Registered Report

Embodied perceptual moderation: How interoceptive and proprioceptive engagement affect perceptual performance

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Abstract

According to the framework of embodied cognition, perception is actively constructed across exteroceptive, interoceptive, and proprioceptive modalities. Exteroception relies on the senses to detect external stimuli originating outside the body, which generally remain stable and out of the person's control. Interoception and proprioception gather information from internal organs and body status, respectively. This information is more variable because it can be influenced by active engagement. However, active engagement's effect on interoceptive and proprioceptive processes regarding perception remains nebulous. By resorting to the principles of predictive coding, we hypothesize that the active engagement of interoceptive and proprioceptive modalities will provide a perceptual advantage as the result of physiological recruitment which drives attention (higher precision) to the objective reality. In a three-factor repeated-measures design, 39 participants will perform a visual rotation detection task at the end of each 20-minute, randomized condition: a) Diaphragmatic Breathing, for active interoceptive engagement, b) Isometric Handgrip Task, for active proprioceptive engagement, and c) Arithmetic Task, as the control condition. Low-frequency/High-frequency heart rate variability will be measured throughout to account for emotional affect. Behaviorally, performance will be measured with signal detection accuracy (*d'*), and reaction times modeled via drift-diffusion modeling with confidence rating as parameters. Attention to the presented stimuli will be measured with the EEG-elicited P300 component amplitude. We hypothesize that Diaphragmatic Breathing will lead to more accurate perceptual performance (higher accuracy, faster response times, larger P300 amplitude), followed by the Isometric Handgrip Task, and the control task. This hypothesis is based on previous work supporting that interoception maintains an optimal range of physiological states to promote advantageous behavior and cognition. If the hypothesis is supported, it will suggest that actively engaged physiological processes act as an "anchor" to the environment, providing new grounds for supplemental interventions to assist with perceptual disturbances, such as hallucinatory phenomena. If the hypothesis is not supported, it will suggest that perception and physiology are not as co-dependent, supporting the need for further research on the efficacy of body-oriented interventions.

Introduction

Perception has been regarded as the organization and interpretation of sensory information to represent and understand the external environment.[1] Recently, it has been theorized that perception is grounded in physiological processes through recurrent sensorimotor feedback loops that have co-evolved with the cognitive system.[2] This theory of embodiment assumes cognition is inseparable from the body, and that brain-body rhythms exert key influences on perception.[3,4]

The body can be understood in terms of three interconnected modalities: exteroceptive, proprioceptive, and interoceptive.[5] Exteroception refers to the perception of stimuli originating outside of the body (external), such as visual, acoustic, or tactile, which are detected through the senses.[6] Interoception is the perception of the body “from within”, referring to the integration of autonomic, cardiovascular, hormonal, visceral, and immunological signals stemming from internal organs, such as the heart, lungs, and gut to maintain physiological homeostasis.[7,8] Proprioception is the awareness of body position, movement, posture, and the amount of effort being exerted by the muscles, realized via specialized sensory receptors (proprioceptors) located in muscles, tendons, and joints.[9,10]

