Weaker implicit interoception is associated with more negative body image: Evidence from gastric-alpha phase amplitude coupling and the heartbeat evoked potential

Jennifer Todd[1,2], Pasquale Cardellicchio[3], Viren Swami[1,2], Flavia Cardini[1], & Jane E. Aspell[1]

[1]School of Psychology and Sport Science, Anglia Ruskin University, Cambridge, United Kingdom

[2]Centre for Psychological Medicine, Perdana University, Kuala Lumpur, Malaysia

[3]IIT@UniFe Center for Translational Neurophysiology, Istituto Italiano di Tecnologia, Ferrara, Italy

Abstract word count: 181

Manuscript word count: 6931

Tables and figures: 3

Address correspondence to: Dr Jennifer Todd, School of Psychology and Sport Science, Anglia Ruskin University, East Road, Cambridge, Cambridgeshire, UK, CB1 1PT. Email: jennifer.todd@aru.ac.uk

Abstract

Interoception refers to the processing of internal bodily stimuli, while body image refers to appearance-related perceptions, affect, and cognitions. Previous research has found that body image is associated with self-reported and behavioural indices of interoception. Here, we extended this research by examining associations between measures of positive (i.e., body appreciation, functionality appreciation) and negative body image (i.e., body shame, weight preoccupation) and two electrophysiological indices of interoceptive processing, namely the heartbeat evoked potential (HEP) and gastric-alpha phase-amplitude coupling (PAC), in a sample of 36 adults. Significant negative associations were identified between the indices of negative body image and the interoception variables. Specifically, more negative HEP amplitude and lower gastric-alpha PAC were both associated with greater body shame and weight preoccupation. However, no significant associations were identified for the indices of positive body image. These findings extend previous work by demonstrating that there are significant associations between negative body image and previously unexplored components of cardiac and gastric interoception. This, in turn, could have important clinical applications, such as the HEP and gastric-alpha PAC both serving as biomarkers of negative body image.

Keywords: Interoception; Heartbeat Evoked Potential; Gastric; Phase-amplitude coupling; Body Image; Negative Body Image

Highlights

- Heartbeat evoked potential amplitude is negatively associated with negative body image
- Gastric-alpha phase-amplitude coupling is negatively associated with negative body image
- Neither of the electrophysiological indices were associated with positive body image

1. Introduction

The processing of bodily signals can be divided across the internal and external domains of the body. The brain's processing of internal (physiological) signals from the body is termed *interoception* (Craig, 2003; Khalsa et al., 2018). Internal organs and bodily systems produce signals that continuously convey their present condition to the brain. This signalling occurs across both conscious and unconscious levels (Cameron, 2002). The nervous system then detects, interprets, and integrates this information to generate continuously updated representations of the body's internal states (Craig, 2003). Interoceptive processing is multidimensional and several conceptualisations exist, including models comprised of three (Garfinkel et al., 2015) and eight (Khalsa et al., 2018) interoceptive facets. According to both models, *interoceptive sensibility*[1] refers to the self-perceived tendency to attend to interoceptive stimuli in everyday situations, while *interoceptive accuracy* refers to the objective ability to precisely monitor one's internal bodily state. Both interoceptive sensibility and interoceptive accuracy can be considered *explicit* measures (i.e., they largely assume a level of conscious processing). However, at its core, interoception is a physiological process of signal transmission between viscera and the central nervous system (Vaitl, 1996). Accordingly, psychophysiological measures of visceral-afferent signal transmission should also be considered a central component of interoception as a construct (Forkmann et al., 2016). Such indicators can be considered *implicit* measures of interoception, as they do not necessarily require conscious perception of internal bodily sensations. Examples of such indices include the *heartbeat evoked potential* (HEP; an event-related potential component that reflects the cortical response to cardiac signals; Park & Blanke, 2019; Schandry et al., 1986) and *gastric-alpha phase-amplitude coupling* (PAC; coupling between the phase of the gastric slow wave and the amplitude of the cortical alpha rhythm; Richter et al., 2017).

Regarding the external bodily domain, *body image* refers to purely consciously experienced appearance-related perceptions, affect, and cognitions (Cash, 2004; Cash & Smolak, 2012). Research indicates that negative and positive body image are independent and distinct constructs, rather than opposite ends of the same spectrum (Tylka, 2018; Tylka & Piran, 2019; Tylka & Wood-Barcalow, 2015b). *Negative body image* refers to the negative thoughts, perceptions, and feelings a person has about their body (Cash & Pruzinsky, 2002). It comprises many facets, including appearance dissatisfaction, body surveillance, body shame, and weight preoccupation (Cash, 2004; Cash & Pruzinsky, 2002). *Positive body image* refers to an "overarching love and respect for the body", which is characterised by an active appreciation for the body (Tylka, 2018, p. 9). Indeed, in a recent assessment of the commonality and distinguishability of several core measures of positive body image, Swami and colleagues (2020) found *body appreciation* (i.e., respect and appreciation for the body) to be the core and central component of positive body image, with *functionality appreciation* (i.e., appreciation of the body for the functions it can perform or is capable of performing) found to be a slightly more distal, but nevertheless central, component.

1.1. Interoception and Body Image: Previous Research

Recent theorising suggests that less accurate interoception could result in exteroceptive (e.g., visual, tactile and proprioceptive) cues contributing relatively more strongly to bodily awareness (Tajadura-Jiménez & Tsakiris, 2014; Tsakiris et al., 2011), which could, in turn, result in an excessive focus on the outward, aesthetic characteristics of the body (Ainley & Tsakiris, 2013; Badoud & Tsakiris, 2017) and foster negative body image (Frederickson & Roberts, 1997). Indeed, participants with body image disturbances and eating disorder symptomology have been found to prioritise exteroceptive cues over interoceptive cues in manipulations of body ownership, such as the rubber hand illusion (Eshkevari et al., 2012, 2014; see also Mussap & Salton, 2006), and feeling detached from one's own body appears to be a key experience that distinguishes clinical participants from non-clinical participants (Stanghellini et al., 2012, 2015). A growing number of studies support this theory (for a review, see Badoud & Tsakiris, 2017). The majority of this research has reported that lower interoceptive sensibility is associated with less positive body image, more negative body image, and greater body image disturbances (e.g., Brown et al., 2017; Cascino et al., 2019; Daubenmier, 2005; Jenkinson et al., 2018; Myers & Crowther, 2008; Todd et al., 2019a, 2019b).

Associations between body image and interoceptive accuracy have also been identified. Specifically, research has indicated that lower cardiac interoceptive accuracy (assessed using the heartbeat tracking task; e.g., Schandry, 1981) is significantly associated with indices of negative body image, including higher body dissatisfaction (e.g., Emanuelsen et al., 2014; cf. Drew et al., 2020), self-objectification (Ainley & Tsakiris, 2013), and body image disturbances (e.g., Klabunde et al., 2013; Pollatos et al., 2008, 2016). Conversely, higher cardiac interoceptive accuracy has been associated with greater body satisfaction (Duschek et al., 2015). The same trends have also been identified using assessments of gastric sensitivity (i.e., a two-stage water load task; van Dyck et al., 2016), where a lower sensitivity to satiation signals has been associated with more negative body image and symptoms of body image disturbances (van Dyck et al., 2016) and a greater sensitivity to satiation signals has been associated with more positive body image (Todd et al., 2020).

From this brief summary of the extant literature, it is clear that associations between body image and explicit facets of interoception are well-documented (for a further review, see Badoud & Tsakiris, 2017). However, to our knowledge, no previous study has examined direct associations between implicit components of interoception and body image. The closest body of related literature concerns studies that have examined neural components of interoception in groups with presumed body image disturbances, such as samples of individuals with disordered eating. For example, Lutz and colleagues (2019) found the amplitude of the HEP to be significantly larger in participants with anorexia nervosa in comparison to a group of healthy control participants ($d = 1.06$), who were matched for age, education, and socioeconomic status, and did not significantly differ in resting heart rate. However, other research has indicated that HEPs increase in amplitude after short-term food deprivation (Schulz et al., 2015), which may mean that the findings of Lutz and colleagues (2019) are attributable to long-term fasting in anorexia nervosa.

1.2. The Present Study

To summarise, extant literature largely supports the existence of relationships between body image and explicit components of interoception in both clinical and community samples. However, associations between body image and implicit components of interoception have not been fully explored to date. Such research could have important applications: a more comprehensive understanding of the relationship between interoception and body image could lead to the development of novel interventions that reduce negative body image and/or promote positive body image by improving bodily awareness. Therefore, the aim of the present study was to examine whether there are associations between indices of positive and negative body image, and signals originating in the cardiac and gastric organ systems: the HEP and gastric-alpha phase-amplitude coupling (PAC).

