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Frontal EEG asymmetry moderates the association between attentional bias towards food and body mass index

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ABSTRACT

High global incidence of obesity has led to efforts to identify factors that may contribute to elevated body mass index (BMI). Studies have shown individuals with obesity tend to display an attentional bias (AB) towards food. Left frontal EEG alpha asymmetry (FA) has been associated with motivation to approach rewards and may heighten reactivity to food cues. The current study thus explored whether the association between AB to food and BMI is moderated by FA. EEG was recorded while 93 female participants watched a video confederate incidentally consume potato chips. Participants subsequently completed a visual-probe task to assess AB towards food. Results revealed that AB was positively associated with BMI when FA was skewed left but not right. Individuals' predisposition to approach appetitive stimuli may interact with a bias to attend to food to facilitate overconsumption in obesogenic food environments. Future studies should examine this interaction in relation to consumption.

1. Introduction

Over half a billion of adults are estimated to be within the obese weight category worldwide (Kemps, Tiggemann, & Hollitt, 2014), and it is projected that by 2025, 18% of males and 21% of females worldwide will be classified as obese (Benton & Young, 2017). Individuals' tendency to overeat may factor into subsequent weight gain and the development of obesity (Ochner, Green, van Steenburgh, Kounios, & Lowe, 2009). It has been suggested that the neurobiological correlates of appetitive drive may account for one's vulnerability to overeat (Ochner et al., 2009). In particular, differences in neural circuitry related to motivational behaviours and reward-seeking, as well as attentional processing, may play a role by increasing food cue reactivity among individuals who are overweight and those with obesity (Hume, Howells, Rauch, Kroff, & Lambert, 2015). Individuals who exhibit hypersensitivity to food cues may be particularly vulnerable to engage in chronic overeating (Brignell, Griffiths, Bradley, & Mogg, 2009), which may lead to elevated body mass index (BMI) over time. The "right brain hypothesis" notably posits that obesity may be related to dysfunction in the right prefrontal cortex (Alonso-Alonso & Pascual-Leone, 2007). Compared to their leaner counterparts, individuals classified as obese tend to display lower gray matter density in the right frontal operculum and frontal gyri (Pannacciulli et al., 2006). In accordance, these individuals may be anticipated to exhibit greater activity within the left frontal regions of the brain.

A longstanding literature has demonstrated that the differential lateralization of frontal cortical activity is associated with opposing motivational propensities (Kelley, Hortensius, Schutter, & Harmon-Jones, 2017; Smith, Reznik, Stewart, & Allen, 2017). In particular, greater relative left frontal activity has been deemed characteristic of an approach-motivated tendency associated with heightened responsivity to appetitive stimuli, whereas greater relative right frontal activity has been associated with the predominance of withdrawal or avoidance of aversive stimuli (Kelley et al., 2017; Pizzagalli, Sherwood, Henriques, & Davidson, 2005; Smith et al., 2017). This relative balance between left and right frontal cortical activity has been referred to as frontal asymmetry (FA). Approach and withdrawal motivation have their foundation within Gray's (1970) theory of motivation. Gray (1970) suggests that the Behavioural Activation System (BAS) is sensitive to signals of conditioned reward and appetitive stimuli. By contrast, the Behavioural Inhibition System (BIS) is posited to inhibit behaviour, with increased sensitivity to signals of conditioned punishment and nonreward (Gray, 1970). One's resting FA is proposed to reflect one's trait motivational response tendency towards either behavioural activation (i.e., approach) or behavioural inhibition (i.e., withdrawal; Kelley et al., 2017; Smith et al., 2017). Using electroencephalography (EEG), FA is defined as the difference in alpha activity between the left and right frontal electrode sites (Smith et al., 2017). Though asymmetries in cortical activity have also been identified across the scalp and within various frequency bands, the present analysis focuses on frontal EEG asymmetry in the alpha band.

Individuals' self-reported BAS has been associated with greater relative left FA (Coan & Allen, 2003). Left FA has also been associated

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with a number of approach-related behaviours, dispositional traits, and affective states. For example, left FA has been associated with positive, approach-based affective states (see Harmon-Jones & Gable, 2016 for a review), decreased cortisol response to stress (Quaedflieg, Meyer, Smulders, & Smeets, 2015), proneness to symptoms of hypomania and mania (Harmon-Jones et al., 2002), aggression (Harmon-Jones & Sigelman, 2001), and emotion regulation (Hannesdóttir, Doxie, Bell, Ollendick, & Wolfe, 2010). Neal and Gable (2016) also found that certain facets of self-reported impulsivity were related to greater left FA. Specifically, both positive and negative urgency (i.e., the tendency to act rashly in response to positive or negative emotion states, respectively), lack of premeditation, and lack of perseverance displayed significant associations to left FA (Neal & Gable, 2016). This reward responsivity may be linked to greater dopamine binding within left frontal regions (Tomer et al., 2013, 2014). By contrast, right FA has been associated with withdrawal motivation (Smith et al., 2017), greater physiological stress arousal (Hannesdóttir et al., 2010), and negative affect (Harmon-Jones & Gable, 2016), among others. FA has also been shown reflect state-based changes in approach motivation (Harmon-Jones & Gable, 2016).

The capability model of frontal EEG asymmetry advanced by Coan, Allen, and McKnight (2006) suggests that rather than reflecting a static disposition regardless of the situation, individual differences in FA may more aptly reflect an interaction between the demands of a situation and the traits or abilities that an individual brings to a given situation. The capability model therefore hypothesizes that motivational challenges will elicit more pronounced individual differences that will be more resistant to measurement error. Furthermore, it is suggested that individual differences in FA assessed during motivationally- or emotionally-relevant challenges will be more stable over time than those derived from resting states, and will exhibit stronger associations with important criterion variables (Coan et al., 2006). Corroborating this notion, Coan et al. (2006) found approximately 50% of FA variance across emotional state manipulations reflected an individual by condition interaction, whereas only 26% represented stable individual differences. FA in response to food exposure may be particularly relevant to real-world behavioural response tendencies. As left FA reflects a motivational orientation prone to respond to rewards, left FA to food exposure may reflect a tendency to gratify one's appetitive desires, which may manifest in hedonic eating.