Studies investigating perception across these modalities indicate that passive awareness of their associated processes (e.g., breathing for interoception) leads to variant performance outcomes. Regarding interoception, researchers investigated the effect of ongoing cardiac vagal tone on perception and attention.[11] Participants’ cardiac activity was monitored as they completed a visual perception and attention task. The visual perception task invited participants to rate the emotional valence of presented images, while the attention task had them identify a target image from a rapid sequence while ignoring distractors. Results showed that there were faster reaction times in participants with higher heart rate variability when identifying emotional valence in the images. In terms of the attentional task, those with higher heart rate variability also had higher accuracy and faster reaction times in detecting the target image. This evidences that ongoing vagal tone provides a perceptual performance advantage. Interoceptive awareness has also been associated with beneficial outcomes, such as increases in emotional awareness and regulation.[12] For example, researchers asked participants to take part in eight weeks of mindfulness practice while self-reporting their interoceptive awareness before and after. Results found significant improvements in aspects of interoceptive awareness including attention regulation, self-regulation, body listening, and trusting when compared to a control group.[12] At the same time, excessive interoceptive awareness can interfere with perceptual processes through increased arousal and anxiety.[13] In particular, it was found that participants with higher interoceptive awareness displayed greater cardiovascular reactivity and greater anxiety during an isometric handgrip task (IHT), a task requiring one to grip and squeeze an object for a certain period of time. The production of anxiety during this task evidences potential detriments to perceptual performance.[13] Additional research has shown that when cardiac signals were presented synchronously to participants' heartbeats, they were more likely to have their awareness of visual stimuli suppressed.[14] Expanding on this, some research evidenced how attentional interference directly disrupts interoceptive awareness. For example, when participants were asked to rate the emotional valence of different pictures while performing a secondary task involving counting (attention interference), they showed impaired cardiac interoceptive awareness with a more pronounced effect in those participants with already low levels of interoceptive awareness.[15] Another study investigated perceptual effects when physiological arousal unexpectedly increased using the subliminal presentation of emotional pictures just before participants had to decide whether dots on a screen were moving to the left or the right. As the task became more difficult, participants were less confident about their decision while performance outcomes remained unchanged. However, increased arousal immediately before a trial countered this effect, suggesting that unexpected arousal changes regulate perceptual precision such that subjective confidence reflects the integration of both external sensory stimuli and internal body states.[16] Taken together, passive exposure to interoceptive activity seems to have variant results on perception and performance.

Regarding proprioception, similar variant effects on perception have been identified. For example, the rubber hand illusion demonstrates how passive awareness of the hand's location and position can affect one's body perception. In the rubber hand illusion participants look at a fake hand while their other hand is lightly stroked with a brush, creating the illusion wherein they feel that the fake hand is part of their own body.[17] Further research on passive awareness of proprioception shows that during a low-intensity IHT dissociative thoughts tended to increase.[18] Since dissociative thoughts are, by definition, task-unrelated this suggests that passive awareness of a proprioceptive process creates confounds that can negatively affect perceptual performance outcomes. This is further supported by research on kinesthetic repetition and daydreaming. Research has shown that immersion in a daydream is associated with repetitive, compulsive motor functions such as flipping a coin, pacing, or tearing leaves.[19–21] Together, this shows that when the proprioceptive modality is operating "in the background" of awareness variant outcomes on perception are also observed.

The active engagement of these modalities, though, seems to have more straightforward positive effects on perception and behavior. For example, mindfulness meditation or breathwork involves the willful manipulation of the respiratory system.[22] Diaphragmatic breathing, a technique involving the contraction and relaxation of the diaphragm muscle, has been shown to benefit the perceptual domain by leading to increases in sustained attention and decreases in false memory rates.[23–25] Similarly, active engagement of the proprioceptive modality also employs attention which is necessary to monitor body movements,[26] with ensuing perceptual benefits.[27] For example, when participants were given congruent proprioceptive cues, like applying a brief lateral force to the arm in the direction of a visual stimulus, accuracy rates increased when needing to detect a dimming stimulus.[28] Another study found that bilateral knee extensions led to rapid improvements in inhibitory control when performing the Stroop Task.[29] This is further supported by evidence of improved short-term attention in participants who received haptic feedback in force control tasks.[30] Another study found that the perceived size of an object changed based on one's intent to reach for it or grasp it. Here, a fixation target remained on the screen while a bar intermittently appeared on the left or right side and then disappeared after an acoustic signal. Participants had to indicate the perceived horizontal size of the bar by extending their right thumb and index finger within a marked square on the table. Then, participants were required to perform either a reaching, closed fist, action toward the presented bar or a grasping, extension of thumb and index finger, toward the bar. Results found that participants perceived the stimuli to be smaller after a grasping action, supporting how active engagement of the proprioceptive modality can distort our perception.