We elected to focus on implicit interoceptive markers in the cardiac and gastric systems because of the aforementioned body of literature documenting direct associations between facets of body image and explicit behavioural indices of cardiac and gastric interoception (e.g., Ainley & Tsakiris, 2013; Duschek et al., 2015; Emanuelsen et al., 2014; Todd et al., 2020; van Dyck et al., 2016). While a range of positive body image variables exist, body appreciation and functionality appreciation were selected to provide coverage of positive body image because recent evidence suggests that they are core facets of the construct (Swami, et al., 2020), and they have been significantly associated with explicit components of interoception. Likewise, body shame and weight preoccupation were selected to provide coverage of negative body image because they have been previously associated with explicit components of interoception in the extant literature (e.g., Todd et al., 2019a, 2019b).

To formulate hypotheses for the HEP, we considered evidence of previously identified associations between body image indices and cardiac perceptual accuracy (e.g., Ainley & Tsakiris, 2013; Duschek et al., 2015; Emanuelsen et al., 2014), and moderate associations between the HEP and cardiac perceptual accuracy ($g = 0.39$; Coll et al., 2020). Considering these findings in tandem, we extrapolated that if there are associations between implicit and explicit components of interoception, then the relationships between body image and explicit components of interoception might also be observed for implicit components of interoception. Accordingly, we expected that there would be a negative association between the HEP and the negative body image variables, with a lower HEP amplitude associated with more negative body image. Relatedly, we expected there would be a positive association between the HEP and positive body image, where a higher HEP amplitude is associated with more positive body image.

To generate hypotheses for gastric-alpha PAC, we drew on the findings of associations between body image and interoceptive accuracy in the gastric domain (van Dyck et al., 2016; Todd et al., 2020). Building on these studies, we expected to identify a negative association between gastric-alpha PAC and negative body image, with a lower modulation index (MI) associated with more negative body image (i.e., higher scores on the weight preoccupation and body shame measures). Moreover, a positive association between the gastric-alpha PAC and the positive body image indices was predicted, with a higher MI associated with more positive body image (i.e., higher scores on the body appreciation and functionality appreciation measures; after Todd et al., 2020).

2. Method

2.1. Participants

The participants of this study were 36 right-handed citizens of the United Kingdom enrolled at Anglia Ruskin University (men n = 15, women, n = 21). Participants ranged in age from 19 to 40 years (M = 23.78, SD = ± 5.71) and in body mass index (BMI) from 19.69 to 30.45kg/m^2 (M = 24.67, SD = ± 2.94). Most participants self-reported their ethnicity as British White (80.6%; mixed = 11.1%; British Asian = 8.3%). None of the participants reported any previous history of neurological or psychiatric conditions in a screening questionnaire prior to the study (see Section 2.4).

2.2. Body Image Measures

Body appreciation. To assess a facet of positive body image, participants were asked to complete the 10-item Body Appreciation Scale-2 (BAS-2; Tylka & Wood-Barcalow, 2015a). The BAS-2 comprises 10 items that assess body-related positive opinions and acceptance (regardless of actual physical appearance), respect for the body by engaging in healthy behaviors, and protection of body image in relation to sociocultural appearance ideals. All items were rated on a 5-point scale, ranging from 1 (*never*) to 5 (*always*), and an overall score was computed as the mean of all items. Higher scores on this scale reflect greater body appreciation. Scores on the BAS-2 are unidimensional and invariant across gender, have adequate internal consistency and test-retest reliability over a 3-week period, and evidence good patterns of convergent, incremental, and discriminant validity (for reviews, see Swami, 2018; Tylka & Wood-Barcalow, 2015b). In the present study, McDonald's ω for body appreciation scores was .86 (95% CI = .77, .91).

Functionality appreciation. To assess a second facet of positive body image, participants were asked to complete the 7-item Functionality Appreciation scale (FAS; Alleva et al., 2017). The FAS is a 7-item scale that assesses the extent to which an individual appreciates and respects the body for the functions it can perform. Items were rated on a 5-point scale ranging from 1 (*strongly disagree*) to 5 (*strongly agree*) and an overall score was computed as the mean of all items, with higher scores reflecting greater functionality appreciation. Scores on the FAS have a unidimensional structure, are invariant across gender, have adequate internal consistency and test-retest reliability over a 3-week period, and good convergent, discriminant, and incremental validity (Alleva et al., 2017). In the present study, McDonald's ω for functionality appreciation scores was .85 (95% CI = .73, .91).

Body shame. To measure a facet of negative body image, participants were asked to complete the 8-item Body Shame subscale from the Objectified Body Consciousness Scale (McKinley & Hyde, 1996), which assesses the degree to which individuals feel shame when their body does not conform to cultural ideals. In the original measure, participants rate their agreement with each item on a 7-point scale, ranging from 1 (*strongly disagree*) to 7 (*strongly agree*) or indicate that the item does not apply to them. However, due to an administrative error, items were rated on a 5-point scale, ranging from 1 (*strongly disagree*) to 5 (*strongly agree*). Scores were calculated as the mean of all items, with higher scores indicating greater body shame. Scores on the body shame subscale have been previously found to evidence good patterns of convergent validity and discriminant, and adequate test-retest and internal consistency reliability (McKinley & Hyde, 1996). In the present sample, McDonald's ω for body shame scores was .83 (95% CI = .71, .89)[3].

Weight preoccupation. To measure a second facet of negative body image, participants were asked to complete the Overweight Preoccupation subscale from the Multidimensional Body-Self Relations Questionnaire Appearance Scales (MBSRQ-AS;

Cash, 2000), which assesses weight-related anxiety and vigilance, as well as eating restraint (4 items). Cash (2000) reported that scores on the MBSRQ-AS have adequate internal consistency and 1-month test-retest reliability for both men and women. In the present sample, McDonald's ω for weight preoccupation scores was .78 (95% CI = .58, .88).

Demographics. Participants were asked to complete a demographic questionnaire, which included items related to gender identity, age, and ethnicity. These details were used for descriptive purposes. Height and weight measurements were also collected as part of the study and these data were used to compute BMI as kg/m^2. Height was measured to the nearest 0.1 cm using a portable stadiometer (Seca 213, Seca, USA). Weight was measured using a floor scale (Marsden M-430, Marsden, UK) to the nearest 0.1 kg, with participants wearing light clothing.

2.3. Data acquisition

A BrainAmp amplifier system (Brain Products GmbH, Germany) was used to record the data. Thirty-two active scalp electrodes (FP1, FP2, F7, F3, FZ, F4, F8, FC5, FC1, FC2, FC6, T7, C3, CZ, C4, T8, TP9, CP5, CP1, CP2, CP6, TP10, P7, P3, PZ, P4, P8, PO9, O1, OZ, O2, PO10) were positioned in accordance with the 10-20 System. The electrogastrogram (EGG) and electrocardiogram (ECG) were recorded simultaneously with the EEG data. For the EGG, six disposable cutaneous electrodes were positioned across the abdomen in accordance with the 6-lead layout described by Chen and colleagues (1999). To ensure that impedances were kept below 10 KΩ, participants were asked to clean and exfoliate the skin on their abdomen with a skin preparation gel prior to electrode positioning (Yin & Chen, 2013). For the ECG, three disposable cutaneous electrodes were positioned in standard 3-lead configuration. The ECG and EGG electrodes shared the same ground electrode. All data were collected at a sampling rate of 1000 Hz, with a low-pass filter at 330 Hz, and BrainVision Recorder software (Brain Products GmbH, Germany) was used to monitor signal acquisition.

2.4. Procedures

Prior to data collection, ethics approval was obtained from relevant ethics committee at Anglia Ruskin University (approval code: FST/FREP/17/75). Participants were recruited via advertisements on university and social media websites and the online SONA research participation scheme. Eligibility was limited to adults aged 18 to 50. Exclusion criteria for the study included diagnosis of a physical disorder (e.g., diabetes or Crohn's Disease) or present use of medications that affect diet or weight (Wolpert et al., 2020), diagnosis of a neurological or psychiatric condition, pregnancy, and left-hand dominance (consistent with Richter et al., 2017). Participants were required to fast for a minimum of three hours before the study protocol and to refrain from drinking for two hours before the study protocol (Wolpert et al., 2020), and all participants reported adhering to these requirements in a screening questionnaire. To reduce participant burden, the body image measures were completed using online survey software a maximum of seven days prior to the session. The body image measures were presented in a randomised order.

Upon arrival, participants were presented with an information sheet and provided written informed consent. Participants were then taken to a Faraday cage for the data recording. Participants were positioned in a semi-reclined sitting position. Data were recorded for 12 minutes, during which time participants were instructed to avoid any voluntary movements and to keep their eyes open (aside from blinking). Participants were asked to let their mind wander and to avoid any structured mental strategies during the recording, such as counting or mentally reciting a text. All participants received written debriefing information and had the opportunity to ask any questions at the end of the study. Participants were offered a retail voucher or course credits as remuneration for their time. Participation (including set-up time) took an average of 90 minutes.

