Food Quality and Preference 106 (2023) 104805

Contents lists available at ScienceDirect

Food Quality and Preference

journal homepage: www.elsevier.com/locate/foodqual

EEG measures of attention toward food-related stimuli vary with food neophobia

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ARTICLE INFO

Keywords:
Physiological synchrony
Inter-subject correlation
EEG
Food neophobia
Food experience
Event-related potentials

ABSTRACT

Humans differ strongly in their willingness to try novel foods. Hesitance to try new foods is referred to as food neophobia. Understanding food neophobia is important, as it can be a significant barrier to adopt a healthy, balanced or plant-based diet. We here use electroencephalogram (EEG) recordings to obtain insight in the early attentional processes towards food stimuli as a function of food neophobia. 43 Dutch participants completed the food neophobia scale after which they were presented with pictures of familiar and unfamiliar foods and a 15-minute movie about the origin and production of an unfamiliar food. We extracted two EEG-based metrics of attention: the late positive potential (LPP) amplitude in response to the food pictures, and inter-subject correlations (ISC-EEG) during the movie. The latter is a novel metric, based on similarities in EEG over time between individuals who are presented with the same stimulus, and suitable for examining attention towards continuous stimuli such as movies. Additionally, participants were asked to taste familiar and unfamiliar soups, and they were asked to rate the pictures and soups for valence and arousal. ISC-EEG and the LPP amplitude increased and sip size decreased with food neophobia, not only for unfamiliar food pictures, but also for familiar food pictures. Self-reported emotional experience was affected by food neophobia for unfamiliar food pictures or soups, but not for familiar ones. We conclude that food neophobia is associated with increased attentional processing and immediate implicit behavior, for all food stimuli and not only for unfamiliar food stimuli. This indicates that all food-related stimuli are of high importance to food neophobic individuals and that self-reported emotion does not capture the entire experience of food. The results also indicates that, unlike the name suggest, food neophobia does not only affect processing of novel foods, but of any food regardless of familiarity.

1. Introduction

Humans differ strongly in their willingness to try novel foods. This willingness can be captured through the food neophobia scale (Pliner & Hobden, 1992). Individuals that score high on the food neophobia scale are generally hesitant to try or buy new foods (Arvola, Lähteenmäki, & Tuorila, 1999; Bäckström, Pirttilä-Backman, & Tuorila, 2004; Chung et al., 2012; Henriques, King, & Meiselman, 2009; Schickenberg, Van Assema, Brug, & De Vries, 2008; Siegrist, Hartmann, & Keller, 2013; Tuorila, Lähteenmäki, Pohjalainen, & Lotti, 2001), including ethnic, unfamiliar foods (Choe & Cho, 2011; Filippo D'Antuono & Bignami, 2012). Food neophobia can be a significant barrier for a healthy, balanced or sustainable diet and can thereby lead to disordered eating patterns (Eertmans, Victoir, Vansant, & Van den Bergh, 2005; Falciglia, Couch, Gribble, Pabst, & Frank, 2000; S. R. Jaeger, Rasmussen, & Prescott, 2017; Knaapila et al., 2011). Understanding food neophobia is important to remove the barrier and threat eating disorders.

Rozin & Fallon, 1980 proposed three main reasons for rejection of novel foods: dislike of its sensory characteristics, a fear of negative consequences of eating it, and disgust arising from the food's origin. Food neophobia may be part of wider cross-modal avoidance behavior of novel stimuli (Pliner & Hobden, 1992; B. Raudenbush & Frank, 1999). An increasing number of studies demonstrate a role of anxiety mediation in food neophobia, with studies showing significant correlations

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https://doi.org/10.1016/j.foodqual.2022.104805
Received 8 September 2022; Received in revised form 22 December 2022; Accepted 26 December 2022
Available online 28 December 2022

between measures of food neophobia and anxiety (Galloway, Lee, & Birch, 2003; Pliner & Hobden, 1992). Anxiety traits can cause attentional biases toward threatening pictures compared to nonthreatening pictures (Berggren & Eimer, 2021; Holmes, Nielsen, & Green, 2008; Li, Li, & Luo, 2005). In a similar fashion, one could expect that food neophobia is associated with attentional biases toward novel foods. Indeed, there are indications that food neophobia results in changes in attention. For instance, children with high food neophobia showed a greater attentional bias as measured with a visual probe task towards pictures of unfamiliar fruits and vegetables compared to familiar fruits and vegetables than children with low food neophobia (Maratos & Staples, 2015).

We know of only one study that examined effects of food neophobia on neurophysiological measures. (Raudenbush & Capiola, 2012) found that heart rate, electrodermal activity and respiration were significantly higher in individuals with high food neophobia compared to controls when they were presented with a variety of food pictures. This indicated that food phobic individuals experience heightened arousal upon the presentation of food, and heightened arousal often co-occurs with heightened attention.

While the studies above suggest a role for attention in food neophobia, we are not aware of studies using electroencephalogram (EEG) to examine this. EEG is of special interest, because not only is it more directly related to attention than other, peripheral, physiological measures as mentioned above, it also offers a view on the very early stages of the attentional process (Polich, 2007), before any behavioral response has taken place.

In the current work we evaluate the association between food neophobia and attention toward food-related stimuli. We explore two EEG-based measures of attention: event-related potentials (ERP) upon presentation of food pictures and physiological synchrony as captured through inter-subject correlations in EEG (ISC-EEG) over the course of a narrative movie clip about ethnic food.

ERPs are extracted from the EEG in response to repeated presentation of stimuli such as pictures or sounds. Positive potentials obtained from the electrodes over the parietal cortex are often interpreted as reflecting differences in the allocation of attention (Näätänen, 1988). The *P*3 component, a positive deflection at roughly 300 ms after stimulus onset, is known to be larger in response to oddball stimuli or to stimuli that are instructed to be attended (Polich, 2007). In response to affective pictures, similar, positive deflections over the parietal cortex have been reported. These positive deflections are often referred to as the Late Positive Potential (LPP), as the peak of this ERP occurs somewhat later than the traditional *P*3 in response to simpler stimuli. The slight timing difference is assumed to be due to the relatively high information load in affective pictures (Bradley, Hamby, Löw, & Lang, 2007). Still, the LPP can be interpreted as reflecting increased attention for motivationally relevant stimuli (Lang, Bradley, & Cuthbert, 1997). Indeed, larger amplitudes in the LPP are observed for emotionally engaging than for neutral stimuli, where highly arousing pictures result in the largest amplitudes (Bradley et al., 2007).

