per experimental session. SCRs were measured in µSiemens, analyzed offline, and corrected for baseline. ST was expressed as change in temperature over the 10 seconds relative to the temperature at $t = 0$.

5.2.8.2 Facial expressions

The video images of the facial expressions were processed with FaceReader 4.0 software (Noldus Information Technology, Wageningen, The Netherlands) which determined the facial micro-expressions based on Active Appearance Modelling (158) in each time frame (at a frequency of 25 Hz) during 10 seconds after tasting. A more detailed description of the science behind FaceReader can be found at: http://info.noldus.com/free-white-paper-on-facereader-methodology/.

5.2.8.3 Statistical analysis

Inspection of the ANS results and facial expressions indicated largest effects during the first five seconds of tasting. Mixed model ANOVAs were carried out with participants as random factor and time (1-5 seconds), gender, breakfast drink and replicate as fixed factors (IBM SPSS statistics, version 19). Partial Least Square analysis (Unscrambler, CAMO ASA, Oslo, Norway) was used to evaluate associations between facial expressions and ANS measures during 0.25 second intervals after stimulation with valence and intensity of the drinks (reflected by liking and intensity ratings). Correlation coefficients between observed and predicted liking or intensity values were used as indicator for the strength of associations, and regression coefficients were used to identify the facial expression that contribute most to these associations.

5.3 Results

5.3.1 Physiological measurements

5.3.1.1 Skin temperature

Changes in skin temperature vary significantly with gender, drink, and replicate. Replicate affected changes in skin temperature drink with replicate were drink-specific (drink × rep interaction) (see Table 5.1, and Figure 5.2A). All main effects and interactions varied with gender.

5.3.1.2 Heart rate

Heart rates increase during the first seconds of tasting followed by a gradual decrease. Heart rate frequency varies significantly with drink (see Table 5.1, and Figure 5.2B). Gender affected heart rate both as main effect and in interaction with drink, replicate and time.

5.3.1.3 Skin conductance responses

Instead of the expected rise and subsequent decline of SCR during tasting, only decline is observed in this study. Skin conductance responses are not affected significantly by drink or replicate (see Table 5.1 and Figure 5.2C).

5.3.1.4 Facial expressions

The temporal development of facial expressions during tasting is summarized in Figure 5.3 based on the averaged values across drinks and replicates. Some expressions such as happiness, neutral, and surprise show an initial increase after tasting that reaches a maximum at intervals between 0.5 second (surprise) and 4 seconds (happiness). In contrast, expressions of disgust continue to increase over at least 7 seconds. Other expressions such as sadness, scared, and angry show an initial decrease that reaches a minimum between 1.5 (sadness) and 3 seconds (scared). The initial increase or decrease is either followed by a return to baseline (sadness, scared, surprised), a decrease (happiness, neutral) or an increase (angry).

All facial expressions varied with drink, either as main effect (neutral, happy, angry, surprised and scared) and/or in interaction with time (angry, surprised, scared, sad and disgust). Neutral, happy and sad expressions varied with replicate either as main effect (happy) or in interaction with the participant's gender (neutral and sad). All expressions, except surprise, varied significant with gender (see Table 5.1).

Table 5.1 Output of mixed model ANOVAs carried out on physiological ANS measures and facial expressions with participants as random factor, and gender (M/F), replicate (1-5), drink (1-5), and time (1-5 seconds) as fixed factors.

	Physiological measures							Facial ex pressions															
		Heart rate		Skin conductance		Skin temperature			Neutral		Happy		Angry		Sad		Surprised		Scared		Disgusted	
	d.f.	F	p	F	p	F	p	d.f.	F	p	F	p	F	P	F	p	F	p	F	p	F	p
Gender	1,1591	96.9	0.001	168.1	0.001	83.1	0.001	1,1882	130.2	0.001	61.3	0.001	110.2	0.001	184.5	0.001	0.03	ns	56.8	0.001	19.4	0.001
Rep	1,1591	2	ns	0	ns	21.8	0.001	1,1882	2	ns	2.9	0.02	7.7	0.001	1.6	ns	10.8	0.001	5.1	0.001	1.4	ns
Drink	4,1591	63.3	0.001	0	ns	4.1	0.003	4,1882	0.2	ns	3.1	0.01	0.7	ns	0.8	ns	0.7	ns	1.5	ns	1.2	ns
Time	4,1591	12.5	0.001	1.1	ns	0.2	ns	4,1882	3.3	0.01	1.7	ns	1.4	ns	0.8	ns	0.9	ns	5.8	0.001	2.2	ns
Gender*Rep	4,1591	3.7	0.005	0.1	ns	5.2	0.001	4,1882	4.1	0.003	5.4	0.001	7.8	0.001	1.3	ns	1.9	ns	1.8	ns	1.5	ns
Gender*Drink	4,1591	2.9	0.02	0.1	ns	5.5	0.001	4,1882	1.6	ns	4.9	0.001	0.1	ns	3.2	0.01	0.4	ns	0.3	ns	0.7	ns
Gender*Time	4,1591	0.4	ns	0.4	ns	1.4	ns	4,1882	5.1	0.001	2.3	ns	1.7	ns	4.1	0.002	3	0.02	4.6	0.001	1.4	ns
Rep*Drink	16,1591	0.3	ns	0	ns	8.9	0.001	16,1882	0.2	ns	0.5	ns	0.1	ns	0.3	ns	0.3	ns	0.4	ns	0.5	ns
Rep*Time	16,1591	1.5	ns	0.1	ns	0.6	ns	16,1882	1.2	ns	1.4	ns	1.6	0.05	2.4	0.001	2	0.01	3.1	0.001	2.3	0.003
Drink*Time	16,1591	0.2	ns	0	ns	0.3	ns	16,1882	0.2	ns	0.3	ns	0.3	ns	0.2	ns	0.9	ns	0.2	ns	0.3	ns
Gender*Rep*Drink	16,1591	0.1	ns	0	ns	4.4	0.001	16,1882	0.3	ns	0.1	ns	0.2	ns	0.38	ns	0.6	ns	0.2	ns	0.2	ns
Gender*Rep*Time	16,1591	0.6	ns	0.2	ns	0.2	ns	16,1882	2.9	0.001	1	ns	1.9	0.02	2.2	0.004	3.3	0.001	2.7	0.001	4.3	0.001
Gender*Drink*Time	16,1591	0.3	ns	0	ns	0.2	ns	16,1882	0.1	ns	0.3	ns	0.2	ns	0.1	ns	0.6	ns	0.2	ns	0.2	ns
Rep*Drink*Time	64,1591	0.2	ns	0	ns	0.2	ns	64,1882	0.2	ns	0.2	ns	0.1	ns	0.2	ns	0.5	ns	0.3	ns	0.2	ns

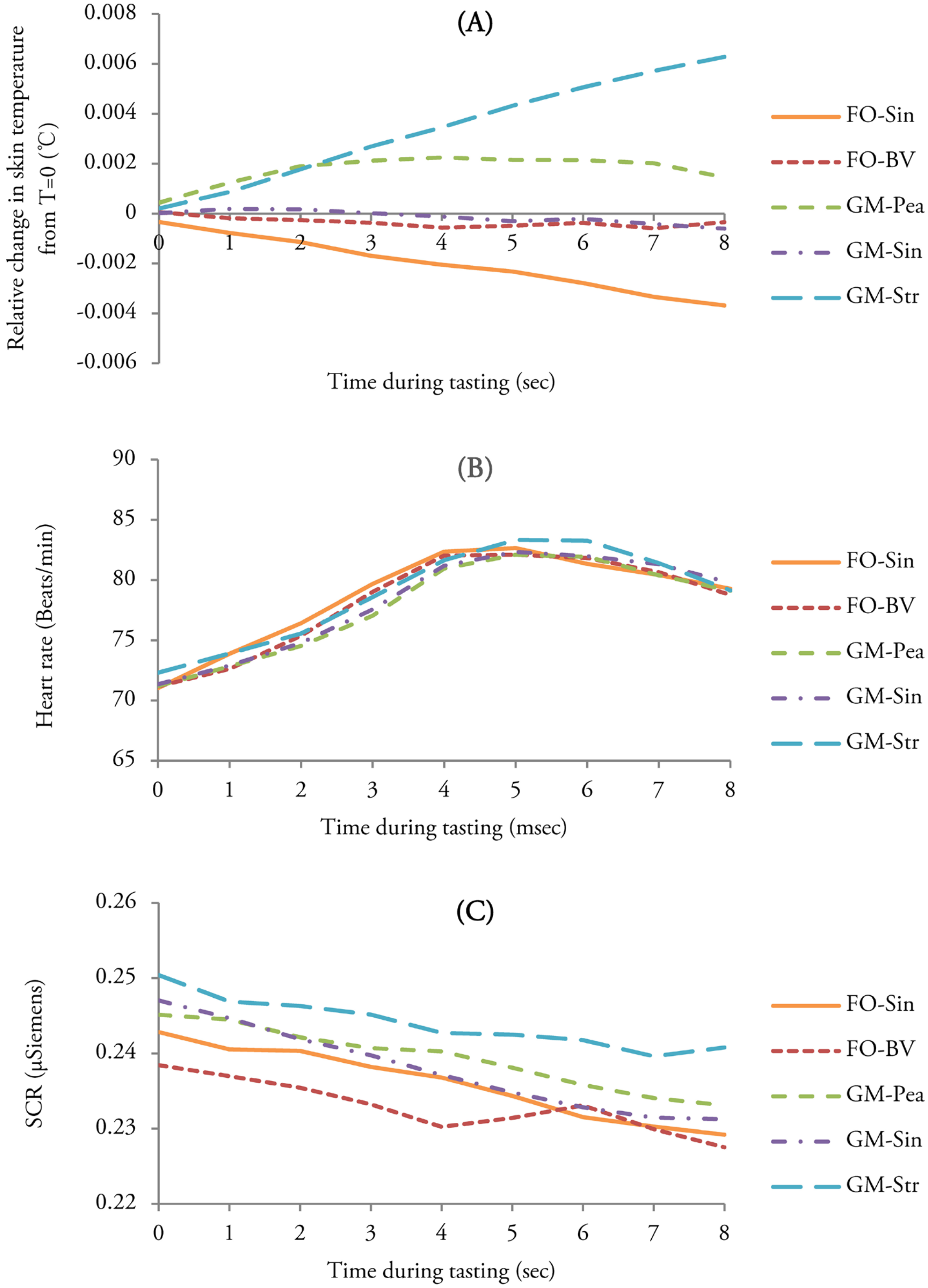


Figure 5.2 Changes in ANS measures during tasting of five breakfast drinks. Results of (A) Skin temperature, (B) Heart rate, and (C) Skin conductance responses are averaged across participants and replicates.

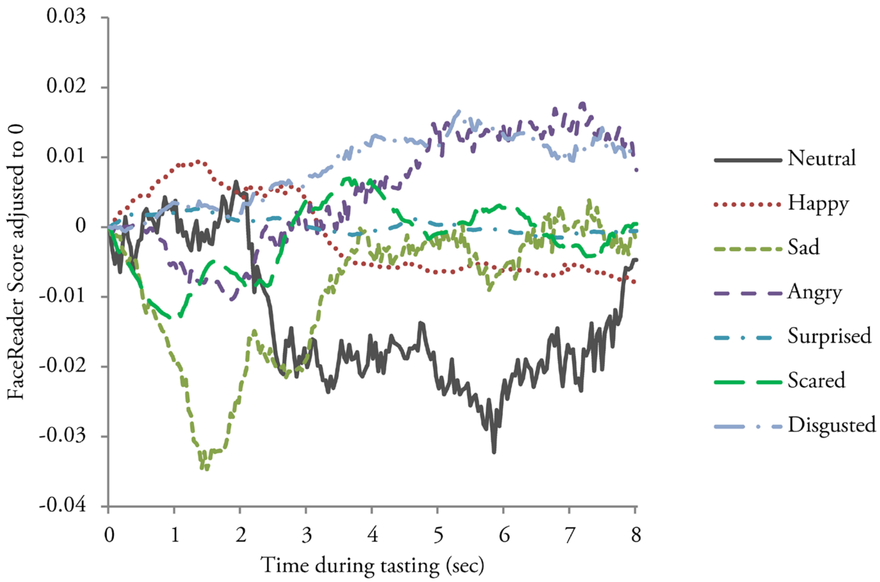


Figure 5.3 Facial expressions averaged across participants, breakfast drinks and replicates, during 10 seconds of tasting.

5.3.2 Liking and intensity

Liking scores did not vary with breakfast drinks, replicate or their interaction (see Table 5.2). Intensities did vary with breakfast drink ($F(5, 31) = 2.6$, $p = 0.04$), replicate ($F(1, 31) = 5.8$, $p = 0.02$) and their interaction ($F(5, 31) = 3.5$, $p < 0.01$ (see Table 5.3).

5.3.3 Liking and intensity scores versus other measures

Despite the fact that liking scores did not vary systematically between drinks and/or replicates, they still showed some variation (between 4.7 and 6.5 on a 10 point ratings scale). Partial least square analysis was used to verify systematic relations between liking scores and physiological measurements and facial expressions at various intervals during tasting. The degree of correspondence between the observed liking scores and the ones predicted from the PLS models, expressed by correlation coefficients, gradually decreased from 0.51 (after 1 second of tasting) to 0.39 and 0.47 (respectively after 3 and 4 seconds of tasting) (critical correlation coefficient ($p = 0.05$) is 0.40 ($n = 25$). The contribution of facial expressions and ANS measures to liking was reflected by the PLS regression coefficients shown in Figure 5.4A. Liking scores were positively associated with increased heart rate, skin temperature, to a lesser degree with increased skin conductance, and with neutral facial expressions. Liking scores were negative associated with all other facial expressions, including those of happiness.

Table 5.2 Liking scores (SD) per breakfast drink and replicate averaged across participants.

Replication	FO-Sin	FO-BV	GM-Pea	GM-Sin	GM-Str
1	5.8 (1.8)	5.0 (1.9)	5.9 (1.4)	5.9 (1.4)	6.1 (1.6)
2	5.4 (1.8)	5.3 (2.0)	5.6 (1.5)	5.5 (1.4)	6.5 (1.2)
3	5.3 (1.7)	5.3 (1.9)	5.6 (1.3)	5.5 (1.5)	5.9 (1.5)
4	5.3 (1.7)	5.0 (1.6)	5.1 (1.7)	5.4 (1.4)	6.2 (1.8)
5	5.7 (2.0)	4.7 (1.8)	5.0 (2.2)	5.5 (1.8)	6.2 (1.4)

Table 5.3 Intensity scores (SD) per breakfast drink and replicate averaged across participants.

Replication	FO-Sin	FO-BV	GM-Pea	GM-Sin	GM-Str
1	6.0 (1.0)	5.4 (1.4)	6.0 (0.9)	6.1 (1.1)	5.7 (1.6)
2	6.4 (1.5)	5.7 (1.2)	5.4 (1.3)	6.2 (1.0)	6.3 (1.0
3	6.4 (1.2)	6.2 (1.2)	5.6 (1.0)	6.2 (1.3)	5.9 (1.4)
4	6.4 (1.2)	6.4 (1.2)	5.6 (1.1)	6.0 (1.0)	6.2 (1.1)
5	6.8 (0.9)	6.4 (1.4)	6.0 (1.5)	6.0 (1.3)	5.7 (1.2)

Liking scores were best predicted from facial expressions during the first replicate, i.e., the observed and predicted liking scores were most similar for the first replicate. During subsequent replicates the average deviation between observed and predicted liking scores grew from 2% (replicate 1) to 9% (replicate 5).

The degree of correspondence between the observed intensity scores and the ones predicted from the PLS models grows from 0.47 for the first second to 0.62 for the second second after which it gradually decreases to 0.55 for the fourth second (critical correlation coefficient (p = 0.05) is 0.40 (n = 25). Intensity scores were negatively associated with skin temperature and to a lesser degree with heart rate, and with expressions of happiness, disgust, and scared. Intensity scores were positively associated with skin conductance, and with expressions of neutral, surprise, sad and anger (see Figure 5.4B)

Similar to liking scores, intensity scores were best predicted from facial expressions during the first replicate. During subsequent replicates the average deviation between observed and predicted intensity scores grew from 2% (replicate 1) to 5% (replicate 5).