Hedonic eating refers to the consumption of food that occurs in the absence of metabolically-driven need (Berthoud, 2011; van Bochove et al., 2016). Rather than metabolic need, hedonic eating is driven by the reinforcing impact of eating elicited by the activation of reward-related regions in the brain (Berthoud, 2011). Hedonic eating has been implicated as a risk factor for the development of obesity (van Bochove et al., 2016), and may be one of many factors that can contribute to an elevated BMI. Left FA has been related to self-reported hedonic hunger among those with a BMI in the normal to overweight range (Winter et al., 2016), and with hedonic hunger, behavioural disinhibition, and appetitive responsivity to food among individuals with obesity (Ochner et al., 2009). Left FA may thus be involved in prompting hedonic eating, which may lead to overeating.

van Bochove et al. (2016) also examined the association between cortical asymmetries across the scalp during resting state EEG and hedonic valuation of food. Participants' self-reported hedonic valuation of food on the Dutch version of the Health and Taste Attitudes Scales (Roininen & Tuorila, 1999; Roininen et al., 2001) was found to be associated with greater relative left posterior alpha, reflecting the combined activity of the parieto-occipital sites. However, no association was found with anterior fronto-central EEG asymmetries in the alpha band (van Bochove et al., 2016). It was proposed that this may reflect the fact that hedonic valuation of food reflects a combination of sensory perceptions integrated across visual, olfactory, and gustatory systems (van Bochove et al., 2016). The posterior parietal cortex may have greater relevance for holistic food perception and self-reported hedonic valuation (van Bochove et al., 2016). However, van Bochove et al. (2016) did not examine FA in response to perceiving food stimuli. In light of the capability model of frontal EEG asymmetry, it is plausible that left FA may be more apparent when cues in one's environment signal the presence of reward. Viewing food-related stimuli may be more capable of prompting an associated motivational appetitive drive. Moreover, the use of a pooled index of frontal and central regions may have diluted the association.

Preliminary evidence suggests left FA may also enhance approach behaviour related to one's food consumption. The primary study from which the current analysis was derived (i.e., McGeown & Davis, 2018) examined a social modeling of eating paradigm. The social modeling of eating effect refers to the demonstration that individuals exhibit a robust tendency to match the quantity of their food consumption with that of their eating companion (Cruwys, Bevelander, & Hermans, 2015; Vartanian, Spanos, Herman, & Polivy, 2015). McGeown & Davis (2018) found that left FA in response to viewing a confederate consume food strengthened the association between an individuals' food intake and subsequent potato chip consumption as mediated by mirror neuron activity (McGeown & Davis, 2018). Left FA has also been associated with attentional narrowing, referring to a more narrowed, local scope of attentional focus on details compared to a broader, global focus of attention (Gable & Harmon-Jones, 2010a). This narrowing of attention has been proposed to confer an advantage in responding to motivational stimuli by filtering out irrelevant stimuli and facilitating acquisition of desired objects (Gable & Harmon-Jones, 2010a). As a result, it is possible that left FA may enhance an individuals' pre-existing attentional bias (AB) to food. This combination may create a particularly potent force that may encourage appetitive consumption.

AB towards food has been proposed to index individuals' differential reactivity to food reward (Hou et al., 2011). Notably, BMI has been positively correlated with AB towards food via visual-probe tasks (Kemps et al., 2014; Nijs, Muris, Euser, & Franken, 2010; Yokum, Ng, & Stice, 2011), as well as with activation in attention-related brain regions during initial orienting to food (Yokum et al., 2011). However, AB towards food does not necessarily predict food intake (Nijs et al., 2010). Associations between AB towards food and BMI may depend upon presence of an underlying motivation to act that may play a part in prompting overconsumption for these individuals. To date, no studies have examined whether the association between AB towards food and BMI may be moderated by FA as a proxy for one's motivational orientation. However, a study by Karhunen et al. (2000) found that exposure to food images led to a greater increase in regional cerebral blood flow (rCBF) to the left frontal and prefrontal regions among women with obesity who engaged in binge eating compared to women with obesity and of normal weight who did not binge eat. Karhunen et al. (2000) also reported that greater rCBF to the left frontal and prefrontal regions was associated with elevated feelings of hunger during exposure to food. It was suggested left hemispheric frontal regions may play a role in binge eating (Karhunen et al., 2000). Ergo, previous research seems to implicate left FA as a potentially potent force that may prompt excessive approach-related behaviour when in the presence of food. This may be conducive to patterns of chronic overeating, which may contribute to variation in one's weight. This exploratory analysis thus examined whether FA and AB towards food interact in strengthening associations with BMI.

2. Method

The data reported here are part of a larger study initially reported by McGeown & Davis (2018). The participants are identical to those previously described and do not reflect a new sample of individuals. However, the results of the present analysis have not been published elsewhere.

Fig. 1. Examples of the food and non-food stimuli used in the visual-probe task to assess AB.

2.1. Participants

A total of 107 female undergraduate students (M_{age} = 20.06, SD = 3.66) participated in this study. Only females were recruited for the purposes of the investigation on the social modeling of eating effect from which this data arises (i.e., McGeown & Davis, 2018). Of relevance to the present analysis, there is also evidence to suggest sex differences with respect to FA (Stewart, Bismark, Towers, Coan, & Allen, 2010). Participants were required to be non-smoking, not taking cold or hypertensive medication, and right handed. Participants were also instructed to refrain from exercising, drinking caffeine, or eating 2 h prior to their laboratory session, and consume no alcohol 12 h prior. Fourteen participants were excluded for the following reasons: $<$ 25% utilizable EEG epochs, failure to attend to instructions, outliers on EEG spectral power (z score = $\pm$ 3.29; Field, 2013), or ambidextrous handedness on the Edinburgh Handedness Inventory short-form (EHI; Veale, 2014). The remaining 93 participants were retained in analyses. Participants' BMI ranged from 17.09 to 38.68, M = 24.57, SD = 4.30.