ERPs have been studied in the context of food before. Participants with binge eating disorder showed greater LPP in response to high-caloric food pictures than control participants (Svaldi, Tuschen-Caffier, Peyk, & Blechert, 2010). Similarly, high external eaters – people with the tendency to eat when exposed to food-related cues – showed larger *P*3 amplitudes in response to food pictures than low external eaters (Nijs, Franken, & Muris, 2009).

A recent measure of attention is based on the similarity of the EEG across individuals presented with the same stimulus, as assessed through ISC-EEG. A major advantage of this measure is that it enables the use of more naturalistic and dynamic stimuli than traditional controlled and repeated picture presentation. Parts of narrative stimuli that attract attention, such as engaging scenes of a popular television series, or emotionally salient sounds, result in heightened ISC-EEG (Dmochowski et al., 2014; Stuldreher, Thammasan, Van Erp, & Brouwer, 2020b). Studies have also shown that individuals with higher ISC-EEG have better recall of the narrative, which further substantiates the association between ISC-EEG and attentional engagement (Cohen & Parra, 2016; Stuldreher et al., 2020b).

As for ERPs, top-down guided selective attention affects ISC-EEG. Individuals showed significantly higher ISC-EEG when instructed to focus their attention on the stimulus than when instructed to focus their attention inward upon presentation of the stimulus (Cohen et al., 2018). Furthermore, two groups of individuals with different selective attentional instructions to the same stimulus showed distinct patterns of ISC-EEG, where individuals show higher ISC-EEG with others in the same selective attentional condition than with individuals in the other condition (Stuldreher, Thammasan, van Erp, & Brouwer, 2020a).

In the current study, we investigate how attentional processes in response to food-related stimuli vary with food neophobia, using EEG ERPs in response to familiar and unfamiliar food pictures, and ISC-EEG in response to a movie about unfamiliar food. Dutch and Japanese food serve as familiar and unfamiliar food types for the Dutch participants (cf. (Kaneko et al., 2021)).

Besides EEG measures, we also examine a behavioral measure and explicit self-reports that reflect food experience after the initial attentional stage. To obtain self-reported experience we use the EmojiGrid, a 2D pictorial scale specifically designed to rate experience elicited by food-related stimuli (Kaneko, Toet, et al., 2019; Toet et al., 2018). As a behavioral measure, we record sip size upon tasting a familiar and unfamiliar soups. Sip size has shown to distinguish between high and low-valence drinks with more discriminative power than self-reports, or neuro- and psychophysiological response measures (Kaneko, Hogervorst, et al., 2019). These three types of measures reflect different levels of emotional processing (Kaneko, Toet, Brouwer, Kallen, & van Erp, 2018). Where EEG is an implicit measure that is capable of reflecting unconscious and early processes, and self-report is an explicit measure that can only reflect conscious experience, sip size can be considered as an implicit measure that is somewhere in between.

In sum, we here investigate how attentional processes in response to food-related stimuli, as indicated by EEG, vary with food neophobia. To align these results to explicit judgements, and implicit initial behavior, we additionally examine the association between food neophobia and rated food experience as well as sip size, in the same participants, and partly for the same stimuli that were used to elicit EEG responses. We hypothesize:

1) Food neophobia is positively correlated with attention toward unfamiliar but not toward familiar food stimuli, as captured by LPP ERP amplitude and ISC-EEG.
2) Food neophobia is negatively correlated with rated pleasantness of unfamiliar but not of familiar foods, as captured by EmojiGrid reports.
3) Food neophobia is negatively correlated with sip size of unfamiliar but not of familiar soups.

2. Materials and methods

2.1. Participants

53 participants were recruited through the institutes participant pool. Before performing the study, ethical approval was obtained from the TNO Institutional Review Board (IRB). The approval is registered under reference 2020–117. All participants signed informed consent before participating in the experiment, in accordance with the Declaration of Helsinki. After successful participation, participants received a small monetary compensation for their time and traveling costs.

Due to processing errors in the experiment script, the time-synchronization of the EEG with the stimuli could not be guaranteed for 10 participants. From 53 participants, data of only 43 participants (19 female) are therefore used in further analysis. Their age ranged from