2.5. Data Processing

2.5.1. HEP data processing. The data were analysed using MATLAB software (MathWorks, USA, version 9.4) and EEGLAB (Delorme & Makeig, 2004). The data were resampled to 250 Hz and then filtered between 1-40 Hz using the FIR band-pass filter. QRS complexes in the ECG channels were automatically detected and labelled within the ECG and EGG data using the fMRIB EEGLAB plug-in (Centre for Functional Magnetic Resonance Imaging of the Brain, UK). The data for each participant was then subjected to an Independent Component Analysis. Components were manually inspected to remove eye blinks and cardiac artefacts. For three participants, channels with excessive noise (PO9 for one participant and P8 for two participants) were interpolated using the EEGLAB interpolation function. Next, epochs were extracted from the processed EEG data using the R peak of the QRS complex as a temporal reference, with the epoch length spanning from 200ms before each R peak to 800ms after each R peak. The data was then re-referenced to the average of all EEG channels. Epochs with voltage exceeding ±120 μV were rejected (M = 15.58; SD = 22.19). In line with previous research (e.g., Park et al., 2016; Petzschner et al., 2019), epochs were not baseline corrected because of the potential for artefactual biases from preceding heartbeats.

Given the large variability in the HEP literature regarding the timing and topography of the HEP (Coll et al., 2020; Park & Blanke, 2019), we used a cluster-based permutation procedure (Maris & Oostenveld, 2007) to identify electrode regions and time-windows where HEP amplitude significantly correlated with scores for each of the body image facets, one at a time. The cluster-based permutation procedure was computed in FieldTrip (Oostenveld et al., 2011), on a time-window of 200 ms to 600 ms after the R peak. Candidate clusters were defined in space as channels exceeding the first level t-threshold ($p < 0.05$, two-sided) and that were connected to at least two neighbouring channels that also exceeded the threshold, and across adjacent frequencies that exceeded the first level t-threshold. Each candidate cluster was characterised by a summary statistic corresponding to the sum of the t-values across the channels and time samples defining the cluster. The second-level statistic (i.e., whether a given sum of t-values in the candidate cluster could be obtained by chance) was determined by computing the distribution of cluster statistics under the null hypothesis. The labels ‘empirical’ and ‘chance’ were randomly shuffled 10,000 times and the clustering procedure was applied. The largest positive and negative clusters from each permutation were retained. Across the 10,000 permutations, the distribution of cluster statistics under the null hypothesis (i.e., no correlation between HEP amplitudes and body image scores) was built and then used to assess the empirical clusters for significance. The two-tailed Monte-Carlo *p*-value corresponded to the proportion of the elements in the distribution of shuffled maximal cluster-level statistics that exceeded the observed maximum or minimum original cluster-level test statistics. Because the largest positive and negative clusters were retained at each permutation, this method intrinsically controls for multiple comparisons across time and location (Maris & Oostenveld, 2007). Where significant permutation results were identified, individual mean HEP amplitudes in the identified significant window were correlated to the corresponding individual body image scale scores.

2.5.2. Gastric-alpha PAC data processing. The EGG preprocessing steps were in line with recent best-practise guidelines (Wolpert et al., 2020). Specifically, for the EGG data, gastric frequency in each participant was first determined as the frequency of the largest spectral peak within the normogastric range (0.033–0.066 Hz; Wolpert et al., 2020). The data were low-pass filtered below 5 Hz and down sampled from 1000 Hz to 10 Hz. Spectral density was estimated via Hann tapered FFT for each EGG channel over the continuous EGG signal using Welch’s method, with 200 s time windows moving with 150 s overlap. The electrode exhibiting the largest spectral peak in the 0.05±0.01 Hz range was selected for further analysis.

The preprocessing for the gastric-alpha PAC was based upon both the procedure described by Richter and colleagues (2017) and the data-driven approach described by Mikkuta and colleagues (2019). The EEG and EGG raw data were high-pass filtered below 40 Hz and down-sampled from 1000 Hz to 250 Hz. EGG Data from the selected channel were then bandpass-filtered to isolate the signal related to the gastric basal rhythm (linear phase finite impulse response filter, designed with the Matlab function FIR2). The data were centred at the EGG peak frequency and then filtered with a bandwidth of ±0.015 Hz of the peak EGG frequency and a transition width between the passband and stopband of 15% of the upper and lower passband frequencies (filter order of 5). The data were filtered in the forward and backward directions to avoid phase distortions. The filtered EGG signal was then Hilbert transformed and the analytic phase was derived. No specific artefact gradient procedure was necessary because the gastric frequency (~0.05 Hz) is free from known cardiac and respiratory artefacts (Glerean et al., 2012; Rebollo et al., 2018).

Instantaneous amplitude was estimated from the analytic signals. To calculate the MI, the phase of the slow oscillation was divided into B = 18 bins (each covering 20°) (Mikutta et al., 2019). The mean power of the spindle frequency oscillations enveloped within each bin was estimated. The statistical determination of significant clusters of phase amplitude coupling was a 2-step process. First, for each participant, chance-level PAC at each channel and frequency was estimated. Then, at the group level, channels and frequencies where a significant difference between observed coupling and chance-level coupling differed were determined. The level of PAC expected by chance was estimated in addition to the corresponding chance-level MI for each participant, channel and frequency. For each participant, channel and frequency, a distribution of surrogate MI values was obtained by creating 200 surrogate data sets and computing the associated MIs. For each surrogate data set, the mean μsurr and standard deviation σsurr were computed in addition to MI *z*-scores, which were defined as: $Zsurr = \frac{PACmeasure - \mu surr}{\sigma surr}$ (Penny et al., 2008). The chance level for each participant, channel, and frequency was defined as the median of surrogate MI values. A cluster-based permutation procedure (Maris & Oostenveld, 2007) was computed in FieldTrip (Oostenveld et al., 2011) to examine whether empirical MI *z*-scores differed significantly from chance level MI at the group level. Briefly, this procedure entailed comparing empirical MI z-scores with the corresponding chance level MI value across participants using a *t*-test at each channel and frequency**,** following the steps outlined in Section 2.5.1. This data-driven approach resulted four final ROIs in the peak alpha frequency: (1) left frontal: FP1, F7, F3; (2) right frontal: FP2, F8, F4; (3) left centroparietal: T7, CP1, CP5, P3; and, (4) right centroparietal: T8, CP2, CP6, P4. Due to a recording issue, PAC data was missing for one participant. No other data quality issues or outliers were identified.

3. Results

Bayesian Pearson correlations were computed between the body image variables and significant clusters for HEP amplitude and the ROIs for gastric-alpha PAC, respectively, as identified using the steps in Sections 2.5.1. and 2.5.2. The analyses were computed using a uniform prior distribution in JASP version 0.14.1 (JASP Team, 2019). FDR was controlled for using the Benjamini and Hochberg (1995) procedure. In the following summary, correlation coefficient interpretation thresholds are consistent with those proposed by Cohen (1992), and Bayes Factor (BF) thresholds are consistent with those outlined by Van Doorn and colleagues (2020).

3.1. HEP. The cluster-based permutation procedure indicated the presence of a correlation between HEP amplitude and body shame scores in a significant negative cluster comprising PZ, P4, CP2 and CP6 in the time-window from 300 ms to 340 ms after the R peak (p = .024). Using a one-sided alternative hypothesis, a statistically significant and large correlation was observed (r = -.532; Mdn = -.502; 95% CI = -.23, -.72; BF_{-0} = 88.41; p < .001), indicating very strong evidence in support of the hypothesised negative association between body shame and HEP amplitude, relative to the null (see Figure 1, and Supplementary Figure 1)[2]. One outlier was identified using z-scores for the HEP amplitude in this cluster (z = 3.48), but removal of this data point did not alter the significance of the result (dataset with one outlier removed: r = -.554, p < .001).

The cluster-based permutation procedure also indicated the presence of a correlation between HEP amplitude and weight preoccupation scores in a significant negative cluster comprising CZ, CP1, CP2, and PZ in the time-window from 300 ms to 344 ms after the R peak (p = .026). Using a one-sided alternative hypothesis, a statistically significant and large correlation was observed (r = -.548; Mdn = -.518; 95% CI = -.25, -.73; BF_{-0} = 130.90; p < .001) indicating very strong evidence for the hypothesised negative association between weight preoccupation and HEP amplitude, relative to the null (see Figure 1, and Supplementary Figure 2).

No significant clusters were identified for body appreciation or functionality appreciation (all ps > .05).

3.2. Gastric-alpha PAC. Full results for gastric-alpha PAC are reported in Table 1. Using a one-sided alternative hypothesis, a statistically significant and large association was observed between weight preoccupation and the MI for gastric-alpha PAC in the left centroparietal ROI (r = -.536; Mdn = -.506; 95% CI = -.23, -.72; BF_{-0} = 84.94; p < .001), indicating very strong evidence for the hypothesised negative association between weight preoccupation and the MI for gastric-alpha PAC, relative to the null (see Figure 2, and Supplementary Figure 3). Furthermore, using a one-sided alternative hypothesis, a statistically significant and medium association was observed between body shame and the MI for gastric-alpha PAC in the left centroparietal ROI (r = -.432; Mdn = -.405; 95% CI = -

.12, -.65; BF_{-0} = 10.60; p = .009), indicating moderate-to-strong evidence for the hypothesised negative association between body shame and the MI for gastric-alpha PAC, relative to the null (see Figure 2, and Supplementary Figure 4).