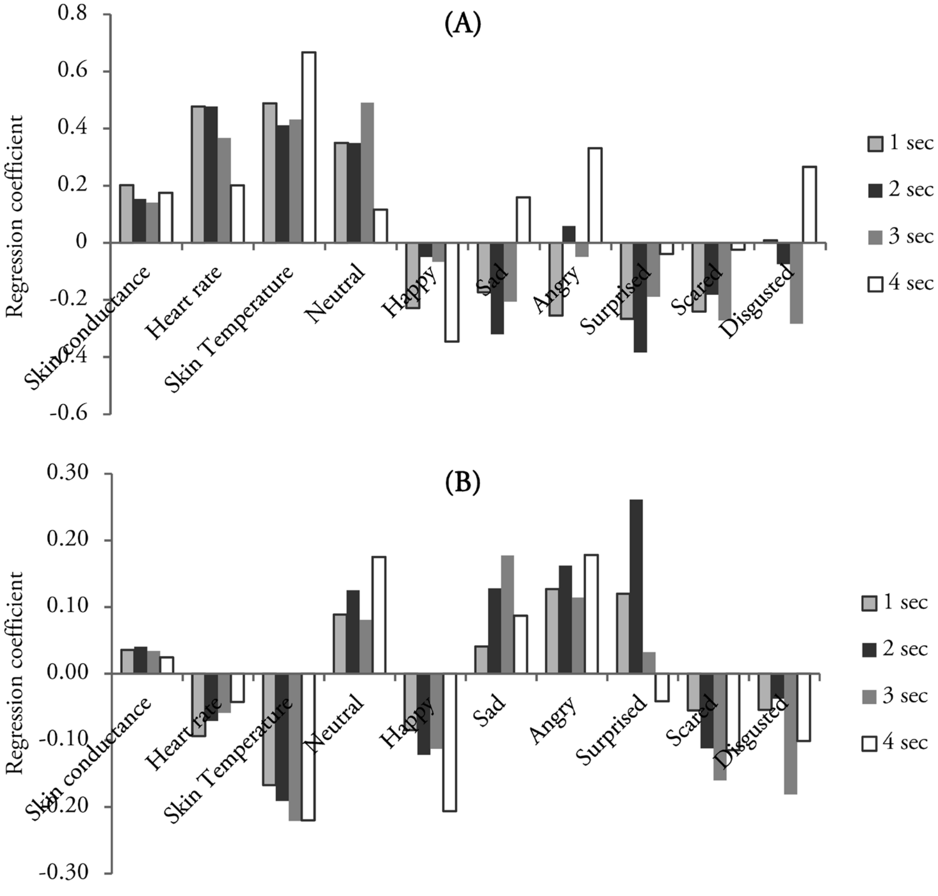


Figure 5.4 Regression coefficients from the partial least squares analysis. ANS measures and facial expressions during 1-4 seconds of tasting are dependent variables. (A) Liking or (B) intensity is independent variables.

5.4 Discussion

The study used facial expressions and ANS responses to verify systematic differences between similar and well-liked breakfast drinks, and to explore associations with liking and intensity. Whereas liking scores, the traditional sensory tool to measure product 'performance', failed to show systematic differences between drinks and/or replicates, physiological ANS measures and facial expressions were sensitive enough to demonstrate differences between drinks and between replicates. The relevance of the differences between liking results and ANS/facial expression results is unclear. Liking scores are probably not the gold standard for the prediction of success of new market introductions because most new food introductions disappear from the market despite high liking scores in prior sensory and marketing tests. Whether ANS/facial expression results offer better predictions remains to be tested, for example with exact sales data per drink. Unfortunately, sales data are typically not available to researchers.

ANS responses and facial expressions proved to be highly dynamical over time with specific time courses for each measure. Heart rate initially increased followed by a decrease, skin temperature either increased or decreased dependent on the breakfast drink, whereas skin conductance typically decreased. Facial expressions proved to be even more dynamical both in terms of their time course and in their magnitude. Early facial expressions are for example dominated by neutral and surprise whereas later expressions are dominated by disgust. The dynamical nature of the responses may be related to their association with liking and intensity; relatively early responses (after approximately 1 second of tasting) show strongest associations with liking scores obtained afterwards whereas somewhat later responses (after approximately 2 seconds) showed strongest associations with intensity scores. These results suggest that different aspects of the stimuli are processed - or appraised - at different times. These results are in line with results from other studies showing for example that relevance appraisal precedes goal conduciveness appraisal (88) and novelty appraisal precedes pleasantness appraisal (50) providing support for current models of emotions by Scherer and colleagues (49).

Liking was positively associated with neutral expressions and negatively associated with facial expressions of sadness, anger, surprise, and scared. This supports previous findings of Zeinstra et al. (79) who demonstrated that facial expressions reflected disliking but not liking of stimuli. Unexpectedly, liking and ANS parameters are also negatively associated with expressions of happiness, i.e., reduced liking is associated with more facial expressions of happiness. Facial expressions of happiness are rarely displayed when one is alone and social interactions are absent suggesting that these expressions serve a social function (67,135). The fact that they did occur in this study in the presence of experimental staff suggests that the happy facial expressions may serve some kind of social signaling function, e.g., to signal the staff that one is OK despite the previous display of for example negative expressions.

Liking was positively associated with heart rate and skin temperature which is in line with previous research that demonstrated a positive association between these ANS parameters and positive emotions of joy (93). The positive association between heart rate and liking found for consumed foods in the present study contradicts previous findings for odors where odor pleasantness is typically inversely related to heart rate (82). Kreibig's review (93) already demonstrates that interpretation of patterns in ANS results is typically not straight-forward but dependent on factors such as task demands and stimulus modality. For example, our findings show that consumption of as little as one sip already increases heart rate by 10-14 beats/min, irrespective of the drink, whereas sniffing an odor led to much smaller increases for unpleasant odors (3-4 beats/min) and unchanged heart rates for pleasant odors (82). These different patterns make a direct comparison of results across modalities difficult.

Very different associations were found for intensity scores. Higher intensities were associated with lower heart rate and skin temperature, patterns that had been associated by others to negative emotions of fear, disgust, sadness, anger and anxiety (93). In the present study, higher intensities also resulted in more facial expressions signaling negative emotions such as sadness and anger, but also with more neutral and surprised expressions and fewer expressions of happiness, scared and disgust. Hence, facial expressions and ANS results are partly inconsistent in the case of intensities for unknown reasons.

Skin conductance and temperature responses suggest that participants not only respond to the actual taste of the breakfast drink but also to the preceding image of the product; the typical ascending phase followed by the descending phase of skin conductance responses is absent in our taste responses suggesting that participants already anticipated the taste during the preceding image of the drink. Similarly, skin temperatures already differ between breakfast drinks at the start of tasting suggesting pre-tasting effects of the preceding images. These pre-tasting effects should be weakest during the first replicate when image-taste associations are relatively new, and should grow stronger with each additional replicate. Indeed, our results demonstrate that facial expressions and ANS responses during tasting best predict liking and intensity for the first replicate and that predictions become poorer with additional replicates. We hypothesize that with stronger image-taste associations participants probably respond more and more to the image of the breakfast drink and less and less to the taste itself; i.e., they have learnt the expected taste from the images. According to this hypothesis, the association between facial expressions/ANS responses and intensity/liking should shift with increasing replicates from responses during tasting to responses during viewing, but this was not tested in this study. Pre-tasting anticipatory responses to visual food stimuli have been investigated previously before where it was demonstrated that facial expressions and ANS responses to visual foods reflected the anticipation of participants to either view, smell, or taste the foods (6).

Contributions to the prediction of market success may not be the only reason for selection of physiological measures and/or facial expressions. These measures offer advantages over other more traditional measures because they are relatively fast (typically a matter of seconds rather than minutes as required for questionnaires) which facilitates linkage to specific phases of product-consumer interactions. In addition, these measures may reflect processes that consumers are not even aware of, and that are therefore difficult to capture with questionnaires, but which may contribute to consumer decisions. On the other hand, facial responses and physiological measurements are technically more challenging than questionnaires and applications are therefore more suitable for laboratory than for real-life.

In conclusion: ANS measures and facial expressions differentiate between repeated exposures to members of a homogeneous group of well-liked breakfast drinks. Relatively fast responses show mostly differentiation based on liking, whereas somewhat later responses show mostly differentiation based on intensity. ANS responses and facial expressions may contribute to the development of new food products that are not only initially liked, but that are also liked over the long term.

CHAPTER 6

New insights into sensory-specific satiety from autonomic nervous system responses and facial expressions

Wei He
Sanne Boesveldt
Sylvain Delplanque
Cees de Graaf
René A. de Wijk

Submitted for publication in revised form

Abstract

As a food is consumed, its perceived pleasantness declines compared to that of other foods. Although this phenomenon, referred to as sensory-specific satiety, is well-established by means of measuring food intake and pleasantness ratings, this study was aimed at gaining more insight into the mechanisms that underlie such cognitive output behavior using two measures used in (food) emotion research, namely Autonomic Nervous System (ANS) responses and facial expressions. Twenty-four healthy female participants visited four times in a hungry state, in which they received 4 different semi-liquid meals (2 sweet and 2 savory) delivered via a time-controlled pump leading to sensory-specific satiety. Before and after the meals they were presented with a sip of all four different test meals where ANS responses (heart rate, skin conductance and skin temperature) and facial expressions were recorded. As expected, pleasantness ratings showed a significant decrease after eating the same meal or a meal similar in taste (sweet or savory) ($p < 0.001$), and less decrease after eating a meals with a different taste. In general, consumption of the test meals resulted in increased heart rate, reduced skin conductance and skin temperature, as well as intensified anger and disgusted facial expressions ($p < 0.05$). In addition, skin conductance, skin temperature, sad and angry expressions also showed effects reflecting sensory-specific satiety. In conclusion, ANS responses and facial expressions indicate that sensory specific satiety of foods (1) not only reduces the food's pleasantness but also arousal and (2) are possibly mediated by changes in food emotions.

6.1 Introduction

In the modern world, where food is plentiful, cheap and energy-dense, we eat not only to fulfil nutritional needs, but also for pleasure. Sensory cues, such as taste, smell and sight of food, contribute a great deal to such pleasure derived from eating. Sensory characteristics and their subsequent physiological and neurobiological effects are thus important determinants in regulating when, what and how much we eat (159,160). However, unlike nutritional composition, pleasantness or hedonic value is not a fixed property of a food, but a momentary evaluation which can change with experience (161). The pleasantness of a food (or similar foods) decreases during and shortly after consumption, whereas the pleasantness of other dissimilar foods not consumed remains unchanged or decreases much less. This phenomenon was first reported by Rolls and her colleagues (10) in humans. They found that the rapid decline in pleasantness accompanying ingestion depended more on the sensory properties of foods than on the nutrient composition or post-ingestive effects. As a result, they coined the term 'sensory-specific satiety'. Sensory-specific satiety may thus contribute to the termination of eating due to decreased pleasantness of a single food (162), but may also enhance intake through a composite meal (11,163). So far, taste (164), olfactory (16), texture (165) and appearance-specific satiety (166) have been demonstrated.

The decrease in pleasantness is not the only consequence of consumption. Consumption also leads to sensations of fullness which have physical and psychological components (167-169). Fullness has been described by physical components such as the feeling of something in the stomach and stretch in the stomach, and by psychological components such as satisfaction, comfort, and ability to focus on tasks (170). Self-reported satiety measures have included scales related to hunger and fullness feelings, desires to eat, prospective consumption, and satisfaction. In contrast, sensory-specific satiety has mainly been investigated using pleasantness ratings, subsequent food intake and few neuroimaging studies (171,172). All in all, satiety and sensory-specific satiety may comprise of a multitude of feelings that cannot be fully captured with such (limited) self-report measures that are frequently used.

Alternative measures that are not based on self-report but on facial expressions or on responses of the autonomic nervous system (ANS) have not yet been used in studies of satiety and sensory-specific satiety, but may prove to be relevant. Facial expressions and ANS responses have been extensively used in emotion studies. As alluded to above, emotional responses play an important role in eating behavior in everyday life (29), both consciously and unconsciously. One way to investigate such emotional responses is through measuring facial expressions (67). Steiner (71) already documented that newborns could clearly show their emotional responses to liked or disliked taste through facial expressions. Furthermore, autonomic nervous system responses can also distinguish among emotions, as reported by Ekman (42). Previous studies (6,81-83) demonstrated that foods or food cues that were liked or disliked by participants elicited differential responses of the Autonomic Nervous System (ANS) as well as different emotional responses measured by facial expressions. It was concluded that autonomic responses provide additional information on food preferences relative to more traditional hedonic tests. Facial expressions may reflect internal appraisals going on in the body during evaluating (anticipated) food, while the autonomic nervous system can be considered a goal-directed system, and can thus act as an intermediate between internal emotional feelings, and external output behavior (such as liking responses, or the decision to continue or stop eating). Therefore, both ANS responses and facial expressions may provide additional insights into the mechanisms underlying sensory-specific satiety.

The present study assessed the effects of sensory specific satiety with traditional hedonic measures, as well as with facial expressions and ANS responses. The following hypotheses were tested:

1. ANS responses and facial expressions change with consumption. No changes would indicate that these responses do not reflect sensory-specific satiety.
2. ANS responses and facial expressions change with consumption but the result patterns are different than found for the hedonic measures. In this case ANS responses and facial expressions reflect satiety but not sensory-specific satiety.
3. ANS responses and facial expressions change with consumption and show similar result patterns as found for hedonic measures. In this case, ANS measures and facial expressions reflect satiety and sensory-specific satiety.

6.2 Material and methods

6.2.1 Experimental design

The study design was a within-subject counterbalanced cross-over intervention experiment with four semi-liquid foods used to induce and assess sensory-specific satiety (see Figure 6.1). All participants visited four times. In each visit, participants first tasted single sips of four test foods (two sweet, two savory, see Table 6.1) before they consumed one of the four foods until pleasantly satiated by means of time-controlled consumption. Finally, they tasted single sips of the four test foods again. Before, during and after consumption, pleasantness, emotional and physiological measures were taken in response to tasting a sip of the four different test foods.

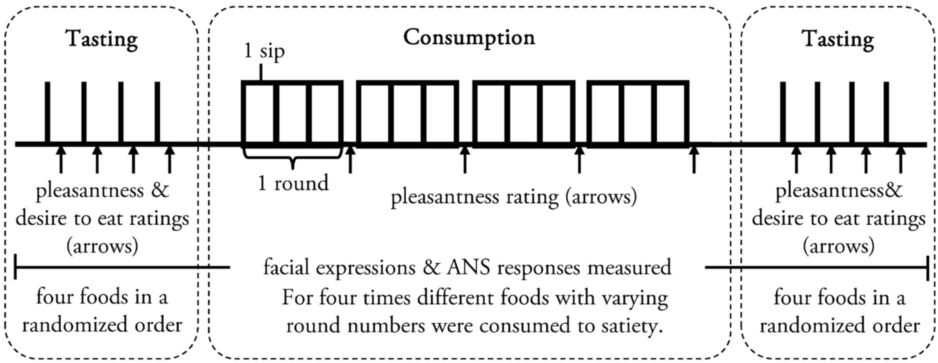


Figure 6.1 Schematic representation of the experimental procedure followed during one experimental session. In total, participants took part in 4 sessions; in each of them they received a different test food to eat until pleasantly satiated.

6.2.2 Participants

6

Twenty-four females were recruited from the participant pools of Food and Biobased Research and the Division of Human Nutrition, part of Wageningen University and Research Centre. Participants were self-reported healthy, had a normal weight (BMI 18.5-25 kg/m^2, mean ± SD 21.2 kg/m^2 ± 1.7), and were aged between 18 and 32 years (mean ± SD 23.0 years ± 3.4). Exclusion criteria were disliking any of the foods used in the study (pleasantness score < 5 on a 9-point hedonic scale), restrained eating (Dutch Eating Behavior Questionnaire (DEBQ) score > 2.79), gained or lost > 5 kg weight during the last year, having a lack of appetite, smoking, having gastrointestinal illness, having diabetes, having thyroid disease or any other endocrine disorder, having hypertension, suffering from kidney diseases and being pregnant or giving breast feeding. Participants were unaware of the aim of the research. Detailed information regarding the experiment was given and an informed consent form was signed by all participants prior to testing. The study was approved by the Medical Ethical Committee of the Wageningen University (NL48361.081.14).

6.2.3 Test foods

Four test foods, two sweet and two savory, had been developed previously in pilot studies with respect to similarity in texture, serving temperature and energy density (1 kcal/g), as well as pleasantness, familiarity and perceived thickness. Semi-liquid foods that can be ingested through a straw without chewing were chosen to minimize motor activity that may produce artefacts in ANS responses and facial expressions. The recipes of the test foods used in this study are shown in Table 6.1. All of the test foods were freshly made within 36 hours and taken out from refrigerator 1.5 hours before each session.