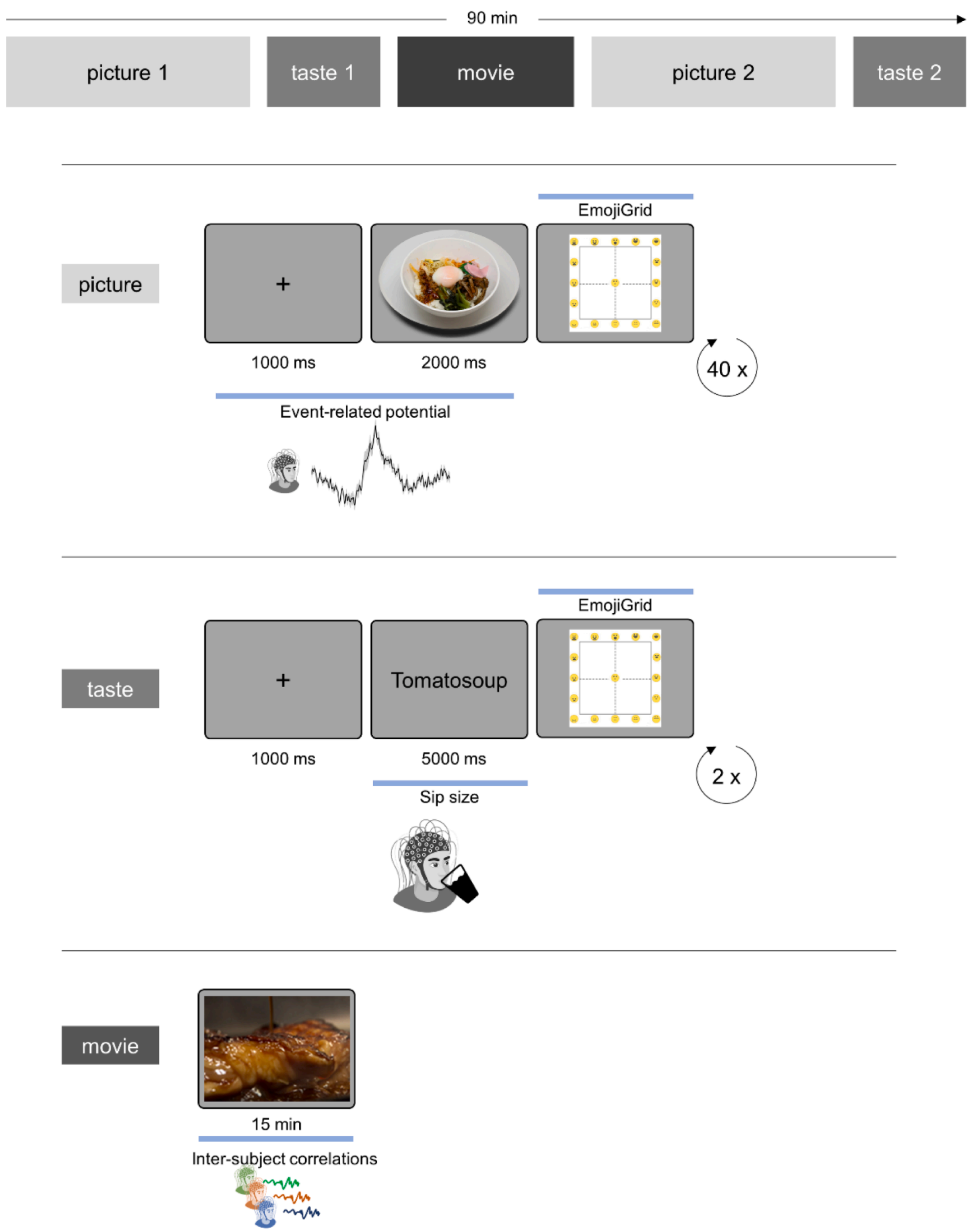

Fig. 1. Overview of the experimental procedure. The experiment consisted of a picture phase and tasting phase, followed by a movie phase and then followed by another picture and tasting phase.

19 to 64 years ($M = 46.6$, $SD = 15.3$) and Body Mass Index ranged from 18.4 to 46.4 ($M = 25.6$, $SD = 5.2$). The average time since their last meal consumption was 2.75 h ($SD = 2.4$).

2.2. Materials

EEG was recorded at 1024 Hz using an ActiveTwo Mk II system (BioSemi, Amsterdam, Netherlands) with 32 active Ag/-AgCl electrodes, placed on the scalp according to the 10–20 system, together with a common mode sense active electrode and driven right leg passive electrode for referencing. The electrode impedance threshold was set at 20 kOhm.

2.3. Stimuli and design

The experiment consisted of three phases: a first picture phase, a movie phase and a second picture phase. The experimental procedure is depicted in Fig. 1.

In each of the two picture phases, participants were presented with 80 images of food from the Cross Cultural Food Images Database (CROCUFID, (Toet et al., 2019)) on a computer screen in a randomized order. The presented images were of four different categories: unfamiliar Japanese food, familiar Dutch food, palatable food (i.e., universal food, such as fruits) and unpalatable food (i.e., molded food and food that was beleaguered by insects or snails). The latter two image

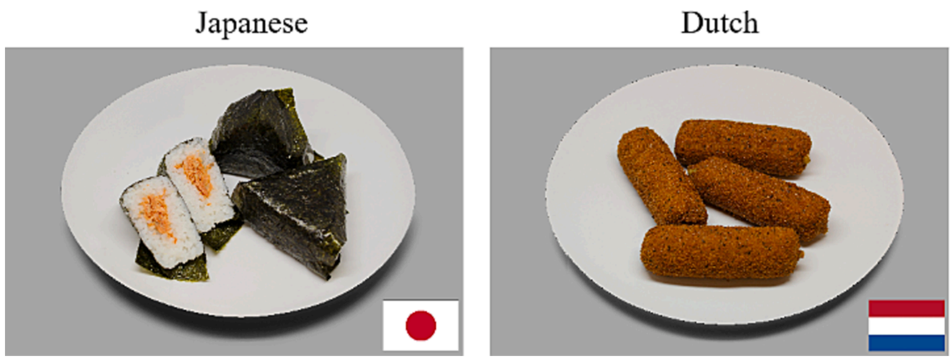

Fig. 2. Examples of CROCUFID pictures in Japanese and Dutch food categories including the symbols indicating either a Japanese or Dutch food picture.

categories represented 'ground truth' pleasant/neutral and unpleasant food and served to allow checking for sensitivity of the different measures and are not further discussed in the present manuscript. Twenty pictures of each category were presented per picture phase. For easier recognition a symbol in the right bottom corner of the food image displayed whether the depicted food is Dutch, Japanese or universal (palatable and unpalatable). An example of the Japanese and Dutch categories with symbols is displayed in Fig. 2. Each image was presented for two seconds preceded by a fixation cross displayed for half a second. Immediately after viewing each picture, participants were prompted to rate their emotion using the EmojiGrid (Toet et al., 2018). The EmojiGrid is a graphical and language-independent self-reporting tool to measure the emotional dimensions of valence (x-axis) and arousal (y-axis) in a food-related context. At the end of each picture phase a Dutch and a Japanese soup were presented in counterbalanced order to the participants to taste. The four soups were vegetable soup, tomato soup (familiar Dutch soups) and sumashi soup, Miso soup (unfamiliar Japanese soups). After tasting each soup, food-evoked emotions were rated using the EmojiGrid. The amount of soup consumed was recorded as an implicit measure of positive emotion.

