

CAN I EAT THIS? EVENT-RELATED POTENTIALS ARE MODULATED
BY FEEDBACK REGARDING EDIBILITY

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I. ABSTRACT

Feedback-related negativity (FRN) is an event-related potential (ERP) component that has been shown to be sensitive to feedback during risk-taking, such that the FRN is larger for negative outcomes. Another ERP wave, the P300, is known to play a role in attentional resource allocation and is typically larger for better outcomes. The present experiment was conducted to examine the sensitivity of the FRN and P300 to processes related to appetitive motivations. Twenty-five undergraduates (15 male, mean age = 21.5 years) viewed ambiguous close-ups of food/drinks or nonfood/drinks, and indicated whether they could consume the objects. Unambiguous feedback about stimulus type was then provided. Analyses focused on ERPs to feedback-related events. In line with our expectations, a stimulus type by outcome interaction was observed for the FRN, such that amplitude was largest when participants incorrectly identified nonfoods as foods. The P300 was also sensitive to feedback, but was highest when participants correctly identified foods. These results provide support for the hypothesis that the FRN is modulated by the magnitude of negative feedback. Additionally, the enlarged P300 waves can be interpreted to represent the salience and reinforcing properties of motivationally relevant feedback to humans, especially information regarding edibility.

II. INTRODUCTION

Human beings evaluate external feedback to learn from the consequences of their decisions or actions. This type of learning is dependent on the brain's ability to rapidly differentiate positive from negative feedback. Electrophysiological studies over the past two decades examining scalp-recorded event-related potentials (ERP) have revealed that the human brain is able to distinguish positive from negative feedback within a few hundred milliseconds (Goyer, Woldorff, & Huettel, 2008; Hajcak, Moser, Holroyd, & Simons, 2006; Miltner, Braun, & Coles, 1997; Nieuwenhuis, Holroyd, Mol, & Coles, 2004). ERP studies on feedback evaluation have indicated two ERP components that are especially sensitive to type of outcome, the feedback-related negativity (FRN) and the later-occurring P300.

The FRN, a negatively-deflecting ERP component which peaks 200-300 ms after feedback over frontocentral electrode sites, has been demonstrated to be sensitive to feedback during risk-taking, such that it is more negative for negative or unfavorable outcomes (Huang & Yu, 2014; Miltner et al., 1997). The FRN is thought to reflect the activity of a generic error detection system used to rapidly evaluate feedback to guide subsequent behaviors (Miltner et al., 1997). Dipole source analysis has indicated the anterior cingulate cortex (ACC) as the likely generator of the FRN (Miltner et al., 1997). However, the reward prediction error signal has also been interpreted as an index of the activity of the mesencephalic dopamine system in response to a mismatch between actual and appropriate actions or decisions (Nieuwenhuis et al., 2004). It is still under debate whether the FRN is a binary evaluation of good versus bad outcomes (Hajcak, et al.,

2006, Nieuwenhuis et al., 2004), or is modulated by both valence and magnitude of feedback (Goyer et al., 2008; Wu & Zhou, 2009).

Another ERP component, the P300, has been highly studied since it was initially reported in 1965 (Sutton, Braren, Zubin, & John, 1965). The FRN and the P300 are known to encode different properties of feedback evaluation (Yeung & Sanfey, 2004). The P300 peaks over centroparietal regions between 250-500 ms after stimulus presentation, although the range can vary depending on stimulus modality, task conditions, subject age, etc. (Polich, 2007). The P300, thought to represent a top-down evaluation of outcome, is known to play a role in a variety of cognitive processes such as attentional resource allocation and updating of mental contexts in response to incoming stimuli (Wu & Zhou, 2009; Polich, 2007). The P300 is thought to be modulated by the motivational salience of the stimuli (Schupp et al., 2000) as well as the magnitude of reward, with a larger positive deflection for larger rewards compared to smaller rewards (Yeung & Sanfey, 2004; Wu & Zhou, 2009). A recent study found that pictures of food elicited significantly larger P300 amplitudes in participants compared to non-food control images (Nijs, Franken & Muris, 2008). However, the exact aspects of feedback evaluation to which the P300 is sensitive remains unclear.