6.2.4 General procedure

Participants were scheduled to always visit at the same time on test days, and were instructed not to eat (only drink water) at least three hours before each session started. After participants were seated in a comfortable chair and placed with electrodes for physiological measurements, the experimenter explained the experimental procedures and instructed participants to orient towards a laptop monitor with instructions and a webcam at eye-level (1 m viewing distance). They were asked to face the camera while tasting and consuming the foods to ensure recognition by the FaceReader software.

On the right-hand side of the participant, four pairs of opaque cups (numbered 1 to 8) with a straw were placed, filled with the four test foods. Participants were instructed to take a sip from a cup and rate pleasantness and desire to eat, for all four test foods in a randomized order. All instructions were presented on the laptop including which cup to pick, when to sip and how to rate the questions.

Table 6.1 Recipe (g/100g) and sensory ratings (mean ± SD, based on pilot studies) of four test foods.

Category	Savory semi-liquid food				Sweet semi-liquid food			
Name	Gazpacho		Pea-spinach soup		Mango smoothie		Strawberry juice	
Recipe	Tomato juice	38.9	Fresh spinach	20.6	Canned mango	41.1	Frozen strawberry	39.5
	Peeled cucumber	26.0	Canned peas	20.6	Water	23.0	Strawberry juice	29.2
	Sieved tomato	11.3	Water	27.4	Fantomalt	16.1	Fantomalt	15.2
	Fantomalt	9.5	Peeled cucumber	16.5	Frozen mango	11.5	Canned strawberry	13.2
	Grilled pepper	8.7	Sour cream	9.2	Quark (full fat)	8.2	Honey	2.9
	Olive oil	5.2	Olive oil	4.1	Salt	0.1		
	Red wine vinegar	0.3	Fantomalt	2.3				
	Salt	0.1	Stock powder	0.4				
Pleasantness	5.9	1.0	6.1	1.2	7.1	1.0	7.7	1.2
Sweetness	4.6	1.5	3.2	1.6	7.0	1.0	7.5	1.6
Savoriness	6.5	1.5	6.5	1.3	2.3	1.6	2.1	1.3
Thickness	5.1	1.3	5.3	1.5	7.0	1.2	5.5	1.5

After rating all four test foods, participants were asked to rate their hunger and were instructed to put a small tube in their mouth to start consumption. When they pressed 'Start', a time-controlled pump (Watson-Marlow, type 323Du, Watson-Marlow Bredel) delivered sips of one of the four test foods to their mouth (3 g/s, 4 s duration, 12 g/sip, 15 s interval between two sips). After every three sips, participants rated their pleasantness for the test food and indicated whether they wanted to continue eating, until they felt comfortably satiated. Afterwards, they rated their hunger feelings again, and repeated tasting and rating all four test foods from the cups.

During the whole session, participants' physiological responses and facial expressions were continuously measured.

6.2.5 Measurements

6.2.5.1 Pleasantness and desire to eat ratings

A digital visual analog scale (VAS) of 100 mm was used to rate pleasantness (from 'very unpleasant' to 'very pleasant'), desire to eat (from 'not at all' to 'very much'), hunger (from 'not hungry' to 'very hungry'), fullness (from 'not full' to 'very full'), as well as prospective consumption for the four foods (from 'not at all' to 'very much').

6.2.5.2 Physiological responses

Physiological measures were transduced using a BIOLAB (Version 3.0, Mindware Technologies Ltd.) physiological system, designed for use in life science investigations, and includes heart rate (HR) expressed in beats per minute, using electrodes placed on the palm of the left hand of the participant; skin conductance level (SCL) expressed in μSiemens measured via surface electrodes covered with electrode gel and placed on in the palm of the left hand; skin temperature (ST) in degrees Celsius using a surface sensor placed on the subject's middle finger of the left hand. Electrodes were used with a surface of 4.1 cm^2 and filled with 1% Chloride wet gel. Signals were transferred to the Acquisition Unit (16-bit A/D conversion) and stored on computer hard disk (sampling rate 500 Hz). Electrocardiographic R waves were detected offline, and intervals between heartbeats were converted to HR, expressed in beats per minute (BPM). SCL activity was recorded by the constant voltage method (0.5 V).

6.2.5.3 Facial expressions

Facial expressions of participants were filmed with a Logitech C600 webcam, mounted on top of a computer monitor placed in front of the participant. Facial expression data were automatically analyzed using FaceReader software version 5.0 (Noldus Information Technology B.V.). FaceReader first find an accurate position of the face in the offline video records. Then an Active Appearance Model is used to synthesize an artificial face model, which describes the location of 491 key points as well as the texture of the face. Finally, the software provides the output of six basic expressions (happy, sad, angry, surprised, scared, disgusted) and one neutral state with 89% accuracy (85) on the basis of the Facial Action Coding System developed by Ekman and Friesen (77).

6.2.6 Data analysis

Only tasting data collected before and after consumption to satiety were analyzed for this paper, in order to assess effects of sensory-specific satiety. Based on the degree of similarity between tasted and consumed food, three conditions were defined: same taste (the tasted food was the same as the food eaten to satiety, e.g. taste gazpacho and consume gazpacho); similar taste (the tasted food was similar in taste (sweet or savory) to the food consumed to satiety, e.g. taste gazpacho and eat pea-spinach soup); and different taste (the tasted food was different in taste from the food consumed to satiety, e.g. taste gazpacho and eat mango smoothie).

The moments that test foods reached the lip of participants were marked manually as tasting moment (T0) in the video recordings. Video data was combined with a trigger in ObserverXT 11 software (Noldus Information Technology) each time when a test food was tasted. Synchronization of data signals was automatic in the case of the skin conductance level, heart rate and skin temperature and video signals. Off-line, the close-up images of the subject's face were then analyzed using FaceReader 5.0 software (Noldus Information Technology), and the resulting log file were imported in the Observer data file.

We conducted repeated measures ANOVAs (IBM SPSS Statistics 21.0, IBM Corporation, Armonk, USA) for a 2 (type of ratings) by 2 (pre-/post-consumption) by 3 (conditions) within-subject design to compare subjective ratings of pleasantness and desire to eat taken before and after consumption.

In order to investigate how heart rates change before and after consumption, we extracted heart rate data within a time window of 20 s (with the tasting moment in the middle) for both pre- and post-consumption. Before and after tasting, heart rate showed a biphasic response, including a decreasing phase of 5 s before tasting and an increasing phase of 5 s after tasting (see Figure 6.2). The decreased HR is during a anticipatory phase, since participants was instructed to take the cup and put the straw in their mouth just before sipping. Thus we took the data of an earlier time window (-10~-5 s) as baseline and subtracted it from corresponding data of the 5 s time window after tasting. We then subtracted pre-consumption data from post-consumption, and averaged these deltas over all participants. The averaged post minus pre consumption deltas were calculated for all outcome measures. We did similar calculations for skin conductance level, skin temperature and facial expressions data except taking 5 s time window before tasting (-5~0 s) as baseline.

Finally, Mixed Models analysis was applied (IBM SPSS Statistics 22.0, IBM Corporation, Armonk, USA) for ANS responses and facial expressions with a 2 (pre- and post-consumption) by 3 (same, similar and different taste conditions) within-subject design. A p-value of 0.05 was considered significant.

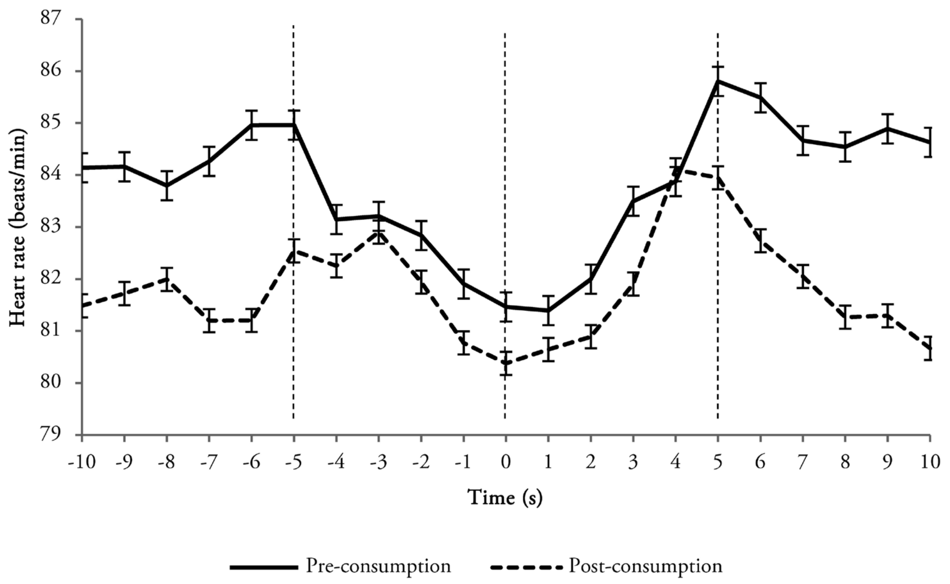


Figure 6.2 Averaged heart rate of pre- and post-consumption over 10 s before and after tasting moment. The broken lines indicate time point of 0 s, -5 s and 5 s, respectively. Error bars represent standard error of the mean.

6.3 Results

6.3.1 Pleasantness and desire to eat ratings

Pleasantness and desire to eat ratings decreased significantly after consumption to satiety ($F(1, 23) = 89.4$, $p < 0.001$). Moreover, there was a significant interaction between pre-/post-consumption and conditions ($F(2, 46) = 32.5$, $p < 0.001$). Post-hoc tests showed that both ratings declined more for the same taste condition than for the similar taste condition (all p < 0.001), and also declined more for the similar taste condition than for the different taste condition (all p < 0.001, see Figure 6.3). Third, desire to eat ratings in all conditions decreased more than the corresponding ratings in pleasantness ratings (F (2, 46) = 7.6, p < 0.01).

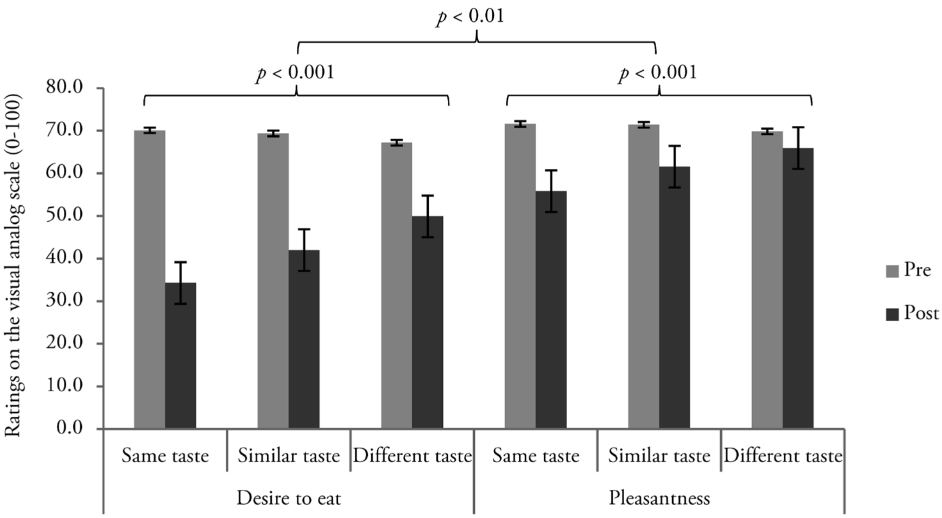


Figure 6.3 Pleasantness and desire to eat ratings of the same, similar and different taste conditions for both pre- and post-consumption. Error bars represent standard error of the mean.

6.3.2 Physiological responses

Results showed that over all conditions heart rate increased significantly after consumption (F (1, 134) = 29.6, p < 0.001). Furthermore, compared to pre-consumption no significant difference between conditions were found (see Figure 6.4A).

Both skin conductance level (F (1, 138) = 30.0, p < 0.001) and skin temperature (F (1, 138) = 29.8, p < 0.001) decreased significantly after consumption to satiety. Furthermore, both responses also showed an interaction between conditions and pre-/post-consumption (SCL: F (2, 69) = 2.9, p = 0.019; ST: F (2, 69) = 4.4, p = 0.012). Post-hoc tests showed that skin conductance level decreased more for the same taste condition than the other two conditions (p < 0.05, see Figure 6.4B). Skin temperature decreased most for the same taste condition and least for the different taste condition (p < 0.001, see Figure 6.4C).

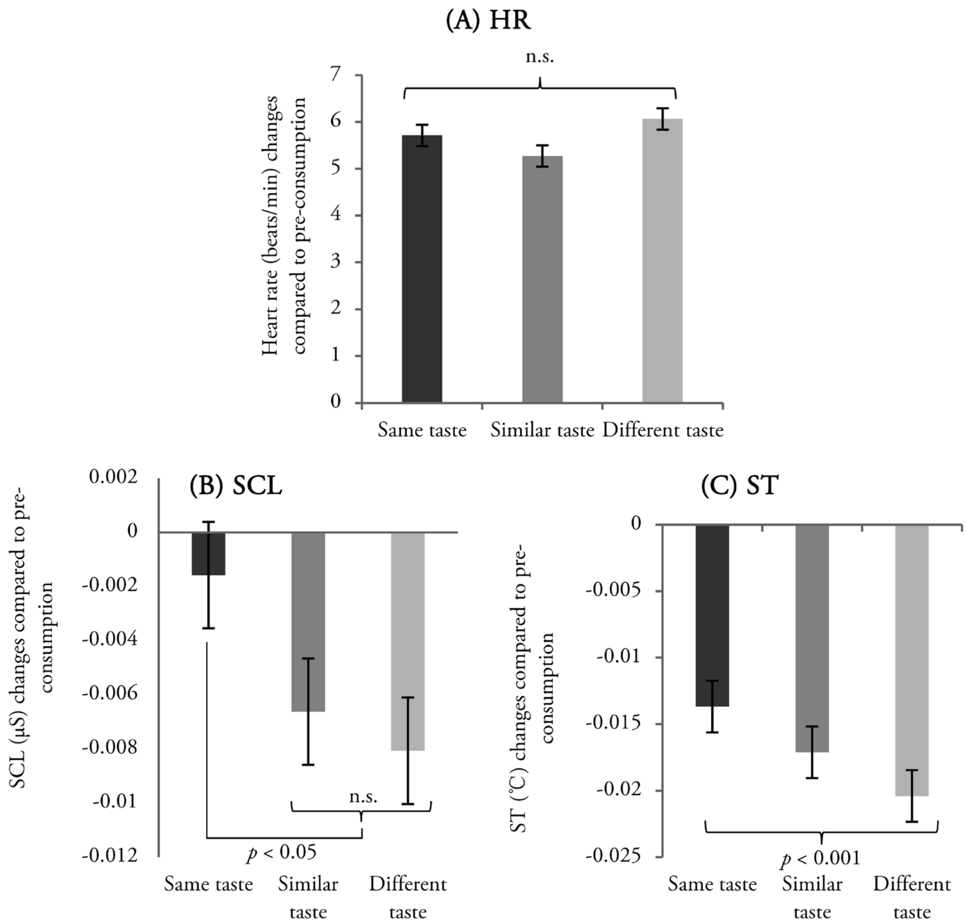


Figure 6.4 Changes in (A) heart rate (B) skin conductance level (C) skin temperature for the same, similar and different taste conditions compared to pre-consumption after subtracting from baseline. Error bars represent standard error of the mean.

6.3.3 Facial expressions

Facial expressions before and after consumption varied in their effects. All expressions varied with the type of test food. Expressions of anger and disgust intensified after consumption ($F(1, 138) = 18.1$, $p < 0.001$; $F(1, 138) = 8.4$, $p < 0.01$, respectively). In addition, angry ($F(2, 69) = 7.5$, $p < 0.01$) as well as sad ($F(2, 69) = 14.6$, $p < 0.001$) expressions showed effects of condition (in interaction with pre-post consumption). The condition effects on expressions of anger and sadness are shown in Figure 6.5.