Following the first picture phase, participants were presented with a 15-minute movie about the origin and production of Japanese Kikkoman soy sauce. Prior to the movie, participants were instructed differently based on a social pressure condition they were assigned to. Participants in the control group were told that their EEG sensors would be calibrated and meanwhile they could watch this movie. Participants in the social pressure condition were told a story aimed to increase social pressure to report liking of Japanese food after watching the movie.

After the movie phase the second picture phase started. The entire experimental procedure, including fitting the EEG electrodes, took about 60 min.

The social pressure intervention did not result in any between-group difference (Sabu et al., 2022). For the purpose of the current study, we collapse over the two social-pressure related instructions.

2.4. Self-report measures

Before the presentation of food pictures, participants answered a set of questionnaires. They provided a number of descriptives. In addition, participants filled out the food neophobia scale (Pliner & Hobden, 1992). This questionnaire consists of ten statements, for which a rating on a 7-point Likert scale, ranging from'strongly disagree' to'strongly agree', can be given. The outcome – a score from 10 to 70 – indicates the willingness to try novel foods. High scores indicate high food neophobia, meaning unwillingness to try new foods, while low scores indicate enthusiasm to try novel food.

2.5. Analysis

2.5.1. Pre-processing

EEG was processed using MATLAB 2021a (Mathworks, Natick, MA, United States) and the EEGLAB v14.1.2 toolbox for MATLAB (Delorme & Makeig, 2004). Potentials reflecting ocular or muscle-related artifacts were removed using logistic infomax independent component analysis (ICA; Bell & Sejnowski, 1995). Before doing so, EEG was down-sampled to 256 Hz and high-pass filtered with a 1 Hz passband frequency using the standard FIR-filter implemented in the EEGLAB function pop_eegfiltnew. The 1 Hz high-pass cut-off frequency was chosen as it has shown to work better for ICA compared to lower cut-off frequencies (Winkler, Debener, Muller, & Tangermann, 2015). 50 Hz line noise was then removed using the cleanline plugin as implemented in PREP pipeline (Bigdely-Shamlo, Mullen, Kothe, Su, & Robbins, 2015). Further artifacts were then removed using the clean_rawdata plugin for EEGLAB. Removed channels were interpolated and an average channel reference was applied. For ERP analysis, continuous data was epoched from −500 to 2000 ms with respect to the onset of pictures. For ISC analysis, the continuous EEG over the course of the movie was used. ICA was performed on either the epoched or continuous data and ICLabel was used to identify and remove artifactual independent components reflecting ocular or muscle-related artifacts (Pion-Tonachini, Kreutz-Delgado, & Makeig, 2019).

2.5.2. Event-related potentials in response to the pictures

For each individual, the event-related potentials in response to unfamiliar and familiar food pictures were extracted. First, the epoched data were lowpass filtered with a passband at 30 Hz using pop_eegfiltnew. Then, data were baselined by extracting the average value of the signal from 200 ms to 0 ms before stimulus onset. Data of each participant were averaged over all pictures from the same picture category, aggregating over the picture phases before and after the movie. For each picture category and each participant, the LPP amplitude was extracted by finding the maximum of the averaged ERP at the midline-parietal site (electrode Pz) from 500 to 1000 ms after picture onset.

2.5.3. ISC-EEG in response to the movie

We computed physiological synchrony by computing ISC-EEG. ISC-EEG was evaluated in the correlated components of the data, following earlier work (Dmochowski et al., 2014; Dmochowski, Sajda, Dias, & Parra, 2012; Stuldreher et al., 2020b). The goal of the correlated component analysis is to find underlying neural sources that are maximally correlated between participants, using linear combinations of electrodes. The components were extracted based on all datasets, after which EEG data from each participant were projected on the component vectors. Participant-to-group ISC-EEG was then computed as the sum of correlations in the first three component projections. The first three components were used as correlations in higher order projections are usually close to chance level (Ki, Kelly, & Parra, 2016).

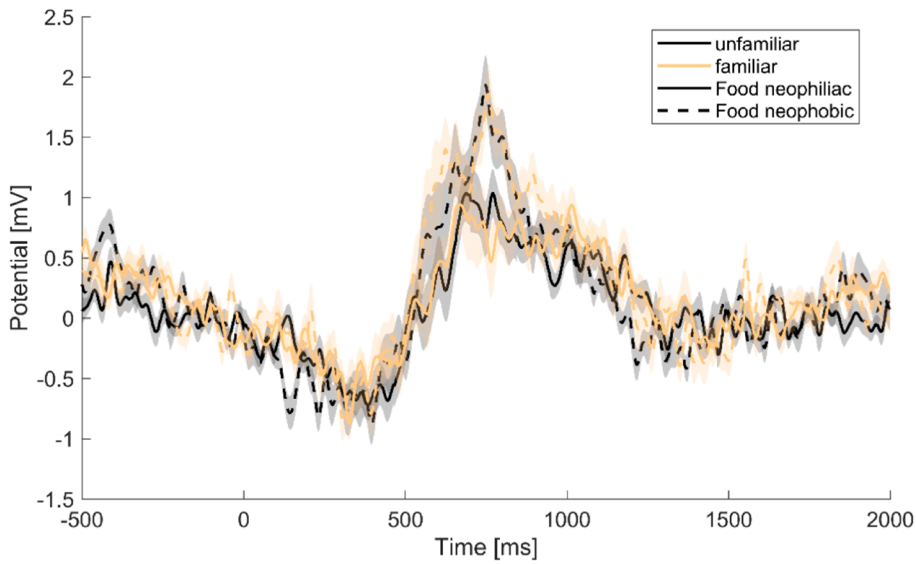

Fig. 3. Event-related potentials averaged over familiar and unfamiliar picture types and averaged over neophobic and neophiliac participants. Shaded areas depict standard error of the mean.