2.2. Materials

2.2.1. Video stimuli

A video was created displaying a 24-year-old female confederate (BMI = 26.3) "incidentally" eating LAY'S® Classic chips for 10 min 27 s in the same laboratory setting while making emotional expressions on cue from the experimenter off camera. The video was recorded using a Canon EOS 7D camera and EF-S 17–85 mm image stabilizer lens mounted on a tripod at a 45° angle in front and to her right. In accordance with the capability model of frontal EEG asymmetry described above (Coan et al., 2006), participants' FA was recorded while they watched the confederate eating. It was reasoned that viewing food- and eating-related stimuli may more adequately capture one's approach tendency towards food. Recent recommendations for assessing and conceptualizing frontal EEG asymmetry have stated that a motivationally-relevant elicitation may be preferable so as to increase the power to uncover meaningful associations between brain activity and participants' state responses (Smith et al., 2017).

2.2.2. Visual-probe task

Stimuli consisted of 20 food (e.g., strawberries) and 20 non-food (e.g. hammer) pictures photographed using an Olympus E-M5 camera against a white background. To determine the food items that would comprise the food pictures, the normative data contained in the *food-pics* database (Blechert, Meule, Busch, & Ohla, 2014) were consulted. The *food-pics* database consists of 568 food images and 315 non-food images made available under the creative commons license to facilitate standardization of research on food cues (Blechert et al., 2014). The food images made available by Blechert et al. (2014) were not used, as the larger study also examined AB towards other stimuli not included in this database. All photographs were taken in the laboratory to standardize the appearance across categories. All food and non-food items were presented on the same shallow, white serving dish. Photographs were edited in Adobe Lightroom (Version 6.0) to have 1920 × 1080 pixel resolution (240 dpi, sRGB format), and to standardize brightness, exposure, and white balance.

Normative participant ratings of valence, arousal, palatability, complexity, and craving accompany each given food image in the *food-pics* database. To maximize the likelihood that all individuals would crave and attend to the food items utilized, normative craving ratings guided the selection of food stimuli. Food craving was indicated by participants' response on a visual analogue scale to the question, "How much would you like to eat this food right now if it was in front of you?" anchored by "*not at all*" to "*extremely*," scored from 0 to 100 (Blechert et al., 2014). Images that received a normative rating of 50 or higher were considered for inclusion. Complexity was also considered, which referred to images characterized by "many components, details and subobjects" (Blechert et al., 2014, p. 5) as rated on a visual analogue scale anchored by "*very low*" to "*very high*," scored from 0 to 100. Food items that received a normative complexity rating below 50 were considered for inclusion to minimize complexity. Images that contained meat were also excluded to minimize the effect that a vegetarian or vegan diet may have on attention towards the food items. To summarize, the food items photographed for the visual-probe task were those that received the highest ratings on food craving in conjunction with a low complexity rating within the normative female vegetarian sample of the *food-pics* database. Based on these ratings, the food stimuli utilized primarily included fresh fruits (i.e., blackberries, strawberries, watermelon), with only a few items that would be considered more energy-dense, palatable foods (i.e., pancakes, spaghetti). Trials consisted of picture pairs presenting either food versus non-food or non-food versus non-food cues. Fig. 1 provides example food and non-food pairings.

2.2.3. Grand hunger scales

Given that hunger has been previously shown to enhance AB for food-related stimuli (Mogg, Bradley, Hyare, & Lee, 1998; Placanica, Faune, & Soames, 2002; Tapper, Pothos, & Lawrence, 2010), participants were required to rate their hunger by filling in the Grand Hunger Scales (Grand, 1968) at the beginning of their laboratory session. The Grand Hunger Scales have been used in previous studies of AB to food cues (e.g., Brignell et al., 2009; Hepworth, Mogg, Brignell, & Bradley, 2010; Hou et al., 2011). Four indices of hunger are assessed by the measure: the number of hours since last eating, estimated to the nearest 15 min; a rating of their subjective hunger on a 7-point Likert scale anchored by "*not hungry at all*" and "*extremely hungry*"; a rating of the amount of their favourite food they would be able to eat at the present time on a 6-point Likert scale anchored by the points "*none at all*" and "*as much as I could get*"; and an estimate of the time duration until their next expected meal, estimated to the nearest 15 min (Grand, 1968). In the current study, self-reported hunger was not significantly related to FA or AB to food.

2.2.4. Electroencephalogram (EEG) recording

EEG activity was sampled at 1024 Hz via a 24-channel Waveguard cap (Advanced Neuro Technology; Enschede, Netherlands) with activity recorded at F3, F4, C3, Cz, C4, O1, O2, M1, and M2 electrode sites. Signals were filtered through a 72-channel amplifier into a computer with ASA 4.7 Experiment Manager (Version 9.2) software. Electrodes were placed above and below the right eye to index eyeblinks and optical artifacts, and one was attached below the left clavicle as the ground electrode. ElectroGel was applied to the scalp to attain impedance levels below 10 kΩ prior to recording. Offline processing was conducted using ASA (Version 4.8.0) software. EEG signals were re-referenced to the average of the mastoids (i.e., M1 and M2). Epochs encompassing artifacts exceeding ± 100 μV and those coinciding with eyeblinks were detected and excluded from analyses. EEG data was high-pass filtered at 24 Hz, with low and high cut-off frequencies of 0.49 Hz and 100 Hz, respectively. Data were segmented into 1 s epochs with 0.5 s intervals between epochs and 50% overlap. To extract power spectral densities in the 8–12 Hz alpha frequency band, fast Fourier transform was performed at 0.5 Hz intervals using a Hanning window. Two separate EEG recordings blocks comprised the baseline data and the confederate video data. Frequency data was derived as an average across each block, respectively.

