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Neurophysiological responses during cooking food associated with different emotions

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ABSTRACT

Neurophysiological correlates of affective experience could potentially provide continuous information about a person's experience when cooking and tasting food, without explicitly verbalizing this. Such measures would be helpful to understand people's implicit food preferences and choices. This study examined for the first time the relation between neurophysiological variables and affective experiences under real cooking and tasting circumstances, using ingredients that were a priori expected to evoke different affective reactions. 41 participants cooked and tasted two stir-fry dishes in random order following an identical, strictly timed protocol. Once the main ingredient was chicken and the other time mealworms. EEG, ECG and skin potential were recorded continuously. Participants scored subjective valence and arousal after each cooking and tasting session. Frontal EEG alpha asymmetry showed the expected effect throughout the whole cooking and tasting session, consistent with 'approach' motivation for chicken and 'avoidance' for mealworms. Skin potential effects differed between cooking intervals but were in the expected direction. ECG variables showed an interaction with order of cooking the different dishes. Based on EEG alpha asymmetry, ECG and skin potential variables, we can estimate with 82% accuracy whether a single participant is preparing a dish with mealworms or with chicken. Our study provides evidence that it is possible to estimate experienced emotion during real-life cooking and tasting. We argue that it is important to consider that different neurophysiological and subjective measures reflect different underlying affective processes, to map them out more precisely, and to take advantage of these differences.

1. Introduction

Positive emotions are critical for the success of food products in the market place. Yet, surprisingly little is known about emotional processes during consumer-product interactions in food preparation and cooking. Recent years have witnessed a growing body of research on the development of measurement tools to capture emotional responses towards foods. These tools include a range of explicit (self-reported) questionnaires to measure food product-evoked emotions (King & Meiselman, 2010; Cardello et al., 2012; Laurans & Desmet, 2012; Jaeger & Hedderley, 2013; Den Uijl, Jager, Zandstra, De Graaf, & Kremer, 2016), implicit measures that rely on reaction times to capture approach-avoidance motivations to food stimuli (Davies, El-Deredy, Zandstra, & Blanchette, 2012; Piqueras-Fiszman, Kraus, & Spence, 2014; Kraus & Piqueras-Fiszman, 2016), and autonomic nervous system responses on the sight, smell and taste of odors and foods (De Wijk, Kooijman, Verhoeven, Holthuysen, & De Graaf, 2012; He, Boesveldt, De Graaf, & De Wijk, 2014, 2016; De Wijk, He, Mensink, Verhoeven, & De Graaf, 2014). However, despite these developments, this area of research is still in a stage of relative infancy and additional research is needed to develop valid measures of emotions evoked by dynamic continuous interactions and experiences with food (*i.e.*, throughout cooking). So far, research in the area of cooking and food preparation investigated mainly functional aspects such as cooking skills and home cooking equipment in relation to healthy eating behavior (Short, 2003; Larson, Perry, Story, & Neumark-Sztainer, 2006; Bongoni, Steenbekkers, Verkerk, van Boekel, & Dekker, 2013; Bongoni, Verkerk, Dekker, & Steenbekkers, 2015). New methods need to be developed that quantify people's emotional experiences in

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response to food stimuli throughout dynamic cooking processes. Acquiring such methods is essential if we want to be able to successfully deliver emotional benefits and health to consumers by making nutritious cooking and eating desirable, enjoyable, easy to understand and do.

If we want to know people's emotions or feelings, we can simply ask them. However, verbalizing emotions can be difficult and will be affected by cognitive and memory processes. Verbal reports will only include conscious experience that the individual chooses to share. Asking people about their affective processes can even change their normal way of affective evaluation and behavior as indicated by Wilson et al. (1993). They asked participants to verbalize and motivate their liking of art posters, after which they could choose a poster of their liking. Compared to a control group, these participants chose a different poster and were less satisfied about this choice three weeks later. Neurophysiological correlates of affective experience could add information to subjective ratings because they do not require verbalization and in principle provide continuous information without requiring distracting questions about currently felt emotions.

Reviews on reported associations between emotions and physiological signals show that these links are far from clear-cut (Kreibig, 2010; Dockray & Steptoe, 2010). This is not surprising when one considers that the function of physiological processes is not to inform us about experienced emotions but rather to prepare for relevant action. These can coincide (*e.g.* the emotion of anger is likely to be associated with implicitly preparing to fight) but this is not always clearly the case. As long as we do not know the exact mapping between psychological concepts and physiological processes yet (Cacioppo & Tassinary, 1990), it is important to look at this within the context and under the circumstances of interest. In the present study, we investigated the association between emotion and physiological signals during cooking and tasting. We examined whether estimating emotions on the basis of these signals is possible on the level of an individual person, given the noise that movements will introduce into the signal. Different physiological signals and their combinations were explored.

As a start, we focussed on a case where we expected quite extreme types of emotions: we compared cooking with chicken to cooking with mealworms. While insects are highly valued and considered tasty in some cultures (Hanboonsong, 2010; Ramos-Elorduy, 1997), in Western countries individuals often react with disgust to the idea of eating insects (Looy, Dunkel, & Wood, 2014; Rozin & Fallon, 1987; Tan et al., 2015; Yen, 2009; Verbeke, 2015). In the light of the valence-arousal model of emotions (Russell, 1980), characterizing emotions by respectively their pleasantness and intensity, cooking with mealworms was expected to evoke higher arousal and lower valence than cooking with chicken.