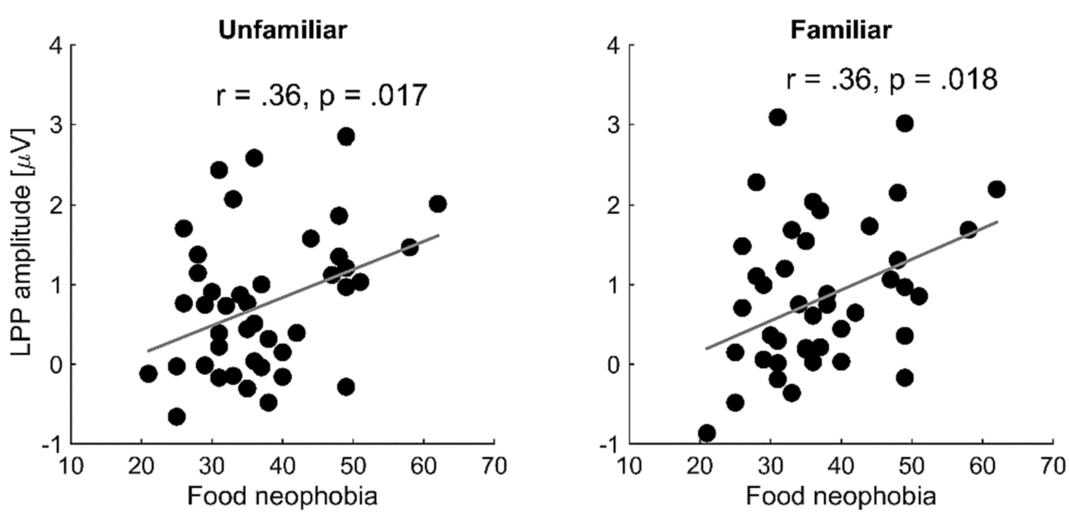

Fig. 4. Correlations between food neophobia and LPP amplitude in response to unfamiliar and familiar food pictures. Each data point represents a participant.

2.5.4. Association with food neophobia

Results were analyzed in relation with the food neophobia score. We performed correlation analyses to highlight the continuous spectrum of the food neophobia scale, following (Jaeger, Chheang, Jin, Ryan, & Worch, 2021). We investigated correlations with all the implicit and explicit measures included in the study, i.e. LPP amplitude, ISC-EEG, sip size and self-reported valence and arousal. These analysis were performed using Pearson correlations as implemented in the 'corr' function of MATLAB 2021a (Mathworks, Natick, MA, United States).

3. Results

3.1. Event-related potentials in response to food pictures

We investigated the relation between LPP ERP amplitude and food neophobia score. Fig. 3 shows the average event-related potentials separately for each picture category, food neophobic and food neophiliac participants (participants scoring above and below the median food neophobia score, respectively – note that this is not an absolute categorization, but relative to scores in our specific sample of

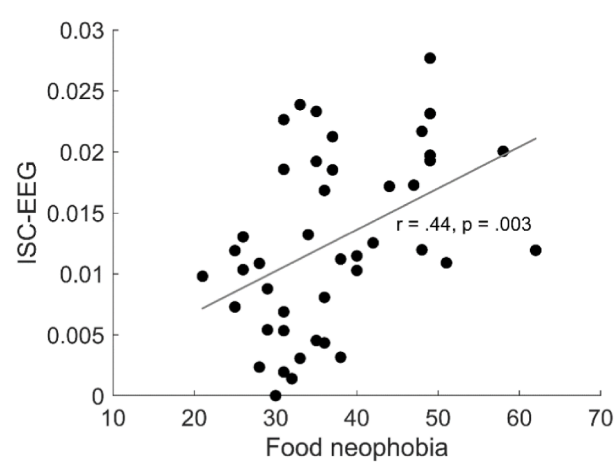

Fig. 5. Correlation between food neophobia and ISC-EEG during presentation of the movie on the origin and production of an unfamiliar food. Each data point represents a participant.

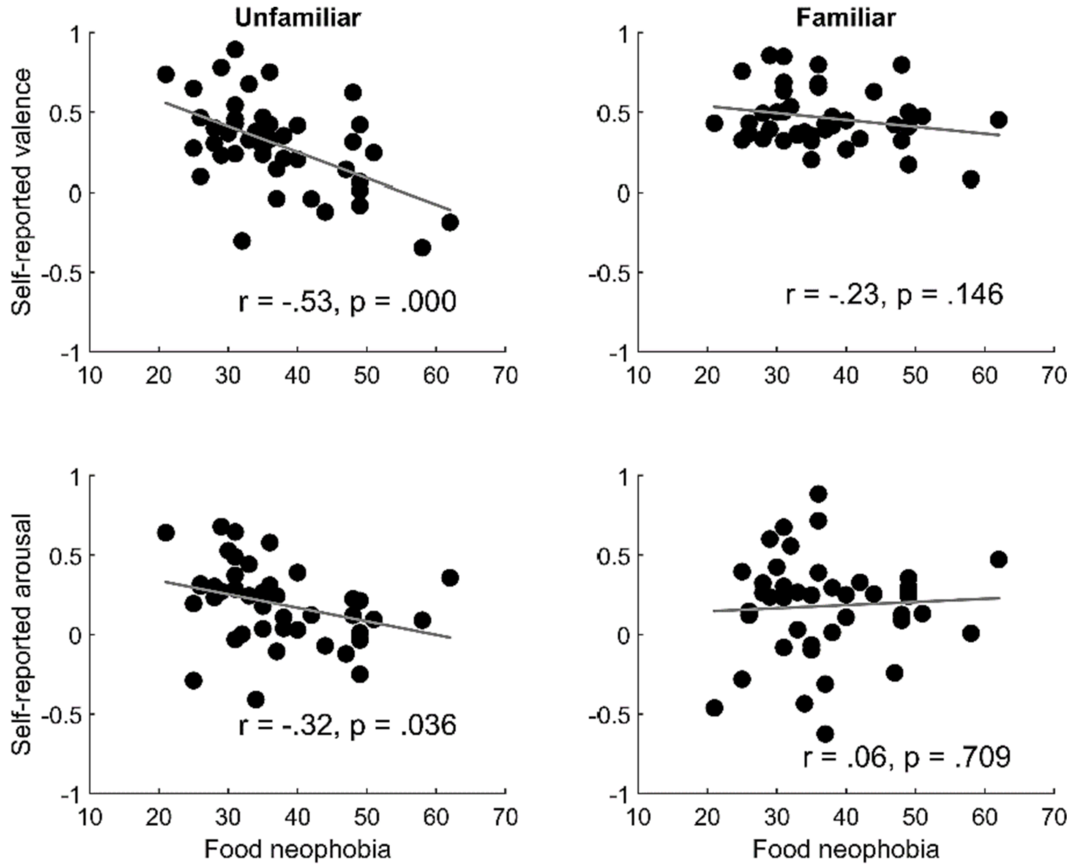

Fig. 6. Correlations between food neophobia and self-reported valence (top) and arousal (bottom) for unfamiliar (left) and familiar (right) food pictures. Each data point represents a participant.

participants). The figure suggests higher LPP amplitudes for neophobic compared to neophiliac participants for all picture categories. In line with this, Fig. 4 shows significant correlations between LPP amplitude in response to unfamiliar and familiar food pictures and food neophobia ($r = 0.36$, $p = .017$; $r = 0.36$, $p = .018$).