2.3. Procedure

The procedure was approved by Lakehead University's Research Ethics Board. All timeslots were scheduled at either 9:30 a.m., 11:30 a.m., 1:30 p.m., 3:30 p.m., or 5:30 p.m.[1] Once consent was obtained, participants were fit with an appropriately sized EEG cap. The stimuli were viewed on a 72-inch diagonal wide Samsung DLP television 2 m in front of the seated participant. Participants began the study by completing the Grand Hunger scales. Baseline EEG was then recorded during a 5-min neutral video of non-human stimuli (animals interacting, fireworks display). Decreased alpha activity (i.e., enhanced brain activation) has been associated with visual processing and visual stimulation (Barry, Clarke, Johnstone, Magee, & Rushby, 2007; Herring, Thut, Jensen, & Bergmann, 2015). To ensure that alpha was not substantively altered solely due to visual processing demands from the baseline to the confederate video, a neutral video was selected that would maintain participants' attention for the 5-min duration of the baseline. Participants then watched the confederate video while EEG activity was recorded in a separate block under the guise of rating her empathy based on her emotional expressions. Participants were apprised that this rating would be completed at the conclusion of the confederate video on a brief questionnaire. The contrived empathy rating was a 17-item questionnaire created solely to have face validity to bolster the study's cover story. Each item was responded to on a 9-point Likert scale from "*strongly disagree*" to "*strongly agree.*" Participants were subsequently provided ad libitum access to consume the potato chips the confederate was displayed eating, as described in McGeown & Davis (2018).

The visual-probe task was then presented using Inquisit™ software (Version 4.0). Participants began with 12 practice trials, followed by two blocks of 160 test trials. Each trial presented a fixation cross for 500 ms, followed by a picture pair for either 500 or 2000 ms to discern between initial orienting and maintenance of attention towards food, respectively (Brignell et al., 2009; Hepworth et al., 2010). Each picture pair had an equal probability of being shown for either time duration. Pictures then disappeared and were replaced by the target probe (i.e., an 'X'). Participants indicated the probe's location as quickly as possible by pressing either the " < " or " > " key if shown on the left or right, respectively. Subsequent trials began after a response or 2000 ms. Of the 160 test trials, 80 presented a food-related and a non-food cue and the remaining 80 trials were filler trials, which presented two non-food cues. Each type of cue had an equal probability of being shown on either the left or right side of the screen. Given that only 20 food and non-food pictures were included, these photos were shown multiple times across trials. All pictures were shown the same number of times across trials. The visual-probe trials consisted of the same picture pairings shown in the same order for each participant. In total, there were an equal number of trials in each of the trial types as a function of stimuli duration, location of the cue, and probe location. Researchers then measured participants' weight using a Brecknell (LPS-400) digital scale and height with a tape measure prior to dismissal.

3. Results

3.1. Data preparation

Table 1 displays the raw EEG power recorded at the electrode sites sampled across the scalp. Prior to computing FA, alpha power at left (F3) and right (F4) electrodes was subjected to the natural log transformation, as per convention (Smith et al., 2017). Separate difference scores for the baseline and confederate videos were then calculated to summarize relative alpha activity across the right and left frontal cortex (i.e. F4*ln* − F3*ln*). Asymmetry scores were similarly computed from the natural log transformed alpha power across the left and right occipital (i.e., O2*ln* − O1*ln*) and central electrode sites (i.e., C4*ln* − C3*ln*). As alpha power is inversely associated with cortical activity (i.e., greater power equates to less activity), positive FA indicates greater left-hemispheric activity whereas negative FA reflects greater right-hemispheric activity (Smith et al., 2017). FA during the confederate video was of primary interest for the moderation analysis, while baseline FA served as a covariate to control for baseline differences.

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[1] FA was unrelated to the time of their laboratory session, $r = -0.01$, $p = .90$, as was AB to food, $r = 0.06$, $p = .55$.

Table 1
Means, Standard Deviations, and $z_{skewness}$ of Raw EEG Power of Baseline and Confederate Video Recording Blocks.

	Baseline raw power		Confederate video raw power	
Electrode site	*M*(*SD*)	$z_{skewness}$	*M*(*SD*)	$z_{skewness}$
F3	7.53 (4.40)	7.34	8.87 (6.32)	8.11
F4	7.78 (4.49)	7.04	9.08 (6.10)	6.95
C3	8.10 (5.89)	4.88	10.26 (8.03)	4.99
C4	7.96 (5.40)	6.00	10.39 (8.16)	5.82
O1	4.70 (3.90)	14.08	6.80 (6.16)	9.80
O2	5.03 (6.78)	29.78	6.38 (5.31)	8.34

Note. $N = 93$. Raw EEG alpha power expressed in μV^2 within the 8–12 Hz band.

For the visual-probe data, outlier RTs less than 200 ms and 2000 ms (0.2%), and incorrect trials (2.7%) were excluded. AB towards food was calculated by subtracting participants' mean RT to probes replacing food from the mean RT to probes replacing non-food cues at 500 and 2000 ms (i.e. Brignell et al., 2009; Hepworth et al., 2010; Hou et al., 2011). RTs were collapsed into a single composite AB score as no significant differences emerged across time durations, $t(92) = 0.185$, $p = .854$. Positive values indicate faster RTs to probes replacing food, indicative of AB. Table 2 displays associated descriptive statistics and intercorrelations of the EEG asymmetries, AB towards food, and BMI. Left FA and greater AB towards food were both independently significantly correlated with BMI, as displayed in Fig. 2.

3.2. Moderation analysis

Hayes' (2013) PROCESS macro model 1 was utilized to conduct a moderated linear regression. Participants' FA during the confederate video was utilized as the moderator. It has been noted that FA exhibited during motivationally-relevant challenges is likely to provide a more powerful index of individual differences relevant to state-based responding than FA during resting states (Smith et al., 2017). The moderation analysis was conducted while controlling for baseline differences in FA. A significant interaction emerged between FA during the confederate video and AB towards food pictures in the association with BMI, $b_3 = 0.484$, $SE = 0.177$, $p < .01$, 95% CI [0.133, 0.835], $\Delta R = 0.04$. To probe the interaction, the conditional effect of AB (*X*) on BMI (*Y*) was estimated at values of FA (*M*) corresponding to the mean and ± 1 *SD* (Hayes, 2013; see Table 3). Among those with left FA, greater AB towards food pictures was significantly associated with higher BMI; those exhibiting right FA demonstrated a nonsignificant association (see Fig. 3).