Conversely, there were no statistically significant associations between the positive body image indices and the MI for gastric-alpha PAC in any of the ROIs. Using a one-sided hypothesis, there was anecdotal evidence in favour of a positive correlation between body appreciation and the MI for gastric-alpha PAC in the left centroparietal ROI (BF_{+0} = 1.54; see Table 1). For the remainder of the correlations, there was anecdotal-to-moderate evidence in favour of the null hypothesis.

3.3. Intercorrelations and exploratory analyses. Intercorrelations between the HEP and gastric-alpha PAC, and between all four body image variables are reported in Supplementary Materials (see Supplementary Table 1 and Supplementary Table 2). The effect sizes for the inter-correlations between HEP amplitude and the MI for gastric-alpha PAC were generally small, and none of the correlations were statistically significant (all *p*-values ≥ .090). Using two-sided tests, there was anecdotal-to-moderate support for the null hypothesis that the HEP and gastric-alpha PAC indices are not correlated.

The intercorrelations between the negative and positive body image indices were small-to-medium, and negative (ranging from r = -.05 to -.46). Using one-sided tests, there was moderate-to-strong support for the hypothesis that body appreciation is negatively correlated with the negative body image indices, and statistically significant correlations were observed. There was anecdotal-to-moderate support for the null hypothesis that functionality appreciation is not correlated with the negative body image indices, and the correlations were not statistically significant.

Finally, we conducted exploratory analyses to examine whether demographic variables (namely, BMI and age) were associated with any of the body image variables or either of the electrophysiological indices. Using two-sided tests, there was anecdotal-to-moderate support for the null hypothesis (i.e., no correlation) for all variables (all $BF_{10} \leq 0.90$, all p values $\geq .081$; for full results see Supplementary Table 3). We also computed Bayesian independent samples *t*-tests to examine gender-differences in all study variables, as implemented in JASP using the default effect size priors (a Cauchy distribution centred on an effect size of zero, with a width of 0.707). Using two-sided tests, there was anecdotal support for the null hypothesis (i.e., no gender-differences) for all variables (all $BF_{10} \leq 0.54$, all p values $\geq .256$; for full results see Supplementary Table 4).

4. Discussion

In this study, we examined associations between facets of negative and positive body image and two implicit components of interoception: the HEP and gastric-alpha PAC. Overall, significant negative associations were identified between the indices of negative body image and the interoception variables; that is, a more negative HEP amplitude in two centroparietal clusters and a lower MI for gastric-alpha PAC in a left centroparietal ROI were both associated with greater body shame and weight preoccupation. In contrast, no statistically significant associations were identified between the two markers of interoceptive processing and the indices of positive body image (i.e., body appreciation and functionality appreciation).

The negative body image findings are consistent with our hypotheses. These findings also extend previous research, which has indicated associations between facets of negative body image and behavioural components of interoception in the cardiac (Ainley & Tsakiris, 2013; Emanuelsen et al., 2014) and gastric domains (van Dyck et al., 2016; Todd et al., 2020). As outlined previously, current theorising suggests that less accurate interoceptive processing could result in exteroceptive cues being utilised as the primary basis for bodily awareness (Tajadura-Jiménez & Tsakiris, 2014; Tsakiris et al., 2011), which could, in turn, result in an excessive focus on the outward, aesthetic characteristics of the body (Badoud & Tsakiris, 2017) and foster negative body image (Frederickson & Roberts, 1997). We can apply this hypothesis to the present HEP findings in the following way. Previous research has indicated that a lower HEP amplitude is associated with reduced cardiac interoceptive accuracy (for a recent review and meta-analysis, see Coll et al., 2020). Furthermore, the brain's processing of cardiac signals that is indexed by the HEP has been shown to be functionally relevant for both bodily self-consciousness (Park et al., 2016; see also Aspell et al., 2013) and visual perception (Park et al., 2014). As such, a possible mechanism that might explain the present findings is that a lower HEP amplitude may indicate that an individual has a less robust self-representation, which is more susceptible to the influence of exteroceptive visual inputs (Park et al., 2014, 2016). It is also possible that individuals with a less robust self-representation might be more susceptible to broader social influences, such as pressure to adhere to prescriptive appearance ideals, which in turn foster negative body image (Thompson et al., 1999), but this possibility remains to be examined experimentally.

Regarding the association between gastric-alpha PAC and negative body image, emerging evidence indicates that the stomach and the brain influence each other via bidirectional (i.e., both ascending and descending) pathways (Mayeli et al., 2021; Monti et al., 2021; Rebollo et al., 2018; Richter et al., 2017). Specifically, in the initial identification of gastric-alpha PAC, transfer entropy analysis indicated that gastric-alpha coupling is attributable to an ascending influence from the stomach to the brain (Richter et al., 2017). In a recent extension of this work, fMRI data indicated that the coupling between the gastric rhythm and resting-state brain dynamics extended across a large cortical network – the gastric network – which is temporally organised according to the phase of the gastric cycle (Rebollo et al., 2018). The network comprises multiple regions with convergent functional properties involved in mapping bodily and external space. In particular, it includes several regions of the brain that are known to contain neural representations of body parts, such as the extrastriate body area. As such, it is possible that stronger ascending gastric inputs could be associated with greater (e.g., stronger or more regular) activation of neural representations of the body, which could, in turn, be protective against the development of negative body image. A weaker connection between the stomach and the brain (i.e., a lower MI for gastric-alpha PAC), could also indicate a less accurate perception of bodily cues, which could lead to high levels bodily uncertainty (e.g., regarding the perception of hunger and satiety signals). Excessive levels of bodily uncertainty could, in turn, lead to weight- and shape-related anxiety (see Barca & Pezzulo, 2020). However, given the novelty of this field of research, these hypotheses also remain to be tested experimentally.

The processing of interoceptive signalling is not yet fully understood, with domain specific (Spunt & Adolphs, 2017), functionally coupled (Azzalini et al., 2019), and unitary accounts of interoceptive processing all plausible (Khalsa et al., 2018). It is noteworthy that the negative body image findings were consistent across the HEP and gastric-alpha PAC, despite the lack of statistically significant correlations between the two implicit components of interoception (there was anecdotal-to-moderate evidence in favour of the null hypothesis that the two indices represent distinct processes). Nevertheless, for both interoceptive indices, significant correlations with the negative body image indices emerged in centroparietal areas. One possible interpretation of these present findings is that the processing of cardiac and gastric interoceptive stimuli may be domain-specific, but there is, nonetheless, a generalised association between implicit components of interoception and negative body image, where a weaker connection between the brain and internal organs is associated with a more negative body image. Given the novelty and cross-disciplinary nature of the present work, and the spatial limitations of EEG, it is not possible at present to offer more in-depth theorising as to why significant clusters were identified in some regions but not others, or to better examine the overlap between the two interoceptive indices. Future research could seek to address this issue using imaging techniques such as fMRI, which can more accurately localise the neural correlates for the associations between facets of negative body image and the HEP and gastric-alpha PAC, respectively (e.g., building upon the procedure described by Rebollo et al., 2018).

In contrast to the negative body image findings, the positive body image findings were not consistent with our expectations. This finding could stem from the divergence between the constructs of positive and negative body image: while negative body image and positive body image are often negatively correlated – indeed, in the present study correlations between the positive and negative body image indices ranged from $r = -.05$ to $-.46$ (see Supplementary Table 2) – the two constructs are also theoretically distinct (Tylka, 2018). For example, they have been associated with outcome variables in unique ways (e.g., Davis et al., 2019; Gillen, 2015; Thomas & Warren-Findlow, 2019). It is possible that the implicit components of interoception are associated with negative body image because there is an emphasis on the appearance of physical characteristics of the body (e.g., body size, shape, and weight) within the negative body image construct, particularly within the facets of body shame and weight preoccupation (Cash, 2000; McKinley & Hyde, 1996). Conversely, there is a wider focus on 'holistic' body-self relations within the positive body image construct, which might include aspects of appearance that are less likely to be based on the physiological condition of the body, such as attitudes of corporeal self-care or unique body characteristics.

Consequently, an important direction for future research is to examine the multi-level interactions between components of interoception and facets of body image simultaneously. Such research will help to determine the relative contribution of different components of interoception to facets of body image. The implicit components of interoception under examination within the present work can be considered as markers of low-level processing (Azzalini et al., 2019), but positive body image encompasses many components that are contingent upon higher-order processing skills, such as filtering incoming information in a body-protective manner (Wood-Barcalow et al., 2010). Correspondingly, previous research has identified associations between facets of positive body image and components of interoception that are also contingent upon higher-order (top down) processing, such as the interoceptive sensibility facets of body trust and attention regulation measured by the Multidimensional Assessment of Interoceptive Awareness (Todd et al., 2019a, 2019b). In contrast, the findings from the present work and previous research indicate that behavioural and implicit components of interoception have small-to-large inverse associations with facets of negative body image, but small-to-negligible associations with facets of positive body image (e.g., Badoud & Tsakiris, 2017; Todd et al., 2019a, 2019b, 2020).