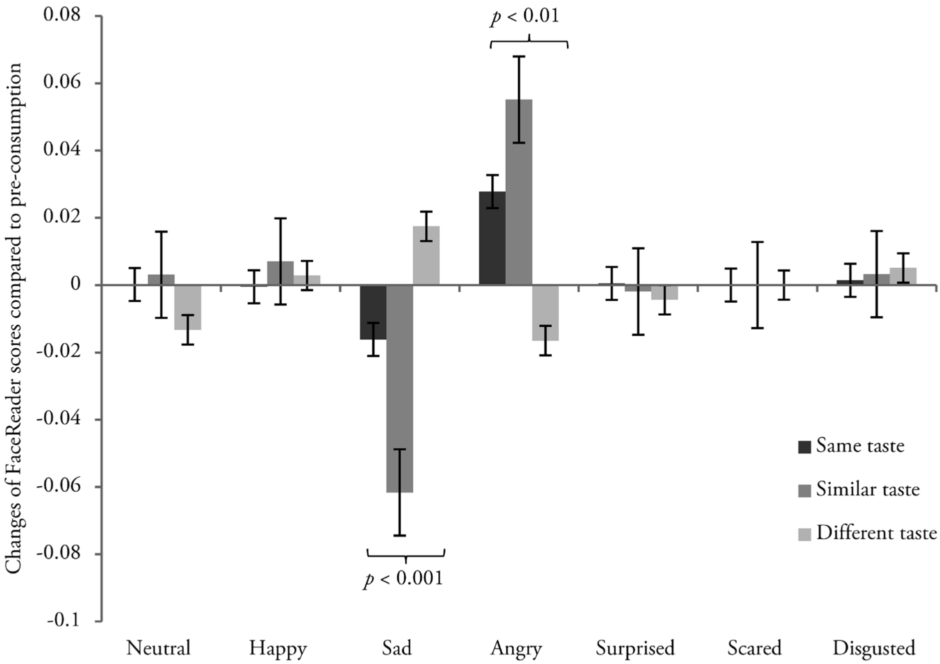


Figure 6.5 Changes of facial expression scores for the same, similar and different taste conditions compared to pre-consumption after subtracting from baseline. Error bars represent standard error of the mean

6.4 Discussion

The present study tested the effects of Sensory-specific Satiety (SSS) with traditional hedonic measures, as well as with facial expressions and ANS responses to test the three hypotheses outlined in the introduction. The traditional pleasantness measure showed the result pattern commonly found for SSS, namely the largest decrease in pleasantness after consumption of the same food, a smaller decrease after consumption of a similar food and the least decrease after consumption of a different food. This demonstrates that SSS indeed was induced in this study, at least when traditional hedonic measures are used. Moreover, desire to eat ratings changed more than pleasantness ratings for all conditions. This difference may reflect the distinction between processes associated with affective versus motivational consequences of ingesting food, in short, liking versus wanting (173). Mela (161) in a review defined 'liking' as the immediate experience or anticipation of pleasure from the sensory stimulation of eating a food, and 'desire' or

6

'wanting' as the intrinsic motivation to engage in eating a food. It seems plausible that the motivation to eat declines more than the appraisal of sensory stimulation during consumption. In addition, all of the absolute pleasantness ratings after consumption were still above neutral, whereas the absolute desire to eat ratings declined to below neutral, even for uneaten foods (see Figure 6.3). This distinction indicates that at the beginning of eating, appraisals of liking and wanting were similar to each other. During the process of consumption, however, internal motivational state may contribute more than that of sensory stimulation to the termination of a meal.

Facial expressions and ANS responses also change with consumption which indicates that they reflect satiety, and for specific facial expressions and ANS measures also (but not necessarily) sensory-specific satiety. In general, consumption was associated with increased heart rate, decreased skin conductance and skin temperature, and intensified expressions of anger and disgust, irrespective of the specific food. Increased heart rate had also been found in previous food studies (174-177) and probably reflects the increased motor activity associated with eating and may be unrelated to SSS. Skin conductance reflects arousal and reduced skin conductance and skin temperature after consumption probably reflects the increased familiarity with the test situation resulting in lower physiological arousal. In contrast to the lowering effect of satiety on physiological arousal, facial expressions associated with arousal (anger and disgust) (44,178) intensified with satiety. The differences between ANS results and facial expressions may reflect differences between their mechanisms. Facial expressions are rapidly changing and reflect the results of ongoing appraisals of aspects such as the food's novelty and pleasantness. ANS responses probably reflect a goal-directed system that determines whether consumption is continued or stopped. This determination is probably based on the multiple appraisals reflected by facial expressions whereby different appraisals probably carry different (unknown) weights. These differences in functions and mechanisms between ANS responses and facial expressions may explain some of their apparent contradictories. In summary, however, our results suggest that satiety results in a shift in emotions associated with shifts in the foods' pleasantness as well as the arousal triggered by the food.

Not only are specific ANS measures and facial expressions sensitive to variations in satiety but also to SSS. The decrease in skin temperature and SCL are larger after consumption of a different food than after consumption of the same or similar food. As skin conductance typically increases in response to novel stimuli, as orienting response, this decrease can be interpreted as sign of familiarity, or perhaps even boredom, with the (same) food. Similarly, facial expressions of anger and sadness after consumption of a different food differ from the expressions after consumption of the same of similar food. Consumption of the same or similar food is associated with reduced sadness and intensified anger indicating a shift towards higher arousal, and may signal 'being fed up' with the test food. A reversed shift towards lower arousal is observed after consumption of a different food.

In the present study, sensory-specific satiety was induced by ad libitum consumption in which participants were instructed to consume as much as they like. Moreover, we adopted three tasting conditions based on the same foods, similar uneaten foods and different uneaten foods, compared to the food consumed to satiety. This study design allows us to disentangle effects related to satiety versus sensory-specific satiety. Clearly, the current study used an experimental, not real-life setting, in which participants sipped semi-liquid foods through a straw, and results may thus not be directly translatable to real life. Despite this limitation, this setup was successful in inducing SSS, given the explicit liking ratings. Further exploration may focus on dynamic emotional changes during consumption in more natural eating situations. Additionally, our used methods (e.g. FaceReader) are able to recognize basic emotions, but not others that might be relevant in eating behavior (such as satisfaction, guilt). However, given the novel combination of methods and study design, we feel we have adopted a good way to start explorations in the field of emotions and eating behavior.

Taken together, the ANS results and facial expressions reflect effects of SSS that overlap as well as expand on results of traditional hedonic measures. Similar to hedonic results, ANS results and facial expressions show effects of SSS on the food's pleasantness. In addition, they show effects on the arousal triggered by the foods. Finally, results for skin conductance and skin temperature, but not heart rate, as well as facial expressions suggest that SSS is mediated by emotional responses.

CHAPTER 7

General discussion

The aim of this thesis was to investigate the effects of food stimuli varying in sensory modality (smell and taste), pleasantness and intensity, on emotional and physiological responses leading up to liking appraisal. In this thesis the following research questions are addressed:

- Can emotional and physiological responses differentiate between (and within) liked and disliked food stimuli?
- If and how are emotional and physiological responses related to liking appraisal of food stimuli?
- Do emotional and physiological responses reflect dynamic unfolding of liking appraisal of food stimuli?

7.1 Main findings

The main findings described in this thesis are presented in Table 7.1. To determine how liking and intensity are reflected in separate measures of emotional and physiological measurement, responses to pleasant (orange) or unpleasant food odors (fish) varying in intensity were measured discretely using pleasantness ratings, intensity ratings and non-verbally reported emotions, as well as continuously using facial expressions and autonomic nervous system (ANS) responses. Both non-verbal reported emotions and emotional facial expressions were able to discriminate between the food odors with opposing pleasantness and within the same food odor with varying intensity (chapter 2). Odor pleasantness was positively associated with neutral and surprised expressions, and skin temperature, as well as negatively associated with disgusted expressions, heart rate and skin conductance responses. Odor intensity was positively associated with disgusted expressions and heart rate, as well as negatively associated with neutral expressions (chapter 2&3). In addition, facial expressions, varying dynamically after odor stimulation, associated best with odor valence and odor intensity at 1250 and 2000 ms, respectively. The correlation between non-verbally rated emotions and facial expressions was greatest during the 2nd second after odor exposure (chapter 2). Continuously measured facial expressions and ANS responses became odor-specific at different rates over time. Neutral and disgusted facial expressions, as well as heart rate differentiated between odors immediately after the start of the odor presentation within half a second. Surprised, sad and scared expressions became odor specific around 1 s after odor presentation, followed by happy expressions around 2 s. Skin conductance responses differentiated between odors relatively late around 4 s. Skin temperature became odor specific either at the beginning or later phase of odor presentation (chapter 3).

Equally intense food odors with a wider range of valence were then used to further investigate the relation between non-verbally rated emotions, facial expressions and ANS responses. Non-verbally reported emotions, facial expressions and ANS responses correlated with each other best in different time windows after odor presentation: facial expressions and ANS responses correlated best with the explicit emotions of the arousal dimension in the 2^{nd} second of odor presentation, whereas later ANS responses correlated best with the explicit emotions of the valence dimension in the 4^{th} second (chapter 4).

To investigate possible differences between responses to food stimuli differing in sensory modality, facial expressions and ANS responses were measured in response to induced by equally liked breakfast drinks. The results showed that liking was associated with increased heart rate, skin temperature and neutral facial expressions. Intensity was associated with decreased heart rate and skin temperature, as well as increased neutral, sad, angry surprised facial expressions. Moreover, strongest associations with liking were found after 1 second of tasting, whereas strongest associations with intensity were found after 2 seconds of tasting (chapter 5).

To investigate reduced pleasantness of a single food due to consumption, semi-liquid meals with distinct flavors were used to induce sensory-specific satiety and to compare changes in pleasantness after eating to satiety between eaten and uneaten foods. ANS responses, as well as facial expressions of anger and disgust were changed after eating to satiety. Further differences between eaten and uneaten foods, suggesting effects of sensory-specific satiety, were also reflected by changes in skin conductance, skin temperature, as well as facial expressions of sadness and anger (chapter 6).

Figure 7.1 Overview of the main findings

Outcome measure		Food odor (chapter 2-4)	Food flavor (chapter 5)	After eating (chapter 6)
Explicit ratings	Pleasantness	Different	Similar	Decreased
	Desire to eat	–	–	Decreased
	Intensity	Different (2, 3), Similar (4);	Different	Similar
	Non-verbal emotions	Differentiate between odors (2, 4)	–	–
Facial expressions	Neutral	Odor-specific within 100 ms after smelling (3)	Positively associated with pleasantness	No significant change
	Happy	Odor-specific around 1780 ms after smelling (3)	Negatively associated with pleasantness; Positively associated with intensity	No significant change
	Sad	Odor-specific around 820 ms after smelling (3)	Negatively associated with pleasantness	Associated with sensory-specific satiety
	Angry	Odor-specific around 500 ms after smelling (3)	Negatively associated with pleasantness	Associated with satiety and sensory-specific satiety
	Surprised	Odor-specific around 580 ms after smelling (3)	Negatively associated with pleasantness	No significant change
	Scared	Odor-specific around 1020 ms after smelling (3)	Negatively associated with pleasantness; Positively associated with intensity	No significant change
	Disgusted	Odor-specific around 180 ms after smelling (3)	Negatively associated with pleasantness; Positively associated with intensity	Associated with satiety
ANS responses	Heart rate	Odor-specific around 400 ms after smelling (3)	Positively associated with pleasantness; Negatively associated with intensity	Increased
	Skin conductance	Odor-specific around 3920 ms after smelling (3)	Positively associated with pleasantness; Positively associated with intensity	Decreased and associated with sensory-specific satiety
	Skin temperature	Odor-specific between 520 and 1000ms as well as between 2690 and 3880 ms (3)	Positively associated with pleasantness; Negatively associated with intensity	Decreased and associated with sensory-specific satiety

	Pleasantness & Facial expressions	Associated best around 1 second after smelling (2)	Associated best after 1 second of tasting	_
	Intensity & Facial expressions	Associated best around 2 seconds after smelling (2)	Associated best after 2 seconds of tasting	_
Correlation	Non-verbal emotions & Facial expressions	Associated best in the 2nd second of smelling (2) with arousal (4)	_	_
	Non-verbal emotions & ANS responses	Associated best in the 2nd second of smelling with arousal(4), in the 4th second with valence (4)	_	_
	Facial expressions & ANS responses	Associated in the first 2 seconds of smelling with arousal (4)	_	_

'Different' and 'Similar' in the table only indicate how stimuli are manipulated. '_' represents the relationships that are not tested in the thesis.

7.2 Discussion and interpretation of the results

7.2.1 Explicit liking and emotions

Pleasantness appraisal plays an important role in emotion processes, and has been identified as the principal dimension of emotional responses (54). One could wonder if it is worthwhile to investigate other aspects involved in emotional processes besides pleasantness. Indeed, results from our studies showed that non-verbally self-reported emotions were primarily reflecting stimuli's valence (chapter 2&4). Another Study exploring verbally and non-verbally rated emotions also showed this uni-dimensional effect with liquid foods (62). However, consumers do not always choose or eat the food they like, and liking ratings do not fully explain all the variance in the results, indicating there is more to liking than a single dimension.

Several studies investigated emotional responses to food products have demonstrated that measuring food-induced emotions may improve the discrimination between products with similar liking ratings (58,62) and better explain choice behavior (63,179). Dalenberg et al. (180) measured consumers' emotional responses using the EsSense Profile and PrEmo to differentiate between similar products from the same product category. They found that both methods differentiated successfully between similar groups of breakfast drinks and significantly improve food choice prediction over merely liking scores. Results of PrEmo in this thesis also showed that non-verbally self-reported emotions successfully discriminated between food odors that are equally liked or disliked (chapter 2&4).

7.2.2 Facial expressions

Implicit emotion measurements chosen to use in this thesis were facial expressions, which demonstrated to be able to discriminate between food odors with varying or similar valence or varying in intensity (chapter 2-4), between food products with similar valence (chapter 5), as well as to detect changes in valence of food stimuli upon consumption (chapter 6).

In chapter 2 and 3, pleasant odors were associated with neutral and surprised expressions, whereas unpleasant odors were associated with disgusted and angry expressions. When more odors varying in valence were further explored, facial expressions of happiness, sadness, surprise, scare and disgust varied significantly between odors (chapter

4). During a single sip of breakfast drinks, liking was associated with neutral facial expressions (chapter 5). In a study measuring facial expressions in response to orange juice, Danner et al. (80) found a high negative correlation of the neutral facial expression with disliking and a high positive correlation of angry and disgusted expressions with disliking. However, no correlation between happy expression and pleasantness was found either in this thesis or in other studies (79,80). Facial expressions normally associated with positive emotions such as happiness are rarely used in response to foods. Instead, positive food emotions are associated with neutral expressions, resulting from the absence of negative expressions. Happy expressions indeed developed as odor-specific in chapter 3, but relatively slower than all the other facial expressions. Possibly, happy response may represent more communicative motives than emotions, which thus make happiness less expressive while smelling or tasting alone and more related to cognitive processes (67). Similarly, only negative facial expressions were related to food consumption, with satiety reflected by facial expressions of disgust and anger, as well as with sensory-specific satiety reflected by angry and sad expressions (chapter 6).

Facial expressions analyzed by FaceReader software include only one positive facial expression (happy) versus four negative ones (sad, angry, scared and disgusted), plus two neutral expressions (neutral, surprised). The relative small number of positive facial expressions employed by FaceReader may limit its capability to distinguish between positive emotions elicited by food stimuli, especially most food-related emotions appearing to be mild positive as concluded by King & Meiselman (58) and Desmet & Schifferstein (59). The result that facial expressions reflect the food odors' arousal rather than their valence (chapter 4) is probably driven by the fact that facial expressions to food stimuli tend to reflect only negative emotions, and thus cover only part of the full valence spectrum. This thesis demonstrate that this is not a problem, but probably is an accurate reflection of consumer reactions to these type of stimuli. Finally, the number of possible facial expressions or emotional responses to our stimuli may exceed the six expressions identified by FaceReader, which could result in incorrect identification of some facial expressions.

7.2.3 Autonomic nervous system responses

Heart rates, skin conductance and skin temperature were used in all studies to determine whether emotion/stimuli/valence-specific ANS patterns could be elicited. We found in our studies that unpleasant food odors triggered higher heart rate (chapter 3&4). This finding is in line with other studies in the olfactory modality showing heart rate acceleration when unpleasant odors are presented to human subjects (39,40,45,46,181). Alaoui-Ismaili et al. (40) related various autonomic parameters to the pleasantness of five odorants. They found that unpleasant odors were associated with increased heart rate and longer skin conductance responses as compared to pleasant odors. Previous research also indicated a strong correlation between arousal level and odor intensity (45). Bensafi et al. (45) related ANS measures to rated pleasantness, arousal, intensity and familiarity for a set of six odorants and found that their results could be explained by two main factors: pleasantness, inversely related to heart rate; arousal, positively related to skin conductance and rated intensity. Among food odors varying in intensity, we did find higher skin conductance level for more intense fish odor (chapter 3), but not for breakfast drinks (chapter 5). In addition, we also found skin temperature associated with odor pleasantness (chapter 3) and intensity of breakfast drinks (chapter 5). Moreover, heart rate increased after eating to satiety, which is in line with several studies (174-177). Skin conductance and skin temperature showed effects reflecting both satiety and sensory-specific satiety (chapter 6). Several studies showed that food-induced emotions can elicit craving which is accompanied by autonomic responses (174,182), but interactions between food consumption and ANS measures are still not fully investigated. Taken together, the results show consistencies as well as inconsistencies. Relations between specific ANS measures and factors, such as valence, arousal and hunger/satiety are still ambiguous.