Arousal is a component of emotion that has relatively clear physiological correlates in electrodermal activity (Roth, 1983). Sweat glands, that are mainly responsible for electrodermal activity, are exclusively innervated by the sympathetic 'fight-or-flight' autonomous nervous system. Strong activation of the sympathetic system relative to the parasympathetic 'rest-and-digest' autonomous nervous system reflects physiological arousal. The heart is innervated by both sympathetic and parasympathetic systems. However, high frequency heart rate variability, mainly reflecting the extent to which heart rate is tuned to breathing, is mostly determined by the parasympathetic system. High heart rate variability is reported to be associated with low stress or arousal and vice versa (Grossman & Taylor, 2007; Berntson et al., 1997). In contrast to what is often believed, heart rate and arousal do not seem to be directly associated. Heart rate rises with arousal, *e.g.* in situations with (social) anxiety (Kirschbaum, Pirke, & Hellhammer, 1993; Brouwer & Hogervorst, 2014; Hogervorst, Brouwer, & Vos, 2013), recalling emotional (versus neutral) memories (Vrana & Lang, 1990; Cuthbert et al., 2003; Rainville, Bechara, Naqvi, & Damasio, 2006) or smelling unpleasant odors and tasting disliked foods (He et al., 2014; De Wijk et al., 2012), but the reverse relation has been found as well, *e.g.* in reading emotional sections in a book (Brouwer, Hogervorst, Holewijn, & 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 sensory attention and heart rate (Lacey & Lacey, 1970; Venkatraman et al., 2015).

For valence, there are no clear correlates found in peripheral physiology. While research on viewing emotional images consistently finds that positively valenced images generate heart rate acceleration (*e.g.* Greenwald, Cook, & Lang, 1989; Lang, Greenwald, Bradley, & Hamm, 1993), this does not generalize to other situations (Kreibig, 2010). However, brain signals may provide us with information about experienced valence. Focusing on what we can detect using EEG, a suitable variable would be asymmetric frontal cortical activation where the inverse of EEG alpha power (8–13 Hz) can be taken as an indication of regional brain activation (Cook, O'Hara, Uijtdehaage, Mandelkern, & Leuchter, 1998). Originally, strong left activation has been associated with positive valence and strong right activation with negative valence. Later research (reviewed by Harmon-Jones, Gable, & Peterson, 2010) indicated that rather than positive and negative valence, the distinction is more consistent with approach and avoidance motivation (where valence and motivation often overlap, but not always, such as in the case of anger which can be described as a low valence emotion paired with an approach motivation). The approach-avoidance dimension maps perfectly well onto our case of food stimuli, where we expect stronger avoidance for mealworms compared to chicken. Indeed, the literature on disgust has explicitly associated this emotion with avoidance or withdrawal in order to protect the body from possibly harmful elements (Croy et al., 2013; Rozin, Haidt, & McCauley, 2000; Davidson, Ekman, Saron, Senulis, & Friesen, 1990). 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).

While the starting point of our study was to examine responses to two foods that differ in valence and arousal, we already referred to two other emotion-related constructs, namely approach-avoidance and disgust. With respect to peripheral measures associated with disgust, both increases in sympathetic activity and parasympathetic activity measures have been found. Relatively strong sympathetic activity may be related to disgust-related avoidance and escape behavior (Ottaviani, Mancini, Petrocchi, Medea, & Couyoumdjian, 2013). Kreibig (2010) proposes a distinction between disgust related to contamination or pollution, and mutilation-related disgust. The former type is closer to our type of disgust, and generally coincides with sympathetic-parasympathetic co-activation (Kreibig, 2010). Kreibig (2010) summarizes published reports on contamination-related disgust as usually showing increased HRV (which might be related to faster, shallow breathing that is also observed), an increase or no change in heart rate and increased electrodermal activity. Note that a disgust-related increased HRV goes in the opposite direction as the arousal-related decrease in HRV (Grossman & Taylor, 2007; Berntson et al., 1997) that we mentioned in earlier in this introduction.

In the present study, each participant cooked and tasted two times a stir-fry dish following a strictly timed protocol. This protocol was exactly the same except for the fact that once, the main ingredient was chicken and the other time it was mealworms. The protocol was divided in distinct phases for which we compared different physiological and subjective variables. As discussed above, we expected high arousal for mealworms compared to chicken (*i.e.* intense emotion and sympathetic activation) as reported by participants themselves, and as reflected in high electrodermal activity. From the viewpoint of arousal, we expected heart rate variability to be relatively low, but from the perspective of concurrent sympathetic and parasympathetic activation in disgust, heart rate variability was expected to be high. Furthermore, we expected participants to report lower valence for mealworms compared to chicken, and relatively stronger right frontal brain activation as indicated by EEG frontal alpha asymmetry, associated with avoidance. In the current experiment it was not a priori clear whether and if so how heart rate would differ between the conditions. If mealworms mainly provoke anxiety and implicit escape behavior, we would expect an increase. If mealworms mainly provoke attention we would expect a decrease. In sum, we here examined the type and strength of physiological responses to foods that were a priori associated with different emotions in a real cooking and tasting context. Furthermore, we made a first step in estimating an individual person's reaction to a certain food on the basis of physiological data by training and testing a classification model.

2. Methods

2.1. Participants

41 participants took part in the experiment. Due to loss of physiological data, we analyzed data from 39 participants. They were between 20 and 64 years old, with a mean age of 36. 19 participants were female, 20 were male. All participants signed an informed consent before participating in the study and received reimbursement for their time and travel upon completion. Before participants were invited, the following inclusion criteria were checked: non-vegetarian, no food allergies, cook regularly (at least 2 days a week for over 15 min), no use of psychopharmaca, not suffering from neurological or cardiac diseases. Participants were instructed to refrain from eating for one hour prior to the experiment. The study was approved by TNO's internal ethical review board on experiments with human participants.

2.2. Task and design

Participants were asked to cook and taste two stir-fry dishes, following aurally presented step-by-step instructions that were equal for both dishes. The ingredients used for these stir-fry dishes were exactly the same (*i.e.*, a dash of liquid margarine, one onion, a quarter bell pepper, 2 tablespoons leek, 25 ml bouillon and a dash of sesame oil), with the exception of the main ingredient. One of the stir-fry dishes contained chicken (50 g) as main ingredient (expected to evoke pleasant emotions and intermediate arousal), the other one blanched mealworms (8 g in freeze-dried condition) (expected to evoke unpleasant emotions and high arousal). The order of dishes was counterbalanced between participants.

