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Measuring cooking experience implicitly and explicitly: Physiology, facial expression and subjective ratings

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ABSTRACT

Understanding consumers' emotional experience during the process of cooking is important to enable the development of food products. In addition to verbal ('explicit') reports, physiological variables and facial expression may be helpful measures since they do not interfere with the experience itself and are of a continuous nature. This study investigated the potential of a range of implicit and explicit measures (1) to differentiate between subtle differences in pleasantness of ingredients, and (2) to identify emotionally salient phases during the process of cooking. 74 participants cooked and tasted a curry dish following standardized timed auditory instructions, either with 'basic' or 'premium' versions of ingredients. Heart rate, skin conductance, EEG and facial expression were recorded continuously during cooking and tasting. Subjective ratings of valence and arousal were taken directly after. Before and after cooking, participants performed 'dry cooking' sessions without ingredients to acquire changes in the physiological variables caused by physical activity only. We found no differences between the 'basic' and 'premium' groups, neither in implicit, nor in explicit measures. However, there were several robust physiological effects reflecting different cooking phases. Most notably, heart rate was relatively high for two specific phases: adding curry paste from a sachet during cooking, and tasting the prepared dish. The verbal reports of valence and arousal showed similar patterns over phases. Thus, our method suggests that physiological variables can be used as continuous, implicit measures to identify phases of affective relevance during cooking and may be a valuable addition to explicit measures of emotion.

1. Introduction

Emotional experience has been identified as one of the crucial factors in determining the choice of food products (Cardello et al., 2012; Dalenberg et al., 2014; Kuenzel et al., 2010). Evaluating food products with respect to emotion is commonly done by evaluating consumers' response to the package or to the taste of a product. The consumers' interaction with food, such as preparing and cooking the dish leading up to consumption, has not been well studied. A challenging factor is that interacting with food, i.e. cooking, seeing, smelling and tasting it, is a continuous process that can be associated with changing emotional experiences. Seeing butter melt in the pan, smelling the scent of stir frying onions or spices, and tasting the dish can be pleasant and relatively exciting compared to e.g. waiting for water to boil. If we want to (re-)formulate products to create positive experiences during cooking and eating, we need to view and study these food experiences as a continuous process. Individuals can be asked to describe their experience afterwards, using questionnaires or interviews, or they can verbally describe their experience during the process. While this is a sensible method that is cost-effective, discriminative and relatively easy to use (Churchill & Behan, 2010; Dorado, Chaya, Tarrega, & Hort, 2016), verbal reports suffer from certain weaknesses, especially when used for describing past experiences and when a continuous measure is needed. When asked to describe experiences that happened earlier, retrospective biases may occur (Moskowitz & Young, 2006; Trull & Ebner-Priemer, 2013). Verbally describing experience as it happens can affect the experience itself (Wilson et al., 1993), which is undesirable when one is interested in the normal daily experience. Furthermore, emotions

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can be difficult to verbalize (Köster & Mojet, 2015), where the 'emotional' lexicon also varies across individuals, cultures and languages, particularly when it comes to foods (Gutjar et al., 2015; Prescott, 2017). Finally, verbal self-reports have been argued to only reflect emotions that individuals want to socially communicate (Picard & Daily, 2005), and to only capture conscious, declared opinions (Venkatraman et al., 2015; Winkielman, Berridge, & Sher, 2011). We are therefore interested in additional measures that can help fill this gap (Kaneko, Toet, Brouwer, Kallen, & van Erp, 2018), i.e., implicit (unconscious), continuous measures that can be harnessed to monitor experiences during the cooking process and during eating. Ultimately, this may support product developers to design and adapt products that bring out the best overall food experience in consumers, reducing boring or annoying episodes in cooking, and capitalizing on arousing, pleasant elements.

In an earlier study (Brouwer, Hogervorst, Grootjen, van Erp, & Zandstra, 2017), we recorded EEG, ECG and electrodermal variables while participants were cooking the same dish in two conditions. The only aspect that varied between the conditions was the main ingredient: either chicken or mealworms. These ingredients were chosen to induce different emotions during cooking. While recording physiological variables in real-life circumstances is challenging, we found differences between the emotional conditions. Using a machine learning model with EEG alpha asymmetry, ECG and electrodermal variables as input, we could estimate with 82% accuracy whether a single participant was in the chicken or mealworm condition. This study provided evidence that it is possible to estimate experienced emotion during real-life cooking and tasting based on implicit physiological measures.

In the current study, we built on the previous cooking experiment (Brouwer, Hogervorst et al., 2017) and investigated emotional experiences during cooking with less extreme, more realistic stimuli that differed more subtly in expected affective experience than mealworms and chicken. Two groups cooked and tasted two stir-fried curry dishes: the 'basic' group cooked with regular brands, dried herbs and canned vegetables; the 'premium' group cooked with premium brands, fresh herbs and fresh vegetables. We investigated for a number of variables whether they are sensitive enough to distinguish between both groups. In addition, we explored emotional experience as reflected by implicit variables as it varies across cooking phases. Verbal explicit measures were recorded as a comparison.

While, as described above, verbal, explicit measures for measuring emotional experience have their problems, implicit variables have their own drawbacks. Implicit variables that convey information about emotion are usually affected by other processes as well. Notably, physiological variables such as heart rate are associated with body movements. This can obscure effects of mental processes on physiology, or, in case of confounds, changes in physiology that are thought to be caused by emotion can actually be caused by body movement (Brouwer, Zander, van Erp, Korteling, & Bronkhorst, 2015). Thus, when investigating affective experience using implicit variables during cooking with different ingredients of interests, one should take care that body movements are the same, and that the only aspect that differs are these ingredients. When one aims to use implicit variables to study differing affective experience across cooking phases, such equalizing of body movements is not possible. We here explore for the first time whether different implicit variables systematically vary across cooking phases. Furthermore, we used a new approach to take the effect of body movements into account by comparing our physiological data to data as acquired in 'dry cooking' sessions where participants made similar movements as during 'real cooking' sessions but without ingredients, and thus, without the emotional experience associated with real cooking.

The implicit variables under study were heart rate, electrodermal activity (phasic skin conductance), EEG frontal alpha asymmetry and facial expression. With respect to explicit variables, participants were asked to indicate their experienced level of valence and arousal. While affective experience can also be viewed in the light of discrete emotions such as fear, disgust and happiness (Ekman & Friesen, 1971), we chose to view affective experience in the light of the 'core affect' circumplex model of valence and arousal (Russell, 1980). In this model, emotions can be characterized along the axis of valence (pleasantness) and arousal (intensity of the emotion). As recently reviewed in the context of sensory and consumer research (Prescott, 2017), this model evades certain problems associated with discrete emotions such as unclarity about which are the relevant emotions. It also facilitates linking affective experience to (neuro)physiological variables, where especially arousal has been shown repeatedly to be detectable using physiological variables. Even so, linking affective experience to (neuro)physiological variables is a hard endeavor. While physiological variables and affective experience can be associated reliably within a given context, links between emotion and (neuro)physiological variables do not always generalize across situations (Dockray & Steptoe, 2010; Kreibig, 2010). It is therefore important to study these links within the context of interest, in this case cooking. Below, heart rate, electrodermal activity, EEG frontal alpha asymmetry and facial expression are discussed in terms of their relation between valence and arousal, with a focus on tasting and cooking.

In the context of viewing emotional images, heart rate has repeatedly been shown to accelerate when pleasant pictures were shown (Greenwald, Cook, & Lang, 1989; Lang, Greenwald, Bradley, & Hamm, 1993). However, this positive association between valence and heart rate does not hold across contexts. For example, Kreibig (2010) reports in her review that contentment generally goes together with decreased heart rate, while joy is associated with increased heart rate, and anticipatory pleasure has been associated with both increases and decreases in heart rate. Film induced 'crying sadness' shows an increased HR, and 'non-crying sadness' a decreased heart rate. While these examples suggest a closer relation between arousal and heart rate than valence and heart rate, also for arousal, a mixed picture emerges. Both positive and negative associations with heart rate have been found (where it is not possible for all studies to disentangle arousal and valence). Examples of increasing heart rate with arousal include social anxiety (Brouwer & Hogervorst, 2014; Kirschbaum, Pirke, & Hellhammer, 1993), recalling emotional (versus neutral) memories (Cuthbert et al., 2003; Rainville, Bechara, Naqvi, & Damasio, 2006; Vrana & Lang, 1990), and in the context of food, tasting arousing drinks (Kaneko et al., submitted), or smelling unpleasant odors and tasting disliked foods (He, Boesveldt, de Graaf & de Wijk, 2014; de Wijk, Kooijman, Verhoeven, Holthuysen, & de Graaf, 2012). Examples of decreasing heart rate and arousal are reading emotional sections in a book (Brouwer, Hogervorst, Reuderink, Van Der Werf, & Van Erp, 2015), and viewing negatively valenced images (Bradley & Lang, 2000). The negative relation between arousal and heart rate is possibly mediated through a negative relation between heart rate and sensory attention (or the orienting reflex) (Graham & Clifton, 1966; Sokolov, 1963). In our previous cooking experiment, no consistent effect of affective condition (where mealworms represent high arousal, low valence; chicken low arousal, high valence) on heart rate was found. Still, heart rate may be informative in an experiment with a more modest emotional manipulation or for identifying arousing phases during the cooking process.