Examining FA and AB by BMI categories (Table 4), it is apparent that overall, individuals who were categorized overweight, or with class I or class II obesity simultaneously displayed greater relative left FA and elevated AB towards food as compared to their leaner counterparts. Fig. 4 displays topographic maps of the average alpha power (μV^2) across the scalp averaged over participants within each BMI category. Disaggregated topographic maps for each participant can be found in Supplementary File 1 divided by their respective BMI category in Figs. S1–S4.

Table 2
Means, Standard Deviations, and Intercorrelations Among BMI, EEG Asymmetries, and Attentional Bias towards Food.

Variables	*M*	*SD*	FA	CA	OA	AB	BMI
FA	0.03	0.11	–	.30**	.31**	−.07	.22*
CA	0.03	0.17		–	.099	−.06	.11
OA	−0.03	0.21			–	−.12	.04
AB	5.89	20.87				–	.22*
BMI	24.57	4.30					–

Note. $N = 93$. FA = Frontal asymmetry, CA = Central asymmetry, OA = Occipital Asymmetry, AB = Attentional bias towards food, BMI = Body mass index. All EEG asymmetry scores reflect EEG activity recorded during the confederate video.

* $p < .05$.

** $p < .01$.

When participants' baseline FA was examined as a moderator controlling for FA during the confederate video, the interaction became nonsignificant, $b_3 = 0.336$, $SE = 0.195$, $p = .09$, 95% CI [−0.052, 0.723]. It was additionally explored whether asymmetries across other sites may have similarly moderated this relationship. Neither occipital asymmetry, $b_3 = 0.125$, $SE = 0.110$, $p = .26$, 95% CI [−0.094, 0.344] nor central asymmetry, $b_3 = 0.164$, $SE = 0.115$, $p = .16$, 95% CI [−0.065, 0.392] during the confederate video exhibited a significant interaction with AB towards food in relation to BMI, controlling for baseline asymmetries at each site in respective analyses.

4. Discussion

The present study demonstrated that the relationship between AB towards food and BMI may be conditional on one's FA when exposed to motivationally-relevant food stimuli. As Fig. 3 demonstrates, AB towards food pictures was only significantly positively correlated with BMI among those exhibiting left, but not right, FA during exposure to a confederate eating potato chips. These findings support Hume et al.'s (2015) recent assertion that EEG may enable the identification of endophenotypic markers associated with increased risk for externally-mediated food consumption. Previous studies have conceptualized attentional and approach biases as closely related facets of an underlying responsivity to external cues of food reward (e.g., Brignell et al., 2009). The present findings appear to corroborate this notion, and further implicate that it may be the joint interaction between biased attention towards food stimuli and the motivation to approach appetitive stimuli that is particularly potent. Though the methodology of the current study was not devised to enable the prediction of eating behaviour in this regard, AB towards food and FA together may enhance the likelihood that one's food-cue responsivity is actualized in eating behaviour. That is, responsivity to food cues may, in turn, prompt hedonic eating. This may have long-term implications in influencing one's body weight status. A theoretical model empirically validated by C. Davis et al. (2007) somewhat similarly demonstrated that one's self-reported sensitivity to reward, as assessed by the BAS scale, positively predicted self-reported overeating, as well as preference for food high in sugar and fat, which in turn predicted elevated BMI.

AB and FA measurements reported here reflect state-based responses to food stimuli rather than trait tendencies. When baseline FA was examined as a moderator, the interaction became nonsignificant. As previously described, the capability model of FA posits that meaningful individual differences are best reflected within interactions between situational demands and individuals' regulatory capabilities (Coan et al., 2006). FA during motivationally relevant challenges enhances the ability to discover associations with behavioural responding (Smith et al., 2017). State-based goal relevance is thus important to identify. Both AB and FA can be influenced by the contextual motivational relevance of stimuli. Hunger, for example, can enhance AB for food-related stimuli (Mogg, Bradley, Hyare, & Lee, 1998; Placanica et al., 2002; Tapper et al., 2010). With respect to other appetitive stimuli such as alcohol, contextual factors have been noted to activate AB and interact with self-reported motivations in determining drinking decisions (Emery & Simons, 2015). It is possible that in a state of hunger when one's AB towards food would naturally be heightened, individuals who display greater relative left frontal alpha activity (i.e., left FA) may be more vulnerable to approach and consume palatable food items in one's immediacy. In the "obesogenic" environment of Western culture, high-calorie foods are readily available with low physical demand (Kemps et al., 2014). It is possible that this relationship may also factor into selection of unhealthy food items, which may lead to weight gain over time.