Table 1 shows the instructions as presented to the participants (translated to English) and their timing. At the beginning and at the end of each cooking block, there were intervals in which participants stood relatively motionless for about half a minute (starting a few seconds after event number 3: waiting for the cooking plate to heat, and event number 13: waiting for the dish to cool down). These intervals were included to obtain physiological data that is relatively clean of motion artefacts. For these intervals we also obtained subjective valence and arousal ratings. For the interval following the first exposure to either chicken or mealworms (event 4) we expected the largest difference between the mealworms and chicken condition. Large differences were also expected after adding either chicken or mealworms in the cooking pan (event 8), the interval in which participants are waiting for the dish to cool down (after event 13, probably anticipating having to taste), and after the instruction to take a bite (event 14).

2.3. Materials

The experiment took place in a kitchenette at the research institute (TNO Soesterberg, The Netherlands). Kitchen tools and pre-cut ingredients were arranged in specified locations. The ingredients were all visible from the start, except for the chicken or mealworms that were placed in a bowl covered with a lid. Cooking instructions were mp3 files played at specified times using a customary made program. Speakers were used to ensure that instructions were well audible.

Physiological signals (EEG, ECG and electrodermal activity) were recorded at 500 Hz using a Mobita amplifier and sensor system (TMSi, Oldenzaal, the Netherlands). Sintered Ag/AGCl Waterbased EEG electrodes were placed at 24 locations (AFz, Fpz, Fz, Cz, Pz, Oz, Fp1, Fp2, F7, F8, F3, F4, FC1, FC2, FC5, FC6, C3, C4, CP1, CP2, P3, P4, O1, O2). CAR was used (including only well-connected electrodes) during recording. Self-adhesive foam-hydrogel ECG electrodes (Kendall, MedCaT) were placed on the right collar bone and the left lower rib. A water-soaked elastic wristband served as a ground. For electrodermal activity, we measured the endosomatic skin potential using electrodes that were attached to the fingertips of the middle finger and ring finger of the left hand. All sensor wires were shielded to reduce artefacts caused by movement of the wires. Data were displayed to the experimental leader through a Wi-Fi connection and were stored for analysis on a disk connected to the amplifier and worn by the participant.

A videorecorder was placed in order to record the general behavior and reactions of the participant during the experiment for possible later analysis.

Prior to cooking, participants filled out questions about age, subjective feelings of hunger and satiety and cooking experience. Immediately after cooking and tasting each of the two dishes, they filled out several SAM valence and arousal scales (Bradley & Lang, 1994) reflecting their emotions. With respect to the different cooking phases, these reflected on 1. waiting for the cooking plate to heat (*baseline*), 2. after removing the plate from the bowl (display of either chicken or mealworms: *exposure*), 3. during stir frying the chicken or mealworms (*frying*), 4. after scooping the dish on the plate (*cooling*), 5. right after the instruction to taste the dish (*eating*). The SAM scales displayed the 5 mannikins, going from left to right from aroused to calm (arousal scale), and from happy to sad (valence). Immediately below was a slider that could be positioned in the appropriate location, where the most leftward (most aroused and most pleasant value) translated to a value of 0, and the most rightward value (most calm and most unpleasant value) translated to a value of 10. These values were flipped before analyzing, since conventionally, high arousal and high valence correspond to high score values.

After cooking and tasting, participants indicated whether they had eaten mealworms before (yes, several times; once or twice; never) and whether they were in doubt about eating the mealworms or not during preparing the dish. They filled out the Food Neophobia Scale that is designed to measure reluctance to eat and/or avoidance of novel foods (Pliner & Hobden, 1992). It consists of 10 items, with 7-point Likert scales. Participants also filled out the revised Dutch version of the Disgust Scale (Haidt, McCauley, & Rozin, 1994, modified by Olatunji et al., 2007). It consists of 27 items with 5-point Likert scales and measures sensitivity to disgust. Possibly relevant personality aspects were recorded by the Dutch version of the subscales 'openness to experience' and 'neuroticism' (sensitive/nervous versus secure/confident) from the NEO-PI-R (Hoekstra, Ormel, & de Fruyt, 1996), as well as the 16 items from the emotionality domain in the Dutch version of the

Table 1
Outline of the instructions and intervals of interest within the cooking and eating procedure.

Event number	Starting time	Spoken instruction	Special purpose	Rating	Interval of interest
1	00:12	Press button 1 on the cooking plate			
2	00:19	Press button 2			
3	00:25	Press button 3 until the cooking plate is on heating level 8	Waiting for the plate to heat and no-movement physiological *baseline*	x	0:34–01:04 (30 s)
4	01:04	Remove the lid from the bowl	*Exposure*: large difference between mealworms and chicken expected	x	01:05–01:35 (30 s)
5	01:20	Press button 4 until the cooking plate is on heating level 4			
6	01:29	Add a squeeze of baking product in the cooking pan			
7	01:44	Add the onion and stir fry the onion			
8	02:14	Add the contents of the bowl and keep on stir frying	*Frying:* Large difference between mealworms and chicken expected	x	02:14–04:14 (2 min)
9	04:14	Add the vegetables and keep on stir frying			
10	04:39	Add the broth and keep on stir frying			
11	04:54	Press button 1 to turn off the cooking plate			
12	05:04	Add the sesame oil and stir			
13	05:19	Use the spatula to place a scoop of the dish on the plate	*Cooling:* Large difference between mealworms and chicken expected, cooling of dish, no-movement physiological baseline	x	05:29–05:59 (30 s)
14	05:59	Take a bite	*Eating:* Large difference between mealworms and chicken expected	x	05:59–06:44 (45 s)
15	06:44	This is the end of this part			

HEXACO-PI-R (consisting of items measuring fearfulness, anxiety, dependence on others and sentimentality; Ashton & Lee, 2009). Personality questions were also answered using 5-point Likert scales. The data acquired through the personality questionnaires are not reported here.