Although most studies have utilized time-estimation or monetary gambling tasks to examine the FRN and P300 (Goyer et al., 2008; Hajcak, et al., 2006; Huang & Yu, 2014; Miltner et al., 1997; Wu & Zhou, 2009) judgments about edibility and their associated feedback may also modulate ERPs associated with motivational salience such as the FRN and the P300 because of the self-relevance of these judgments. Rozin, Fallon, and Augustoni-Ziskind (1986) propose that perceptions of edibility and the rejection of

items as food are driven by four basic psychological categories: distaste (rejection of a substance due to its taste, smell, or texture), danger (rejection due to the potential harmful consequences of ingesting a substance), inappropriateness (rejection due to the substance not being considered a food), and disgust (rejection of a substance due to both knowledge of its origin or significance, as well as distaste). According to Rozin and Fallon (1987), the rejection of an item as food is central to the concept of disgust, and can be thought of as a form of revulsion triggered by the thought of oral incorporation of the offending substance. Therefore, judgments and feedback associated with edibility judgments should maximize the focus on oral incorporation, since the mouth represents the border between the self and the non-self (Rozin & Fallon, 1987). This, in turn, should maximize the self-relevance of feedback regarding edibility judgments. If these notions are correct, they have important implications for feedback associated with errors, in that errors regarding the edibility of food items should not be considered as serious as errors regarding the edibility of nonfood items that are dangerous, inappropriate, or disgusting. In other words, believing that something is edible when it is not should encode a larger magnitude error than believing that something is inedible when it is indeed food. Similarly, magnitude differs across both positive valence (correct) trials types. Due to the motivational value of food, correctly identifying food/drinks should represent a larger reward than correctly identifying nonfood/drinks (Nijs et al., 2008). To our knowledge, no studies have systematically examined this possibility.

The present experiment was conducted to examine the sensitivity of the FRN and P300 to processes related to appetitive motivations. It was hypothesized that incorrectly identifying nonfood/drinks as food/drinks should elicit the largest FRN because this

outcome would possess both negative valence and have the greatest self-relevance (i.e., thinking that you can eat something that is, in fact, inedible). It was also hypothesized that correctly identifying food/drinks should elicit the largest P300, since this outcome would possess both positive valence and high self-relevance. Disgust sensitivity (i.e., individual differences in the predisposition to experience disgust; Haidt, McCauley, & Rozin, 1994) was also assessed to examine the potential contribution of individual differences in disgust to FRN and P300 magnitude.

III. METHODS

Participants

Twenty-five subjects (15 males) between the ages of 18 and 26 years ($M = 21.5$ years) participated in the experiment. Individuals with a personal history of neuropathology, seizures, head injury, or loss of consciousness for more than 20 minutes within the last 6 months were excluded. All participants had normal or corrected-to-normal vision. Participants were reimbursed at the rate of \$10 per hour. Although a total of 33 participants completed the task and questionnaire, 8 were excluded from ERP analyses due to poor data quality (e.g., equipment problems, excessive artifact, insufficient trials for ERP analysis). Procedures for human subjects were approved by the Institutional Review Board at Texas State University. Informed consent was obtained from each participant.

Self-Report Measures

Disgust sensitivity (DS) was assessed using the original 32 item Disgust Scale (Haidt, McCauley, & Rozin, 1994). The scale included items for each of 7 domains of disgust elicitors (food, animals, body products, sex, body envelope violations, death, and hygiene). The possible scores range from 0 to 32. The average score for American adult samples is approximately 16 (14 for men, 18 for women). Higher numbers indicate that a person is more disgust sensitive than average. The results were used to create 2 groups: a moderate/high ($n = 12$; 14+ for males, 18+ for females) and a low ($n = 13$; 0-13 for males, 0-17 for females) group.

Task and Stimuli

All of the nonfood/drink stimuli fell into one of the four psychological categories proposed by Rozin, Fallon, and Augustoni-Ziskind (1986) that could lead humans to reject an item as food; distaste, danger, inappropriateness, and disgust. The stimuli used in the experiment were found via google image search and modified using Adobe Photoshop. Original stimuli were cropped to produce a close-up, ambiguous version of the image (500 x 500 pixels; 13.3 x 13.3 cm). Stimulus type was denoted with either a green or red border (50 pixels) surrounding the image, indicating food/drink or nonfood/drink images, respectively (600 x 600 pixels; 15.9 x 15.9 cm). All stimuli were presented at a visual angle of approximately 5.0 °. Figure 1 provides an example of stimuli used in the procedure.