Combined heart rate, skin conductance and skin temperature responses of the autonomic nervous system showed strong associations to valence in the 3rd and the 4th second of odor presentation in chapter 4. Individually, only skin conductance showed a significant negative correlation, which supports the notion that the patterns across ANS parameters are more relevant for valence/arousal/emotions than any of the single parameter. This is in line with previous research that was summarized by Kreibig (93) and shows that emotions are associated with specific patterns across ANS responses rather than with individual responses. For example, an increased skin conductance response reflects arousal than can be caused by positive as well as negative emotions. It is only when skin conductance responses are combined with other responses that the valence of emotions becomes apparent.

7.2.4 Temporal development of facial expressions and ANS responses

Continuously measured facial expressions and ANS responses also showed temporal development of appraisal processes for food stimuli. ANS responses and facial expressions proved to be highly dynamic over time with specific time courses for each parameter. For odors opposing in pleasantness, neutral and disgusted facial expressions, as well as heart rate differentiated between (valence of) odors immediately after the start of the odor presentation within half a second. Surprised, sad and scared expressions became odor specific around 1 s after odor presentation, followed by happy expressions around 2 s. Skin conductance responses differentiated between odors relatively late around 4 s. Skin temperature became odor specific either at the beginning or later phase of odor presentation (chapter 3).

Moreover, results from both odors and tastants demonstrated that facial expressions associated strongest with valence/liking after 1 s of stimuli presentation (chapter 2&5). Facial expressions were associated best with the valence dimension of non-verbally reported emotions in the 2nd second of odor presentation in chapter 2, whereas with the arousal dimension of non-verbally reported emotions in the 2nd second of odor presentation in chapter 4. The arousal dimension was lacking probably due to the limited number of odors tested (two) that differed strongly in valence, suggesting that when a more complex set of test odors is used, temporal separation takes place in the processes that result in emotions related to arousal and valence.

Based on the componential appraisal model of emotions (explained in section 1.2.1), appraisals are continuous and recursive evaluations of events, involving several components (49,50): (a) the cognitive system responsible for appraisal of the situation, (b) the autonomic system in charge of system regulation, (c) the motor system responsible for communication of reaction and behavioral intention, (d) the motivational system responsible for preparation and direction of action, and (e) the monitor system in charge of subjective feeling. The model claims that the outcome of each sequential evaluation changes the state of all other components, and that the changes produced by the result of a preceding evaluation are modified by a subsequent evaluation (48). In this thesis, we continuously measured facial expressions associated with the motor system component that is responsible for communication of reaction and behavioral intention, as well as ANS responses associated with the autonomic component in charge of system regulation, similar as investigated by Delplanque et al. (50). They found that the earliest effects on facial muscles and heart rate occurred in response to odor novelty detection, whereas later effects on facial muscles and heart rate were related to odor pleasantness evaluation. Therefore, the automated reflexes to novel and potentially dangerous stimuli may precede the later responses reflecting a conscious processing of a sequence of different emotions, each resulting from a different appraisal of the stimulus by the observer (49). Unfortunately, novelty or familiarity of odors wasn't manipulated in this thesis, which makes it difficult to directly compare early responses between two studies. The results of this thesis did reveal similar later effects of odor valence where the specific timing is also not comparable due to differences in measurement and experiment settings (chapter 4).

This postulation also has its evolutionary roots. Organisms constantly scan their external and internal environment for the occurrence of events requiring deployment of attention, further information processing, and possibly adaptive reaction (52). This continuous appraisal may lead to approach or avoidance behavior. In relevance detection, therefore, a first appraisal is related to detection of potential threat in that any change in the ongoing flow of processed stimuli could require attention and demand further processing. In this step, detecting a threat and reacting fast automatically before cognitive analysis of the stimulus are of crucial value for survival. The early responses reflecting arousal in chapter 4 may related to relevance check of situations or events. For instance, an initial detection of a predator may elicit fast and automated responses with a high arousal that leads to fear and subsequently avoidance behavior. Evidence has shown that initial judgements are different and independent from hedonic evaluation (27,142). If no threaten stimuli are detected, the organism evaluates whether a stimulus event is likely to result in pleasure or pain in a second check. This is also in line with our results that valence appraisal is at least after 1s of stimulus presentation. Several studies on reaction time have demonstrated that unpleasant odor stimuli of ecologically-relevance are detected faster and more accurate than either non-food odor or pleasant odor (119,145). This is also partly reflected by the result in this thesis that unpleasant odors have elicited more intense facial expressions in chapter 2.

7.3 Methodological considerations

7.3.1 Test stimuli

The test stimuli were chosen to increase complexity over a total of four studies, from basic and simple stimuli to more real-life consumption, with two studies using food odors varying in valence or intensity and the other two studies using equally liked semi-liquid foods with different flavors. Food stimuli in more than one modality could be used to test whether the parameters used in this thesis were modality specific or not. Facial expressions in response to both food odors and flavors prove to be associated best with liking after 1 second of exposure and with intensity after 2 seconds of exposure (chapter 2&5). These consistent results indicate that unfolding of liking appraisal reflected by facial expressions can be generalized to different sensory modalities.

Moreover, to take into account the restrictions posed by the methods chose, ANS responses and facial expressions ask for timed onsets of stimuli, which is difficult to achieve with real foods. Also, the face must not be partially obscured by hair or when handling samples for facial expressions measures. Thus, odors or liquid foods that can be delivered through a straw or tube is better suited than solid foods. In addition, motor artifacts, caused by eating and drinking, easily disturb recording of ANS responses and facial expressions, hence make it necessary to use liquid samples which need less processing in the mouth than solid samples.

7.3.2 Measurement tools

Responses to food stimuli were measured discretely using pleasantness ratings, intensity ratings and non-verbal reported emotions, as well as continuously using facial expressions and ANS responses in chapter 2-4. Pleasantness, intensity and non-verbal reported emotions were rated after each stimulus, and may lead to boredom due to repetition. In contrast, facial expressions and physiological responses can be monitored simultaneously without extra effort put in by participants. Such measures thus offer advantages over other more traditional measures, because they are relatively fast and effortless (typically a matter of seconds rather than minutes as required for questionnaires).

In addition, given the novel use (and combination) of methods, there is no 'golden standard' for analyzing data from studies described in this thesis, specifically when it comes to their temporal dynamics. This also makes it difficult to compare the results of this thesis with other studies and interpret such results. Most facial expressions measured in this thesis are subject to very fast changes, which may thus reflect momentary appraisal of the stimuli, whereas ANS responses develop relatively slow and need to be compared with baseline in order to detect the direction of change over time. Moreover, we observed that before smelling or tasting selected stimuli, participants already show slight responses to some degree, suggesting anticipatory responses that may draw influence on subsequent responses. To overcome these issues, it may be better to adopt a baseline covering longer time or an earlier time window before anticipatory phase.

Furthermore, facial expressions and physiological measurements are technically more challenging than questionnaires. As a result, their applications are more suitable for laboratory than for real-life. To minimize head rotation and motor artifacts caused by eating and drinking that may affect face recognition of FaceReader software and recordings of ANS responses, only odors and semi-liquid foods that can be delivered by straw or tube were selected in this thesis. This setting is unlike real-life situations due to technical limitations, thus may limit the possibility to generalize the results to real-life behavior, though this a good step in the right direction.

7.4 Implications and suggestions for future research

This thesis investigated effects of food stimuli on emotional and physiological responses involved in three phases, anticipation, satiation and satiety, of eating behavior. However, the temporal development of such responses during food consumption haven't been fully investigated in this thesis. Since most studies on eating behavior focus on discrete measurements that make continuous monitor of eating process without intervening extremely difficult. Therefore, such implicit measures chosen in this thesis are of particular usage to predict continuing consumption behavior.

Furthermore, temporal development of implicit measures like facial expressions and ANS responses were investigated in this thesis, whereas temporal development of explicit measures still lacks of exploration. Recently, measurement exploring temporal development of subjective ratings, such as Temporal Dominance of Sensations (TDS), Temporal Dominance of Liking (TDL), Temporal Dominance of Emotions (TDE), has been more and more reported, instead of commonly used static measures of emotional responses (183). Thus it is valuable to combine temporal dynamics of appraisal processes measured by implicit and explicit techniques. The comparison and even cross-validation between two types of measures may provide more detailed information on affective processing.

The findings of this thesis emphasize the particular importance of distinguishing between initial and later reactions. Future research should clarify the role of initial reactions in choice/purchase/intake behavior, especially for those expressions and physiological responses that may change immediately after a food cue is presented. Primary emotional responses when a stimulus is first encountered may determine approach or avoidance behavior, i.e. whether a product on the supermarket shelf is further inspected or ignored. These initial reactions may be based on the novelty of the product and detected by facial expressions despite the technical challenges.

Moreover, the developments of the psychological research on intuitive thinking and decision making have revealed that the intuitive system is characterized by operations that are fast, automatic, effortless, implicit (not available to introspection) and often emotionally charged and governed by habit (184). In contrast, the operations in the reasoning system are slower, effortful, more likely to be consciously monitored and deliberately controlled. Thus, the intuitive system that governs most of our daily doings operates quite independently of our conscious convictions(185). This is especially the case when there is little time or in dealings with repeated decisions like food choice and intake (28). Visitors to supermarkets may have less than one hour to select their weekly groceries from enormous products. This task becomes even more daunting considering the fact that many of these selections are not planned but made in the supermarket. Given the abundance of choices, consumers need a fast and partly automated selection mechanism that combines affect, appraisal, action readiness and autonomic arousal. This fast selection mechanism may be based on fast and probably automated ANS responses and facial expressions similar to the ones explored in this thesis. These fast responses may not only be triggered by smelling and tasting the food, but also by seeing product packages and brand names.

To explore real-life applications, future studies should measure ANS responses and facial expressions in relation to consumer choice behavior. Starting with consumer behavior assessed in the semi- real-life test environment like a virtual supermarket, followed by real-life assessment in an actual supermarket may lead to. Such studies will allow a proper evaluation of ANS measures and facial expressions as tools for marketing research because their associations with consumer product interactions and purchasing behaviors will be tested directly.

7.5 Main conclusions

Both non-verbal reported emotions and emotional facial expressions were demonstrated to be able to discriminate between food odors differing in pleasantness and/or intensity. Explicit and implicit emotional responses, as well as physiological patterns are related to liking appraisals involved in smelling foods. Implicit measures such as facial expressions and ANS responses can provide more multidimensional information for both food odors and tastes than explicit measures and prove to be highly dynamic over time with specific time courses. Early implicit facial and ANS responses primarily reflect emotion arousal, whereas later ANS responses reflect emotion valence, suggesting dynamic unfolding of different appraisals of food stimuli. Furthermore, ANS responses and facial expressions can reflect pleasantness, satiety, and a combination of both: sensory-specific satiety. This suggests that implicit processes play an important role in dynamic liking appraisals with respect to eating behavior.

References

References

1. Blundell JE, Rogers PJ, Hill AJ. Evaluation the satiating power of foods: implications for acceptance and comsumption. In: Solms J, Booth DA, M. PR, Raunhardt O, editors. Food Acceptance and Nutrition. Academic Press; 1987. p. 205–19.
2. Sobal J, Bisogni CA. Constructing Food Choice Decisions. Ann Behav Med. 2009 Dec;38(S1):37–46.
3. Wooley SC, Wooley OW. Salivation to the sight and thought of food: a new measure of appetite. Psychosom Med. 1973;35(2):136–42.
4. Feldman M, Richardson CT. Role of thought, sight, smell, and taste of food in the cephalic phase of gastric acid secretion in humans. Gastroenterology. 1986 Feb;90(2):428–33.
5. Rodin J. Insulin levels, hunger, and food intake: An example of feedback loops in body weight regulation. Heal Psychol. 1985;4(1):1–24.
6. de Wijk RA, Kooijman V, Verhoeven RHG, Holthuysen NTE, de Graaf C. Autonomic nervous system responses on and facial expressions to the sight, smell, and taste of liked and disliked foods. Food Qual Prefer. 2012 Dec;26(2):196–203.
7. Ramaekers MG, Boesveldt S, Lakemond CMM, van Boekel MAJS, Luning PA. Odors: appetizing or satiating? Development of appetite during odor exposure over time. Int J Obes. 2014 May 6;38(5):650–6.
8. Rolls ET. Taste, olfactory, and food texture processing in the brain, and the control of food intake. Physiol Behav. 2005 May 19;85(1):45–56.
9. Small DM. Flavor is in the brain. Physiol Behav. 2012 Nov 5;107(4):540–52.
10. Rolls BJ, Rolls ET, Rowe EA, Sweeney K. Sensory specific satiety in man. Physiol Behav. 1981 Jul;27(1):137–42.
11. Rolls BJ, Rowe EA, Rolls ET, Kingston B, Megson A, Gunary R. Variety in a meal enhances food intake in man. Physiol Behav. 1981 Feb;26(2):215–21.
12. de Graaf C, Blom WAM, Smeets PAM, Stafleu A, Hendriks HFJ. Biomarkers of satiation and satiety. Am J Clin Nutr. 2004 Jun;79(6):946–61.
13. Blundell JE, Tremblay A. Appetite Control and Energy (Fuel) Balance. Nutr Res Rev. 1995 Jan;8(01):225–42.
14. Smeets PAM, Erkner A, de Graaf C. Cephalic phase responses and appetite. Nutr Rev. The Oxford University Press; 2010 Nov 1;68(11):643–55.
15. Yeomans MR. Olfactory influences on appetite and satiety in humans. Physiol Behav [Internet]. 2006 Apr 15 [cited 2014 Oct 16];87(4):800–4. Available from: http://www.sciencedirect.com/science/article/pii/S0031938406000552
16. Rolls ET, Rolls JH. Olfactory Sensory-Specific Satiety in Humans. Physiol Behav. 1997

Mar;61(3):461–73.

17. de Graaf C, Kramer FM, Meiselman HL, Lesher LL, Baker-Fulco C, Hirsch ES, et al. Food acceptability in field studies with US army men and women: relationship with food intake and food choice after repeated exposures. Appetite. 2005 Feb;44(1):23–31.
18. Yeomans MR. Rating changes over the course of meals: what do they tell us about motivation to eat? Neurosci Biobehav Rev. 2000 Mar;24(2):249–59.
19. Monneuse M, Bellisle F, Louis-Sylvestre J. Responses to an intense sweetener in humans: Immediate preference and delayed effects on intake. Physiol Behav. 1991 Feb;49(2):325–30.
20. Pérez C, Dalix A-M, Guy-Grand B, Bellisle F. Human Responses to Five Concentrations of Sucrose in a Dairy Product: Immediate and Delayed Palatability Effects. Appetite. 1994 Oct;23(2):165–78.
21. Zandstra EH, de Graaf C, van Trijp HC., van Staveren WA. Laboratory hedonic ratings as predictors of consumption. Food Qual Prefer. 1999 Jul;10(4-5):411–8.
22. Hellemann U, Tuorila H. Pleasantness ratings and consumption of open sandwiches with varying NaCl and acid contents. Appetite. 1991 Dec;17(3):229–38.
23. Mook DG, Votaw MC. How important is hedonism? Reasons given by college students for ending a meal. Appetite. 1992 Feb;18(1):69–75.
24. Wansink B. Environmental factors that increase the food intake and consumption volume of unknowing consumers. Annu Rev Nutr. 2004 Jan;24(1):455–79.
25. Gibbons C, Finlayson G, Dalton M, Caudwell P, Blundell JE. Metabolic Phenotyping Guidelines: studying eating behaviour in humans. J Endocrinol. 2014 Aug 1;222(2):G1–12.
26. Köster E. Diversity in the determinants of food choice: A psychological perspective. Food Qual Prefer. 2009 Mar;20(2):70–82.
27. Lévy C, Köster E. The relevance of initial hedonic judgements in the prediction of subtle food choices. Food Qual Prefer. 1999 May;10(3):185–200.
28. Köster E, Mojet J. Theories of food choice development. In: Frewer L, Trijp H, editors. Understanding consumers of food products. 1st ed. Cambridge, England: Woodhead Publishing Limited; 2006. p. 93–124.
29. Canetti L, Bachar E, Berry EM. Food and emotion. Behav Processes. 2002 Nov;60(2):157–64.
30. Macht M. How emotions affect eating: a five-way model. Appetite. 2008 Jan;50(1):1–11.
31. Gibson EL. Emotional influences on food choice: sensory, physiological and psychological pathways. Physiol Behav. 2006 Aug 30;89(1):53–61.
32. Macht M, Dettmer D. Everyday mood and emotions after eating a chocolate bar or an apple. Appetite. 2006 May;46(3):332–6.