Given that the present results are novel, a future pre-registered replication is necessary to confirm the findings. The present work was also limited by the fact that the present sample was homogenous in terms of both national identity and handedness, and there was relatively small variance in the data for age and BMI. Future research should seek to examine whether the findings from the present study can be replicated in larger samples and generalised to other groups, including more diverse population segments and clinical groups. For example, EGG parameters are different for individuals with higher BMI values, and are altered by several medications (for a review, see Wolpert et al., 2020). An additional limitation is the inadvertent change to the response scale for the Body Shame subscale (i.e., from a 7-point to a 5-point scale). While alpha coefficients are comparable across the present and previous work, it is possible that the adjusted response options may have resulted in biased responding (e.g., disproportionate selection of a subset of response options; see Baumgartner &

Steenkamp, 2001; Baumgartner & Weijters, 2015). Future replications should seek to examine whether the present findings can be replicated with the 7-point scale.

Furthermore, it was not possible to determine whether causal relationships exist between implicit components of interoception and facets of body image due to the correlational design employed in the present study. Indeed, it is possible that the associations identified in the present work are mediated by other factors. For example, the HEP has been associated with various psychological disorders (for reviews, see Coll et al., 2020; Park & Blanke, 2019), including generalised anxiety disorder (Pang et al., 2019) and depression (Terhaar et al., 2012). Specifically, HEP amplitude has been found to be significantly smaller for patients with depression in comparison to health matched controls ($\eta^2 = 0.18$; Terhaar et al., 2012), and a more negative HEP amplitude has been associated with greater severity of anxiety symptoms (Pang et al., 2019). Therefore, while a previous diagnosis of a neurological or psychiatric condition were exclusion criteria, it is possible that sub-clinical depression and anxiety symptomology could account for some of the variance in the negative association between HEP amplitude and negative body image, and future work should seek to examine this possibility. Our exclusion criteria did not include the presence of pronounced alexithymic or autistic traits and it is possible that these could also explain some variance in the associations between measures. Higher alexythymia is associated with more negative body image (DeBerardis et al., 2007) and autistic traits have been linked with eating disorder symptoms (Huke et al., 2013). Moreover, there is growing evidence for links between alexithymia, autistic traits, and interoception (e.g., Shah et al., 2016; Mul et al., 2018; Zamariola et al., 2018), and between alexithymia, interoceptive sensibility, and negative body image (Pink et al., 2021). Future studies could ascertain whether there are associations between body image and interoception measures are moderated by the presence of alexithymic and/or autistic traits. Future experimental work is also required to determine whether the ability to divide attention across interoceptive and exteroceptive stimuli has a direct impact on body image. This work could be initiated with the use of tasks that force participants to switch between focusing on interoceptive stimuli (e.g., counting heartbeats) and exteroceptive stimuli (e.g., counting auditory tones, or taps on the skin; for an example, see Petzschner et al., 2019).

In summary, the present work provides novel evidence of significant associations between implicit components of cardiac and gastric interoception and facets of negative body image. However, neither of the interoception measures were significantly associated with facets of positive body image. When considered within the context of the extant literature, the present findings indicate that the associations between interoception and affective components of negative body image are present across different hierarchical levels of interoceptive processing: from bottom-up, subconscious visceral-afferent signal transmission to consciously experienced components, such as heart beats and satiety (e.g., Ainley & Tsakiris, 2013; Emanuelsen et al., 2014; Todd et al., 2020; van Dyck et al., 2016), to top-down regulatory elements of interoceptive attention, such as body trust (e.g., Todd et al., 2019a, 2019b).

Levels of body dissatisfaction are commonplace in high socioeconomic status settings internationally (Swami et al., 2010). The identification of associations between HEP, gastric-alpha PAC, and facets of negative body image could have important clinical applications. For example, the HEP and gastric-alpha PAC both have potential to serve as biomarkers of negative body image states and body image disturbances (Khalsa et al., 2018; Khalsa & Lapidus, 2016). This, in turn, could help to improve the diagnosis of body image disorders and provide indications of treatment efficacy. However, future work is required to determine whether the findings from the present work can be generalised to more diverse samples, and to determine whether there are causal associations between interoception and negative body image.

Footnotes

[1]Discussions surrounding interoceptive nomenclature are numerous and ongoing (Garfinkel et al., 2015; Mehling, 2016; Murphy et al., 2020; Khalsa et al., 2018). Our use of the term *interoceptive sensibility* here (i.e., to refer to the self-reported tendency to perceive interoceptive signals), is consistent with widely-cited conceptualisations of interoception outlined by Garfinkel and colleagues (2015) and Khalsa and colleagues (2018). However, please note that what we have termed interoceptive sensibility is equivalent to what other authors may sometimes call *interoceptive awareness*.

[2]One outlier was identified using z-scores for the HEP amplitude in this cluster ($z = 3.48$), but removal of this data point did not alter the significance of the result (dataset with one outlier removed: $r = -.554$, $p < .001$).

[3]Given the erroneous change to the response rating scale, Cronbach's alpha coefficient was also calculated for comparability with previous findings. In the present study $\alpha = .81$ (95% CI = .71, .89). This is within the range of values reported for the body shame scale in the parent study ($\alpha = .70, .74, .84$; McKinley & Hyde, 1996). Indeed, sensitivity analyses suggest that minimal alterations to response options (e.g., from 7- to 5-point scales, as in the present study) are unlikely to substantively increase the likelihood of responses biases or substantively affect score validity and/or reliability (Cox, 1980; Diefenbach et al., 1993).

Open practices

Materials for the study are available at: https://figshare.com/s/1f6cbac9f0baf6a8c931, and data for the study are available at: https://figshare.com/s/cc0173190db7d1035c2d. We have fully reported all data exclusions, all inclusion/exclusion criteria, whether inclusion/exclusion criteria were established prior to data analysis, all manipulations, and all measures in the study. No part of the study procedures or study analyses were pre-registered prior to the research being conducted.

Declaration of competing interest

The authors have no conflict of interest to declare.

Acknowledgement

The first author was supported by a doctoral research grant from Perdana University in Malaysia.