The experiment consisted of four blocks of 60 trials each. The order of trials was randomized across blocks and participants. There were 120 food/drink trials and 120 nonfood/drink trials. At the beginning of each trial, participants were presented with an ambiguous close-up image of food/drinks or nonfood/drinks for 500 ms. The participants' task was to decide if an ambiguous image was a food/drink or a nonfood/drink by pressing a specified key on a computer keyboard. Response mappings were counterbalanced across participants. After indicating whether they believed the image to be food/drinks or nonfood/drinks via key strike, unambiguous visual feedback regarding stimulus type was provided for 1 s.

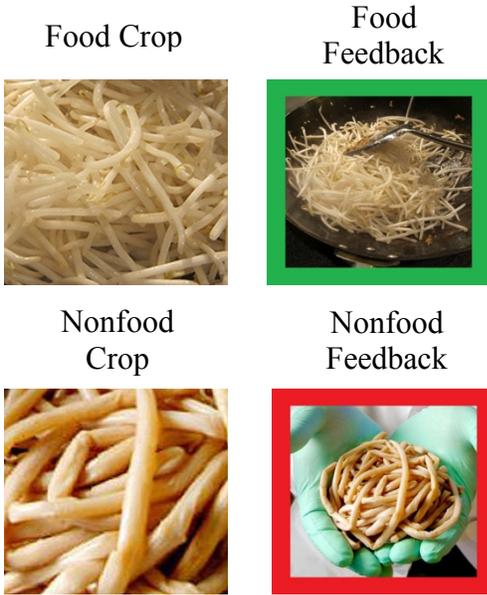


Figure 1. Example of stimuli

Table 1. Respective valence and magnitude of four possible trial types				
Trial type	Food/correct	Food/incorrect	Nonfood/correct	Nonfood/incorrect
Valence	Positive	Positive	Negative	Negative
Magnitude	High	Low	Low	High

Procedure

The experiment was conducted in a single session of approximately 2 h duration. Upon arrival to the lab, participants were informed about the purpose of the experiment and signed a consent form. Participants completed the DS scale while the ERP recording equipment was applied. Participants were then given instructions about the task and were given 3 practice trials of the task prior to starting the experiment.

ERP Recording and Analyses

ERP data were collected in a sound- and electrically-attenuated recording chamber. Tasks were displayed on a high-resolution color monitor approximately 2 meters from the

participant and data were collected continuously throughout the testing session using a 64-channel sintered Ag/AgCl QuikCap with the SynAmps2 system (Neuroscan, Compumedics USA), with a sampling rate of 1000 Hz. Impedances were maintained at or below 5 k Ω . Data was filtered offline with a bandwidth of 0.01Hz to 50Hz and re-referenced offline to linked mastoids. One second feedback stimulus-locked averages with a 100 ms baseline were used to represent ERPs to correctly identified food images, incorrectly identified food images, correctly identified nonfood images, and incorrectly identified nonfood images. Trials were excluded if they had artifacts above 100 or below -100 μ V. Participants with fewer than 16 artifact-free trials per trial type were discarded ($n = 8$).

There were four possible outcomes: correctly identifying food/drinks, correctly identifying nonfood/drinks, mistaking food/drinks for nonfood/drinks, and mistaking nonfood/drinks for food/drinks. ERPs were derived for the four trial types, time-locked to the presentation of the feedback image (correctly identified food images, incorrectly identified food images, correctly identified nonfood images, incorrectly identified nonfood images). Visual inspection of individual averages did not reveal any observable latency differences as a function of trial type. Therefore, the FRN was identified as a negative peak occurring between 175-225 ms over midline frontocentral areas and average voltages associated with this latency epoch were obtained from FCz. The P300 was identified as a positive peak occurring between 375-475 ms over frontocentral and centroparietal sites, and average voltages over this latency were obtained from the FCz, Cz, and CPz (see Figures 2-4).