33. Thomson DMH, Crocker C, Marketo CG. Linking sensory characteristics to emotions: An example using dark chocolate. Food Qual Prefer. 2010 Dec;21(8):1117–25.
34. Darwin C. The Expression of the Emotions in Man and Animals. The American Journal of the Medical Sciences. London: John Murray; 1872. 477 p.
35. Ekman P. Universal and cultural differences in facial expression of emotion. In: Cole JR, editor. Nebraska symposium on motivation. Lincoln: University of Nebraska Press; 1972. p. 207–82.
36. Izard CE. The face of emotion. Century psychology series. New York: Appleton (Century/Crofts); 1971.
37. Tompkins S. Affect Imagery Consciousness, (Vols. 1 and 2). Berlin: Springer; 1962.
38. Ekman P, Sorenson ER, Friesen W V. Pan-Cultural Elements in Facial Displays of Emotion. Science (80-). 1969 Apr 4;164(3875):86–8.
39. Alaoui-Ismaïli O, Vernet-Maury E, Dittmar A, Delhomme G, Chanel J. Odor Hedonics: Connection With Emotional Response Estimated by Autonomic Parameters. Chem Senses. 1997;22(3):237–48.
40. Alaoui-Ismaili O, Robin O. Basic emotions evoked by odorants: comparison between autonomic responses and self-evaluation. Physiol Behav. 1997;62(4):713–20.
41. Vernet-Maury E, Alaoui-Ismaïli O, Dittmar A, Delhomme G, Chanel J. Basic emotions induced by odorants: a new approach based on autonomic pattern results. J Auton Nerv Syst. 1999 Feb 15;75(2-3):176–83.
42. Ekman P, Levenson R, Friesen W. Autonomic nervous system activity distinguishes among emotions. Science (80-). 1983 Sep 16;221(4616):1208–10.
43. Lang PJ, Greenwald MK, Bradley MM, Hamm a O. Looking at pictures: Affective, facial, visceral, and behavioral reactions. Psychophysiology. 1993 May;30(3):261–73.
44. Russell JA. A circumplex model of affect. J Pers Soc Psychol. 1980;39(6):1161–78.
45. Bensafi M, Rouby C, Farget V, Bertrand B, Vigouroux M, Holley A. Autonomic nervous system responses to odours: the role of pleasantness and arousal. Chem Senses. 2002 Oct;27(8):703–9.
46. Bensafi M, Rouby C, Farget V, Bertrand B, Vigouroux M, Holley A. Influence of affective and cognitive judgments on autonomic parameters during inhalation of pleasant and unpleasant odors in humans. Neurosci Lett. 2002 Feb;319(3):162–6.
47. Anderson A, Christoff K, Stappen I, Panitz D, Ghahremani DG, Glover G, et al. Dissociated neural representations of intensity and valence in human olfaction. Nat Neurosci. 2003 Feb;6(2):196–202.
48. Scherer K. Appraisal considered as a process of multilevel sequential checking. Appraisal processes in emotion: Theory, methods, research. New York: Oxford University Press; 2001. p. 92–120.

49. Ellsworth PC, Scherer KR. Appraisal processes in emotion. In: Davidson RJ, Scherer KR, Goldsmith HH, editors. Handbook of affective sciences. New York: Oxford University Press; 2003. p. 572–95.
50. Delplanque S, Grandjean D, Chrea C, Coppin G, Aymard L, Cayeux I, et al. Sequential unfolding of novelty and pleasantness appraisals of odors: evidence from facial electromyography and autonomic reactions. Emotion. 2009 Jun;9(3):316–28.
51. Scherer KR. What are emotions? And how can they be measured? Soc Sci Inf. 2005 Dec 1;44(4):695–729.
52. Scherer KR. Emotion as a Multicomponent Process. Rev Personal Soc Psychol. 1984;5:37–63.
53. Sander D, Grandjean D, Scherer KR. A systems approach to appraisal mechanisms in emotion. Neural Netw. 2005 May;18(4):317–52.
54. Fontaine J, Scherer K. The world of emotions is not two-dimensional. Psychol Sci. 2007;18(12):1050–7.
55. Chrea C, Grandjean D, Delplanque S, Cayeux I, Le Calvé B, Aymard L, et al. Mapping the semantic space for the subjective experience of emotional responses to odors. Chem Senses. 2009 Jan 1;34(1):49–62.
56. Porcherot C, Delplanque S. How do you feel when you smell this? Optimization of a verbal measurement of odor-elicited emotions. Food Qual …. 2010;
57. Delplanque S, Chrea C, Grandjean D, Ferdenzi C, Cayeux I, Porcherot C, et al. How to map the affective semantic space of scents. Cogn Emot. 2012;26(5):885–98.
58. King SC, Meiselman HL. Development of a method to measure consumer emotions associated with foods. Food Qual Prefer. Elsevier Ltd; 2010 Mar;21(2):168–77.
59. Desmet PMA, Schifferstein HNJ. Sources of positive and negative emotions in food experience. Appetite. 2008;50(2-3):290–301.
60. Köster EP, Mojet J. From mood to food and from food to mood: A psychological perspective on the measurement of food-related emotions in consumer research. Food Res Int. 2015 Apr;76:180–91.
61. Desmet PMA. Measuring emotion: Development and application of an instrument to measure emotional responses to products. In: M.A. Blythe, K. Overbeeke, A.F. Monk PCW, editor. Funology: From Usability to Enjoyment. Dordrecht: Kluwer Academic Publishers; 2003. p. 111–23.
62. Gutjar S, de Graaf C, Kooijman V, de Wijk RA, Nys A, ter Horst GJ, et al. The role of emotions in food choice and liking. Food Res Int. 2015 Oct;76:216–23.
63. Gutjar S, Dalenberg JR, de Graaf C, de Wijk RA, Palascha A, Renken RJ, et al. What reported

food-evoked emotions may add: A model to predict consumer food choice. Food Qual Prefer. 2015 Oct;45:140–8.

64. Mauss IB, Robinson MD. Measures of emotion: A review. Cogn Emot. 2009 Feb;23(2):209–37.

65. Ahn SJ, Bailenson J, Fox J, Jabon M. Using automated facial expression analysis for emotion and behavior prediction. Handbook of Emotions and Mass Media. 2003. p. 349–69.

66. Ekman P, Rolls ET, Perrett DI, Ellis HD. Facial expressions of emotion: an old controversy and new findings. Philosophical transactions of the Royal Society of London. Series B, Biological sciences. London: Philosophical Transactions of the Royal Society B; 1992. 63-69 p.

67. Parkinson B. Do facial movements express emotions or communicate motives? Pers Soc Psychol Rev. 2005 Jan;9(4):278–311.

68. Berridge K. Measuring hedonic impact in animals and infants: microstructure of affective taste reactivity patterns. Neurosci Biobehav Rev. 2000 Mar;24(2):173–98.

69. Ganchrow JR, Steiner JE, Daher M. Neonatal facial expressions in response to different qualities and intensities of gustatory stimuli. Infant Behav Dev. 1983 Jan;6(2-3):189–200.

70. Rosenstein D, Oster H. Differential facial responses to four basic tastes in newborns. Child Dev. 1988;59(6):1555–68.

71. Steiner JE. The gustofacial response: observation on normal and anencephalic newborn infants. Symp Oral Sens Percept. 1973;4(4):254–78.

72. Soussignan R, Schaal B, Marlier L, Jiang T. Facial and autonomic responses to biological and artificial olfactory stimuli in human neonates: re-examining early hedonic discrimination of odors. Physiol Behav. 1997 Oct;62(4):745–58.

73. Steiner JE, Glaser D, Hawilo ME, Berridge KC. Comparative expression of hedonic impact: affective reactions to taste by human infants and other primates. Neurosci Biobehav Rev. 2001 Jan;25(1):53–74.

74. Steiner J. Human facial expressions in response to taste and smell stimulation. Adv Child Dev Behav. New York: Academic Press; 1979;13:257–95.

75. Greimel E, Macht M, Krumhuber E, Ellgring H. Facial and affective reactions to tastes and their modulation by sadness and joy. Physiol Behav. 2006 Sep;89(2):261–9.

76. Oster H. The repertoire of infant facial expressions: An ontogenetic perspective. In: Nadel J, Muir D, editors. Emotional Development: Recent Research Advances. New York: Oxford University Press; 2005. p. 261–92.

77. Ekman P, Friesen W. Facial action coding system. Palo Alto, CA: Consulting Psychologists Press; 1978.

78. Wendin K, Allesen-Holm BH, Bredie WLP. Do facial reactions add new dimensions to measuring

sensory responses to basic tastes? Food Qual Prefer. Elsevier Ltd; 2011 Jun;22(4):346–54.

79. Zeinstra GG, Koelen M, Colindres D, Kok FJ, de Graaf C. Facial expressions in school-aged children are a good indicator of "dislikes", but not of "likes." Food Qual Prefer. 2009 Dec;20(8):620–4.

80. Danner L, Sidorkina L, Joechl M, Duerrschmid K. Make a face! Implicit and explicit measurement of facial expressions elicited by orange juices using face reading technology. Food Qual Prefer. 2014 Mar;32:167–72.

81. de Wijk RA, He W, Mensink MGJ, Verhoeven RHG, de Graaf C. ANS Responses and Facial Expressions Differentiate between the Taste of Commercial Breakfast Drinks. Matsunami H, editor. PLoS One. 2014 Apr 8;9(4):e93823.

82. He W, Boesveldt S, de Graaf C, de Wijk RA. Dynamics of autonomic nervous system responses and facial expressions to odors. Front Psychol. 2014 Jan;5:110.

83. He W, Boesveldt S, de Graaf C, de Wijk RA. The relation between continuous and discrete emotional responses to food odors with facial expressions and non-verbal reports. Food Qual Prefer. 2016 Mar;48:130–7.

84. Danner L, Haindl S, Joechl M, Duerrschmid K. Facial expressions and autonomous nervous system responses elicited by tasting different juices. Food Res Int. 2014 Oct;64:81–90.

85. Uyl MJ Den, Kuilenburg H Van. The FaceReader : Online facial expression recognition. 2005;2005(September):589–90.

86. Hu S, Player K a, Mcchesney K a, Dalistan MD, Tyner C a, Scozzafava JE. Facial EMG as an indicator of palatability in humans. Physiol Behav. 1999 Dec 1;68(1-2):31–5.

87. van Reekum C, Johnstone T, Banse R, Etter A, Wehrle T, Scherer K. Psychophysiological responses to appraisal dimensions in a computer game. Cogn Emot. Psychology Press Ltd; 2004 Aug 24;18(5):663–88.

88. Aue T, Flykt A, Scherer KR. First evidence for differential and sequential efferent effects of stimulus relevance and goal conduciveness appraisal. Biol Psychol. 2007 Mar;74(3):347–57.

89. Lanctôt N, Hess U. The timing of appraisals. Emotion. 2007;7(1):207–12.

90. Schmidt A, Thews G. Autonomic Nervous System. In: Janig W, editor. Human Physiology. 2nd ed. New York: Springer-Verlag; 1989. p. 333–70.

91. McCorry LK. Physiology of the autonomic nervous system. Am J Pharm Educ. 2007 Aug 15;71(4):78.

92. Berntson G, Cacioppo JT. From homeostasis to allodynamic regulation. Cacioppo, John T; Tassinary LGBGG, editor. Handb …. Cambridge Univ Press; 2000;2:459–81.

93. Kreibig SD. Autonomic nervous system activity in emotion: a review. Biol Psychol. 2010

Jul;84(3):394–421.

94. Barrett LF. Are Emotions Natural Kinds? Perspect Psychol Sci [Internet]. 2006 Mar [cited 2015 Oct 30];1(1):28–58. Available from: http://pps.sagepub.com/lookup/doi/10.1111/j.1745-6916.2006.00003.x

95. Cacioppo J, Berntson G. The psychophysiology of emotion. In: Lewis R, Haviland-Jones JM, editors. The handbook of emotion. 2nd ed. New York: Guilford Press; 2000. p. 173–91.

96. Cacioppo J, Berntson G. Psychophysiology of emotion across the life span. In: K. Warner Schaie, editor. Annual review of gerontology and geriatrics. New York: Springer Publishing Company; 1997. p. 27–74.

97. Stemmler G. Physiological processes during emotion. In: Philippot P, Feldman RS, editors. The regulation of emotion. Mahwah, New Jersey: Erlbaum; 2004. p. 33–70.

98. Macht M, Meininger J, Roth J. The pleasures of eating: a qualitative analysis. J Happiness Stud. 2005 Jun;6(2):137–60.

99. Stroebele N, De Castro JM. Effect of ambience on food intake and food choice. Nutrition. 2004 Sep;20(9):821–38.

100. de Graaf C, Cardello A V, Matthew Kramer F, Lesher LL, Meiselman HL, Schutz HG. A comparison between liking ratings obtained under laboratory and field conditions: the role of choice. Appetite. 2005 Feb;44(1):15–22.

101. de Castro JM, Brewer EM. The amount eaten in meals by humans is a power function of the number of people present. Physiol Behav. 1992 Jan;51(1):121–5.

102. Feunekes GI, de Graaf C, Meyboom S, van Staveren WA. Food choice and fat intake of adolescents and adults: associations of intakes within social networks. Prev Med (Baltim). 1998;27(5 Pt 1):645–56.

103. Rolls BJ. Sensory-specific Satiety. Nutr Rev. 1986 Apr 27;44(3):93–101.

104. Davis R, Freeman R, Solyom L. Mood and food: An analysis of bulimic episodes. J Psychiatr Res. 1985 Jan;19(2-3):331–5.

105. Hill AJ, Weaver CFL, Blundell JE. Food craving, dietary restraint and mood. Appetite. 1991 Dec;17(3):187–97.

106. Desmet PMA, Hekkert P, Jacobs JJ. When a car makes you smile: Development and application of an instrument to measure product emotions. Adv Consum Res. 2000;27:111–7.

107. Desmet PMA, Porcelijn R, Dijk MB. Emotional design; application of a research-based design approach. Knowledge, Technol Policy. 2007 Sep 11;20(3):141–55.

108. Desmet PMA, Dijkhuis E. A wheelchair can be fun: a case of emotion-driven design. International conference on designing pleasurable products and interfaces. New York, New York, USA: ACM

Press; 2003. p. 22.

109. Overbeeke KJ, Vink P, Cheung FK. The emotion-aware office chair. In: Helander K, Helander T, editors. Affective Human Factors Design Asean. london: Asean Academic Press; 2001. p. 262–7.

110. Reijneveld K, de Looze M, Krause F, Desmet P. Measuring the emotions elicited by office chairs. Proceedings of the 2003 international conference on Designing pleasurable products and interfaces. New York, New York, USA: ACM Press; 2003. p. 6.

111. Den Uyl M, Van Kuilenburg H, Lebert E. FaceReader: an online facial expression recognition system. Measuring Behavior 2005 5th International Conference on Methods and Techniques in Behavioral Research. 2005. p. 589–90.

112. Engen T. The perception of odors. New York: Academic Press. New York: Academic Press; 1982.

113. Chu S, Downes JJ. Proust nose best: Odors are better cues of autobiographical memory. Mem Cognit. 2002 Jun;30(4):511–8.

114. Epple G, Herz R. Ambient odors associated to failure influence cognitive performance in children. Dev Psychobiol. 1999;35(2):103–7.

115. Goel N, Grasso D. Olfactory discrimination and transient mood change in young men and women: variation by season, mood state, and time of day. Chronobiol Int. 2004;21(4-5):691–719.

116. Lehrner J, Marwinski G, Lehr S, Johren P, Deecke L. Ambient odors of orange and lavender reduce anxiety and improve mood in a dental office. Physiol Behav. 2005 Sep 15;86(1-2):92–5.

117. Ferriday D, Brunstrom JM. "I just can"t help myself': effects of food-cue exposure in overweight and lean individuals. Int J Obes. Nature Publishing Group; 2011 Jan;35(1):142–9.

118. Ehrlichman H, Halpern JN. Affect and memory: effects of pleasant and unpleasant odors on retrieval of happy and unhappy memories. J Pers Soc Psychol. 1988;55(5):769–79.

119. Boesveldt S, Frasnelli J, Gordon a R, Lundström JN. The fish is bad: Negative food odors elicit faster and more accurate reactions than other odors. Biol Psychol. 2010 May;84(2):313–7.

120. Hummel T, Schultz S, Witt M, Hatt H. Electrical responses to chemosensory stimulation recorded from the vomeronasal duct and the respiratory epithelium in humans. Int J Psychophysiol. 2011 Aug;81(2):116–20.