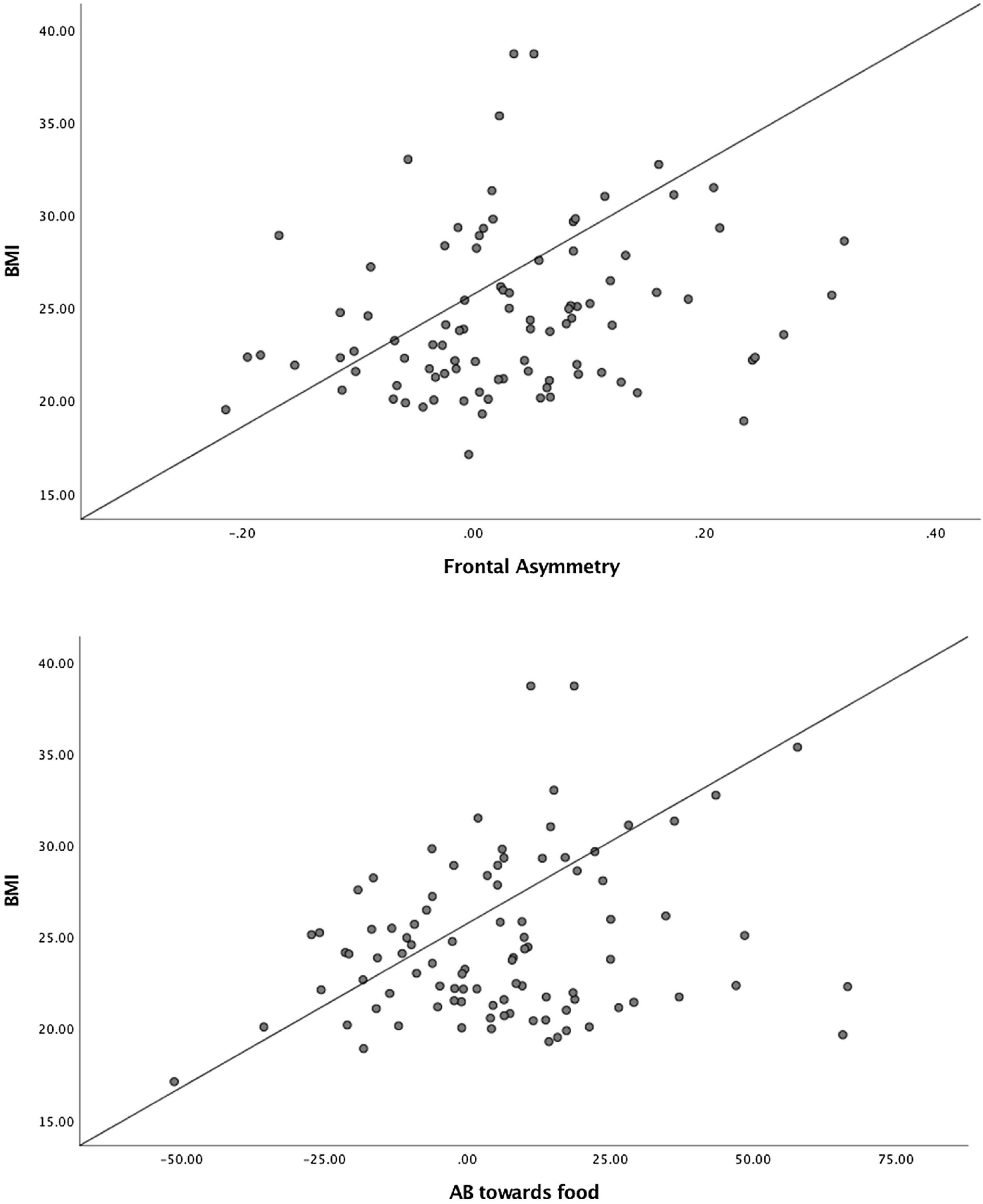

Fig. 2. Scatterplots of the association between BMI and FA (above) and AB towards food and FA (below). Higher values of FA indicate relatively greater left frontal alpha activity, whereas negative values indicate relatively greater right frontal alpha activity. Higher AB towards food scores indicate a greater attentional bias towards food.

The interactive nature of FA and AB to food may help to explain mixed findings of AB training on consumption reduction (van Beurden, Greaves, Smith, & Abraham, 2016). AB training seeks to change individuals' existent bias to attend to palatable, energy-dense food items (van Beurden et al., 2016). AB training utilizes a modified visual-probe procedure to direct attention away from food stimuli towards neutral stimuli by manipulating the location of the target probe. In contrast to the original visual-probe in which the target probe replaces either stimuli with equal frequency, the modified visual-probe is altered so that the probe replaces food pictures on 10% of the trials, while replacing

Table 3

Unstandardized Regression Coefficients, Standard Errors, and Bias-Corrected Bootstrap 95% CIs of PROCESS Model 1 Testing Attentional Bias towards Food (X) on Body Mass Index (Y) as Moderated by Frontal Asymmetry (M).

FA	*b* (*SE*)	*p*	95% CI
−1 *SD* = −0.074	0.005 (0.028)	.864	−0.051, 0.060
M = 0.033	0.057 (0.022)	.013	**0.012, 0.101**
+1 *SD* = 0.141	0.109 (0.031)	.001	**0.048, 0.169**

Note. *N* = 93. FA = Frontal asymmetry. Bolded 95% CI do not straddle zero.

Table 4

Means and Standard Deviations of FA and AB to Food by BMI Category.

Weight Status	BMI	*n*	FA		AB	
			M	*SD*	*M*	*SD*
Underweight	< 18.5	1	−0.00	–	−51.28	–
Healthy weight	18.5–24.9	55	0.01	0.11	5.01	20.06
Overweight	25.0–29.9	26	0.07	0.11	3.73	18.68
Class I Obesity	30.0–34.9	6	0.10	0.10	23.29	15.50
Class II Obesity	35.0–39.9	3	0.04	0.01	29.24	25.05

Note. FA = Frontal asymmetry during confederate video, AB = Attentional bias towards food, BMI = Body mass index. BMI categories are based on CDC (2017).

neutral stimuli on 90% of trials to direct attention away from food cues (Kemps et al., 2014). Kemps et al. (2014) found that AB training away from food images led to significant differences in participants' consumption of chocolate muffins, though not blueberry muffins. By contrast, Hardman, Rogers, Etchells, Houstoun, and Munafò (2013) found no significant difference in AB or food consumption following AB training. Hardman et al. (2013) suggested that individual differences in the motivational salience of food stimuli may factor into actual behaviour. High-intensity approach motivation such as desire may be needed to influence attention and behaviour (Gable & Harmon-Jones, 2010b). Neural vulnerability to approach rewards may heighten the activational potency of AB for food to prompt subsequent consumption. It should also be noted that the food stimuli utilized in the current study largely comprised fresh fruits, with only two images reflecting the typical energy-dense, palatable food items that may be thought to be more problematic. Consequently, it may not be enough to solely train biases away from energy-dense foods or towards nutrient-dense foods. AB training may be most efficacious when a variety of food stimuli is included. Conversely, these findings may be understood apropos of incentive salience theory (IST), which states that biases for appetitive cues are primarily mediated by an incentive salience mechanism (Robinson & Berridge, 1993, 2001).