2.4. Procedure

Participants received a short explanation about the study, mentioning that it was about physiological signals during cooking and tasting, and signed an informed consent form. In this form participants were requested to follow the experimental procedure as far as possible, but that they could quit the experiment whenever they felt it was 'too much'. They filled out a short questionnaire about age, subjective feelings of hunger and satiety and cooking experience. Then, they were fitted with the sensors. Together with the experimental leader they 'mimed' a short version of the cooking and tasting procedure (without getting to see the mealworms or chicken). Participants were asked to not speak during the experiment unless absolutely necessary, and to avoid excessive movements. After the first cooking block, they filled out the valence and arousal scales as described in the materials section considering the cooking block that was just finished. Immediately after, the second cooking block followed, and the accompanying valence and arousal scales. Subsequently, participants filled out the questionnaires as described in the materials section. The experiment leader removed the sensors and debriefed the participants. The complete experiment, including attachment and removal of sensors, lasted about 1,5 h.

2.5. Analysis

2.5.1. Analyzed data intervals

For each participant, each condition (chicken or mealworm) and each interval of interest, we determined several physiological variables: Interbeat Interval (inverse of heart rate), heart rate variability, number of skin potential responses, their maximum value, and alpha asymmetry at F7 and F8.

For the ANOVAs, the definition of the intervals of interest is given in the last column of Table 1. Note that the 'frying' and 'eating' interval lasted longer (120 and 45 s) than the other intervals (30 s). We divided the number of skin potential responses and their summed amplitude in the frying and eating interval by respectively 4 and 1.5 to make them more comparable to the other intervals. For each participant, each physiological variable was baselined by subtracting the value corresponding to the baseline interval (waiting for the cooking plate to heat) from the four consecutive intervals.

For classification analysis, intervals were defined as successive 30 s epochs, starting at 25 s (*i.e.*, the start of the baseline interval). As for the ANOVAs, physiological data were baselined by subtracting for each participant the value corresponding to the baseline interval from the consecutive intervals.

For each participant, each interval as defined above (both for the conventional statistical analysis as for the classification analysis), and each electrodermal and ECG variable, we checked the data for errors in measurement. This was operationalized by data points exceeding a deviation of the mean by more than 5 times the standard deviation. No such errors were found. In order to exclude measurement errors in EEG (alpha asymmetry), we checked for each interval whether alpha at F7 and/or F8 exceeded a deviation of the mean by more than 5 times the standard deviation. For the intervals used in the conventional analysis, this was the case for eleven participants, 10 of which showed such deviations in at least 6 of the intervals. Data of these participants were removed for conventional analysis. For classification analysis, participants were not removed but outlying data were replaced by the median value of the remaining data in that interval. This concerned less than 1% for each of the peripheral physiological features and between 9 and 19% of the different EEG features.

2.5.2. Extraction of physiological variables

For extracting electrodermal variables we used the matlab LedaLab toolbox (Benedek & Kaernbach, 2010). The signal was bandpass filtered between 0.03 and 100 Hz. We examined several variables based on Continuous Decomposition Analysis: the number of individual phasic responses (nSCR), their maximum value (PhasicMax) and tonic skin potential level (Tonic). Classification analysis also included summed amplitudes of the responses (AmpSum), the latency of first significant phasic response within the interval of interest (Latency), average phasic response activity (SCR) and the area (time integral) of phasic response activity (ISCR).

EEG data were processed and analyzed using Matlab and the FieldTrip open source Matlab toolbox (Oostenveld, Fries, Maris, & Schoffelen, 2011). The signals were referenced to the average EEG signal, filtered by a 0.5 Hz high pass- and a 43 Hz low pass filter and resampled to a frequency of 256 Hz. Measurement intervals were divided in smaller, 5 s intervals. For each of these smaller intervals, the spectral power was calculated in ($N = 37$) bands ranging from 0 to 43 Hz (in steps of 0.2 Hz) following an FFT approach using a single Hanning taper. Subsequently, values were integrated in bands of interest (alpha: 8–13 and gamma:32–43 Hz). The median of these values was determined for each band and interval. Finally, frontal alpha asymmetry at F7 and F8 was determined for each 5 s segment. The relative difference between alpha as recorded at the right and the left side of the cortex was computed as $((R - L)/(R + L)) \times 100$ (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 – Cook et al., 1998). Again, the median values for each interval were used as a robust estimate of alpha-asymmetry. For classification, we included frontal alpha asymmetry at F3 and F4, frontal gamma (Fpz) and frontal alpha (Fz) as additional features. Frontal gamma may carry information that can be used to distinguish between classes through muscle artefacts caused by possible differences between conditions in facial movement. Frontal alpha may differ if mental effort or cognitive processing differs between conditions (*e.g.* Hogervorst, Brouwer, & Van Erp, 2014).

Interbeat intervals (IBIs) were extracted from the ECG signal. Mean IBIs (*i.e.*, the inverse of heart rate) were determined for each interval of interest, as well as the RMSSD heart rate variability.

2.5.3. Statistical analysis using ANOVAs

In order to examine whether there was a general effect of food condition on the dependent variables, and whether it differed between intervals, we first conducted repeated measures ANOVAs with food condition (mealworms and chicken) and interval (‘exposure’, ‘frying’, ‘cooling’ and ‘eating’) as independent variables.

We also examined each interval more closely by conducting mixed-design ANOVAs with condition (chicken or mealworms) as within-subjects variable, and order (chicken or mealworms first) as between-subjects variable for each of the intervals ‘exposure’, ‘frying’, ‘cooling’ and ‘eating’ separately. Subjective arousal and valence ratings were analyzed the same way, with the addition of the interval ‘baseline’.