121. Delplanque S, Silvert L, Hot P, Sequeira H. Event-related P3a and P3b in response to unpredictable emotional stimuli. Biol Psychol. 2005 Feb;68(2):107–20.

122. Weiland R, Ellgring H, Macht M. Gustofacial and olfactofacial responses in human adults. Chem Senses. 2010 Nov;35(9):841–53.

123. Schmidt KL, Cohn JF. Human facial expressions as adaptations: Evolutionary questions in facial expression research. Am J Phys Anthoroplogy. 2001;116(33):3–24.

124. Hess U, Banse R, Kappas A. The intensity of facial expression is determined by underlying affective state and social situation. J Pers Soc Psychol. 1995;69(2):280–8.

125. Poels K, Dewitte S. How to capture the heart? Reviewing 20 years of emotion measurement in advertising. KUL Work Pap. 2006;

126. Bradley MM, Codispoti M, Cuthbert BN, Lang PJ. Emotion and motivation I: Defensive and appetitive reactions in picture processing. Emotion. 2001;1(3):276–98.

127. Crawford C. Marketing research and the new product failure rate. J Mark. 1977;41(2):55–61.

128. Greenwald A. Supplemental Material for Understanding and Using the Implicit Association Test: III. Meta-Analysis of Predictive Validity. J Pers Soc Psychol. 2009;97(1):17–41.

129. Royet J-P, Koenig O, Gregoire M-C, Cinotti L, Lavenne F, Bars D Le, et al. Functional Anatomy of Perceptual and Semantic Processing for Odors. Journal of Cognitive Neuroscience. Cambridge: MIT Press; 1999. p. 94–109.

130. Distel H. Perception of Everyday OdorsCorrelation between Intensity, Familiarity and Strength of Hedonic Judgement. Chem Senses. 1999 Mar 1;24(2):191–9.

131. Kobal G, Hummel C. Cerebral chemosensory evoked potentials elicited by chemical stimulation of the human olfactory and respiratory nasal mucosa. Electroencephalogr Clin Neurophysiol Potentials Sect. 1988 Jul;71(4):241–50.

132. Ekman P. Facial expressions of emotion: an old controversy and new findings. Bruce V, Cowey A, Ellis AW, Perret DI, editors. Philos Trans R Soc London - Ser B Biol Sci. JSTOR; 1992;335(1273):63–9.

133. Terzis V, Moridis C, Economides A. The effect of emotional feedback on behavioral intention to use computer based assessment. Comput Educ. 2012;

134. D'Arcey T, Johnson M, Ennis M. Assessing the validity of FaceReader using facial electromyography. APS 24th annual meeting. Chicago, IL; 2012.

135. Gilbert AN, Fridlund AJ, Sabini J. Hedonic and social determinants of facial displays to odors. Chem Senses. 1987;12(2):355–63.

136. Levenson R. Emotion and the autonomic nervous system: A prospectus for research on autonomic specificity. In: Wagner HL, editor. Social psychophysiology and emotion: Theory and clinical applications. London: John Wiley & Sons; 1988. p. 17–42.

137. Dimberg U, Thunberg M, Grunedal S. Facial reactions to emotional stimuli: Automatically controlled emotional responses. Cogn Emot. 2002 Jul;16(4):449–71.

138. de Wijk RA. Temporal factors in human olfactory perception. Doctoral dissertation. State University of Utrecht, The Netherlands; 1989.

139. Olofsson JK, Bowman NE, Khatibi K, Gottfried JA. A time-based account of the perception of

odor objects and valences. Psychol Sci. 2012 Oct;23(10):1224–32.

140. Lundström JN, Boesveldt S, Albrecht J. Central Processing of the Chemical Senses: An Overview. ACS Chem Neurosci [Internet]. American Chemical Society; 2011 Jan 19 [cited 2015 Sep 7];2(1):5–16. Available from: http://dx.doi.org/10.1021/cn1000843

141. Soudry Y, Lemogne C, Malinvaud D, Consoli S-M, Bonfils P. Olfactory system and emotion: common substrates. Eur Ann Otorhinolaryngol Head Neck Dis. 2011 Jan;128(1):18–23.

142. Stevenson R. An initial evaluation of the functions of human olfaction. Chem Senses [Internet]. 2010 [cited 2013 Mar 31];30(1):3–20. Available from: http://chemse.oxfordjournals.org/content/35/1/3.short

143. Yeshurun Y, Sobel N. An odor is not worth a thousand words: from multidimensional odors to unidimensional odor objects. Annu Rev Psychol. 2010 Jan;61(1):219–41, C1–5.

144. Khan RM, Luk C-H, Flinker A, Aggarwal A, Lapid H, Haddad R, et al. Predicting odor pleasantness from odorant structure: pleasantness as a reflection of the physical world. J Neurosci. 2007 Sep 12;27(37):10015–23.

145. Bensafi M, Rouby C, Farget V, Vigouroux M, Holley A. Asymmetry of pleasant vs. unpleasant odor processing during affective judgment in humans. Neurosci Lett. 2002 Aug;328(3):309–13.

146. Bensafi M, Pierson A, Rouby C. Modulation of visual event-related potentials by emotional olfactory stimuli. Clin Neurophysiol. 2002;32(6):335–42.

147. Bensafi M, Rouby C, Farget V, Bertrand B, Vigouroux M, Holley A. Psychophysiological correlates of affects in human olfaction. Neurophysiol Clin Neurophysiol. 2002 Nov;32(5):326–32.

148. Masago R, Shimomura Y, Iwanaga K, Katsuura T. The Effects of Hedonic Properties of Odors and Attentional Modulation on the Olfactory Event-Related Potentials. J Physiol Anthropol Appl Human Sci. 2001 Apr 10;20(1):7–13.

149. Pause BM, Krauel K. Chemosensory event-related potentials (CSERP) as a key to the psychology of odors. Int J Psychophysiol. 2000 May;36(2):105–22.

150. Grabenhorst F, Rolls ET, Margot C, da Silva MAAP, Velazco MI. How Pleasant and Unpleasant Stimuli Combine in Different Brain Regions: Odor Mixtures. J Neurosci. 2007 Dec 5;27(49):13532–40.

151. Gottfried JA, Deichmann R, Winston JS, Dolan RJ. Functional heterogeneity in human olfactory cortex: an event-related functional magnetic resonance imaging study. J Neurosci. Society for Neuroscience; 2002;22(24):10819–28.

152. Rolls E. Different representations of pleasant and unpleasant odours in the human brain. Eur J Neurosci. 2003;18:695–703.

153. Zarzo M. Psychologic dimensions in the perception of everyday odors: Pleasantness and edibility. J Sens Stud. 2008 Jun;23(3):354–76.

154. Lundström JN, Gordon AR, Alden EC, Boesveldt S, Albrecht J. Methods for building an inexpensive computer-controlled olfactometer for temporally-precise experiments. Int J Psychophysiol. 2010 Nov;78(2):179–89.

155. Rozin P. Preadaptation and the puzzles and properties of pleasure. In: Kahneman D, Diener E, Schwarz N, editors. Well-being: The foundations of hedonic psychology. New York: Russell Sage Foundation; 1999. p. 109–33.

156. Frijda N. Emotions and hedonic experience. In: Kahneman D, Diener E, Schwarz N, editors. Well-being: The foundations of hedonic psychology. New York: Russell Sage Foundation; 1999. p. 190–210.

157. Maier A. Early variety experiece at weaning predicts hedonic reponse (liking) to new foods by infants. In: Maier A, editor. Influence des pratiques d'allaitement et de sevrage sur l'acceptation de flaveurs nouvelles chez le jeune enfant: variabilité intra-et inter-régionale. Dijon: University of Bourgogne; 2007. p. (Chapter IV).

158. Kuilenburg H Van, Wiering M, Uyl M Den. A model based method for automatic facial expression recognition. In: Gama J, Camacho R, Brazdil P, Jorge A, Torgo L, editors. Machine Learning: ECML 2005. Springer Berlin Heidelberg; 2005. p. 194–205.

159. Blundell J, de Graaf C, Hulshof T, Jebb S, Livingstone B, Lluch A, et al. Appetite control: methodological aspects of the evaluation of foods. Obes Rev. 2010 Mar;11(3):251–70.

160. Sørensen LB, Møller P, Flint A, Martens M, Raben A. Effect of sensory perception of foods on appetite and food intake: a review of studies on humans. Int J Obes Relat Metab Disord. 2003 Oct;27(10):1152–66.

161. Mela DJ. Eating for pleasure or just wanting to eat? Reconsidering sensory hedonic responses as a driver of obesity. Appetite. 2006 Jul;47(1):10–7.

162. Hetherington M. Sensory-specific satiety and its importance in meal termination. Neurosci Biobehav Rev. 1996 Jan;20(1):113–7.

163. Hetherington MM, Foster R, Newman T, Anderson AS, Norton G. Understanding variety: tasting different foods delays satiation. Physiol Behav. 2006 Feb 28;87(2):263–71.

164. Rolls BJ, Van Duijvenvoorde PM, Rolls ET. Pleasantness changes and food intake in a varied four-course meal. Appetite. 1984 Dec;5(4):337–48.

165. Guinard JX, Brun P. Sensory-specific satiety: comparison of taste and texture effects. Appetite. 1998 Oct;31(2):141–57.

166. Rolls BJ, Rowe EA, Rolls ET. How sensory properties of foods affect human feeding behavior.

Physiol Behav. 1982 Sep;29(3):409–17.

167. Hams A, Wardle J. The feeling of hunger. Br J Clin Psychol. 1987 May;26(2):153–4.

168. Mattes RD, Friedman MI. Hunger. Dig Dis. 1993;11(2):65–77.

169. Monello LF, Seltzer CC, Mayer J. Hunger and satiety sensations in men, women, boys and girls: a preliminary report. Ann N Y Acad Sci. 1965;131(1):593–602.

170. Murray M, Vickers Z. Consumer views of hunger and fullness. A qualitative approach. Appetite. 2009 Oct;53(2):174–82.

171. O'Doherty J, Rolls ET, Francis S, Bowtell R, McGlone F, Kobal G, et al. Sensory-specific satiety-related olfactory activation of the human orbitofrontal cortex. Neuroreport. 2000 Mar;11(4):893–7.

172. Small DM, Zatorre RJ, Dagher A, Evans AC, Jones-Gotman M. Changes in brain activity related to eating chocolate: from pleasure to aversion. Brain. 2001 Sep 1;124(Pt 9):1720–33.

173. Finlayson G, King N, Blundell JE. Liking vs. wanting food: importance for human appetite control and weight regulation. Neurosci Biobehav Rev. 2007 Jan;31(7):987–1002.

174. Nederkoorn C, Smulders FT, Jansen A. Cephalic phase responses, craving and food intake in normal subjects. Appetite. 2000 Aug;35(1):45–55.

175. Vaz M, Turner A, Kingwell B, Chin J, Koff E, Cox H, et al. Postprandial sympatho-adrenal activity: its relation to metabolic and cardiovascular events and to changes in meal frequency. Clinical science (London, England : 1979). 1995.

176. Yi JJ, Fullwood L, Stainer K, Cowley AJ, Hampton JR. Effects of food on the central and peripheral haemodynamic response to upright exercise in normal volunteers. Heart. 1990 Jan 1;63(1):22–5.

177. Kelbaek H, Munck O, Christensen NJ, Godtfredsen J. Central haemodynamic changes after a meal. Heart [Internet]. 1989 Jun 1 [cited 2015 Sep 29];61(6):506–9. Available from: http://heart.bmj.com/content/61/6/506.short

178. Russell JA. Core affect and the psychological construction of emotion. Psychol Rev. 2003;110(1):145–72.

179. Gutjar S, de Graaf C, Palascha A, Jager G. Food choice: The battle between package, taste and consumption situation. Appetite. 2014 Sep;80:109–13.

180. Dalenberg JR, Gutjar S, Ter Horst GJ, de Graaf K, Renken RJ, Jager G. Evoked emotions predict food choice. PLoS One. Public Library of Science; 2014 Jan 18;9(12):e115388.

181. Brauchli P, Rüegg PB, Etzweiler F, Zeier H. Electrocortical and autonomic alteration by administration of a pleasant and an unpleasant odor. Chem Senses. Oxford University Press; 20(5):505–15.

182. Nederkoorn C, Smulders F, Havermans R, Jansen A. Exposure to binge food in bulimia nervosa: finger pulse amplitude as a potential measure of urge to eat and predictor of food intake. Appetite. 2004 Apr;42(2):125–30.
183. Jager G, Schlich P, Tijssen I, Yao J, Visalli M, de Graaf C, et al. Temporal dominance of emotions: Measuring dynamics of food-related emotions during consumption. Food Qual Prefer. 2014 Oct;37:87–99.
184. Kahneman D. A perspective on judgment and choice: Mapping bounded rationality. Am Psychol. 2003;58(9):697–720.
185. Wilson T. Strangers to ourselves: Self-insight and the adaptive unconscious. Cambridge: The Belknap Press of Harvard University Press; 2002.

Summary

Traditional liking ratings are typically seen as an important determinant in eating behavior. However, in order to better understand eating behavior, we need to first better understand (the dynamic and implicit features underlying) liking appraisal. The aim of this thesis was to investigate the effects of food stimuli varying in sensory modality (smell and taste), pleasantness and intensity, on emotional and physiological responses leading up to liking appraisal. In this thesis the following research questions are addressed:

- Can emotional and physiological responses differentiate between (and within) liked and disliked food stimuli?
- If and how are emotional and physiological responses related to liking appraisal of food stimuli?
- Do emotional and physiological responses reflect dynamic unfolding of liking appraisal of food stimuli?

To determine how liking and intensity are reflected in separate measures of emotional and physiological measurement, responses to pleasant (orange) or unpleasant food odors (fish) varying in intensity were measured discretely using pleasantness ratings, intensity ratings and non-verbally reported emotions, as well as continuously using facial expressions and autonomic nervous system (ANS) responses. Both non-verbal reported emotions and emotional facial expressions were able to discriminate between the food odors with opposing pleasantness and within the same food odor with varying intensity (chapter 2). Odor pleasantness was positively associated with neutral and surprised expressions, and skin temperature, as well as negatively associated with disgusted expressions, heart rate and skin conductance responses. Odor intensity was positively associated with disgusted expressions and heart rate, as well as negatively associated with neutral expressions (chapter 2 & 3). In addition, facial expressions, varying dynamically after odor stimulation, associated best with odor valence and odor intensity at 1250 and 2000 ms, respectively. The correlation between non-verbally rated emotions and facial expressions was greatest during the 2nd second after odor exposure (chapter 2). Continuously measured Facial expressions and ANS responses became odor-specific at different rates over time. Neutral and disgusted facial expressions, as well as heart rate differentiated between odors immediately after the start of the odor presentation within half a second. Surprised, sad and scared expressions became odor specific around 1 s after odor presentation, followed by happy expressions around 2

s. Skin conductance responses differentiated between odors relatively late around 4 s. Skin temperature became odor specific either at the beginning or later phase of odor presentation (chapter 3).

Equally intense food odors with a wider range of valence were then used to further investigate the relation between non-verbally rated emotions, facial expressions and ANS responses. Non-verbally reported emotions, facial expressions and ANS responses correlated with each other best in different time windows after odor presentation: facial expressions and ANS responses correlated best with the explicit emotions of the arousal dimension in the 2^{nd} second of odor presentation, whereas later ANS responses correlated best with the explicit emotions of the valence dimension in the 4^{th} second (chapter 4).

To investigate possible differences between responses to food stimuli differing in sensory modality, facial expressions and ANS responses were measured in response to equally liked breakfast drinks. The results showed that liking was associated with increased heart rate, skin temperature and neutral facial expressions. Intensity was associated with decreased heart rate and skin temperature, as well as increased neutral, sad, angry surprised facial expressions. Moreover, strongest associations with liking were found after 1 second of tasting, whereas strongest associations with intensity were found after 2 seconds of tasting (chapter 5).

To investigate reduced pleasantness of a single food due to consumption, semi-liquid meals with distinct flavors were used to induce sensory-specific satiety and to compare changes in pleasantness after eating to satiety between eaten and uneaten foods. ANS responses, as well as facial expressions of anger and disgust were changed after eating to satiety. Further differences between eaten and uneaten foods, suggesting effects of sensory-specific satiety, were also reflected by changes in skin conductance, skin temperature, as well as facial expressions of sadness and anger (chapter 6).