According to IST, rewards and their predictive cues are attributed incentive salience through repeated consumption (Berridge, 2009). This sensitizes stimuli's motivational value to trigger ‘wanting’ and enhances attention towards them (Berridge, 2009). There is some evidence to suggest that repeated consumption of palatable food for hedonic rather than homeostatic reasons may alter individuals' reward response to food more generally due to chronic activation of reward systems (Ely, Winter, & Lowe, 2013). That is, overconsumption of highly palatable foods appears to downregulate dopamine receptors. Among individuals who are within the overweight and obese weight classes, dopamine signaling appears to shift such that a greater reward response occurs in anticipation of food rather than in response to consumption itself, relative to those of average weight (Ely et al., 2013). As greater dopamine binding has been found in left frontal regions (Tomer et al., 2013, 2014), it is possible that greater relative left FA upon viewing food stimuli may reflect dopaminergic sensitization to food cues among those of an elevated BMI. Perhaps low BMI individuals may be less prone to exhibit approach-based neural activation to food (i.e., less ‘wanting’), as it has not gained incentive salience via repeated hedonically-driven consumption. Nevertheless, as the current study was solely correlational in nature, the precedence of such neurophysiological responding cannot be established. BMI, FA, and AB to food were only examined at one time point. This negates the ability to delineate the direction of causality. Prospective research designs may be advantageous to tease apart the origin and precedence of left FA in response to food stimuli.

A number of additional limitations are deserving of note. It is possible that the timing of the assessment of AB towards food may have influenced the extent to which participants displayed such a bias. The assessment of AB towards food followed the observation of another individual eating as well as ad libitum access to the same chips the confederate was shown eating to explore the social modeling of eating effect, as described in McGeown & Davis (2018). It is possible that this may have influenced participants' attentional focus towards food stimuli. However, it should be noted that the amount of chips participants

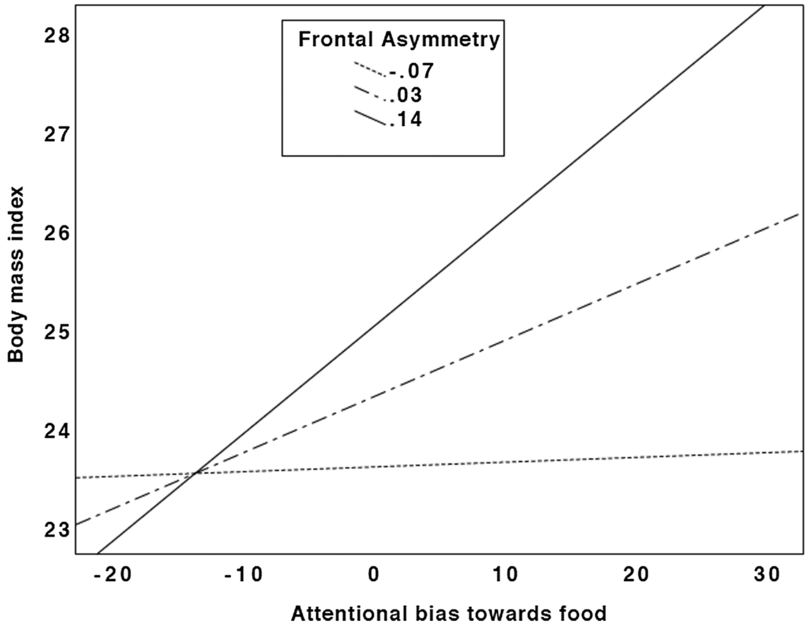

Fig. 3. Body mass index plotted as a function of attentional bias towards food moderated by frontal asymmetry.