Since the subjective arousal and valence scores showed the largest difference between food conditions in respectively the exposure and the cooling interval, we correlated the chicken-mealworm physiological difference scores to the accompanying subjective difference scores for those intervals. Any correlation between the two should show up at least in these conditions.

2.5.4. Classification analysis

While analyses as described above are suitable to explore general effects of emotional food condition on physiology, this does not tell us whether physiological differences can be used to monitor food-related emotion for a single individual. For this, classification models are suitable. These are for instance used in brain-computer interfaces, where it is necessary to estimate a state of interest on (high-dimensional) neurophysiological data from one individual at one point in time (Brouwer, Zander, Van Erp, Korteling, & Bronkhorst, 2015). General descriptions of this methodology can be found in Domingos (2012), and Lemm, Blankertz, Dickhaus, and Müller (2011). The challenge of our classification model was to identify whether a set of physiological data originated from a participant in the mealworm condition or the chicken condition, based on datasets of other participants (*i.e.*, across subjects), and which combination of features worked best. To avoid possible effects of time and interaction effects with order of food condition, we only used data originating from the first cooking block in the classification analyses. We used linear SVM models that were trained to distinguish between mealworm and chicken using 10-fold cross validation. Classification was performed using the Donders machine learning toolbox (DMLT) developed by Van Gerven, Bahramisharif, Farquhar, and Heskes (2013) and implemented in the FieldTrip open source Matlab toolbox (Oostenveld et al., 2011). The features were standardized to have mean 0 and standard deviation 1 on the basis of data from the training set. Models were trained and tested using combinations of the features as listed in the Table 2. Log values were taken from all features except for the electrodermal-tonic level and alpha asymmetries. To test whether classification was significantly above chance level (50% correct), binomial tests were performed. The classification approach as described above is essentially the same as we used before (Brouwer et al., 2015; Hogervorst et al., 2014).

3. Results

3.1. Responses to questionnaires and general behavior

Participants cooked on average 5 days in the week (for longer than 15 min). Of the 41 participants, 3 had eaten mealworms several times before, 11 had eaten them once or twice before, and 27 never had eaten them before. 14 of the participants were in doubt whether or not to eat them, 27 made up their mind whether or not to eat them immediately.

Responses at the time of discovering the mealworms, as noticed by the experimental leader and as videotaped, varied from not or hardly noticeable reactions (*i.e.*, neutral) through clear facial expressions of disgust or verbal expressions of surprise. Most participants kept to the instruction of not speaking and moving too much, and only smiled.

The experimental leader noticed that five participants refused to taste mealworms while none refused to taste chicken. However, at least two more participants probably did not eat the mealworms since they had not filled out the valence and arousal question to rate how they felt during eating (*i.e.*, they may have sampled some of the dish without mealworms).

3.2. Subjective measures

Fig. 1 shows the valence and arousal scores for the intervals from baseline up to eating.

Table 2
Tested features.

Type of feature	Abbreviation	Feature
Electrodermal	PhasicMax	Maximum amplitude of phasic responses
	nSCR	Number of phasic responses
	Tonic	Tonic level
	AmpSum	Summed amplitude of phasic responses
	Latency	Latency of first significant phasic response within the interval of interest
	SCR	Average phasic response activity
	ISCR	Area (time integral) of phasic response activity
ECG	IBI	Inter beat interval (inverse of heart rate)
	RMSSD	Heart rate variability
EEG	asymm F7F8	Alpha asymmetry at F7 and F8
	asymm F3F4	Alpha asymmetry at F3 and F4
	gammaFpz	Power in the gamma band at Fpz
	alphaFz	Power in the alpha band at Fz

From the time of exposure on, valence was lower for mealworms than for chicken (repeated measures ANOVA: $p = 0.02$; no effect of interval and no interaction). Table 3 shows the results of the mixed-design ANOVAs in which the intervals were examined separately. Valence was significantly lower in the cooling interval ($p < 0.01$), though the main effect of food condition was close to significance during exposure ($p = 0.07$) and frying ($p = 0.05$). There were no main effects of order and no interactions between condition and order on valence scores. For all intervals, and both food conditions, valence was on the positive side of the spectrum (the smiling manikins of the SAM).

From the time of exposure on, subjective arousal was higher for mealworms than for chicken (repeated measures ANOVA main effect of food $p < 0.01$). It differed between intervals (main effect of interval: $p = 0.01$), and the effect of food condition was stronger for some intervals than others (interaction $p < 0.01$). The mixed-design ANOVAs showed a significant effect of food for all intervals after the baseline (all p-values < 0.01). There were no effects of order, but interactions between order and condition for the baseline ($p < 0.01$) and cooling ($p = 0.04$). These interactions can be described as the effect of food condition being stronger when mealworms are presented first. This is consistent with arousal generally being higher during the first than the second session.

3.3. Electrodermal measures

Fig. 2 shows the electrodermal data. The repeated measures ANOVAs did not show an overall effect of food condition across all intervals ($p = 0.82$ for maximum amplitude, $p = 0.35$ for number of responses and $p = 0.13$ for tonic level). For maximum amplitude and tonic level, there were also no significant effects of interval (respectively, $p = 0.07$ and $p = 0.63$) and no interactions ($p = 0.31$ and $p = 0.11$). Number of responses differed between intervals (effect of interval: $p < 0.01$) and the effect of food differed significantly between intervals (interaction effect: $p < 0.01$). The mixed-design ANOVAs showed that maximum amplitude was significantly higher for mealworms compared to chicken right after the first exposure (main effect of condition $p = 0.02$). The number of phasic potentials were significantly higher for mealworms than chicken in the cooling condition ($p = 0.03$). The mixed-design ANOVAs did not show effects for tonic level though the main effect was close to significance for the last (eating) interval ($p = 0.08$). There were no main effects of order or food-order interaction effects for all electrodermal variables.