3.2. ISC-EEG during the movie

We investigated the relation between ISC-EEG and the food neophobia score. Fig. 5 shows that food neophobia and ISC-EEG are significantly correlated ($r = 0.44$, $p = .003$) where higher food neophobia scores are associated with higher ISC-EEG.

3.3. EmojiGrid after image presentation

Fig. 6 shows that self-reported valence in response to unfamiliar food pictures is strongly correlated with food neophobia ($r = -0.53$, $p < .001$) where high food neophobia is associated with low valence scores. As shown in the same figure, this correlation is not significant for any of the familiar food pictures. Although to a lesser degree than for valence, self-reported arousal in response to unfamiliar food pictures is also significantly correlated with food neophobia ($r = -0.32$, $p = .036$), where high food neophobia is associated with low arousal scores. Again, no significant correlations are found for familiar food pictures.

3.4. Sip size

Fig. 7 shows significant correlations between food neophobia and average sip size for all soups (unfamiliar sumashi: $r = -0.47$, $p = .002$; unfamiliar miso: $r = -0.44$, $p = .004$; familiar vegetable: $r = -0.15$, $p = .336$; familiar tomato: $r = -0.33$, $p = .033$), where food neophobia is associated with smaller sip size, except the familiar vegetable soup.

3.5. EmojiGrid after soup tasting

Fig. 8 shows a significant negative correlation between food neophobia and self-reported valence after tasting the unfamiliar miso soup ($r = -0.31$, $p = .047$) and a near significant negative correlation after tasting the unfamiliar sumashi soup ($r = -0.28$, $p = .069$). No significant correlations with self-reported valence are found after tasting familiar soups. No significant correlations between food neophobia and self-reported arousal are found for any of the soups.

4. Discussion

In the current work we investigated how food neophobia is associated with attention toward food-related stimuli as elucidated by two EEG measures: ERPs and ISC-EEG. We also examined the association between food neophobia and self-reported emotional experience, as well as the association between food neophobia and an implicit behavioral response (sip size). Below, the results will first be discussed for each of the hypotheses, followed by overall conclusions.

4.1. LPP ERP amplitude

As hypothesized, the LPP amplitude in response to unfamiliar food pictures correlated with food neophobia, where participants with higher food neophobia showed higher LPP amplitude. However, nearly identical results were found for familiar food pictures. A higher LPP amplitude indicates increased attention to, and facilitated processing of motivationally relevant stimuli (Schupp et al., 2000; Schupp, Junghöfer, Weike, & Hamm, 2003). It appears that, unlike its name suggests, food

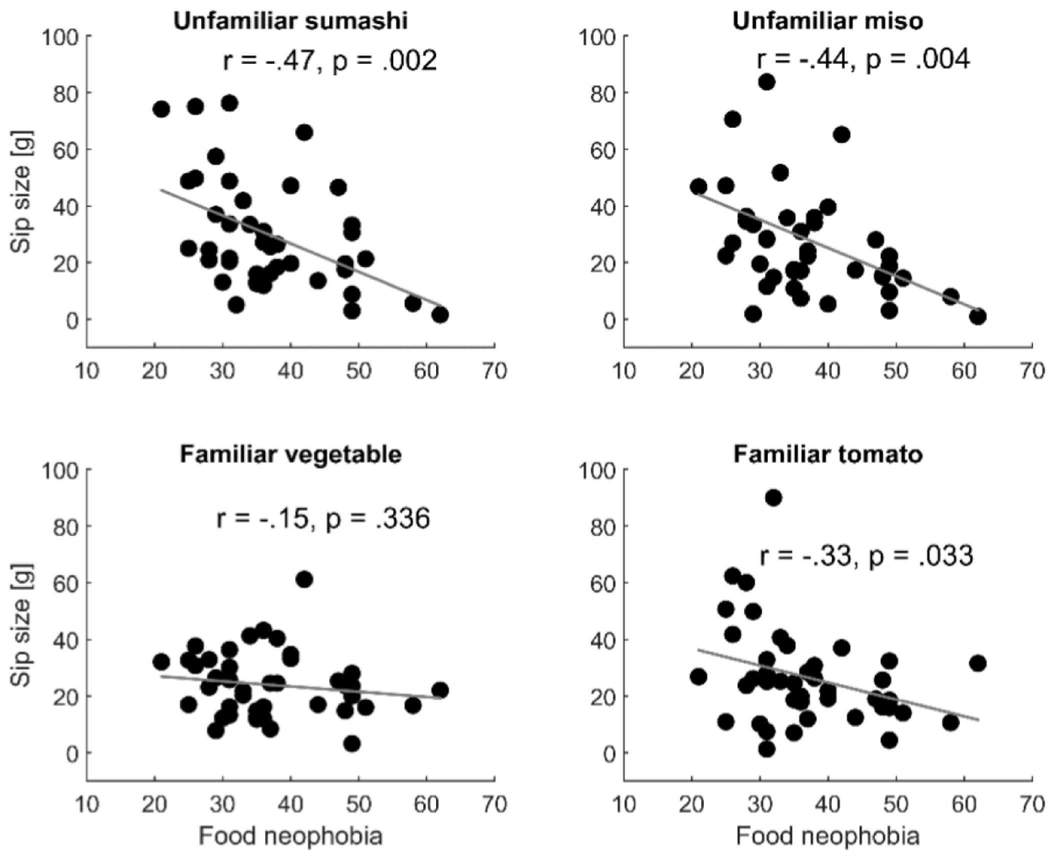

Fig. 7. Correlation between food neophobia and sip size for unfamiliar sumashi and miso soups and familiar vegetable and tomato soups and. Each data point represents a participant.

neophobia does not only have an effect on the attentional processing of novel foods, but on any food-related stimulus.