Electrodermal activity is mainly affected by activity of the sweat glands (Andreassi, 2007). Production of sweat increases conductivity of current through the skin, which can be measured. Sweat glands are exclusively innervated by the 'fight or flight' sympathetic branch of the autonomous nervous system (Benedek & Kaernbach, 2010; Dawson, Schell, & Filion, 2007). Strong activation of the sympathetic system relative to the parasympathetic 'rest-and-digest' autonomous nervous system reflects physiological arousal, and electrodermal activity is thus seen as a good measure of arousal (Roth, 1983). In line with this, studies show a consistent positive relation between electrodermal activity and arousal (Boucsein, 1992, 1999) rather than the mixed picture that emerges from studies relating emotion to heart rate as described above.

A few tasting studies reported stronger electrodermal responses for highly arousing (unpleasant) drinks (de Wijk et al., 2012; Kaneko et al., submitted). Also, our previous cooking study showed higher electrodermal activity when cooking with mealworms compared to cooking with chicken.

Frontal alpha asymmetry as extracted from EEG brain signals may provide information akin to experienced valence. This variable reflects the asymmetric frontal cortical activation where the inverse of EEG alpha power (8–13 Hz) is taken as an indication of regional brain activation (Cook, O'Hara, Uijtdehaage, Mandelkern, & Leuchter, 1998). In a review by Harmon-Jones, Gable, and Peterson (2010), this variable is argued to reflect approach and avoidance motivation. EEG asymmetry studies on pictures of desserts showed greater left activation for individuals with stronger approach motivation (longer time since eaten, more liking for dessert; Harmon-Jones & Gable, 2009; Gable & Harmon-Jones, 2008). Also in our previous cooking study, we found the expected effect on alpha asymmetry of cooking with chicken (approach) and mealworms (avoidance).

Several studies on judging food taste and odor provide evidence that facial expression, as recorded with a camera and interpreted using dedicated software, correlates with explicit ratings (Danner, Sidorkina, Joechl, & Duerrschmid, 2014; de Wijk et al., 2012; de Wijk, He, Mensink, Verhoeven, & de Graaf, 2014; Garcia-Burgos & Zamora, 2013; He, Boesveldt, de Graaf, & de Wijk, 2016). Reported associations are not always as one would intuitively expect. Notably, it has been found that all facial expressions tend to become more intense for relatively unpleasant tastes, even positive facial expressions such as happiness, while there is not much facial expression in general for relatively pleasant tastes (Danner et al., 2014; de Wijk et al., 2012; de Wijk et al., 2014; He et al., 2016). Danner et al. (2014) contend that facial expression should be examined in a more real-life situation rather than during explicit judging tasks, which requires concentration and analytical thinking. It has also been noted that facial expression may be less informative and more difficult to interpret when individuals are tasting alone, without social interaction (He et al., 2016; Zeinstra, Koelen, Colindres, Kok, & De Graaf, 2009). The current experiment reflected a new, real-life case where participants smell, taste and interact with food without being asked for explicit judgements during the task. They were not alone in the room and they may have realized they were being observed, but there was no social interaction with others during the task. In line with the design of our study, we focused on the facial expressions of valence and arousal.

In sum, in the current study we investigated the potential of several implicit measures to provide continuous information about affective experience during cooking. We compared two pleasantness conditions where the 'premium' group of participants cooked with ingredients that were expected to be perceived as slightly more pleasant than the ingredients that the 'basic' group of participants cooked with. We examined whether and which implicit and explicit measures reflect higher valence and perhaps higher arousal in the premium group compared to the basic group. For physiological measures, this would come down to a higher heart rate, higher skin conductance, and positive alpha asymmetry for the premium compared to the basic condition. Previous studies on facial expression in judging food reported little facial activity for pleasant tastes and scents. Since both our groups cooked a pleasant dish, we may not find effects in facial expression. However, given that the current experiment reflects natural interaction with food, without a concurrent explicit judgment task, we may still find higher facial valence and arousal in the premium group than in the basic group. Furthermore, we examined the data across cooking phases for an impression of whether and how continuous, implicit measures vary as a function of auditory instruction and time for dry and real cooking. Do we observe changes in implicit variables that cannot be ascribed to effects of movements or other factors in principle unrelated to emotion? If so, how do these relate to emotion as indicated by explicit ratings of valence and arousal?

2. Materials and methods

2.1. 1 Participants

Participants were recruited through the participant pool of the research institute where the study took place (TNO) and social media. Inclusion criteria were aged between 18 and 55 years and self-reported right-handedness. Right-handedness was a criterium to keep the predefined locations of cooking utensils and ingredients relative to the dominant hand constant across participants. Participants were also required to have cooking experience (defined as cooking at least 2 days per week, for over 15 min at a time). Exclusion criteria were being vegetarian, having food allergies, having a history of cardiovascular, psychiatric, or neurological diseases and use of psychopharmaca. A total of 78 participants (54 female) completed the experiment. Participants were randomly allocated to the premium or the basic group. Due to problems with the ECG measurement 4 participants (3 female) were dismissed from the analyses, resulting in a set of 74 participants that was used for the analyses: 39 in the 'premium' and 35 in the 'basic' group. Participants received a monetary reward to compensate for time and travel costs. All participants signed an informed consent form in accordance with the Helsinki Declaration of 1975 as revised in 2014 (World Medical Association, 2014), before participating in the study. The study was approved by the TNO institutional review board (TCPE).

2.2. Task and design

Participants cooked and tasted a stir-fried red Thai chicken curry dish following strictly timed auditory instructions that guided them through the cooking process (Table 1). Before and after cooking, they performed a 'dry cooking' session, again following timed auditory instructions (Table 2). The purpose of this was to have participants perform movements similar to the movements performed during real cooking, but without the affective experience associated with cooking. The same utensils were used, but rather than real food, participants used paper balls or confetti, or they pretended to add food using sealed or empty packages. For the liquid baking product, a visibly sealed bottle was used, for the coconut milk an unopened tetra package, and an empty curry paste bag for curry. No brand or content information was visible in the dry cooking sessions.

In the premium group, fresh ingredients and high end brands were used while in the basic condition, canned or dried ingredients and basic brands were used (details are in Table 1). Otherwise, the cooking ingredients and procedures were identical.

2.3. Materials

2.3.1. Cooking utensils, ingredients and auditory instructions

The experiment took place in a kitchenette at the research institute (see Fig. 1AB). Kitchen utensils, dishes and locations of the (pre-cut) ingredients were the same for all participants, and the same between real and dry cooking as far as possible. Dishes (bowls, plate) were white stoneware. Cooking instructions were mp3 files played at specified times using a custom-made program. Speakers were used to ensure that instructions were well intelligible.

2.3.2. Questionnaires

After cooking and tasting, participants filled out two questionnaires, presented on a screen that was located over the cooking plate in front of them (Fig. 1B).

The first one was the valence and arousal questionnaire. Participants judged their affective experience during several cooking phases (printed in italics in Table 1) using 9-point Self-Assessment Manikin (SAM) scales of Bradley and Lang (1994) for valence and arousal. They were asked to go back in their mind to the time that they

Table 1
Cooking instructions and differences between the premium and basic group. Differences in affective experience between the groups are expected during the five phases in which the ingredients differ, as well as in the tasting phase. Phases that participants were asked to explicitly judge later with respect to experienced valence and arousal are printed in italics.