The assessment of attention in terms of performance outcomes has been widely approached with EEG measurements. Visual detection is one such component of performance in the perceptual domain that is often assessed through detection tasks consisting of grating changes, go-no-go, masking, or the visual oddball.[31–33] Evoked-related potentials (ERPs) are specific EEG responses that occur as a direct result of a sensory event with specific components. One such component, the P300 (sometimes called "P3" or "late positive component/LPC) is an electrophysiological signature that arises as positive voltage deflection.[33,34] Of interest, is the P3b subcomponent which comes from temporal-parietal activity (i.e., parietal maximum of the target stimulus) and is associated with attention and memory processing.[34,35] Overall the P300, via its P3b subcomponent, reflects decision-making and is measured through amplitude (μV) and latency (ms).[34,36]

Given the variant perceptual outcomes of passive exposure to interoceptive and proprioceptive processes, the results of their active engagement remain unclear. Here, we first hypothesize that active engagement of the interoceptive and proprioceptive modalities will have a beneficial effect on perceptual performance because they will act as a controlled means to manipulate bodily states and eventually perception. This stance is well embraced by the framework of predictive coding which stipulates that the weight given to sensory noise depends upon bodily states.[8,37] In short, predictive coding is a biological scheme according to which we constantly sample our environment through our senses to encode expectations about the causes of sensory input, to minimize the "surprise" of sensory data (i.e. prediction errors).[38] Prediction errors, therefore, represent the difference between (ascending) sensory input and (descending) predictions of that input. The minimization of prediction errors can happen either by changing one's internal states or by keeping the model constant and selectively sampling the world, hence changing the input. The expectations about the precision of incoming sensory input are crucial for minimizing prediction errors effectively because expected precision can inform confidence in that error, which further influences the extent to which the error is weighted in updating predictions.[39] As an example, the expected precision of visual prediction errors varies between light and dark, such that there is greater confidence in errors in daylight conditions than in the dark. It has been proposed that such weighting of prediction errors according to their estimated precision is, in essence, attention. Attention, therefore, has been thought of as an emergent property of prediction, in that goal-directed behaviors lead to high-precision predictions.[39] Translated to our hypothesis, we first assume that the active engagement of interoceptive and proprioceptive processes will provide a perceptual advantage due to physiological recruitment which drives attention (higher precision) to the task at hand. Our hypothesis fits well with the performance of a simulated psychophysics model using synthetic heart-rate variability analyses.[40] The model simulated interactions between the cardiac cycle and perception. It revealed that during diastole (relaxed), subjects had a relatively precise perception of the presented stimuli. However, during systole (aroused), this mapping became imprecise, leading to attenuated perception.[40] Second, we hypothesize that interoceptive engagement will have a greater effect on perceptual outcomes. This is due to previous work that supports the idea of interoception maintaining an optimal range of physiological states to promote advantageous behavior and cognition.[5] If our hypotheses are supported, it will suggest that actively engaged physiological processes act as an "anchor" to the environment, providing new grounds for supplemental interventions to assist with perceptual disturbances, such as hallucinatory phenomena. If the hypothesis is not supported, it will suggest that perception and physiology are not as co-dependent, supporting the need for further research on the efficacy of body-oriented interventions.

Methods

Ethics Information

The study was approved by the University of Liège Centre Hospitalier Universitaire (CHU) ethics committee (Nr Belge: B7072022000020) and conforms with the Declaration of Helsinki and the European General Data Protection Regulation (GDPR). Before the experiment, participants will provide informed consent for their participation in the study. Participants will receive monetary compensation of 10€ for their participation.