Mixed ANOVAs were conducted on accuracy and ERP amplitudes with stimulus (food vs. nonfood) and outcome (correct vs. incorrect) and electrode site (FCz vs. Cz vs. CPz) as within-subjects variables, and disgust sensitivity (low or mid/high) as a between-subjects variable.

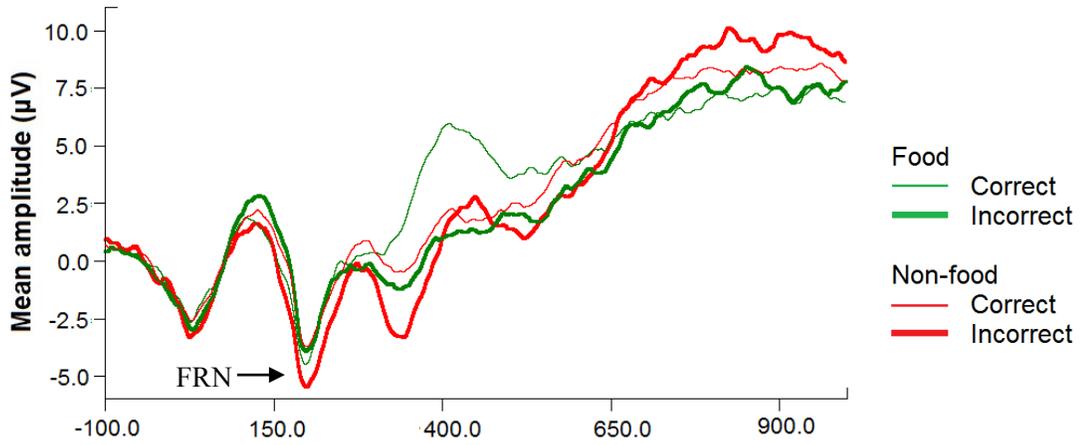


Figure 2. ERP waveforms time-locked to feedback at electrode FCz

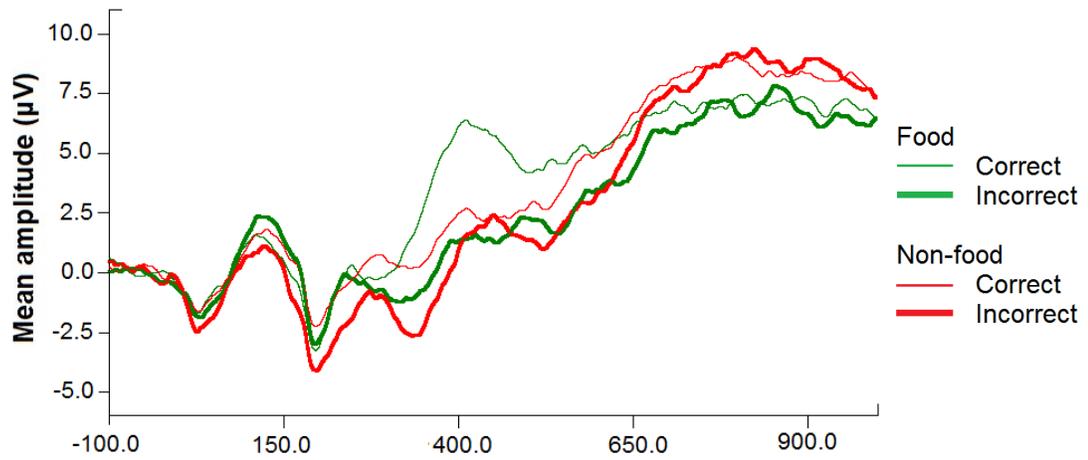


Figure 3. ERP waveforms time-locked to feedback at Cz

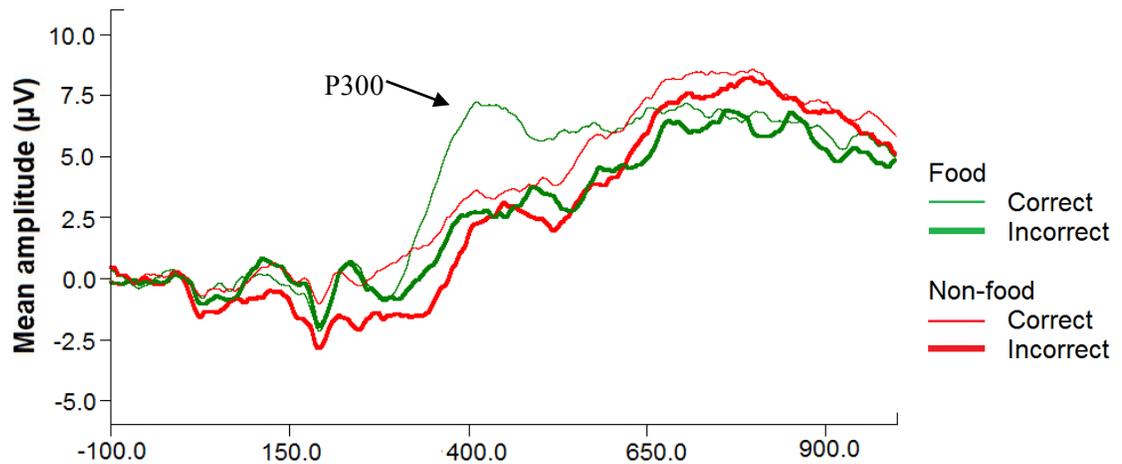


Figure 4. ERP waveforms time-locked to feedback at CPz

IV. RESULTS

Behavioral Results

Participants were marginally more accurate in judging nonfood images; $F(1, 23) = 4.10, p = .055, \eta_p^2 = .151$. Participants identified nonfood with 65.3% accuracy and with 57.1% accuracy when identifying food/drinks.

Self-Report Results

Participants scored an average of 14.46 ($SD = 6.32$) on the DS scale. Although males consistently scored lower ($M \pm SD = 13.37 \pm 5.89$) than females (16.10 ± 6.91), these differences were insignificant ($p = .30$). The effect of DS group did not significantly modulate FRN or P300 amplitude.

ERP Results

FRN Results

A 2 (stimulus type: food/drink vs. nonfood/drink) x 2 (outcome: correct vs. incorrect) repeated measures ANOVA of FRN amplitude (defined as the mean amplitude of FCz in the 175-225 ms time window) revealed a significant stimulus type by outcome interaction (see Figure 5), $F(1, 24) = 4.67, p < .05, \eta_p^2 = .163$, such that incorrectly identifying nonfood/drinks as food/drinks elicited a significantly larger FRN ($-4.54\mu V \pm 3.49$) than correctly identifying nonfood/drinks ($-2.79 \mu V \pm 3.94$). These results were confirmed with post hoc analyses using Bonferroni adjusted alpha levels of 0.083 per test ($.05/6$). All other effects were not significant, $p > .05$. Figure 6 illustrates the FRN occurring over frontocentral electrode sites, with the largest amplitude in the nonfood/incorrect condition.