Event number	Duration (s)	Auditory instruction	Ingredient specifics	
			premium	basic
1	30	*Stand still and calm*		
2	5	Press button 1 on the cooking plate		
3	8	Press button 2 on the cooking plate		
4	8	Press button 3 until the cooking plate is on heating level 8		
5	10	*Add a squeeze of the liquid baking product into the cooking pan*	Opened plastic bottle high-end brand	Opened plastic bottle basic brand
6	15	Divide the baking product in the cooking pan		
7	20	Press button 4 until the cooking plate is on heating level 7		
8	75	*Add the chicken into the cooking pan and stir-fry the chicken. Keep stir-frying*	Diced chicken filet	
9	10	Press button 4 until the cooking plate is on heating level 5		
10	55	Keep on stir-frying		
11	30	Add the onions and keep on stir-frying	Diced onion	
12	60	*Add the baby corn and keep on stir-frying*	Fresh baby corn, cut in quarters, in bowl	Baby corn from can in bowl
13	60	*Add the curry paste and keep on stir-frying*	Plastic opened sachet with Thai red curry paste	
14	45	*Pour the coconut milk into the cooking pan and keep on stir-frying*	High-end brand, opened tetra package	Basic brand, opened tetra package
15	75	Press button 4 until the cooking plate is on heating level 3		
16	8	*Add the tomatoes and keep on stir-frying*	Diced fresh tomatoes in bowl	Diced canned tomatoes in bowl
17	120	Let the dish simmer. Occasionally stir in the cooking pan		
18	15	Press button 1 to turn of the cooking plate		
19	30	*Sprinkle chives over the dish*	Chopped fresh chives in bowl	Dried chives in bowl
20	20	Use the spatula to pace a scoop of the dish onto the plate		
21	45	*Stand still and calm while the dish is cooling down*		
22	20	*Take a bite of the dish*		
23	5	This is the end of this part of the experiment		

were cooking, and rate their feeling during the requested phase with respect to 'feelings of pleasantness' (valence) and 'feelings of calmness, apart from pleasantness' (arousal). For arousal, the examples of 'stressed' and 'excited' were given for the high arousal end of the scale, and 'calm, relaxed, sleepy, bored' for the low arousal end of the scale. This questionnaire was filled out immediately after cooking and tasting.

After the second dry cooking phase, at the end of the experiment, participants filled out the second questionnaire. They were asked to indicate how much they liked to use one ingredient over the other for the premium and basic version of the ingredients that differed between the groups (liquid baking product, corn, coconut milk, tomatoes and chives). For each of these ingredients, a picture of each version was presented at one of both ends of a horizontal line, with a slider in the center. Using the mouse, participants dragged the slider to the location that best indicated their relative preference. The line did not show visible labels but was transformed to a scale with 1 signifying the end of the scale closest to the basic version of the product, and 9 signifying the end of the scale closest to the premium version of the product.

2.3.3. Recording equipment

EEG (for frontal alpha asymmetry), ECG (for heart rate) and electrodermal activity (for phasic skin conductance) were recorded using a Biosemi Active Two MkII system (BioSemi B.V., Amsterdam, the Netherlands), with a sampling frequency of 512 Hz. For EEG, 32 active silver-chloride electrodes were placed according to the 10–20 system. ECG electrodes were placed on the right clavicle and on the lowest floating left rib. Electrodermal activity was measured by placing gelled electrodes on the lower phalanges of the index finger and the middle finger of the non-dominant (left) hand. Three Panasonic CCTV WV-CP 150E cameras (Panasonic Corporation, Osaka, Japan) were used to obtain a top view, a side view and a frontal view recording. The data from the frontal view camera was used in this study to extract facial expression. A Mio Fuse watch (Mio Technology, Taipei, Taiwan) was attached to the left wrist to validate heart rate as obtained using this wearable device by comparing it heart rate as extracted from ECG signals (results not described here). In the current manuscript, we only use heart rate as extracted from ECG. Three Shimmer Inertial Measurement Units (Shimmer, Dublin, Ireland) were attached using

Table 2
Dry cooking instructions and specifics. As indicated by multiple event numbers in the first column, some instructions were repeated.

Event number	Duration (s)	Auditory instruction	Targeted cooking comparison
1	30	Stand still and calm	Stand still
2, 3, 4	10	Press button 2 on the cooking plate	Press button
5, 6	12	Pretend to add a squeeze of water from the bottle into the cooking pan	Add liquid baking product
7	10	Add the balls of paper from bowl 1 into the cooking pan	Add chicken, onion, corn, tomatoes
8	10	Add the balls of paper from bowl 2 into the cooking pan	Add chicken, onion, corn, tomatoes
9	15	Pretend to squeeze the content of the bag into the cooking pan	Add curry paste
10, 11	10	Sprinkle a little bit of confetti in the cooking pan	Sprinkle chives
12	60	Pretend to stir-fry the balls of paper and confetti	Stir-fry
13, 14	15	Pretend to pour the liquid from the tetra package into the cooking pan	Pour coconut milk
15, 16	15	Scoop with the spatula some balls of paper and confetti on the plate	Scoop dish
17, 18	10	Pretend to take a bite with the spoon	Take bite
19	30	Stand still and calm	Stand still
20	30	This is the end of this part of the experiment	

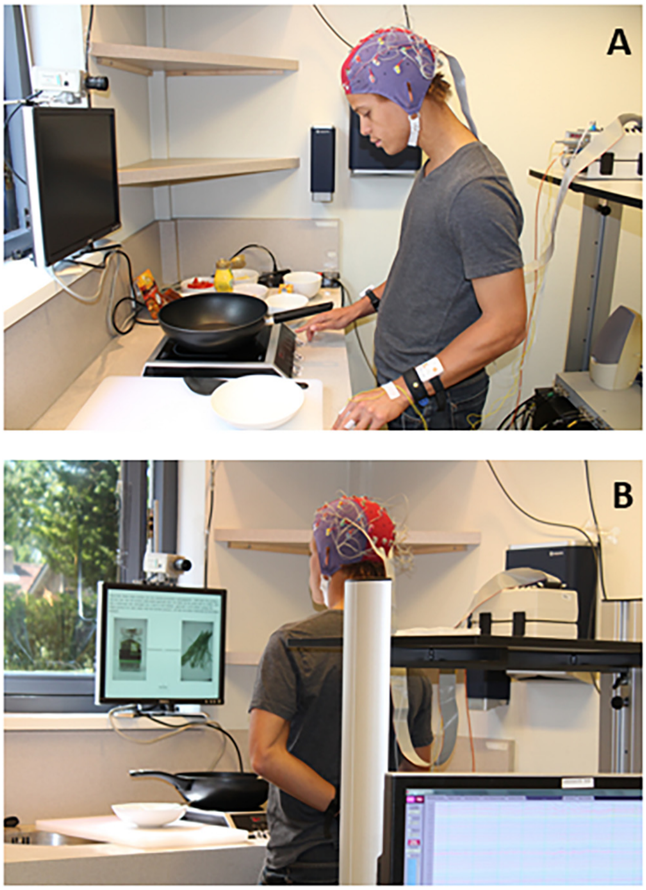

Fig. 1. Depiction of the setup as viewed just before cooking started (A) and when answering the questionnaire comparing the ingredients (B).

Velcro straps to the right wrist, the left wrist and the right hip. These data were collected in case differences were found between the pleasantness groups, so that we would be able to check whether these differences could have been caused by differences in movement. They also served the purpose of giving an overall impression of the amount of movement over the experiment.

2.4. Procedure

Participants received an explanation about the study, mentioning that it was about physiological signals during cooking and tasting. The dry cooking was explained as 'as if' cooking that was important to us to capture physiological signals that were associated with cooking movements, without the food actually being present. In an effort to have participants understand all auditory instructions immediately and respond to them in a similar way, participants read all auditory instructions that they were to receive and they were explained in detail. Participants were encouraged to ask questions, signed an informed consent form and filled out the short generic questionnaire. Then, they were fitted with the sensors. Participants were asked to not speak during the experiment unless absolutely necessary, to avoid excessive movements and to not exert pressure on the skin conductance sensors. After the first dry cooking session, the experiment leader replaced the dry cooking materials with real cooking materials according to whether the participant was assigned to either the premium or the basic group. Subsequently, the participant carried out the real cooking and tasting session. After finishing this, he or she answered the valence and arousal questionnaire on the different cooking phases. Then, the experiment leader switched the real cooking material for dry cooking material, and a second dry cooking session was performed. At the end of the experiment, participants filled out the questionnaire comparing the basic and premium ingredients. Sensors were detached and participants debriefed. Participants were offered to take the packaged curry home.