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Tables and Figures

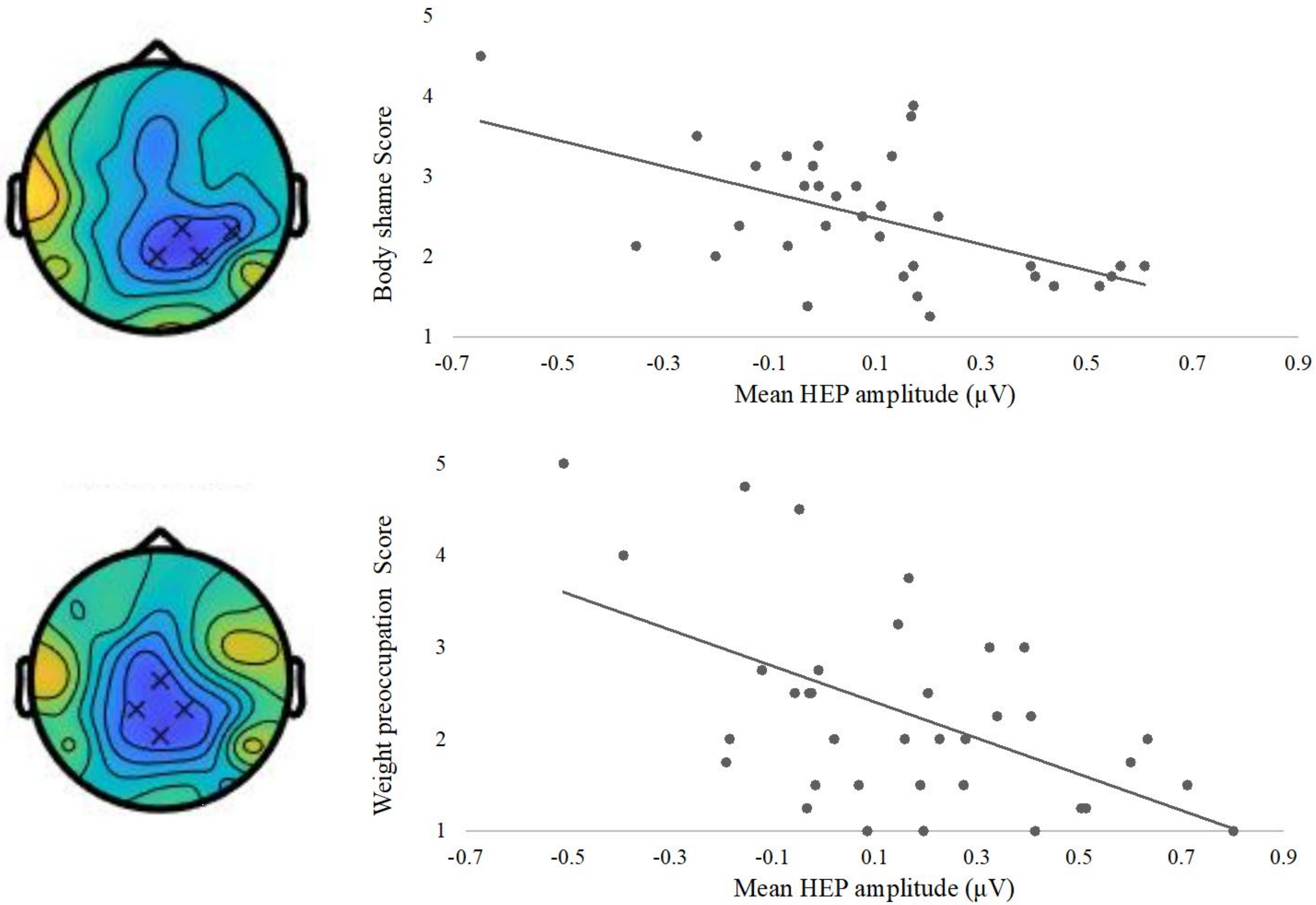


Figure 1. Top left: Topographical representation of the significant negative cluster for body shame. Top right: The association between mean HEP amplitude across 300 – 340 ms in the significant cluster and body shame scores. Bottom left: Topographical representation of the significant negative cluster for weight preoccupation. Bottom right: The association between mean HEP amplitude across 300 – 344 ms in the significant cluster and weight preoccupation scores. HEP = Heartbeat evoked potential.

Table 1

Bayesian Pearson Correlations between the Modulation Index for Gastric-Alpha Phase-Amplitude Coupling and All Body Image Variables

Body image variable	gastric-alpha ROI	Pearson's *r*	BF_{10}	Lower 95% CI	Upper 95% CI
Body appreciation	- Left Frontal	<.01	0.21	.005	.364
	- Right Frontal	-.15	0.12	.003	.285
	- Left Centroparietal	.29	1.54	.032	.552
	- Right Centroparietal	.07	0.29	.007	.403
Functionality appreciation	- Left Frontal	.05	0.27	.007	.396
	- Right Frontal	.08	0.31	.008	.412
	- Left Centroparietal	.11	0.38	.009	.434
	- Right Centroparietal	-.06	0.17	.004	.331
Body shame	- Left Frontal	-.28	1.38	-.544	-.030
	- Right Frontal	-.25	1.10	-.528	-.024
	- Left Centroparietal	-.43*	10.60	-.653	-.117

	-	Right Centroparietal	-.16	0.51	-.464	-.012
Weight preoccupation	-	Left Frontal	-.11	0.38	-.434	-.009
	-	Right Frontal	-.12	0.40	-.439	-.010
	-	Left Centroparietal	-.54*	84.94	-.724	-.233
	-	Right Centroparietal	-.24	0.95	-.517	-.021

Note. ROI = region of interest; CI = credible interval. All *ps* are > .05 except those marked * which are <.01. For Body appreciation and functionality appreciation, the alternative hypothesis specifies that the correlations are positive. For body shame and weight preoccupation, the alternative hypothesis specifies that the correlations are negative.

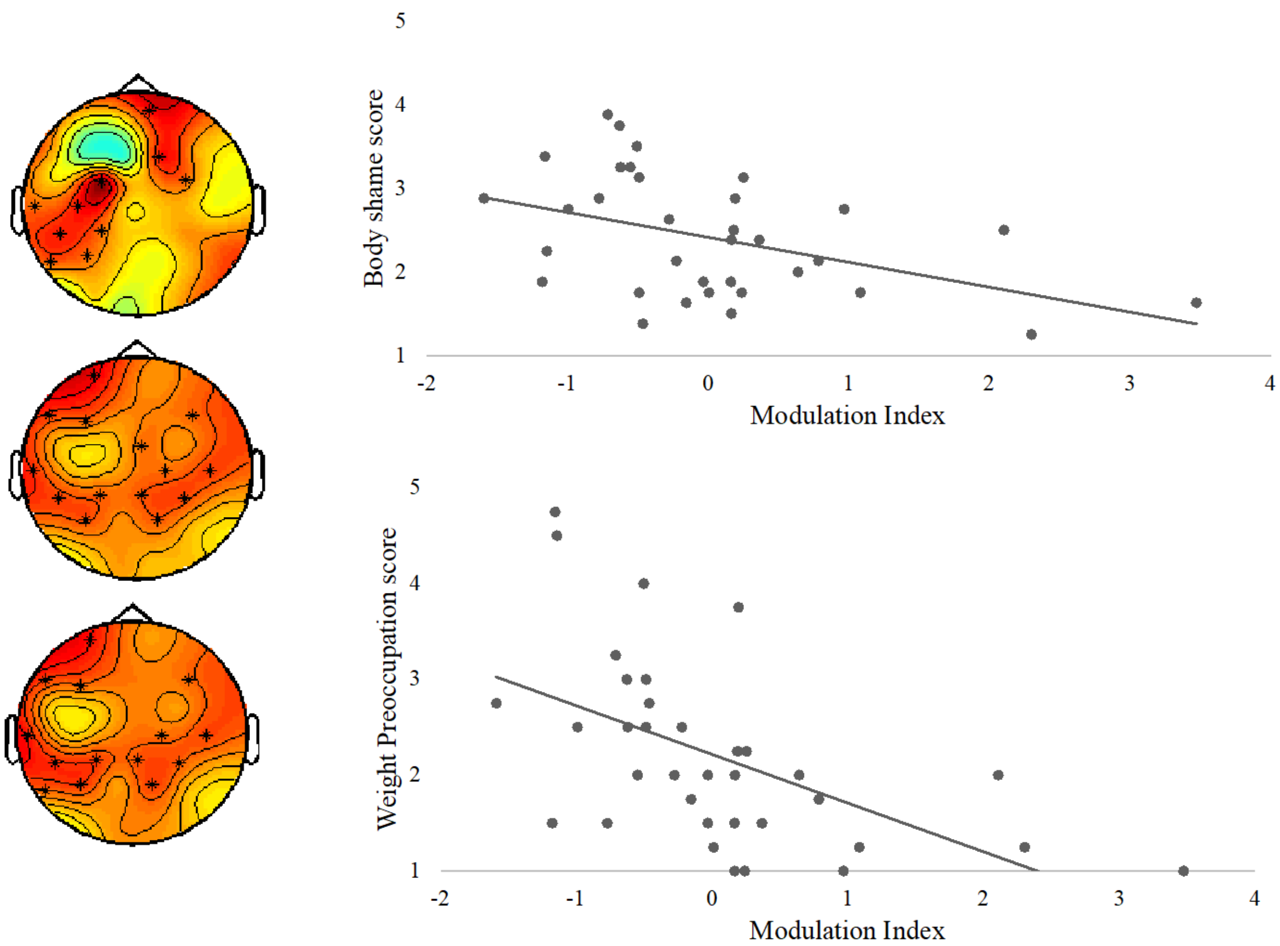


Figure 2. Left: Topographic maps indicating electrodes where significant gastric-alpha PAC was identified. Right: Scatterplots to show the correlations between the modulation index for gastric alpha phase-amplitude coupling and body shame scores (top) and weight preoccupation scores (bottom). MI = modulation index.

Supplementary Materials

Supplementary Table 1. *Bayesian Pearson Correlations between All Body Image Variables.*

			Pearson's *r*	BF_{10}	Lower 95% CI	Upper 95% CI
Body appreciation	-	Functionality appreciation	.38*	4.85	.076	.612
Body appreciation	-	Body shame	-.46*	18.69	-.669	-.148
Body appreciation	-	Weight preoccupation	-.42*	8.70	-.639	-.105
Functionality appreciation	-	Body shame	-.11	0.38	-.429	-.009
Functionality appreciation	-	Weight preoccupation	-.05	0.27	-.390	-.007
Body shame	-	Weight preoccupation	.64**	2222.72	.378	.791

Note. *p > .05, **p > .001. For Body appreciation and functionality appreciation, the alternative hypothesis specifies that the correlations are positive. For body shame and weight preoccupation, the alternative hypothesis specifies that the correlations are negative. For the correlations between the positive body image variables (body appreciation and functionality appreciation) and the negative body image variables (body shame and weight preoccupation), the alternative hypothesis specifies that the correlations are negative.

Supplementary Table 2.

Bayesian Pearson Correlations between the Modulation Index for Gastric-Alpha Phase-Amplitude Coupling and Mean Heartbeat Evoked Potential Amplitude.

HEP ROI		Gastric-alpha ROI	Pearson's *r*	BF_{10}	Lower 95% CI	Upper 95% CI
Body shame cluster	-	Left Frontal	.06	0.22	-.266	.373
	-	Right Frontal	.11	0.25	-.226	.409
	-	Left Centroparietal	.16	0.32	-.175	.452
	-	Right Centroparietal	-.04	0.22	-.358	.282
Weight preoccupation cluster	-	Left Frontal	.11	0.26	-.217	.417
	-	Right Frontal	.13	0.28	-.201	.431
	-	Left Centroparietal	.29	0.83	-.048	.551
	-	Right Centroparietal	.17	0.33	-.166	.460

Note. HEP = Heartbeat evoked potential; ROI = region of interest. All *p* values ≥ .090.