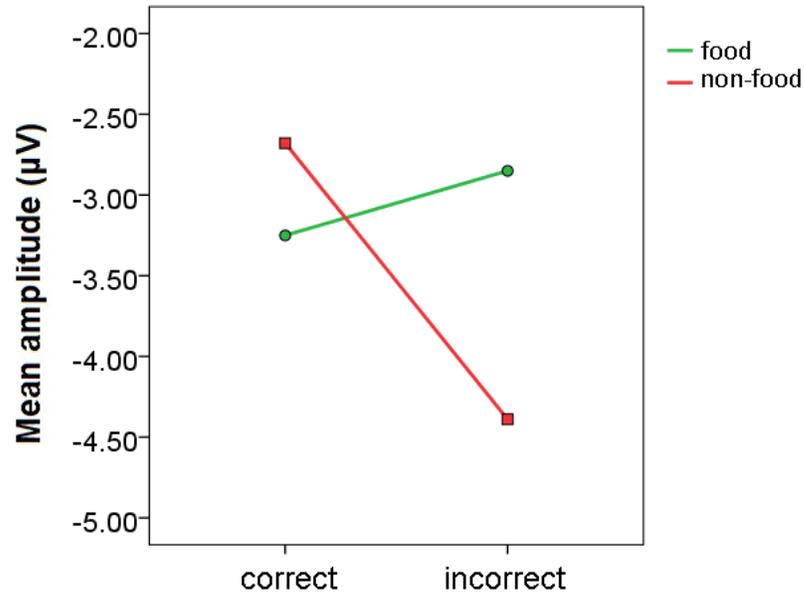


Figure 5. Stimulus-type x outcome interaction for FRN amplitude over FCz

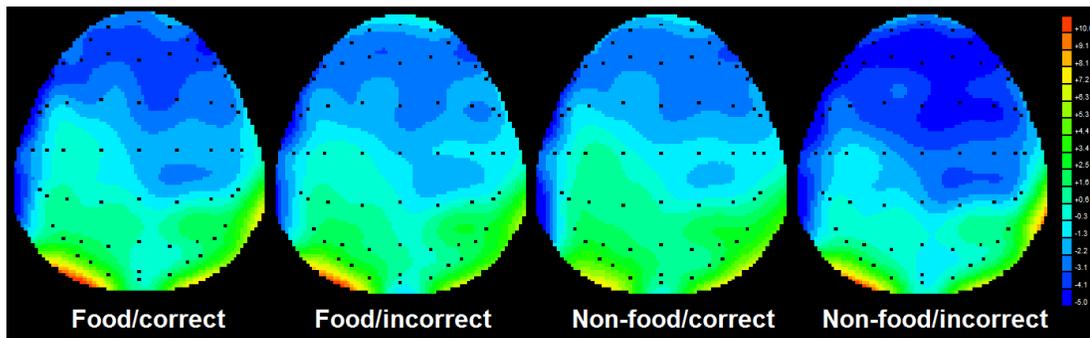


Figure 6. Topographical map of FRN (175-225 ms)

P300 Results

A 2 (stimulus type) x 2 (outcome) x 3 (electrode site: FCz vs. Cz vs. CPz) repeated measures ANOVA of P300 amplitudes (defined as the mean amplitude in the 375-475 ms time window) yielded a significant main effect for stimulus type, $F(1, 24) = 15.42, p = .001, \eta_p^2 = .391$, with larger P300 elicited by food/drink trials ($3.54 \mu V \pm 4.30$) than nonfood/drink trials ($2.04 \mu V \pm 4.15$). The main effect of outcome was also significant, $F(1, 24) = 55.49, p = .000, \eta_p^2 = .698$, with larger P300 amplitude for correct outcomes

($4.04 \mu\text{V} \pm 4.30$) than incorrect outcomes ($1.54 \mu\text{V} \pm 4.12$). The main effect of electrode site was also significant, $F(2, 23) = 6.18, p < .01, \eta_p^2 = .254$, with larger P300 amplitude over CPz ($3.69 \mu\text{V} \pm 3.74$) than FCz and Cz ($2.17 \mu\text{V} \pm 4.68$ and $2.51 \mu\text{V} \pm 4.37$, respectively). Additionally, an interaction of stimulus type and outcome interaction (see Figure 7), $F(2, 46) = 10.56, p < .01$, was observed such that correctly identifying food/drinks elicited significantly larger P300 ($6.58 \mu\text{V} \pm 4.64$) than correctly identifying nonfood/drinks ($3.37 \mu\text{V} \pm 3.60$), incorrectly identifying food/drinks ($2.43 \mu\text{V} \pm 4.02$), or incorrectly identifying nonfood/drinks ($2.40 \mu\text{V} \pm 4.37$). These results were confirmed with post hoc analyses using Bonferroni adjusted alpha levels of 0.083 per test ($.05/6$). All other effects were not significant, $p > .05$). Figure 8 shows the P300 over centroparietal electrode sites, with the highest amplitudes occurring in the food/correct condition.