2.5. Extracting variables and excluded data

Values of each of our variables of interest (heart rate, phasic skin conductance, alpha asymmetry, facial valence, facial arousal and acceleration of the right wrist) were extracted from the raw data for each second during the dry and real cooking blocks (except for alpha asymmetry where 5 s intervals were used). Data were baselined by subtracting each participant's mean value (or in case of EEG, the median value) as recorded during the two dry cooking phases. This procedure 'shifted' the continuous data trace for each participant and each variable such that it centered around its overall value during dry cooking (i.e., during performing movements without the experience associated with cooking food). This facilitates the comparison of the data between groups since it reduces differences between participants that are unrelated to emotion, namely, individual differences in variables during performing cooking movements, and drift over time (differences between the first and second dry cooking session that may be caused by time related effects non-specific to emotion, see e.g. Brouwer, Hogervorst, et al., 2015). The reason that the median rather than the mean was used in EEG was to reduce the effect of datapoints that may be considered outliers.

For physiological data, segments that were unrealistic were excluded from analysis. What was considered unrealistic is specified for each variable below. Such segments were spread across participants and phases. Below the percentage of left-out data is indicated per variable. For facial expression, accelerometry and subjective reports data could not be recovered for a few participants, as further specified below.

2.5.1. Heart rate

The Matlab Implementation of Pan Tompkins ECG QRS detector (Sedghamiz, 2014) was used to extract inter beat intervals from the ECG signal. Of the data, 2% of the inter beat intervals was considered invalid and removed from analysis. Inter beat intervals were converted to heart rate.

2.5.2. EEG alpha asymmetry

Using EEGlab (Delorme & Makeig, 2004), the signals were referenced to the average EEG signal, bandpass filtered between 0.5 and 43 Hz and resampled to 256 Hz. We followed the same procedure to compute alpha asymmetry as we used in our earlier studies that demonstrated a link between affect and alpha asymmetry (reading: Brouwer, Hogervorst, et al., 2015; cooking: Brouwer, Hogervorst et al., 2017). Measurement intervals were divided in 5 s intervals. Only intervals with EEG signals that were between −100 and 100 microvolt were considered reliable. For each 5-second interval, spectral power in the alpha band (between 8 and 13 Hz) was determined for F7 (left frontal electrode) and F8 (right frontal electrode). Besides the outlier criterion as just defined, intervals with data that were > 5*standard deviation from the median value, as observed within a participant, were considered to be outliers and removed from analysis. Subsequently, the same criterion was applied to the data of all participants as a group. The total proportion of excluded data in the 74 participants was 6% in real cooking and 8% in dry cooking. Then, alpha asymmetry was computed as the difference in power between the right (F8) and left (F7) hemisphere relative to the total power: $((R - L)/(R + L))*00$ (Papousek et al., 2014). Positive values indicate lower alpha power in the left than in the right hemisphere (i.e., relatively greater left hemisphere cortical activity). The same alpha asymmetry steps were also followed using 1 s intervals rather than 5 s intervals. This did not lead to essentially different results.

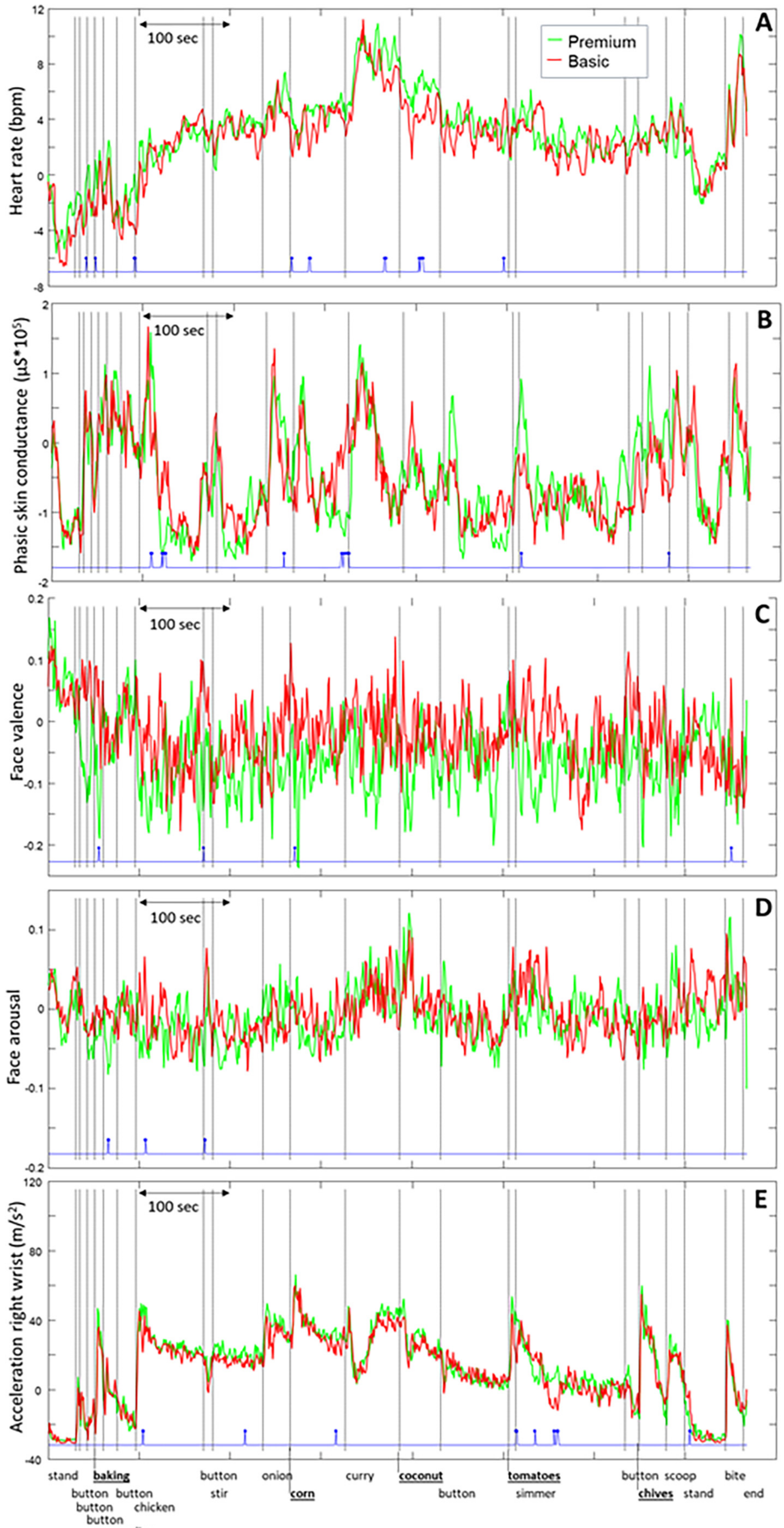

Fig. 2. Baselined heart rate (A), phasic skin conductance (B), facial valence (C), facial arousal (D) and movement of the accelerometer on the right wrist (E) over time in the real cooking session. The two groups of participants (premium and basic) are presented separately. Bold, underlined phases indicate phases in which products differed between the groups. Peaks in the horizontal blue lines indicate instances where the two groups differed significantly according to a running paired *t*-test (no correction for multiple comparison). Data are baselined for each participant by subtracting their mean value as recorded in the two dry cooking sessions, and subsequently averaged across participants for each second. Median, unbaselined values for the real cooking session are for heart rate: 82 bpm, for phasic skin conductance: 1.6 $\mu S*10^5$, for face valence: −0.17 arb. unit, and for acceleration: 44 m/s^2. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

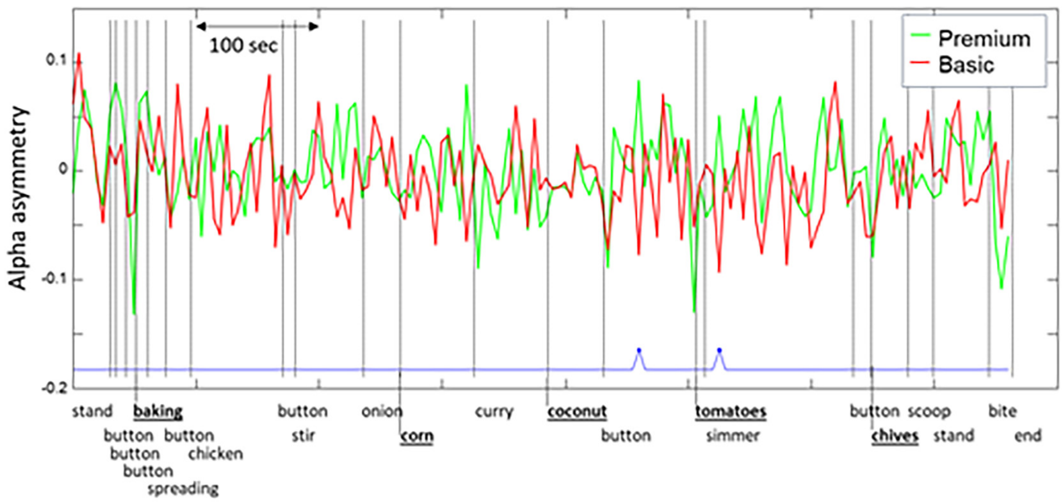

Fig. 3. Baselined alpha asymmetry over time in the real cooking session. The two groups of participants (premium and basic) are presented separately. Bold, underlined phases indicate phases in which products differed between the groups. Peaks in the horizontal blue lines indicate instances where the two groups differed significantly according to a running paired *t*-test (no correction for multiple comparison). Data are baselined for each participant by subtracting their median value as recorded in the two dry cooking sessions, and subsequently averaged across participants for each point in time. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2.5.3. Phasic skin conductance