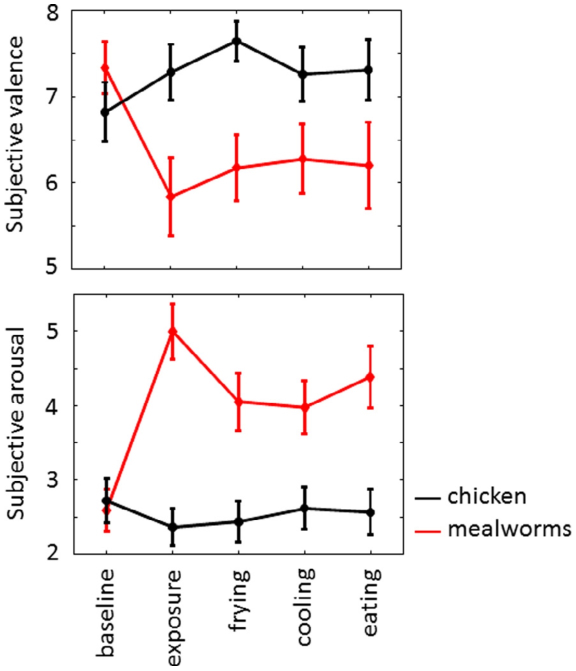

Fig. 1. Valence and arousal scores for the intervals from baseline up to eating, for each of the two food conditions. Error bars indicate standard errors of the mean.

3.4. ECG measures

Fig. 3 shows the ECG variables. The repeated measures ANOVA on IBI showed an effect of food condition ($p = 0.02$), interval ($p < 0.01$) and an interaction effect ($p < 0.01$). The mixed-design ANOVAs show a lower IBI (*i.e.* higher heart rate) in the chicken compared to the mealworms condition for the exposure ($p = 0.03$), frying ($p < 0.01$) and eating ($p < 0.01$) interval. However, there were also interactions with order for all intervals (consecutive p-values of < 0.01,<0.01, 0.03 and 0.02) indicating that the lower IBI (higher heart rate) for chicken was only found or only strong when chicken was presented first. There were no main effects of order on IBI.

The repeated measures ANOVA on RMSSD only showed an effect of interval ($p = 0.02$; food condition: $p = 0.55$; interval: $p = 0.65$). The mixed-design ANOVAs showed no (interaction) effects of food condition or order for any of the intervals, except for an interaction between order and food condition for the exposure interval ($p = 0.01$) that suggested a higher heart rate variability for the second session than for the first.

3.5. EEG measures

The repeated measures ANOVA on alpha asymmetry at F7F8 (Fig. 4) showed an effect of food condition ($p = 0.03$) with higher values, *i.e.* relatively higher alpha in the right hemisphere, for chicken than for mealworms. There were no effects of interval ($p = 0.67$) and no interaction effects ($p = 0.98$). The mixed-design ANOVAs showed a significant effect of food condition in the frying interval. There were no effects of order and no interaction between order and interval.

3.6. Correlations

We did not find correlations between physiological responses and subjective responses (where responses are defined as the difference between mealworms and chicken), not for the exposure and not for the cooling interval.

3.7. Classification

The feature set with the best classification performance included three electrodermal features (nSCR, PhasicMax and Tonic), both ECG features (IBI and RMSSD) and two EEG features (asymm F7F8 and asymm F3F4). With this feature set, classification accuracy was 82%, which was significantly above chance performance of 50% ($p < 0.01$). Table 4 gives a comparison of model performance based on the optimal feature set and the consequences of leaving out each of the seven features. These results suggest that maximum amplitude and alpha asymmetry at F7F8 are relatively important. Leaving PhasicMax out decreases classification performance from 82% to 69%, and leaving asymmF7F8 out decreases performance from 82% to 72%. However, any of the features can be left out without performance dropping below 0.01 significance level. An alternative test where we compared performance not to a chance level of 50% but to chance level generated by randomly re-assigning labels before training and testing the models (therewith controlling for effects that may have artifi-

Table 3
P-values reflecting effects of food condition as resulting from the mixed-design ANOVAs. P-values printed in grey signify that there was an interaction between food condition and with order, which means that significant effects of food are difficult to interpret (especially in the case of IBI where direction of the food effect could be opposite depending on the order). P-values <0.05 are printed in bold.

	Exposure	Frying	Cooling	Eating
Valence	.07	.05	<.01	.10
Arousal	<.01	<.01	<.01	<.01
PhasicMax	.02	.52	.60	.76
nSCR	.53	.78	.03	.31
Tonic	.68	.17	.28	.08
IBI	.03	<.01	.95	<.01
RMSSD	.37	.77	.99	.31
Asymm F7F8	.16	.04	.14	.07