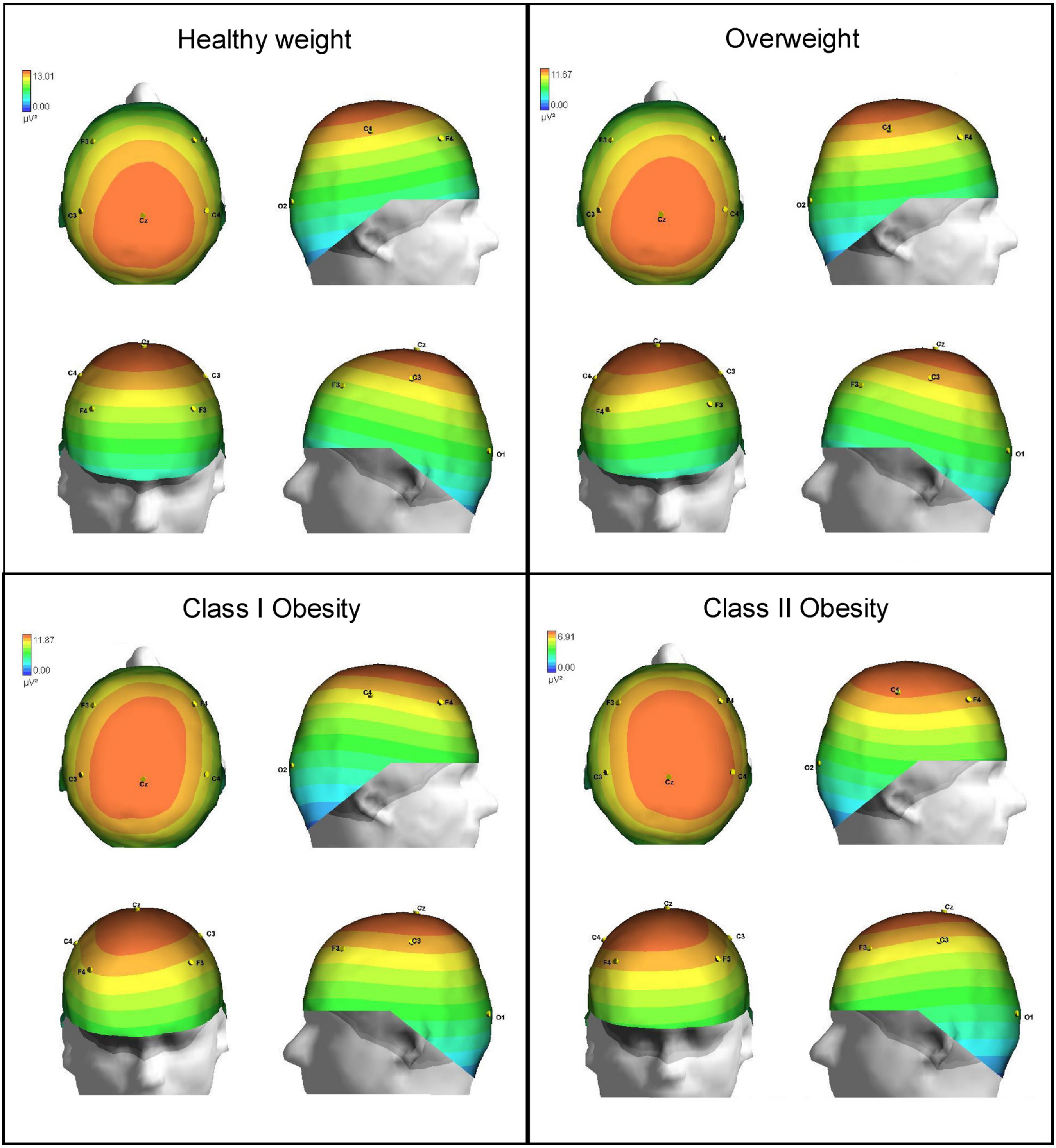

Fig. 4. Topographic map displaying hemispheric activation in the alpha (8.0–12.0 Hz) frequency band while participants viewed a confederate eating. Topographic maps display the average alpha power (μV^2) during this recording block across all participants in each BMI category.

consumed was not related to their AB towards food, $r = 0.150$, $p = .15$. A profitable future direction may be to examine the effect of the interaction of FA and AB to food on individuals' subsequent eating behaviour when provided ad libitum access to food.[2] Both FA and AB ought to be measured *prior* to eating to account for the influence that recent consumption may have on one's attention or motivational orientation towards food. It is also conceivable that individuals' FA as measured during confederate video may have reflected their approach tendencies towards the confederate or the contrived empathy rating task, rather than the chips, per se. However, on the contrived empathy questionnaire, questions were interspersed to examine the extent to which participants may have expressed positive, approach-related affect in relation to the confederate. The extent to which they would be

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[2] The interaction between FA and AB to food was not significantly associated with participants' chip consumption in the current study, $b_3 = -0.129$, $SE = 0.099$, $p = .20$, 95% CI [-0.195, -0.326]. However, this study was arguably not effectively designed to explore such an association.

want to become friends with the confederate, $r = -0.002$, $p = .984$, how likeable the confederate appeared, $r = -0.02$, $p = .841$, and how similar they felt to the confederate, $r = -0.076$, $p = .471$ were not significantly correlated with FA during the confederate video. Therefore, it is likely that participants' variable FA during this video was owing more specifically to the chip consumption they observed.

The effect found in the foregoing analysis also should not be overstated. The interaction effect only accounted for an additional 4% of the variance with respect to the association with BMI, suggesting that the combined influence of both FA and AB to food does not substantially account for one's BMI when assessed concurrently. An additional limitation is that as neurophysiological index, EEG has relatively poor spatial resolution compared to techniques such as fMRI (Cohen, 2017). Although Cohen (2017) notes that EEG is capable of reasonably accurate anatomical localization within centimeters, it must be noted that evidence of electrophysiological asymmetry does not necessarily indicate cortical asymmetry. It is possible that EEG activity recorded at particular sites may not necessarily reflect cortical activity directly below those electrodes (Cohen, 2017). The lack of evidence of an interaction between asymmetries at the central and occipital sites with AB may enhance confidence in the potential origin of the asymmetry at more frontally-located sites. Nevertheless, posterior asymmetry at parietal EEG sites was not assessed and this is another considerable limitation. As discussed, van Bochove et al. (2016) previously found a relationship between posterior alpha asymmetry in the parietal cortex and hedonic eating. Given that the present analysis arose from another primary study, the study's design was admittedly not optimized to explore potential asymmetries across the entirety of the scalp. van Bochove et al. (2016) astutely indicate, however, that asymmetries beyond the frontal cortex and beyond those in the alpha frequency band are worthy of exploration in relation to hedonic eating behaviour. van Bochove et al. (2016) found that posterior asymmetry in both the alpha and beta frequency bands were linked to hedonic food valuation. In response to visual food cues, Hume et al. (2015) also demonstrated that women with a BMI in the overweight class exhibited greater right parietal P4 ERP P200 amplitudes compared to women of a normal weight, denoting pronounced early attentional processing of visual food cues. Future studies seeking to explore hedonic eating and reactivity to food cues should prudently examine asymmetries arising over additional areas of the scalp in multiple EEG frequency bands.

Examination of the neurophysiological and neurocognitive underpinnings associated with elevated BMI may have important implications with respect to devising appropriate treatments for obesity and eating disorders. A recent review by Val-Laillet et al. (2015) highlighted that a number of promising non-invasive, neuromodulation approaches may be fruitful to alter maladaptive patterns of eating behaviour. Future studies could explore whether manipulating FA can attenuate consumption of palatable foods in the laboratory. Research has demonstrated, for example, that EEG neurofeedback can enable individuals to modulate patterns of FA (Quaedflieg et al., 2016). Based on real-time analysis of EEG signals, neurofeedback training protocols provide individuals with rewarding feedback when FA changes in the desired direction (Quaedflieg et al., 2016). Unilateral hand contractions have also been demonstrated to systematically alter FA (Kelley et al., 2017; Harmon-Jones, 2006). In particular, hand contractions in the left or right hand can elicit greater contralateral alpha activity across the hemispheres (Harmon-Jones, 2006). These findings suggest it may be possible to temporarily modify FA.

If it can be demonstrated that FA and AB to food jointly impact one's tendency to engage in hedonic eating, this may have clinical applications outside of the laboratory. Advances in smartphone technology may provide the opportunity for brief neurofeedback sessions, making such hypothetical applications feasible. The Muse Monitor app (Clutterbuck, 2015) utilizes a wireless 4-channel EEG headband and can show moment-to-moment changes in EEG power. This technology could potentially be harnessed for such neurofeedback training in one's day-to-day life. The use of handgrip exercises may be another feasible technique that could be readily transferred into real-world settings. It is possible that the use of such techniques could attenuate hedonic eating within the short-term, and thereby minimize excessive weight gain long term. Findings of the current study may suggest that neuromodulation of FA in conjunction with AB training may be an intriguing future avenue to explore with respect to weight-loss interventions given the identified interactive influence of FA and AB in association with BMI.

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Appendix A. Supplementary data

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