Electrodermal activity can be characterized by several variables. We focus on the fast changes in skin conductance (phasic activity) since this is relatively robustly related to arousal (Brouwer, van Beurden, et al., 2017). Specifically, Continuous Decomposition Analysis as operationalized in the Matlab LedaLab toolbox was used to select the continuous phasic component from the signal (Benedek & Kaernbach, 2010). This did not work for one participant, who was left out in the skin conductance analysis. Intervals with data that were > 5*standard deviation from the median value, as observed within a participant, were considered to be outliers and removed from analysis. Subsequently, the same criterion was applied to the data of all participants as a group. The total proportion of excluded data in the 73 participants was 5% in real cooking and 9% in dry cooking.

2.5.4. Facial expression

For the facial expression analysis, the video data of each participant was loaded into FaceReader software (version 7.0, Noldus Information Technology B.V., Wageningen, The Netherlands) and analyzed at a sampling rate of 750 frames per minute. Calibration procedures were conducted for each participant to correct for his or her person-specific biases towards a certain facial expression, using the first standing still phase as the baseline. The basic emotions, of which we focus on 'valence' and 'arousal' were expressed as a value from 0 to 1 in each frame, indicating the intensity of the emotion. '0' means that the emotion is not visible in the facial expression, '1' means that the emotion is fully present. The imagery did not allow for the extraction of the FaceReader features in 4 participants, resulting in a selection of 70 participants for face analysis.

2.5.5. Accelerometry

For each second, the average absolute acceleration value in each of the three movement directions was determined, i.e. mean($|acc_x|$,$|acc_y|$,$|acc_z|$). This was done for the sensor at the right wrist. Data of one participant was missing in these analyses.

2.5.6. Subjective reports

For the valence and arousal scales as described in 2.3.2, participants had the possibility to click through to the next screen without answering the questions. Out of 74 participants, 72 filled out all of the valence scales, and 67 all of the arousal scales – for each scale, only the participants with complete data were included in the analysis.

2.6. Analysis

2.6.1. Comparison between premium and basic

To answer the question whether and at what moments differences between the (basic and premium) participant groups occurred for the implicit, continuous variables, we applied running, independent sample *t*-tests. Effects of group on rated valence and arousal of cooking phase were evaluated by mixed model ANOVAs with group as a between-subject factor and cooking phase as a within-subject factor. Rated preferences of the basic and premium ingredients as asked in the direct comparison questionnaire were evaluated with one-sample *t*-tests on the scores minus 5 (where 5 indicates 'no preference').

2.6.2. Comparison between cooking phases

Each implicit, continuous variable was averaged across each of the two (basic and premium) participant groups and plotted over time together with the onset of the auditory instruction to examine whether and how continuous, implicit measures vary as a function of auditory instruction and time for dry and real cooking. For variables that are affected by movement as indicated by systematic changes following auditory instructions concerning body movements, both in dry and real cooking, correction for movement is warranted. This is done by subtracting values as obtained in the dry cooking session from corresponding segments in real cooking. Given that the choice of segments depends on the response pattern of the variable, more details are given in the results section. Whether changes in implicit variables in real cooking may be attributed to emotion rather than only to movement, was then tested by comparing the obtained values against zero (one sample *t*-tests). A sanity check of the result was done by targeted post-hoc *t*-test of the valence and arousal ratings of the different cooking phases.

3. Results

3.1. Comparison between premium and basic

3.1.1. Implicit variables

Fig. 2A–E shows respectively heart rate, phasic skin conductance, facial valence, facial arousal and movement of the accelerometer on the

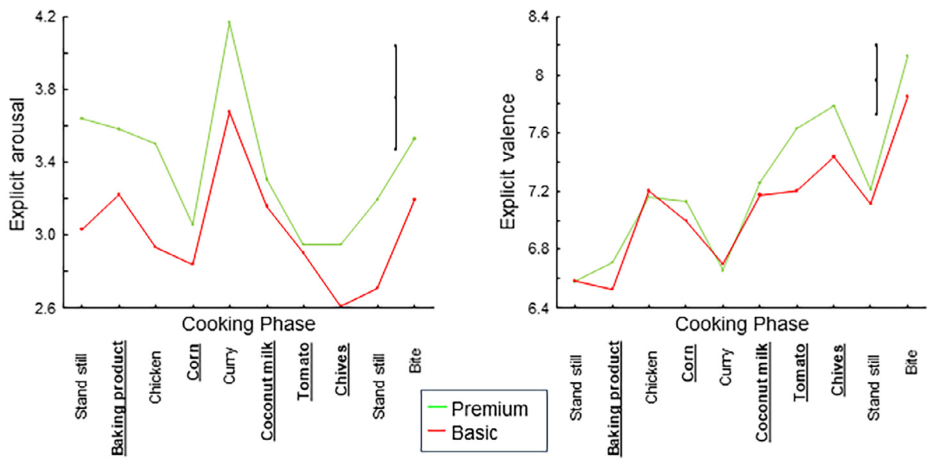

Fig. 4. Mean arousal (A) and valence (B) ratings of different real cooking phases. The scales run from 1 to 9. The two groups of participants (premium and basic) are presented separately. Bold, underlined phases indicate phases in which products differed between the groups. The error bars on the right represent the standard deviation. There was no statistically significant difference between the two pleasantness groups.

right wrist averaged across participants for each second during the real cooking phase, separately for the two groups of participants (premium and basic). None of the depicted variables showed a systematic difference between groups, and neither did alpha asymmetry (Fig. 3) and movement of the left wrist. Running *t*-tests comparing the variables for each second between the groups indicated significant differences for only at most 17 instances (out of a total of 779 s, $p < .01$). In Fig. 2A-E these are indicated by peaks in the blue lines depicted at the bottom of each graph. Fig. 3 shows the same for comparing the 5 s intervals as determined for alpha asymmetry. Genuine differences between groups would have been indicated by sufficiently enough, subsequent seconds showing significant differences (Guthrie & Buchwald, 1991), where these would have been expected especially after auditory instructions concerning the five products that differed between the groups (indicated underlined and in bold in the legend). This was not the case for any of the variables.

3.1.2. Explicit variables

Fig. 4 shows how the participants rated different cooking and tasting phases with respect to arousal and valence. On a scale from 1 to 9, arousal ratings were generally lower than 5 and valence ratings higher than 5, indicating that participants were generally on the calm and pleasant sides of the spectra. Consistent with what we found for the implicit measures, there was neither a difference between the two groups for arousal, nor for valence (mixed-model ANOVA: no main effect of group: $F_{1,65} = 1.25$, $p = .27$ for arousal, $F_{1,70} = 0.31$, $p = .58$ for valence; no interaction between group and cooking phase: $F_{9,585} = 0.45$, $p = .27$ for arousal, $F_{9,630} = 0.51$. $p = .58$ for valence). There was a main effect of cooking phase for both arousal and valence ($F_{9,585} = 5.81$, $p < .01$ for arousal, $F_{9,630} = 15.21$, $p < .01$ for valence), further discussed in the next section on comparison between cooking phases.

Fig. 5 shows rated preferences of the products used in the experiment when participants were asked to directly compare the products as indicated in the pictures. For all products, preference was toward the product that was intended to be more pleasant, except for coconut milk where neither of the products was preferred (one-sample *t*-test on individual ratings minus 5 for tomatoes, corn, chives and baking product: all p-values $< .01$, coconut milk: $p = .66$). This indicates that our general notion of manipulating pleasantness was sound. It is important to realize that this rating was a comparison between two alternatives, while the cooking experience concerned only one of the two alternatives for each participant, without comparison.

3.2. Comparison between cooking phases

3.2.1. Implicit measures

All of the implicit measures shown in Fig. 2 showed modulations over time. This was strongly so for acceleration of the right wrist (Fig. 2E), which was to be expected, but also heart rate (Fig. 2A) and skin conductance (Fig. 2B) strongly depended on the cooking events. The similarity of the curves between the two groups shows that the modulation was robust. Alpha asymmetry did not show systematic modulations over time (see Fig. 3). The modulations over time are described and explored in more detail below for heart rate, skin conductance and facial expression.