The general discussion (chapter 7) describes the main findings and conclusions of this thesis. We found that both non-verbal reported emotions and emotional facial expressions were demonstrated to be able to discriminate between food odors differing in pleasantness and/or intensity. Explicit and implicit emotional responses, as well

as physiological patterns are related to liking appraisals involved in smelling foods. Implicit measures such as facial expressions and ANS responses can provide more multidimensional information for both food odors and tastes than explicit measures and prove to be highly dynamic over time with specific time courses. Early implicit facial and ANS responses primarily reflect emotion arousal, whereas later ANS responses reflect emotion valence, suggesting dynamic unfolding of different appraisals of food stimuli. Furthermore, ANS responses and facial expressions can reflect pleasantness, satiety, and a combination of both: sensory-specific satiety. This suggests that implicit processes play an important role in dynamic liking appraisals with respect to eating behavior.

Acknowledgements

Even looking back at the moment over this nearly-five-year period of my life in the Netherlands, I still feel it like 'Vivian's adventures in wonderland'. Of course, it is not only joy that filled in this adventurous journey, but also mixed emotions investigated (or not) in this thesis. Well, the goodwill I received from all the colleagues, friends, and even strangers smiling at the footpath already made it a wonderful experience. I really feel grateful and hope to express at least a small proportion of my appreciation in this chapter.

Back to the beginning of the story, I have to first thank a very important person, Jan Hak, who initiated my interest and courage to start my new life in the Netherlands. Before knowing him, it can be anywhere; after meeting him, it can only be this country. He functioned like a spiritual mentor, not only helping me explore all kinds of options, but also telling fascinating stories which shaped my view of the world and people. He is an wise person to listen to, as well as a great person to become.

With my never-bad luck, I encountered Rene de Wijk as my internship supervisor. He also helped with my application for the PhD position after knowing my willingness to pursue a PhD. Thus our bonding continued from the internship to the subsequent PhD project. Rene is like a superman for me, always there helping and supporting. First, he knows everything, at least with my perspective, but he never shows off. He always knows how to share his knowledge and points of view in a comfortable and humorous way. Second, he is a problem solver. Every time I got stuck, he never hesitated to take over or show me how to handle them properly and effectively. Third, he is a real gentleman. I'll never forget several wonderful trips to international conferences together with Rene. He took care of even trivial things from transportation to accommodation, which made the trips full of fun and new experience. He also frequently asked how I felt about the workload and if everything was fine in my personal life. Even most times it was only a few minutes' catchup, I could feel he was caring and willing to share his own experience. Rene is much more than a supervisor. What he has taught me is also much more than scientific stuff.

I also met my promotor Kees de Graaf before the start of my PhD project. Even my background wasn't quite fit to the project that I was interested in most, he trusted me and gave me the opportunity to fulfill my enthusiasm. He was extremely busy

as a professor and later the chairman of the division, but he was never absent when I needed his advice or help as well. There were two things that gave me very deep impressions. One thing happened during the second summer after the beginning of my PhD project. I had difficulty in writing a paper on my first study at that time. Then Kees met me almost every week to give me specific guidance on scientific writing during a month or two, even when the other two supervisors weren't able to be present. The other thing was at the beginning of my third study. He attended the pilot study as a participant and checked each step. Later during the first test session, he was also present to make sure everything went smoothly. Kees made a good example of a devoted scientist for me. Even if I won't stay in academia one day, I believe his integrity, hard-working and rigorous scholarship will still profoundly influence me.

Sanne Boesveldt also took responsibility as my daily supervisor. The occasion when I first met her happened to be a group gathering. I still remember that sunny afternoon, like the night would never arrive. She looked so young and lively that I couldn't believe she was my supervisor. Soon enough I found her definitely a qualified supervisor. She is highly efficient and played an important role in keeping my studies on track. She could give suggestions precisely to the point and send back her critical feedback within at most two days. Honestly, I was a bit afraid of meeting her at first, since it was kind of stressful to answer her questions or reach her standard. Strangely, as time went by I found I missed her so much and felt empty when she left for holiday. This transformation was probably because she held a responsible attitude to any work she dealt with and in the meantime she became a good friend in my personal life as well. She is always joyful without losing any elegance and easily make others around her feel happy. She provided many useful suggestions, enjoyed moments of good news coming and shared sadness when things turned out disappointing. I like Sanne very much and believe in her success in the tenure track, as well as in her happy life together with Jelle.

Thinking that my thesis committee members probably belong to a small group in the world who read the entire book, I feel particularly grateful. Hopefully, it was a nice experience, although a painful one might make deeper impressions. Herb Meiselman, an influential figure in the field, was a great source of encouragement and inspiration on conferences and courses. Sylvain Delplanque provided valuable information on physiological measures and co-authored a paper with me. Happy to finally see him in person. I would also like to thank Hans van Trijp and Monique Smeets for taking their precious time to participate in my thesis committee and to be present at my graduation.

Without Manon Mensink all my studies would not run so smoothly. She was a great help from recruiting participants and arranging experiment materials to translating experiment instructions and conducting my first experiment with me. I also need to thank Ilse Polet for teaching me how to use Olfactometer step by step. I would like to thank other colleagues from Food and Biobased Research as well. Nancy Holthuysen, Monique Vingerhoeds, Stefanie Kremer, Gertrude Zeinstra, Mariska Nijenhuis-de Vries, Milou Vrijhof, Anke Janssen and Anna Maaskant contributed to a lot of my great experiences during casual lunches, group dinners, studies, courses, conferences, parties, team building activities, and so on. Rick van de Zedde who shared an office with me for a few months let me enjoy Chopin a lot. Nick van Hamersveld, Sanja Damjanovic, Gerwoud Otten and Eric Boer offered inspiring ideas from a different angle. In addition, I want to say thank you to all the secretaries, Keen-Mun Poon, Marion Hetterscheid, Julia van Dongen, Lea te Dorsthorst and Yvonne Blom, who helped with all kinds of organizational things. Lastly, I have to thank Raoul Bino, Annemieke Beers, Marchel Gorselink and Judith van der Horst who made the whole project happen.

Special thanks to PhD fellows who shared the offices with me, Iris van den Bosch, Swetlana Gutjar, Canan Ziylan, Jet Zoon, Inge van Rijn, Louise den Uijl and Suzanne de Bruijn. I enjoyed all the good times and had a lot of fun with them. Thank these girls for all the chattings, drinks, lunches, parties, trips, conferences, help with my studies and personal experiences they share. Their friendliness was of inestimable value for me to get used to working and living in the Netherlands. I feel proud of them and lucky to be their friends. I am also very happy Canan and Louise are my paranymphs and grateful for their efforts.

Also many thanks to my sensory fellows. Thank Sanne Griffioen-Roose, Yfke de Vries, Elbrich Postma, Marlou Lasschuijt, Maria van Delft, Daniëlle Dull and Cristina Proserpio for knowledge exchange and all the great ideas on the study design, test products, research methods and paper revision during ClubSense meetings. Thank

Apple (Pey Sze Teo), Irene Tijssen, Guido Camps, Anika Oppermann, Grace Tan Hui Shan and Ana Patricia Silva for an unforgettable trip to Copenhagen. Thank Marielle Ramaekers and Dieuwerke Bolhuis for helping with the setup of my studies. Thank Monica Mars, Gerry Jager, Markus Stieger and Paul Smeets for encouragement and guidance on my presentation and teaching skills. Thank Pleunie Hogenkamp, Anne Wanders, Anne Wijlens, Coraline Barends, Victoire de Wild, Astrid van Langeveld, Korrie Pol, Janet van den Boer, Judith Derks, Sara Camacho, Marine Devezeaux De Lavergne for catchups at all occasions and participation in my pilot studies.

For a great time at the Division of Human Nutrition, I also want to thank all the other colleagues and PhD fellows. First, I would like to thank the group of PhD fellows who contributed to a wonderful experience of the PhD trip to Australia together. Next, thank Adrienne Cavelaars, Dione Bouchaut, Jantien Takens and Henriette Fick-Brinkhof for their help with METC, as well as Gea Brussen, Cornelia van Bree-Evers and Jasmijn Mater for helping me out with organizational stuff. Then, I want to thank Jan Harryvan for helping with technical issues and sharing amazing stories of his family. Lastly, Els Siebelink and Desiree Lucassen helped a lot in figuring out the appropriate recipe for the test foods of one study.

I also would like to thank all the other people who made my studies possible. Thank Patrick Zimmerman, Leanne Loijens, Pieter van den Boom, Diana Demmer and Hans Theuws from Noldus Information Technology for providing all the technical support. I also have to thank Marielle de Rijk, Linda Kooistra and Narelle Brugman who undertook a great deal of lab work and finished their Master theses during Flair study. Thanks to Daniëlle Dull and Annemarthe Wijnen, the preaprations of test foods for the Face4Food study went quite well.

To all the Chinese friends I met during my PhD: Wei Zheng, Xiaosu Gao, Mingtian Yao, Yuan Zhao, Shengqian He, Hua Zhu, Yongzhi Ji, Yang Yu, Xinxin Wang, Chunxu Song, Wei Qin, Lin Ma, Xia Liu, Dan Yan, Yong Hou, Yiliya, Lina Zhang, Wei Lu, Fahui Liu, Yongfu Tang, Daohong Yang, Xu Cheng, Feng Zhu, Kun Liu, Lingmin Tian, Yuxi Deng, Fangjie Gu, Jinfeng Peng, Min Chen, Yinghua Xiao, Ya Wang, Ran Gao, Zhaohai Bai, Weijie Guo, Fang Gou, Junqi Zhu, Jingmeng Wang, Sha Wei, Qian Liu, Xuan Xu, Wenfeng Cong, Jingying Jing, Junfei Gu, Guohua Li, Liansun Wu, Hongming Zhang, Lemeng Dong, Lisha Zhang, Chenlei Hua, Yu Du, Tingting Li, Chuchu Liu, Aiguo Ma, Yuping Zhang, Wenjie Yang, Yimin Deng, Xiao Pan. I want to thank them all for the good times in Wageningen filled with dinners, barbeques, drinks, parties ...

Particular thanks to old buddies whom I still met in the Netherlands. Jing Lu and Jing Luo showed me around and helped me settle down when I went abroad for the first time. Xiayan Shen, Qiong Zhang and Ya Liu paid me a visit and illustrated a pleasant surprise. Also thank Mr Feng Bin for his countless help during these years and for several pleasant visits to me. Lastly, thank Jihong Wu and Xiaosong Hu, my supervisors during Master's program. Although the trip was canceled at last, I'm glad to be one of the reasons for their intention to come.

Unlike most of the other parents who don't want their children to be distant, my parents 'kicked' me out of my comfort zone. Like most of the other parents, my parents never missed a single piece of the cheerful or sad episodes in my life. Thanks to Skype we met each other every week face to face. Distance made us even closer. Just like lyrics sang in a song "You raise me up, so I can stand on mountains; You raise me up to walk on stormy seas; I am strong when I am on your shoulders; You raise me up to more than I can be", they paved the way from the past to my future.

Last but not least, I want to thank my husband DuDu (Bruce) for everything he has done for us and every minute we spent together. He was always there for me, suspending his own career to accompany me, being optimistic to make me happy, sharing all the feelings, listening to all my worries, trying hard to deal with my complaints, taking care of all the housework, driving me to every dreaming place…His love and effort have made us an indivisible whole.

About the author

Curriculum vitae

Wei He was born on October 28th, 1984 in Nei Mongol, China. After finishing her high school in Bayannaoer City Middle School in 2002, she started the Bachelor's program of Food Science and Engineering at China Agricultural University in Beijing. She received her Bachelor's degree in 2006 and enrolled in the Master's program of Agricultural Products Processing and Storage Engineering at China Agricultural University thereafter. She completed her Master's thesis in the National Engineering Research Center of Fruit and Vegetable Processing, focusing on the correlation between sensory evaluation and instrumental analysis by HPLC, NIR and electronic tongue for Chinese tea, which resulted in a publication in the journal Food Research International. She graduated in 2009 for her Master's degree.

Wei visited the Netherlands in 2010 for an internship at the institute of Food & Biobased Research of Wageningen University & Research Centre. She explored methods measuring texture perception with Electromyography. Subsequently, she was appointed as a PhD candidate at Food & Biobased Research and the Division of Human Nutrition of Wageningen University & Research Centre in 2011. Her research focused on the psychological and physiological measurement of food induced emotions. During her PhD project, Wei joined the educational program of the graduate school VLAG and attended several international conferences and courses. Furthermore, she participated in teaching practical's as well, supervising two master students and assisting a few master courses as either an assistant or a lecturer.

List of publications

Publications in peer-reviewed journals

He W, Boesveldt S, de Graaf C, de Wijk RA. Dynamics of autonomic nervous system responses and facial expressions to odors. Front Psychol. 2014;5:110.

He W, Boesveldt S, de Graaf C, de Wijk RA. The relation between continuous and discrete emotional responses to food odors with facial expressions and non-verbal reports. Food Qual Prefer. 2016;48:130–7.

de Wijk RA, **He W**, Mensink MGJ, Verhoeven RHG, de Graaf C. ANS Responses and Facial Expressions Differentiate between the Taste of Commercial Breakfast Drinks. Matsunami H, editor. PLoS One. 2014;9:e93823.

Zoon HFA, **He W**, de Wijk RA, de Graaf C, Boesveldt S. Food preference and intake in response to ambient odours in overweight and normal-weight females. Physiol Behav. 2014;133:190–6.

Submitted papers for publication

He W, Boesveldt S, de Graaf C, Delplanque C, de Wijk RA. New insights into sensory-specific satiety from autonomic nervous system responses and facial expressions.

He W, de Wijk RA, de Graaf C, Boesveldt S. Implicit and explicit measurements of affective responses to food odors.

Abstracts and presentations

He W, Boesveldt S, de Graaf C, de Wijk RA. Behavioural and physiological responses to two food odours. Appetite. 2012;59:628. 36th Annual Meeting of the British Feeding & Drinking Group, 2012, Brighton, UK, oral presentation.

He W, Boesveldt S, de Graaf C, de Wijk RA. Implicit and explicit measures of emotions in response to odors. 34th Annual Meeting of the Association for Chemoreception Sciences, 2012, Huntington Beach, USA, poster presentation.

He W, Boesveldt S, de Graaf C, de Wijk RA. The effect of positive and negative food odours on human behavioural and physiological responses. 5th European Conference on Sensory and Consumer Research, 2012, Bern, Switzerland, oral poster presentation.

He W, Boesveldt S, de Graaf C, de Wijk RA. Temporal Development of Facial Expressions and Autonomic Nervous System Responses to Food Odors. 6th European Conference on Sensory and Consumer Research, 2014 , Copenhagen, Denmark, poster presentation.

He W, Boesveldt S, de Graaf C, de Wijk RA. Behavioral and physiological responses to sensory-specific satiety. 39th Annual Meeting of the British Feeding & Drinking Group, 2015, Wageningen, The Netherlands, poster presentation.

He W, Boesveldt S, de Graaf C, de Wijk RA. How do you really feel after eating: results of explicit and implicit tests. 11th Pangborn Sensory Science Symposium, 2015, Gothenburg, Sweden, poster presentation.

Overview of completed training activities

Discipline specific courses and activities

Summer School on Human Olfaction V, 2011 (Dresden, Germany)

36th Annual Meeting of the British Feeding & Drinking Group, 2012 (Brighton, UK)

34th Annual Meeting of the Association for Chemoreception Sciences, 2012 (Huntington Beach, USA)

5th European Conference on Sensory and Consumer Research, 2012 (Bern, Switzerland)

Course 'Sensory Perception and Food Preference', 2013 (Wageningen, The Netherlands)

Course 'Drivers of Liking and Emotion Mapping', 2013 (Brussels, Belgium)

Course 'Sensory Evaluation and Food Preferences', 2014 (Copenhagen, Denmark)

6th European Conference on Sensory and Consumer Research, 2014 (Copenhagen, Denmark)

39th Annual Meeting of the British Feeding & Drinking Group, 2015 (Wageningen, The Netherlands)

11th Pangborn Sensory Science Symposium, 2015 (Gothenburg, Sweden)

General courses and activities

Course 'English III speaking and listening', 2012 (Wageningen, The Netherlands)

Course 'Academic Writing II', 2012 (Wageningen, The Netherlands)

Course 'Philosophy and Ethics of Food Science and Technology', 2013 (Wageningen, The Netherlands)

Course 'Project and Time Management', 2013 (Wageningen, The Netherlands)

Course 'Scientific Writing', 2014 (Wageningen, The Netherlands)

Optional courses and activities

Preparation of research proposal, 2011 (Wageningen, The Netherlands)

Staff seminars, 2011-2015 (Wageningen, The Netherlands)

PhD excursions, 2013 (Australia)

Colophon

The research described in this thesis was financially supported by Hak&Partners B.V..

Financial support from Wageningen University for printing this thesis is gratefully acknowledged.

Cover design and layout
Wei He

Printing
Printed by Digiforce – Proefschriftmaken.nl Vianen