Comparable observations have occurred in other phobic populations. Individuals with social anxiety do not only show increased LPPs to threatening faces, but also to faces overall, regardless of valence (Mühlberger et al., 2009). The authors conclude that faces in general are important stimuli for socially anxious people (Moser, Huppert, Duval, & Simons, 2008). Similarly, our results indicate that not only novel foods, but all food-related stimuli are of high importance to food neophobic individuals. Previous work showed higher arousal in food neophobic individuals than food neophiliacs when presented with successively presented pictures of a range of food types, as indicated by increased heart rate, EDA and respiration rate (Raudenbush & Capiola, 2012). We now show specifically for different types of food images that this increased arousal is likely associated with increased attention to food pictures in general.The current study did not include non-food stimuli. Including such stimuli would have allowed us to examine the specificity of the relation between food neophobia and responses to food, rather than to stimuli more in general. As discussed in the introduction, food neophobia may be part of wider avoidance behavior of novel stimuli (Pliner & Hobden, 1992; B. Raudenbush & Frank, 1999), food neophobia and anxiety are positively associated (Galloway, Lee, & Birch, 2003; Pliner & Hobden, 1992) and anxiety traits can cause attentional biases toward threatening pictures compared to nonthreatening pictures (Berggren & Eimer, 2021; Holmes, Nielsen, & Green, 2008; Li, Li, & Luo, 2005). Therefore, we would expect that higher LPP amplitudes and stronger ISC-EEG in individuals scoring high on food neophobia might be found for other, non-food stimuli as well.

4.2. ISC-EEG

As for the LPP amplitude, ISC-EEG showed the hypothesized positive correlation with food neophobia. As higher ISC-EEG indicate higher levels of attention toward the presented stimulus (Stuldreher et al., 2020b), this result indicates that participants with higher food neophobia also show higher levels of attention directed to a naturalistic, narrative stimulus about the origin of an unfamiliar food product.

Several authors have argued that ISC-EEG is likely driven for a large part by consecutive ERPs occurring from attentionally relevant or emotionally salient events in the stimulus (Poulsen, Kamronn, Dmochowski, Parra, & Hansen, 2017; Stuldreher et al., 2020a). Our current findings that both ERP LPP amplitude and ISC-EEG correlate with food neophobia are in line with this reasoning. Participants with high food neophobia likely showed higher and more consistent ERPs in response to food-related events throughout the movie, leading to higher overall ISC-EEG.

Compared to ERPs, requiring the controlled presentation of successive stimuli, assessing ISC-EEG enables the use of much more naturalistic and continuous stimuli, such as video clips (Cohen et al., 2018; Dmochowski et al., 2014) or audiobooks (Stuldreher et al., 2020b). Up to now, ISC-EEG was shown to be modulated by explicit instructions to focus attention on specific stimulus aspects (Ki et al., 2016; Stuldreher et al., 2020b). To the best of our knowledge, we here show for the first time that ISC-EEG during such naturalistic stimuli is modulated by personal trait. This is an important development for the use of ISC-EEG as implicit measure of attentional processing in natural environments, where one usually does not aim to capture variations in attention due to explicit instructions, but due to natural variations, for instance related to personal trait.