Heart rate

Fig. 2A shows that heart rate decreased during the first standing still phase; it increased when pressing buttons, adding and spreading the baking product; then it decreased again, before slowly increasing during the real cooking. When adding curry paste a strong increase was visible. After this phase, heart rate decreased again slowly until a second standing still phase where a sharp decrease was observed. After being asked to take a bite, heart rate quickly reached maximum levels again.

Fig. 6 shows heart rate over time in the dry cooking session before (A) and after (B) the real cooking session. While for dry cooking, there was no difference between the premium and basic group with respect to the used materials or procedure, results are still given separately for each group since it gives a good indication of the noise relative to the systematic effects of dry cooking phase, similar to what is shown in Fig. 2. The replicability of the results is not only shown by the similarity between the two groups, but also by the similarity between the first and second dry cooking session though overall heart rate was higher in the second session compared to the first. In dry cooking, heart rate was also low during the two standing still phases. After each auditory instruction on discrete actions, heart rate rose and decreased again, presumably after finishing the action. For stirring, which is a more continuous activity, heart rate kept rising. This pattern of results is consistent with a clear effect of movement on heart rate. However, in dry cooking we did not observe that heart rate was especially high after the instruction to add curry paste and to take a bite. This suggests that the particularly high heart rate in those phases during real cooking is likely caused by processes unrelated to physical activity, such as affective processes. To statistically test whether heart rate was indeed higher after adding the curry and take a bite instructions in real cooking compared to dry cooking, we calculated non-metabolic heart rate (Brouwer, van Dam, van Erp, Spangler, & Brooks, 2018) and tested whether it significantly differed from zero. Non-metabolic heart rate was calculated for each participant and each phase ‘adding curry’, ‘take a bite’, as well as for two other comparison phases, ‘standing still’ and ‘stirring’. This was done by subtracting mean heart rate as observed in the dry cooking sessions during those phases, from the mean heart rate as observed in the real cooking session during those phases. Table 3 specifies the exact intervals used. Confirming the observations as described, one sample *t*-tests on the non-metabolic heart rate indicated significantly positive

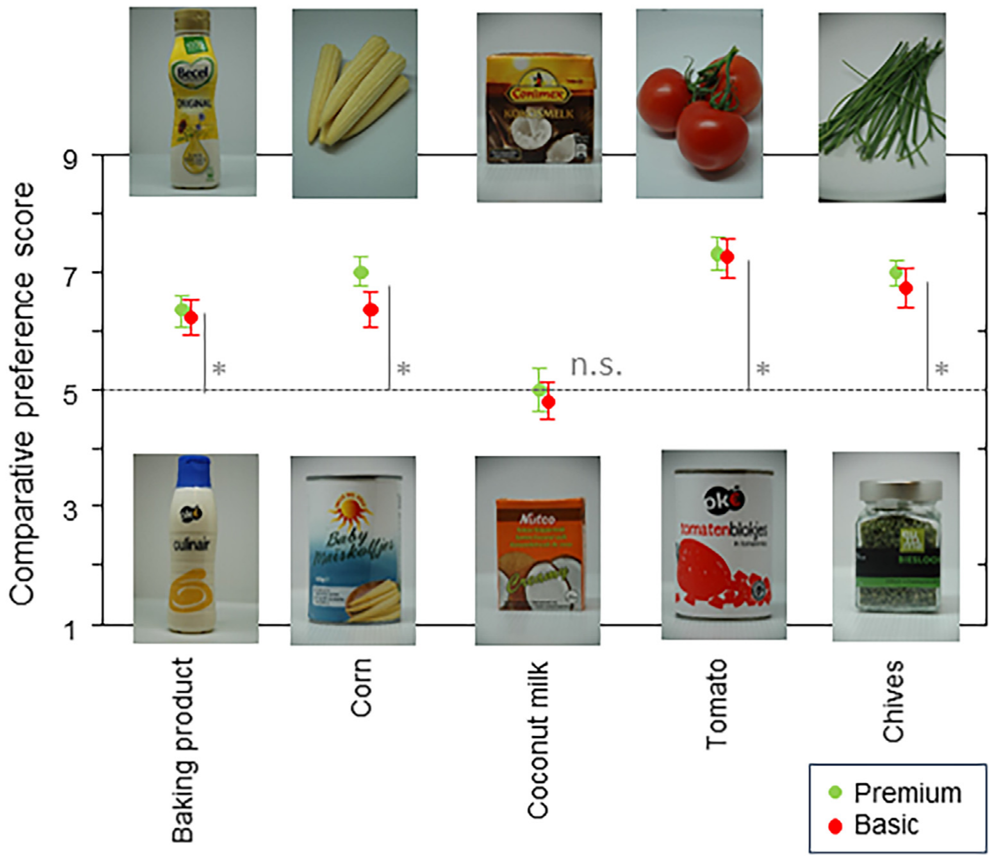

Fig. 5. Mean preference scores of the products used in the experiment when participants were asked to compare the products as indicated in the pictures. The two groups of participants (premium and basic) are presented separately. The scale runs from 1 to 9: A value of 5 indicates no preference, and higher scores are in the direction of the hypothesized preferred product. All ratings are significantly higher than 5, except for the ratings for coconut milk.

values for 'adding curry' (mean = 7.99, $t73 = 17.19$, $p < .01$) and 'take a bite' (mean = 4.37, $t73 = 9.70$, $p < .01$), whereas this was not found for 'standing still' (mean = 0.37, $t73 = 1.38$, $p = .17$). 'Stir-frying' also turned out to be reliably higher than 0 (mean = 2.2, $t73 = 5.78$, $p < .01$).

Phasic skin conductance

Fig. 2B shows a peak in skin conductance after every auditory instruction. Dry cooking showed roughly the same pattern (Fig. 7). In contrast to what can be observed in heart rate (Fig. 6), even the instruction to stand still elicits a peak, suggesting that phasic skin conductance is less related to movement and more to mental processes associated with hearing the auditory instruction. Also note that in dry stirring, skin conductance goes down despite the continuous movement. In general, peaks seemed to decrease from the first dry cooking session, to real cooking to the second dry cooking session. The data do not suggest clear differences in peaks between the different auditory instructions in real cooking or dry cooking.

Facial expression

The facial valence data suggest a consistent initial decrease across the first minute. No other phases stand out.

While modulation over time is not as clear as for the physiological variables, facial arousal rises from the moment that the curry instruction is given (consistent with heart rate), reaching a peak after adding the coconut milk. After the instruction to add tomatoes, arousal rises as well. Finally, a general increase is apparent towards the end of the cooking session.

3.2.2. Explicit variables

As reported in the previous section, on comparing the pleasantness groups, the mixed-model ANOVAs did not show effects of pleasantness on explicitly reported arousal and valence, but there were effects of cooking phase. Our heart rate results, supported by facial arousal, led us to think that emotions during the 'adding curry' and 'take a bite' phase could be relatively strong. Indeed, rated arousal was reported to be relatively high in these two phases where paired *t*-tests indicated that rated arousal for adding curry was higher than rated arousal in all other phases ($p < .05$, *t*-values between 2.35 and 5.32), and that rated arousal for taking a bite was higher than the three previous phases ($p < .05$, *t*-values between 2.19 and 3.20). There is a generally increasing trend in valence across the cooking process (which is consistent with dish understanding observations that commonly suggest increasing involvement – Liesbeth Zandstra, personal communication). The most pleasant cooking phase was 'take a bite' (higher rated valence than all other phases, paired *t*-tests $p < .05$). 'Adding curry' was a relatively unpleasant phase (significantly lower valence than all other phases except for 'standing still (heating)' and 'adding baking product'; paired *t*-tests $p < .05$).

The facial arousal results suggesting a high arousal when adding coconut milk and tomatoes are not reflected in the explicit ratings.