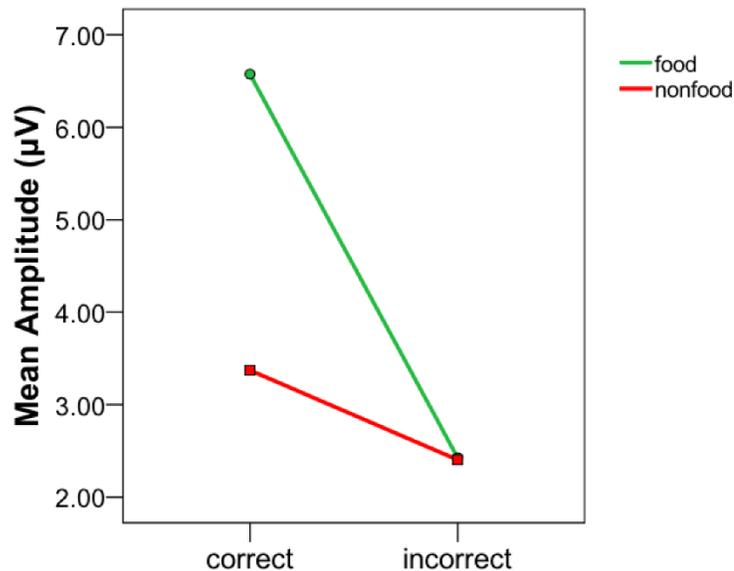


Figure 7. Stimulus-type x outcome interaction for P300 amplitude over CPz

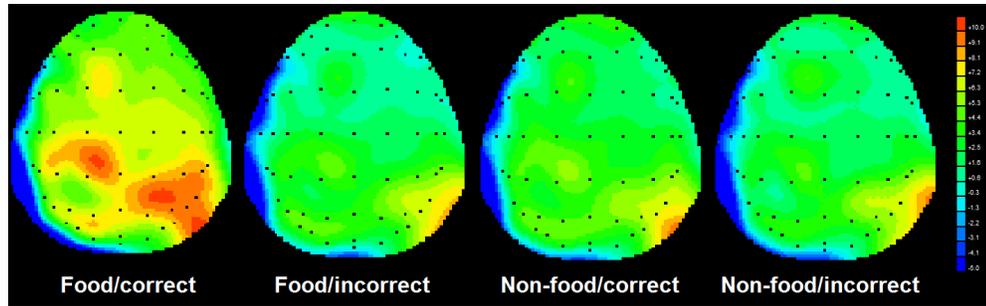


Figure 8. Topographical map of P300 (375-475 ms)

VIII. DISCUSSION

This study investigated neural processing of disgust-related imagery in regards to appetitive motivations by means of ERPs. The modulation of the FRN and P300 waveforms by the specified trial types were consistent with previous reports (Wu & Zhou, 2009). In line with our expectations, the FRN was largest when participants identified a nonfood/drink as a food/drink. Assuming this outcome represents a larger magnitude error than the alternative error, identifying a food/drink as a nonfood/drink, this stimulus type by outcome error provides support for the hypothesis that the FRN is modulated by the both the magnitude and valence of feedback. These findings are consistent with previous reports using a ‘loss-minus-gain’ difference parameterization of the FRN (Goyer et al., 2008) and those using the mean amplitude in a specified time window, the method employed by this study (Wu & Zhou, 2009). However, these results are in contradiction to previous studies using a ‘base-to-peak’ FRN measurement which assert that the FRN is a binary evaluation of good vs. bad and is therefore insensitive to magnitude of outcome (Nieuwenhuis et al., 2004; Yeung & Sanfey, 2004; Hajcak, et al., 2006). The apparent division in findings regarding the sensitivity of the FRN to magnitude may be due to differences in how the FRN is calculated or subtle variations in task design not accounted for in the analyses.

Contrary to our hypothesis, DS group did not significantly modulate FRN amplitude; however, amplitudes were largest for incorrectly identified nonfood stimuli. Although speculative, the insensitivity of the FRN to DS may be due to the existence of a generic neural error detection system prior to the evolution of disgust as a defensive emotion. To our knowledge, no other studies have examined the effect of DS on ERPs related to reward processing or outcome evaluation.