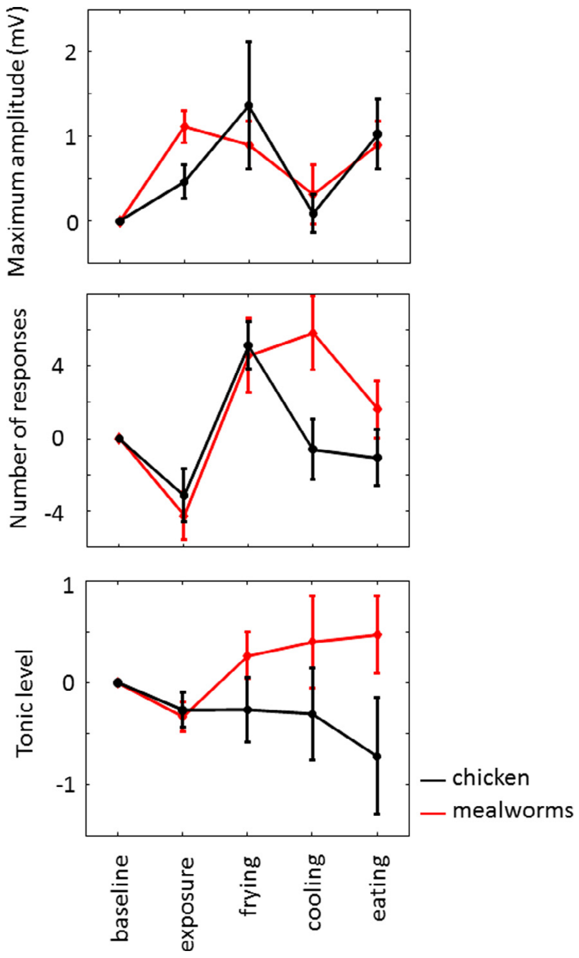

Fig. 2. Maximum skin potential amplitude, number of skin potential responses and tonic level for the intervals from baseline up to eating, for each of the two food conditions. Error bars indicate standard errors of the mean.

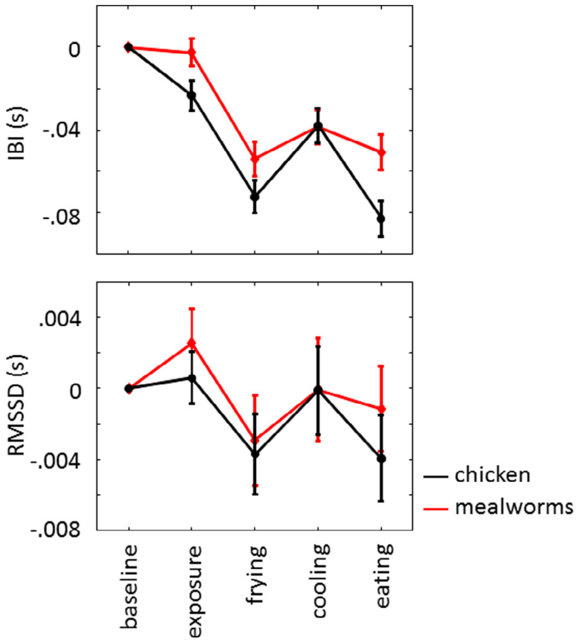

Fig. 3. IBI (inverse heart rate) and RMSSD (heart rate variability) for the intervals from baseline up to eating, for each of the two food conditions. Error bars indicate standard errors of the mean.

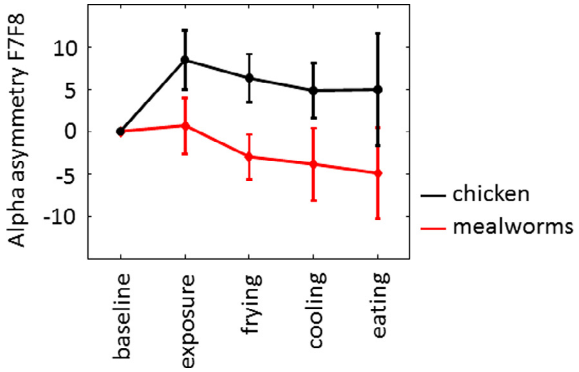

Fig. 4. Alpha asymmetry as determined at electrode locations F7 and F8 for the intervals from baseline up to eating, for each of the two food conditions. High values reflect high alpha power in the right hemisphere compared to the left.

cially inflated performance such as overfitting) still indicated that performance was significantly above chance for all of the models in Table 4.

4. Discussion

This study provides new insights into recording neurophysiological correlates of emotions during cooking and tasting and indicates a new and important approach in this research area for creating innovative, healthy products and dishes. We demonstrated that on the basis of neurophysiological variables, we can

Table 4
Classification performance and significance level of the model based on the 7 features that we found to perform best; and performance of this best model with each of the 7 features left out, in descending order of effect.

Features	Performance	p-value
All 7 features	0.82	0.000
Minus PhasicMax	0.69	0.005
Minus asymm F7F8	0.72	0.002
Minus IBI	0.75	0.001
Minus RMSSD	0.75	0.001
Minus nSCR	0.77	0.000
Minus Tonic	0.79	0.000
Minus asymm F3F4	0.79	0.000

estimate with 82% accuracy whether a single participant is preparing a dish with mealworms or with chicken. Since these variables have been associated with emotion, and we aimed to set up the experiment in such a way that the only aspect that differed between the food conditions was emotion, this provides evidence that it is possible to estimate continuously experienced emotion during a dynamic real-life cooking process and tasting.

We hypothesized that cooking with mealworms would be associated with high arousal relative to chicken. The results of the study showed that this was indeed the case as reflected in the subjective measure of arousal (for all intervals, with the largest difference between mealworms and chicken in the interval 'exposure'. Interestingly, it was also reflected in higher electrodermal activity, but only during the interval 'exposure' in case of maximum amplitude, and during the interval 'cooling' in case of a number of phasic responses. The reasons for different interval effects of food condition on physiological variables may be found in 1) variations in mental activity across intervals, which is differently associated with the various physiological variables, or 2) movements differences across intervals, which differently affects the various physiological variables. For instance, in the case of electrodermal variables, more phasic responses were observed during the interval 'cooling' for the mealworm than for the chicken condition. The interval 'cooling' is an interval in which participants mostly stand still. These form suitable circumstances for detecting spontaneously generated skin potentials. Alternatively or in addition, the interval 'cooling' is the time that participants contemplate about eating mealworms while not being distracted by having to perform other activities, which may have caused a relatively strong type of excitement. The interval 'exposure' is an interval that contains a suddenly presented arousing stimulus which is expected to generate a relatively large skin potential response. For the other intervals, we did not find significant effects of food on the electrodermal variables. In general, it should be noted that in the present study, we measured skin potential and not skin conductance. We expect electrodermal activity to reflect arousal more clearly when skin conductance rather than skin potential would have been measured (Andreassi, 2007). Higher arousal was not reflected in lower heart rate variability for any of the intervals; neither was disgust reflected in higher heart rate variability. These processes may have worked against each other, resulting in no net effect. In addition, the intervals we used to determine measures of heart rate variability are short (Task Force of the European Society of Cardiology the North American Society of Pacing Electrophysiology, 1996) and may have resulted in noisy values.