4. Discussion

In a previous study, physiological variables differed between audio-timed cooking with two types of extreme food stimuli, mealworms and chicken. We were able to estimate whether physiological data of a single individual originated from cooking with mealworms (high arousal, low valence) or from cooking with chicken (low arousal, high valence). This follow-up study, in which we used ingredients with subtle contrasts in affective appreciation, showed that physiology, facial expression and reported emotion are not sensitive enough to distinguish between experiences when cooking the same dish with ingredients that only slightly differ in quality perception. However, we did find evidence for physiology to reflect emotional experience as it varied across cooking phases during the cooking process. More precisely, high heart rate was indicative of emotionally salient moments. We showed that certain intervals were consistently associated with high

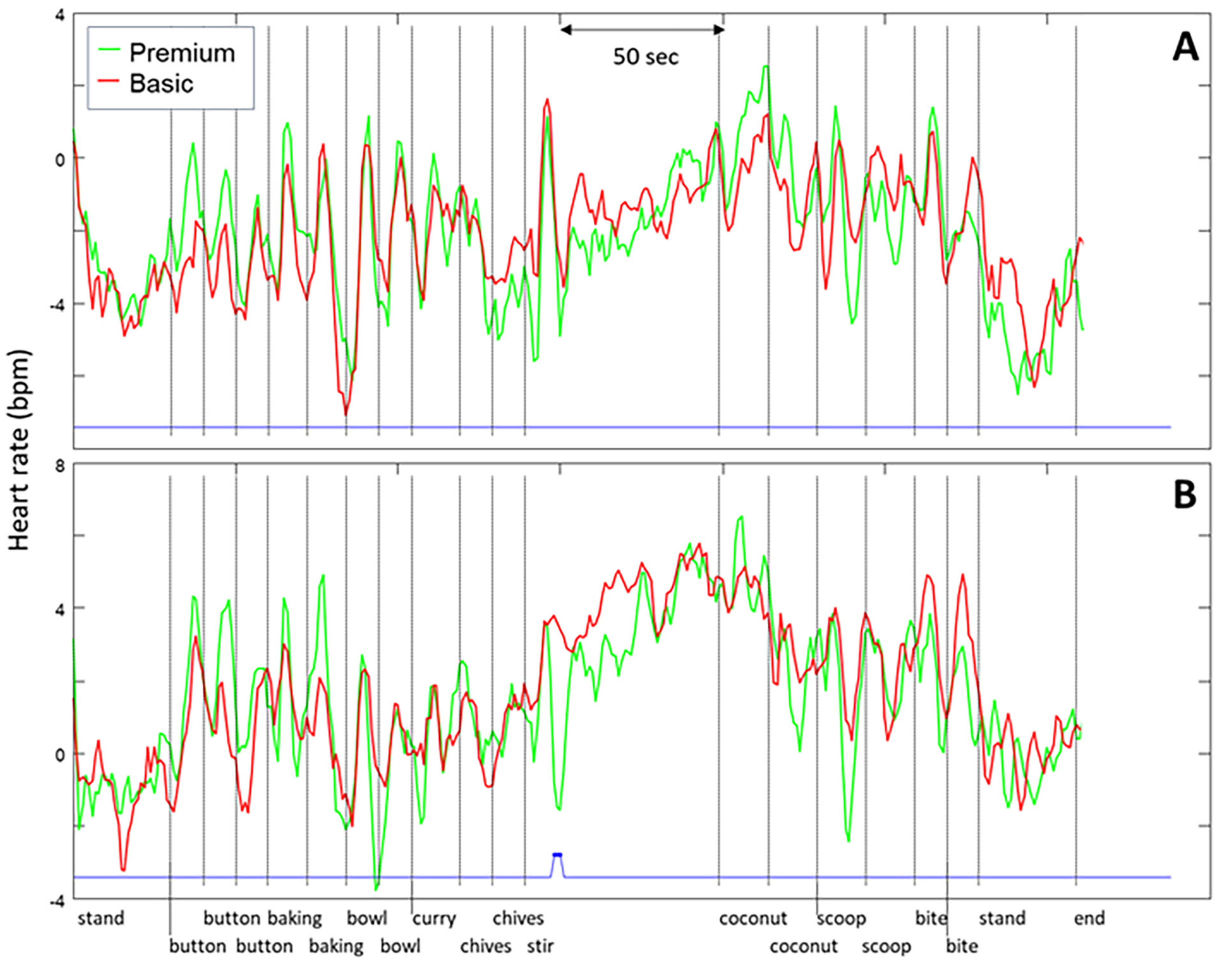

Fig. 6. Baselined heart rate over time in the dry cooking session before (A) and after (B) the real cooking session. Data are baselined by subtracting the mean value as recorded in the dry cooking sessions, and subsequently averaged across participants for each second. The two groups of participants (premium and basic) are presented separately. Peaks in the horizontal blue lines indicate instances where the two groups differed significantly according to a running paired *t*-test (no correction for multiple comparison). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

heart rate that could not be explained by effects of movement, where the emotional salience of these intervals were supported by reported arousal and reported valence. The heart rate corrected for effects of movement was a stronger measure to identify these moments than the verbal ratings as indicated by the test statistics.

4.1. Effects of movement and correcting for it

Continuous, implicit measures of emotion in real life situations have a large value to the food industry since such measures would reflect an actual consumer's experience more closely than measures obtained in a setting where consumers are asked to report on some aspects of their experience, and could therefore lead to better design and adaption of products to consumers. Measuring emotion continuously and implicitly would also be valuable to a multitude of other application areas. The current study is a contribution to arriving at such measures. Besides providing first answers to the research questions as indicated above, several interesting findings are worth noticing in this respect.

Our audio-timed approach, leading to synchronization of movements across participants, revealed quite strong, robust associations of heart rate with even small and short-lasting movements, such as pressing a button. This finding highlights the importance of taking effects of body movements into account when one wants to use heart rate as a source of information about emotional (or other mental) processes. The approach of comparing heart rate as recorded in the real-life situation, associated with rich sensory stimulation and accompanying emotional experience, to the same body movements in a more neutral context appeared to be fruitful. An approach that does not require participants to perform movements in a neutral situation would be even more valuable. Myrtek et al. (1988) formulated a model to determine when heart rate exceeds the heart rate that is expected on the basis of body movements as measured using accelerometers. Occurrence of such ‘additional heart rate’ was argued to reflect emotion. The algorithm was applied in a range of (real-life) studies, for instance by comparing reports of currently experienced emotion during phases with additional heart rate, to phases without additional heart rate. However, no convincing evidence was found that this algorithm correctly filters out effects of body movements (Brouwer et al., 2018). This may be because it is not possible to estimate heart rate due to activation of the muscles precisely enough on the basis of accelerometers. Depending on the location of the accelerometers, some body movements are not captured. In addition, muscle movement and corresponding increase in heart rate can occur without much body movement, for instance, when pushing a car or as an example in our study, squeezing a bag with curry paste. Accelerometers may be used to recognize different types of activities, where these activities are subsequently associated to (individually tuned) heart rate as expected due to muscle activity alone. Such an approach was successfully performed for predicting energy expenditure (oxygen consumption) by Bonomi, Plasqui, Goris, and Westerterp (2009) and Altini, Penders, Vullers, and Amft (2015), even though they studied higher order activities, e.g. cycling and desk work, than would be applicable here where we would want to focus on e.g. stirring and

Table 3
Specification of intervals used to determine non-metabolic heart rate for standing still, adding curry, stir-fry and take a bite.

	Standing still	Adding curry	Stir-fry	Take a bite
Dry cooking (average first and second dry cooking session)	30 s interval after first and second instruction to stand still	15 s interval after adding curry instruction	55 s interval after stir-fry instruction	10 s interval after first and second instruction to take a bite
Real cooking	30 s interval after first and second instruction to stand still (respectively waiting for cooking plate to heat up and dish to cool down)	15 s interval after adding curry instruction	55 s interval after stir-fry instruction	10 s interval after instruction to take a bite

squeezing a bag of curry paste. An additional advantage of taking muscle activity into account when using heart rate as an indicator of emotion through the route of activity recognition would be that information about the time and duration of certain activities becomes available rather than having to use and rely on auditory instructions as in the current study. This potentially enables more precise correction and would allow more freedom in behaviour for the participants under study. The information on performed activity is not only convenient for correcting the heart rate, but also provides potentially interesting information in itself, for instance, the amount of stirring elicited by different versions of a certain ingredient (where this may or may not be related to affective experience).

When aiming to extract heart rate as caused by muscle activity from heart rate in general, ideally one should also model physiological history effects. For long and intense physical activities, heart rate does not remain constant across the activity (Zakynthinaki, 2015), but our results show that also for light activity such as stirring for one minute, there is a change in heart rate (Fig. 6). In dry cooking, heart rate during the subsequent phases (coconut and scoop) may have been high for this reason – there was no chance to return to resting baseline. In real cooking, part of the heightened baseline (at around 3 bpm) may be caused by such a history effect. For skin conductance, which is a slower signal compared to heart rate, these history effects seem aggravated in that even in de phasic response, there is a slow general increase in the period before the auditory instruction to stir for one minute, and after it. This suggests that general phasic skin conductance builds up with relatively quickly successive auditory instructions, making it hard to interpret the effect of a single, specific auditory instruction. In real cooking, time between events is generally longer, and phasic skin conductance can be seen to reach baseline levels. Thus, skin conductance seems less suitable to monitor emotion in situations with events that occur in quick succession.