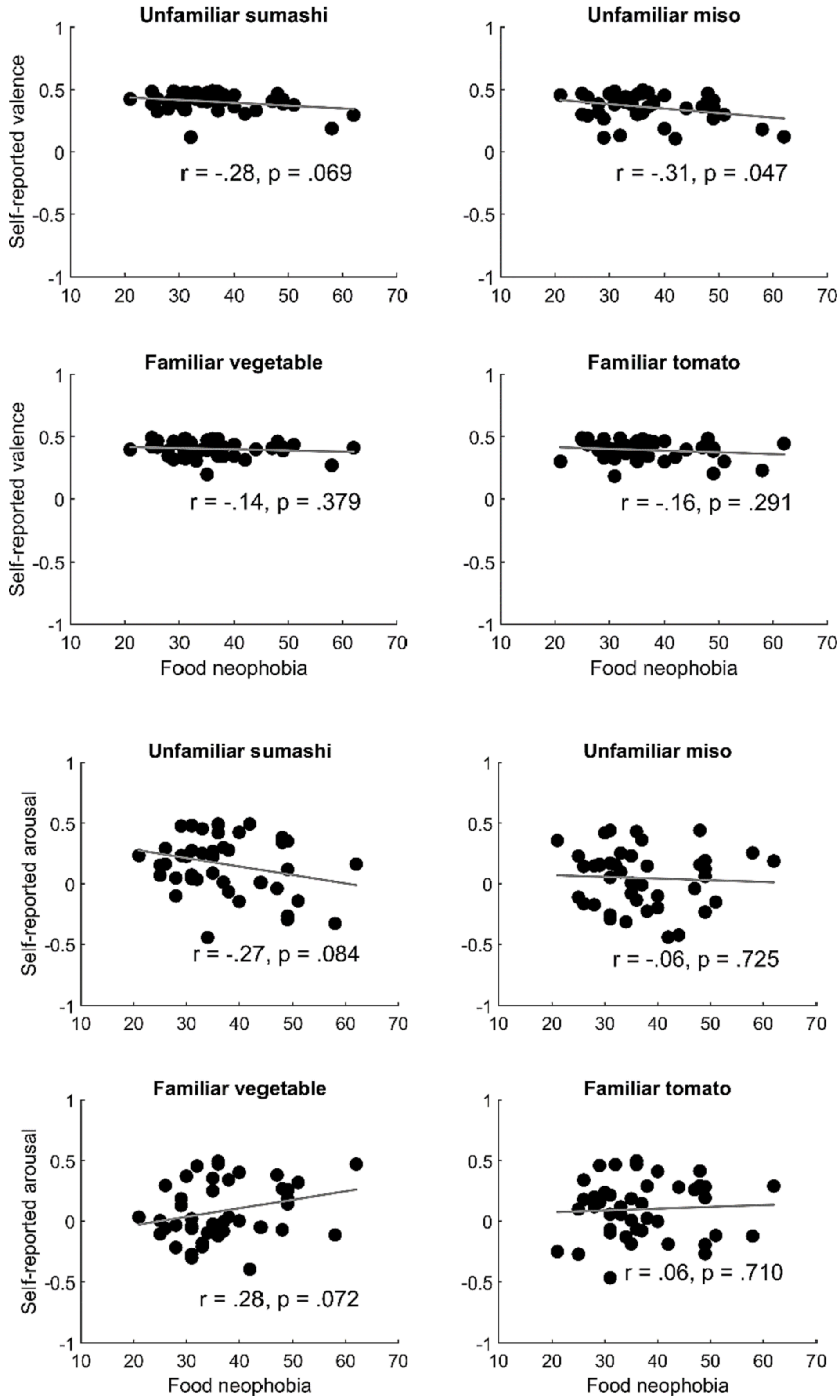

Fig. 8. Correlations between food neophobia and self-reported valence (top) and arousal (bottom) for familiar tomato and vegetable soups and unfamiliar miso and sumashi soups. Each data point represents a participant.

4.3. Self-reported experienced emotion for images

To examine how the early attentional processes culminate in food experience we also obtained self-reported emotional experience. The more pronounced allocation of attentional resources of high food neophobic individuals to all food related stimuli did not result in different reported emotional experience for all food related stimuli.

Whereas food neophobia was positively associated with LPP amplitude for all types of food pictures, food neophobia was only associated with self-reported experienced emotion for unfamiliar food pictures, not for any of the other picture types. Specifically, individuals with higher food neophobia reported a lower valence after being presented with pictures of unfamiliar food, in line with previous reports (Brouwer et al., 2021). These individuals also reported lower arousal, as can be expected for food images scores that are shifted from pleasant to neutral, given the U-shaped relation between reports of valence and arousal (Kaneko, Toet, et al., 2019; Kuppens, Tuerlinckx, Russell, & Barrett, 2013).

In contrast to the short-term attention allocation as captured by the ERPs, self-reported food-evoked emotions only reflected food neophobia after presentation of unfamiliar food pictures. Though individuals with higher food neophobia thus allocate more attentional resources to any food stimulus, only for the pictures of the unfamiliar foods they report different food-evoked emotions than individuals with lower food neophobia.

Note that the pictures of food were presented with either a Japanese or Dutch flag indicating the origin of the food. It might be that these flags also primed the expectations of participants.

4.4. Sip size and self-reported experienced emotion for soups

Similar to LPP amplitude, sip size reflected food neophobia for both familiar (tomato) and unfamiliar (miso and sumashi) soups - food neophobic individuals tend to take smaller sips of soups. However, this association appeared stronger for the unfamiliar soups, and did not reach significance for the familiar vegetable soup.

This association between behavior and food neophobia is in line with a study by (B. Raudenbush, Corley, Flower, Kozlowski, & Meyer, 2003). They reported that severe food neophobic and neophiliac individuals differed in salivary response when presented with food items, regardless of the familiarity with the food item. For participants with average food neophobia, salivary response was dependent on the familiarity with the presented food items.

Just as with picture presentation, self-reported emotional experience of the soups only varies with food neophobia for the unfamiliar food stimulus. Food neophobia scores correlated negatively with self-reported valence for unfamiliar soups, but not for familiar soups.

These results indicate that implicit measures, taken before further evaluation processes took place and outside awareness, can be more sensitive to detect differences in food experience. (Kaneko, Hogervorst, et al., 2019) also found that sip size distinguished between ground truth disliked and liked drinks better than self-reported experience.

4.5. Conclusions

Using different types of measures and stimuli, we here examined and described how early attentional, behavioral and emotional processing of familiar and unfamiliar food stimuli vary with food neophobia. Food neophobia seems to affect the short term attentional processing of all food-related stimuli, regardless of familiarity. Individuals with high food neophobia allocate more attentional resources for the processing of food-related stimuli than individuals with low food neophobia. When tasting, sip size was also found to covary with food neophobia for both familiar and unfamiliar stimuli, even though the association appeared stronger for unfamiliar stimuli. The differences in attentional resource allocation between individuals with varying food neophobia did not result in different emotional experience for all stimuli. After initial attention allocation, the presented stimulus is identified and evaluated in more detail. The result of this appraisal that is accessible for conscious awareness, i.e. the self-reported food experience, only covaried with food neophobia after presentation of unfamiliar food stimuli, both for viewing pictures and for tasting soups.

Taken together, these results indicate that cognitive, self-reported instruments to assess food experience do not capture the entire food experience. Based on those results, one would conclude that food neophobia only affects the experiences of novel food, whereas the implicit behavioral and attentional processing are affected for all food types, regardless of familiarity. One can therefore also argue that the food neophobia scale, unlike the name suggests, does not capture the fear of novel foods, but the fear of food experience in general.

All in all, our work revealed that there is a more profound difference between food neophobic and food neophiliac individuals than only the appreciation of novel food.

Ethical statement

Ethical approval was obtained from the TNO Institutional Review Board (IRB) in November 2020. The approval is registered under reference 2020–117.

Funding

This work was supported by Kikkoman Europe R&D Laboratory B.V.

CRediT authorship contribution statement

Ivo V. Stuldreher: Methodology, Software, Formal analysis, Writing – original draft, Visualization. **Daisuke Kaneko:** Conceptualization, Methodology, Investigation, Writing – review & editing, Funding acquisition. **Haruka Hiraguchi:** Writing – review & editing. **Jan B. F. van Erp:** Conceptualization, Writing – review & editing, Supervision. **Anne-Marie Brouwer:** Conceptualization, Methodology, Writing – review & editing, Supervision, Project administration, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

Acknowledgments

The authors would like to thank Jasper van Beers and Priya Sabu for their help with setting up and running the experiment.

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