While food condition affected heart rate significantly in three out of four intervals, there was a significant interaction between food condition and order for all of the intervals. This interaction showed that the observed main effect of higher heart rate for chicken was only present when chicken was prepared first; when mealworms were prepared first the effect tended to be in the other direction. This probably has to do with time related effects on heart rate (*e.g.* Brouwer & Hogervorst, 2014) which makes interpretation difficult.

We hypothesized that cooking with mealworms would be associated with low valence relative to chicken. While in general, this was confirmed by the subjective measure of valence (Fig. 1A), the difference between the two food conditions was only significant in the interval 'cooling'. Alpha asymmetry was in the 'approach' direction for chicken and in the 'avoidance' direction for mealworms, with a significant difference in the interval 'frying'. The latter may be caused by the fact that this interval was relatively long, resulting in more data available to (reliably) determine alpha asymmetry.

In sum, we found food condition to affect subjective and physiological variables. The fact that food condition affected different variables at different cooking intervals was also reflected in the lack of correlation between the food condition difference in subjective variables and the difference in physiological variables. As mentioned above, the different patterns of food condition effects sketched by the different variables can reflect that different variables are reflecting different underlying mental states, and they can be a result of different sensitivity under the different circumstances (of the measurement interval). Knowing the 'ground truth' in studies on monitoring emotion using physiological variables is inherently difficult (Brouwer, Zander et al., 2015) which makes it hard to pinpoint one 'best' variable. Moreover, as discussed in the introduction, we expected that different variables reflect somewhat different mental states. With respect to the subjective valence, participants probably assigned lower ratings to cooking with mealworms than to cooking with chicken because they felt disgusted or anxious in anticipation of eating them. However, a common visible reaction of participants upon seeing the mealworms was smiling. Conversation after the experiment indicated that 'the mealworm experience' was also seen as humorous, and some participants were curious and excited as to how they would taste. Subjective arousal seemed to be more unequivocally experienced and reported. Similar difficulties with reporting subjective valence versus subjective arousal were reported in Brouwer, Hogervorst et al. (2015). As discussed above, skin potential amplitude was only affected in the interval 'exposure', and number of spike potentials in the interval 'cooling' which we hypothesized to follow from both differences in mental state between the intervals as well as issues with measurement noise. Alpha asymmetry was only significantly affected by food condition in the interval 'frying', but the graphs and statistical results indicated a more constant effect over intervals than was the case with the skin potential amplitude and number of skin potentials. This suggests that 'avoidance' and 'approach'-related mental states are present throughout the cooking process and reflected in alpha asymmetry.

It is promising that we found an effect of food condition on alpha asymmetry that was in the hypothesized 'approach-avoid ance' direction, with a relatively small amount of data (we could present the participants each condition only once) and under quite noisy conditions. This is despite the fact that some past research on cortical asymmetry as being associated with emotion did not find the predicted effects (see a review by Murphy, Nimmo-Smith, & Lawrence, 2003). Failure to find predicted effects is especially prevalent in research on affective pictures (Harmon-Jones et al., 2010). Harmon-Jones and colleagues argue that in most cases, pictures may not evoke sufficiently intense emotions, and that not all types of affective pictures directly correspond to approach and avoidance motivation. Indeed, Schöne, Schomberg, Gruber, and Quirin (2016) found the expected alpha asymmetry for erotic pictures, that they argued to differ from other types of pleasant pictures in (strong) approach motivation. Similarly, Gable and Harmon-Jones (2008) showed that greater left frontal 'approach' activation to images of desserts compared to neutral images was stronger in participants liking desserts and not having eaten for a while than in other participants. We think that real-life cooking and expecting to taste chicken versus mealworms form strong, engaging stimuli, that perfectly map on the approach-avoidance scale rather than on valence. Also, the chicken and mealworm case is interesting because it is a case where neurophysiology may be expected to add to subjective valence ratings. As discussed, these ratings are difficult to interpret since they are probably influenced by factors like disgust, curiosity, interest and demand characteristics (wanting to please the experiment leader or wanting to seem tough).

There is room for improvement with respect to our EEG results. Our measurements were not of the highest quality and we did not apply advanced noise reduction techniques (for which recordings using more electrodes would have been helpful). Other possible improvements for follow-up studies include recording skin conductance rather than skin potential, and play with optimal time intervals to determine the different physiological variables in an optimal fashion.

Different physiological and subjective measures may eventually be used in a toolset to map different aspects of emotional or affective experience. An appropriate choice of tools from the toolset depends on the test circumstances (including involved body movement) as well as the question of interest. Since ground truth of emotion or affective experience is difficult to determine, and arguably not the most important aspect for applications it is of great interest to try and link the variables to subsequent behavior. There is still a scarcity of studies showing unequivocally that (adding) neurophysiological signals predict subsequent behavior, such as product choice and liking over repeated exposure, better than self-reports. However, a few studies showed added value of neurophysiological measures (in these cases, fMRI measures) to self-reports in predicting real-life behavior, namely responses to music predicting sales of music three years later and responses to advertisements predicting advertisement success (Berns & Moore, 2012; Falk, Berkman, & Lieberman, 2012; Venkatraman et al., 2015).

In conclusion, this study showed for the first time that is possible to estimate experienced emotion during real-life cooking and tasting using neurophysiological measures that do not require conscious, explicit judgment. Future research should further build and optimize the techniques and algorithms using more subtle food stimuli. In the end, this may enable to design foods and cooking experiences that are healthy yet emotionally rewarding and liked over time.

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