4.2. Variables for monitoring food experience

Physiological variables as continuous indicators of emotional experience without interfering with the experience by asking to report on it, may be very valuable in addition to commonly used explicit measures when studying food experience (Kaneko et al., 2018). Since it is currently not possible to exactly map physiology on emotion in a general sense, it is important to study this mapping for the specific case of interest. We have seen that heart rate can serve to pinpoint phases of emotional arousal in cooking: intervals after the instruction to add the curry paste and to take a bite were associated with high heart rate and were also judged high in arousal. Adding curry paste was judged relatively low in valence (as informally observed by the experiment leaders, this was probably due to participant's fingers getting dirty) and taking a bite was high in valence. We hypothesized that alpha asymmetry or facial expression of valence could inform us about the valence axis of emotional experience, but we did not find this here, suggesting that these variables are not sensitive enough to capture relatively small differences in valence. Thus, especially when it is not clear beforehand whether all arousing events are positive, probing this using verbal reports would be helpful. This may even be done in real time by triggering questions on experienced pleasantness whenever the heart rate is higher than expected from the current activity (reminiscent of Myrtek, Aschenbrenner, & Brügner, 2005). Such a method would keep disturbing effects of reporting emotion to a minimum, while not having to rely on retrospective reports.

Verbal reports reflect the emotions that users can and want to communicate (Picard & Daily, 2005). Facial expression, being very important in social communication as well, may be considered as a channel in between explicit verbal measures and implicit physiological ones. We found facial expression of valence to be consistently high at the start of the experiment, decreasing over the following minute. This may be caused by participants being aware that they are watched at the

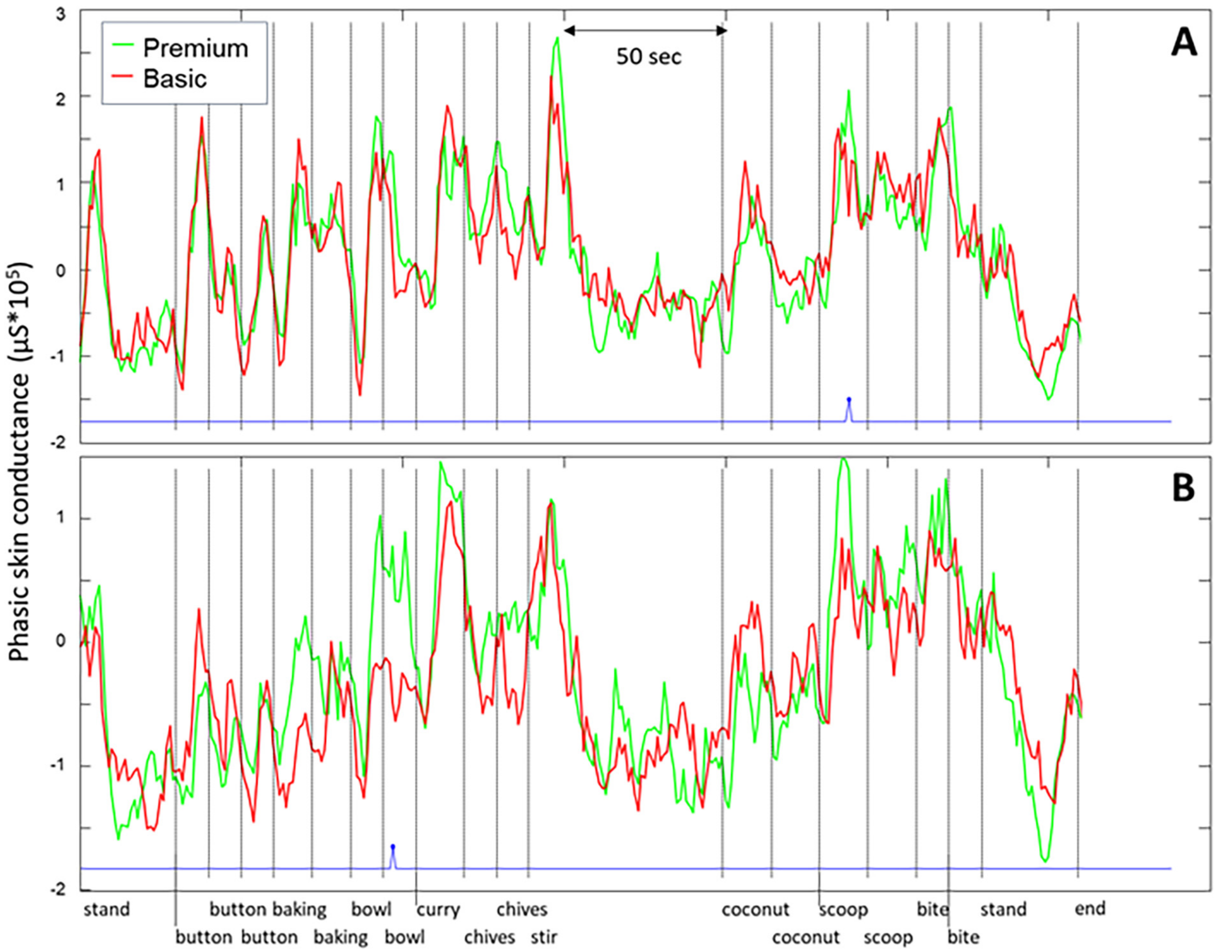

Fig. 7. Baselined phasic skin conductance over time in the dry cooking session before (A) and after (B) the real cooking session. Data are baselined by subtracting the mean value as recorded in the dry cooking sessions, and subsequently averaged across participants for each second. The two groups of participants (premium and basic) are presented separately. Peaks in the horizontal blue lines indicate instances where the two groups differed significantly according to a running paired *t*-test (no correction for multiple comparison). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

beginning and wanting to show a friendly face whereas this dissipated over time. Facial arousal was relatively high during the curry and 'take a bite' phase, consistent with heart rate and explicit measures. It was also high in other phases (adding coconut milk and tomatoes) where we do not have concurrent evidence that these phases were emotionally salient from other explicit or implicit variables. At present it is unclear what this means.

Both our implicit and explicit variables did not distinguish between the groups that we assumed to differ in experienced pleasantness due to the quality of the ingredients. This may not come as a surprise when participants only experienced one of the two types of ingredients; either premium or basic, with only subtle differences in ingredients. In our questionnaire that asked participants to directly compare ingredients, the expected difference between premium and basic ingredients was found. Such a comparison may tap into a direct, cognitive comparison (often referred to as external perspective or affective appraisal) and not necessarily reflects emotional experience or internal perspective (Kaneko et al., 2018; Schreuder, Van Erp, Toet, & Kallen, 2016). It would be of interest to investigate whether implicit variables would reflect these 'higher order' comparative differences as well.

5. Conclusions

Using implicit (physiological) variables to evaluate cooking experience is a developing field. In this life-like study, without gross variations in emotion, we did not find a measure (neither implicit nor explicit) that reflected pleasantness (valence) as we presumed it would vary. Furthermore, we need to model history-related effects on physiology (which e.g. was done for intense movement over longer periods of time by Zakynthinaki, 2015) in order to facilitate interpretation, e.g. it is presently hard to say whether the high heart rate in the second standing still phase compared to the first is caused by emotional arousal or whether it is high because heart rate could not reach resting baseline after the increased heart rate due to the movement history. Analyses of physiological synchrony (Gates & Liu, 2016; Helm, Miller, Kahle, Troxel, & Hastings, 2018) may be less affected by the issue of not returning to baseline, and may prove more sensitive to changes in the signals that are common across individuals as well as across the type of signal (Stuldreher et al., submitted). Still, our study already showed evidence that emotionally relevant events can be detected in a life-like cooking scenario without disturbing experience itself through questions. We do not suggest leaving out questionnaires but argue for optimal combinations of implicit and explicit measures. Questionnaires as currently used to evaluate food or cooking experience can be lengthy, therewith hindering engaged, reliable responses. Also, with explicit measures respondents are asked to reflect on a certain time interval that may not be optimal from an emotional point of view. Professionals in food industry and sensory science could benefit from a procedure such as followed here in order to zoom in on certain, emotionally relevant phases during cooking, and focus questions on these phases of interest rather than asking individuals about every instant of the experience. Real time detection of emotionally salient events based on physiological patterns may help to identify the best time slots to pose a question during cooking and therewith improve product evaluation and development.

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Declarations of interest

None.

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