The P300 was also sensitive to both valence and magnitude, such that correctly identifying food/drinks elicited a larger P300 than any other outcome. These findings replicate previous studies examining ERPs related to reward processing (Yeung & Sanfey, 2004; Hajcak, Holroyd, Moser, & Simons, 2005) as well as studies examining the effect of food stimuli specifically (Nijs et al., 2008). These enlarged ERP waves can be interpreted to represent the coding of salience and reinforcing properties of motivationally relevant feedback to humans, especially information regarding edibility (Nijs et al., 2008; Nieuwenhuis, Aston-Jones, & Cohen, 2005).

Overall, this study provides insight into the effect of appetitive motivations on ERPs associated with error and reward detection such as the FRN and P300. It appears that both the FRN and P300 are sensitive to the valence as well as the magnitude of feedback regarding edibility. Additionally, this study reports the use of a novel task to better understand how appetitive motivations modulate ERPs related to feedback evaluation.

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APPENDIX: DISGUST SCALE

The Disgust Scale, Version 1 (Haidt, McCauley, & Rozin, 1994)

Please circle T (true) or F (false):

- T F 1. It bothers me to see someone in a restaurant eating messy food with his fingers.
T F 2. Seeing a cockroach in someone else's house doesn't bother me.
T F 3. It bothers me to hear someone clear a throat full of mucous.
T F 4. I think it is immoral for people to seek sexual pleasure from animals.
T F 5. It would bother me to be in a science class, and to see a human hand preserved in a jar.
T F 6. I would go out of my way to avoid walking through a graveyard.
T F 7. I never let any part of my body touch the toilet seat in public restrooms.
T F 8. Even if I was hungry, I would not drink a bowl of my favorite soup if it had been stirred by a used but thoroughly washed flyswatter.
T F 9. I might be willing to try eating monkey meat, under some circumstances.
T F 10. It would bother me to see a rat run across my path in a park.
T F 11. If I see someone vomit, it makes me sick to my stomach.
T F 12. I think homosexual activities are immoral.
T F 13. It would not upset me at all to watch a person with a glass eye take the eye out of the socket.
T F 14. It would bother me tremendously to touch a dead body.
T F 15. I probably would not go to my favorite restaurant if I found out that the cook had a cold.
T F 16. It would bother me to sleep in a nice hotel room if I knew that a man had died of a heart attack in that room the night before.

Please rate (0, 1, or 2) how disgusting you would find the following experiences.

- 0 = not disgusting at all
1 = slightly disgusting
2 = very disgusting

If you think something is bad or unpleasant, but not disgusting, you should write "0".

- ___ 17. You see someone put ketchup on vanilla ice cream, and eat it.
___ 18. You see maggots on a piece of meat in an outdoor garbage pail.
___ 19. While you are walking through a tunnel under a railroad track, you smell urine.
___ 20. You hear about a 30 year old man who seeks sexual relationships with 80 year old women.
___ 21. You see someone accidentally stick a fishing hook through his finger.
___ 22. Your friend's pet cat dies, and you have to pick up the dead body with your bare hands.
___ 23. You take a sip of soda, and then realize that you drank from the glass that an acquaintance of yours had been drinking from.
___ 24. A friend offers you a piece of chocolate shaped like dog-doo.
___ 25. You are about to drink a glass of milk when you smell that it is spoiled.
___ 26. You are walking barefoot on concrete, and you step on an earthworm.
___ 27. You see a bowel movement left unflushed in a public toilet.
___ 28. You hear about an adult woman who has sex with her father.
___ 29. You see a man with his intestines exposed after an accident.
___ 30. You accidentally touch the ashes of a person who has been cremated.

- ___ 31. You discover that a friend of yours changes underwear only once a week.
- ___ 32. As part of a sex education class, you are required to inflate a new unlubricated condom, using your mouth.

To score the Disgust Scale: The goal is to calculate how many questions out of 32 were answered in the disgust-sensitive way. First, put a dot next to questions 2,9, and 13, since these questions must be reversed. Then, count the number of Ts circled, except for questions 2,9, and 13. Add to this number the number of Fs circled on questions 2, 9, and 13. This is your score on Part One. Next, add up all the ratings given on questions 17-32, and divide that total by 2. This is your score on Part Two. Add your scores from parts One and Two, which should give you a number between 0 and 32. The average score for American adult samples is approximately 16 (14 for men, 18 for women). Higher numbers indicate that a person is more disgust sensitive than average.