Supplementary Table 3.

Bayesian Pearson Correlations between Body Mass Index, Age, and the Body Image and Electrophysiological indices.

Demographic variable		Study variable	Pearson's *r*	BF_{10}	Lower 95% CI	Upper 95% CI
Body mass index	-	Age	.12	0.26	-.209	.416
	-	Body appreciation	-.23	0.51	-.504	.102
	-	Functionality appreciation	-.05	0.22	-.358	.273
	-	Body shame	-.09	0.23	-.388	.241
	-	Weight preoccupation	.30	0.90	-.038	.552
	-	HEP body shame cluster	-.08	0.23	-.381	.249
	-	HEP weight preoccupation cluster	-.22	0.46	-.495	.113
	-	PAC Left Frontal	.07	0.23	-.263	.375
	-	PAC Right Frontal	.16	0.32	-.176	.452
	-	PAC Left Centroparietal	.07	0.23	-.255	.383
	-	PAC Right Centroparietal	.18	0.35	-.160	.465
Age	-	Body appreciation	-.03	0.21	-.345	.287
	-	Functionality appreciation	-.20	0.40	-.479	.134
	-	Body shame	.25	0.59	-.083	.519
	-	Weight preoccupation	.03	0.21	-.287	.345
	-	HEP body shame cluster	.06	0.22	-.265	.366
	-	HEP weight preoccupation cluster	<.01	0.21	-.319	.313
	-	PAC Left Frontal	-.09	0.24	-.392	.245
	-	PAC Right Frontal	-.10	0.25	-.407	.228
	-	PAC Left Centroparietal	-.01	0.21	-.329	.311
	-	PAC Right Centroparietal	-.06	0.22	-.372	.267

Note. HEP = Heartbeat evoked potential; PAC = phase-amplitude coupling. All *p*s ≥ .081.

Supplementary Table 4.

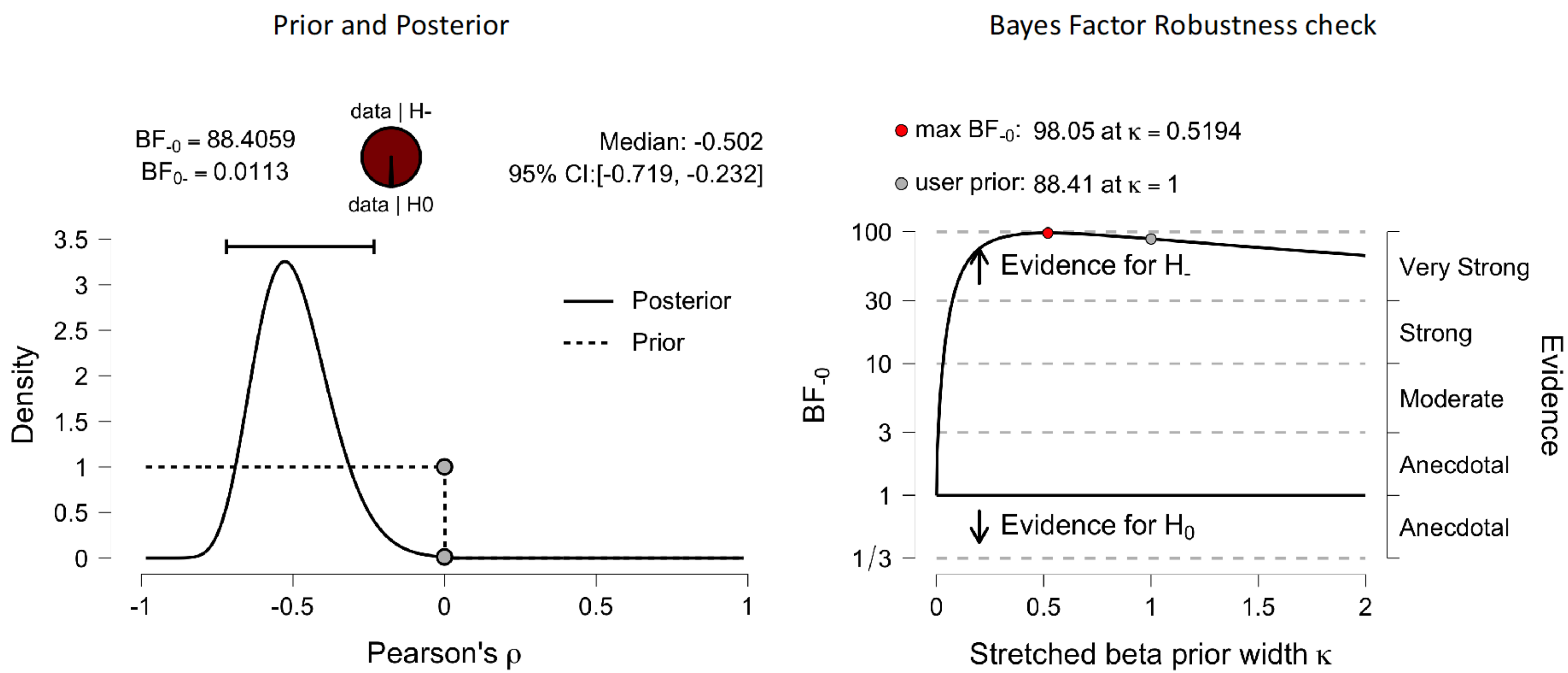
Bayesian Independent Samples t-Tests for all Variables Grouped by Gender

Variable	BF_{10}	error %	Median effect size (δ)	Lower 95% CI	Upper 95% CI	*t*	*p*
Body appreciation	0.33	0.01	-0.07	-0.65	0.51	-0.26	.798
Functionality appreciation	0.36	0.01	-0.13	-0.73	0.44	-0.53	.600
Body shame	0.46	0.01	0.24	-0.33	0.86	0.95	.348
Weight preoccupation	0.37	0.01	0.15	-0.43	0.75	0.57	.569
HEP body shame cluster	0.38	0.01	-0.16	-0.76	0.42	-0.62	.538
HEP weight preoccupation cluster	0.54	0.01	-0.30	-0.93	0.28	-1.15	.256
PAC Left Frontal	0.38	0.02	-0.15	-0.76	0.44	-0.57	.571
PAC Right Frontal	0.33	0.02	-0.01	-0.60	0.58	-0.04	.967
PAC Left Centroparietal	0.34	0.02	0.06	-0.53	0.66	0.23	.819
PAC Right Centroparietal	0.40	0.02	-0.18	-0.80	0.40	-0.70	.488

Note. HEP = Heartbeat evoked potential; PAC = phase-amplitude coupling. The prior was defined by a Cauchy distribution centred on an effect size of zero, with a width of 0.707 (default setting in JASP).

Supplementary Figure 1

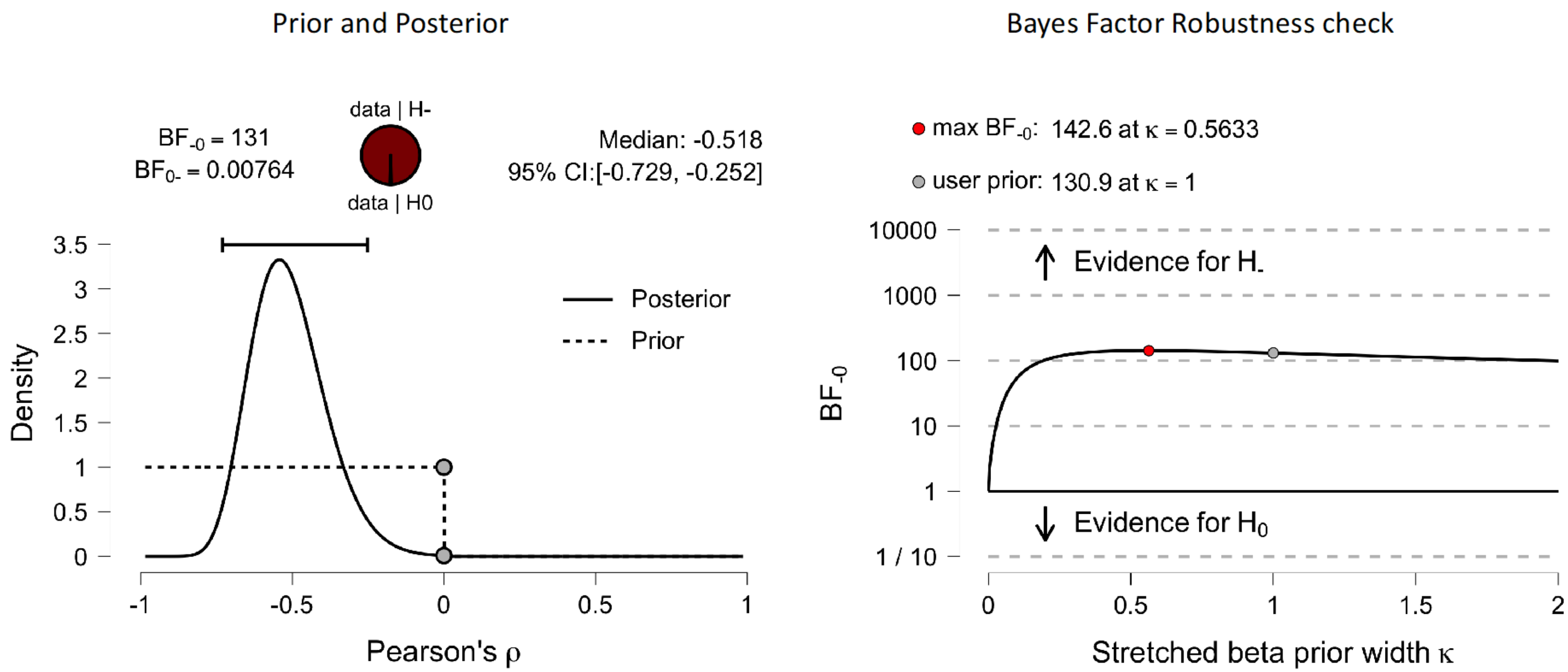
Visualisations of the Prior and Posterior Distributions and the Bayes Factor Robustness Check for the Bayesian Correlation between Body Shame and the HEP Body Shame Cluster



Note. HEP = Heartbeat Evoked Potential

Supplementary Figure 2

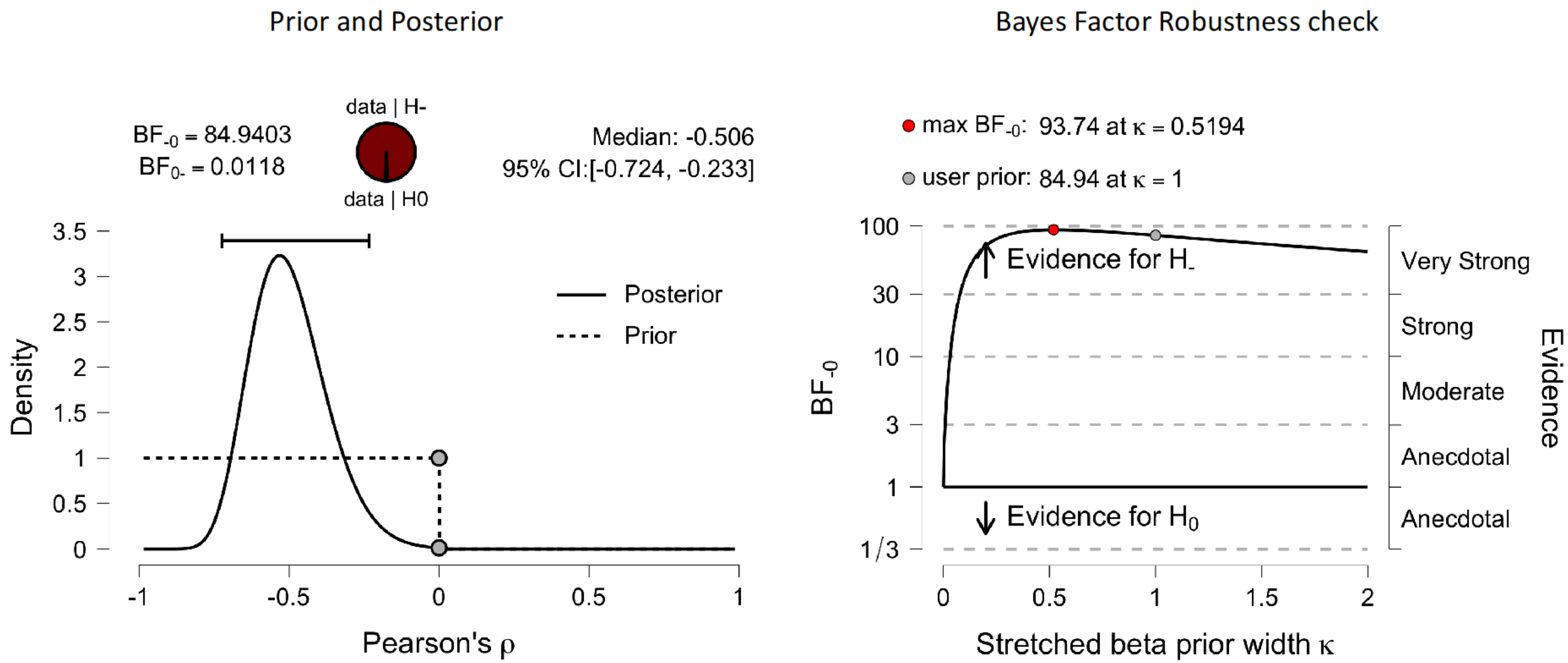
Visualisations of the Prior and Posterior Distributions and the Bayes Factor Robustness Check for the Bayesian Correlation between Weight Preoccupation and the HEP Weight Preoccupation Cluster



Note. HEP = Heartbeat Evoked Potential

Supplementary Figure 3

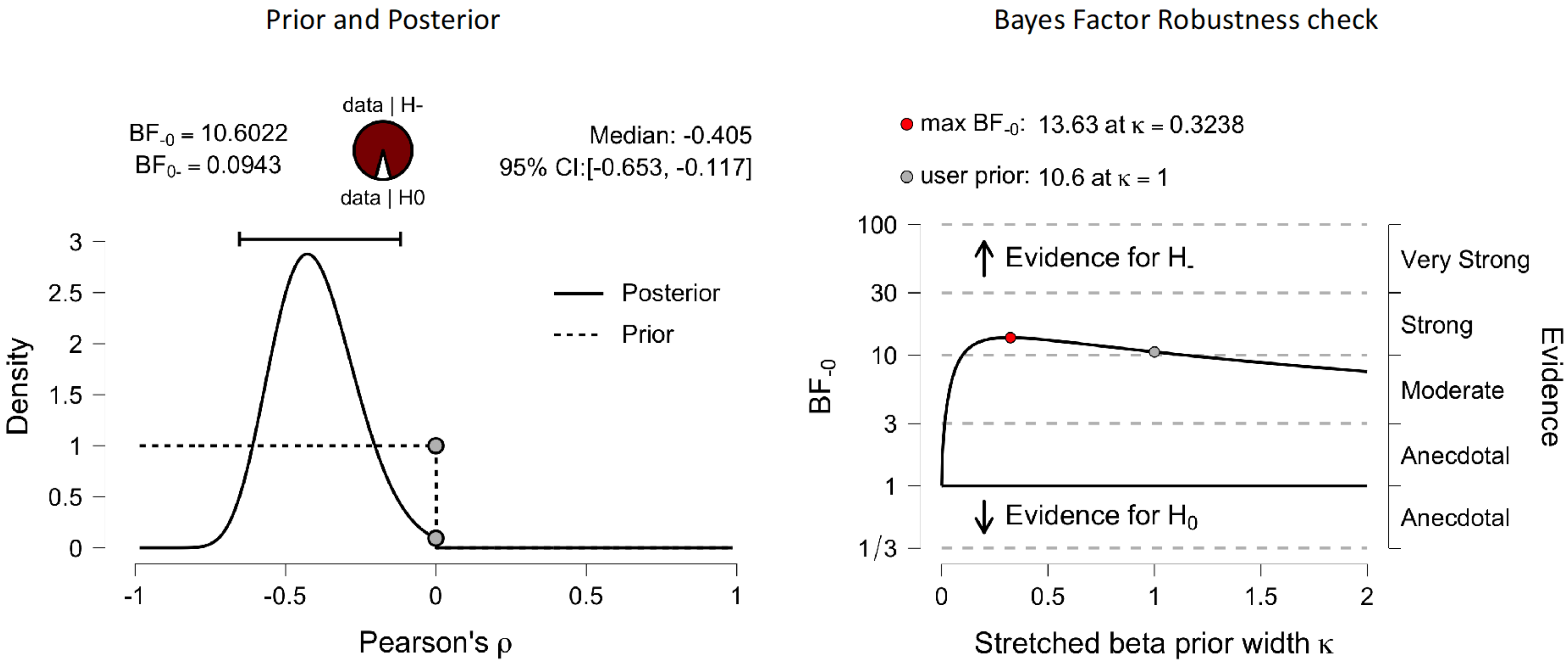
Visualisations of the Prior and Posterior Distributions and the Bayes Factor Robustness Check for the Bayesian Correlation between Weight Preoccupation and the MI for Gastric-Alpha PAC in the Left Centroparietal ROI.



Note. MI = Modulation Index, PAC = Phase-amplitude coupling, ROI = Region of interest

Supplementary Figure 4

Visualisations of the Prior and Posterior Distributions and the Bayes Factor Robustness Check for the Bayesian Correlation between Body Shame and the MI for Gastric-Alpha PAC in the Left Centroparietal ROI.



Note. MI = Modulation Index, PAC = Phase-amplitude coupling, ROI = Region of interest