Participants

The study will include healthy volunteers recruited through campus poster advertisements. Inclusion criteria are right-handedness (a Laterality Index of > 48 according to an adapted form of the Edinburgh Handedness Inventory, scored on https://www.brainmapping.org/shared/Edinburgh.php) and 18-65 years of age due to handedness affecting P300 components (e.g. left-handed persons have shorter P3 latency).[41,42] Additionally, participants will be asked to complete the Multidimensional Assessment of Interoceptive Awareness (MAIA) before proceeding to the study as a general measure of body awareness.[43] Exclusion criteria are: a history of developmental, psychiatric, or neurological illness and an anxiety score < 9 in the General Anxiety Disorder-7 (GAD-7 scale) as anxious participants could bias the sample.[44,45] At the beginning of the visual rotation detection task (VRDT), the Karolinska Sleepiness Scale (KSS) will be used to assess sleepiness as a confound potentially affecting attention and performance.[46] The KSS is a visual analog, ten-item scale that ranges from “1 – Extremely alert” to “10 – Extremely sleepy, can’t keep awake.”[46] Data collection and analysis will not be performed blind to the conditions of the experiments.

Design and Procedure

A three-factor (Interoception v. Proprioception v. Control) repeated-measures design, counter-balanced and randomized for order effects is used (Figure 1). Recordings of respiration, muscle activity, EEG, and heart rate will take place before the start of the physiological conditions using the BIOPAC’s M160 system (BIOPAC SYSTEMS Inc.), and the BrainAmp EEG system (Brain Products GmBH). To obtain respiration data, a respiration belt transducer (TSD221-MRI) will be attached to the participant’s abdomen. For muscle activity, electromyography (EMG) electrodes will be montaged as follows: the ground electrode will placed on the forearm of the participant's non-dominant arm, while the negative and positive electrodes will be placed on the flexor muscles of the dominant arm as they have been shown to best record and respond to grip.[47] Electrocardiogram (ECG) recordings will take place with disposable adhesive skin electrodes using a bipolar arrangement of two electrodes and a ground electrode. The positive electrode will be placed on the non-dominant wrist and the negative on the contralateral ankle. The ground electrode will be placed on the ipsilateral ankle. Heart rate variability (HRV) will be calculated as a physiological proxy to affect as emotional states were shown to be influenced by the aforementioned conditions through their effect on perception.[48,49] All physiological signals will be visualized online using the BIOPAC's *AcqKnowledge* software to ensure that participants are engaging properly with the intervention. For EEG recording, we will use a 64-electrode EasyCap connected to a BrainAmp System. A ground electrode will be placed frontally (e.g. FPz 10-20). From this, we will reference electrodes to the frontal electrode. We will use electrode gel to assist in the conductivity of the signals. Once the participant is fully set up with EEG, the respiration belt, ECG electrodes, and EMG electrodes, they will begin 20 minutes of their randomly assigned intervention. After 20 minutes, they will proceed to the VRDT task, repeating this sequence until all interventions are completed, and the task is completed three times.

Conditions and Tasks

Interoception Condition – Diaphragmatic Breathing (DB): The process of respiration will be engaged through DB to test the interoceptive modality given its prominence in the literature.[44,50–53] Participants will be instructed to breathe in through their nose and out through their mouth as their abdomen expands on the exhale in a self-paced rhythm for 20 minutes while monitoring their breathing in real time.[44,50] Affective words such as "relax" will not be used to avoid biasing the outcome and to minimize the effect of demand characteristics.[54]

Proprioception Condition – Isometric handgrip task (IHT): The IHT will be used to engage muscle activity involved in grip as a means to test the proprioceptive modality given its prominence in the literature.[53] The IHT will involve participants being instructed to squeeze and release a stress ball in both hands for three-second intervals for 20 minutes.[56] Affective words such as "relax" will not be used to avoid biasing the outcome and to minimize the effect of demand characteristics.[48]

Control Condition – Arithmetic task: Participants will complete a time-matched control task (20 minutes) of randomized simple math problems, such as addition, subtraction, multiplication, and division. This control condition is chosen to best represent an ecologically valid task one could encounter in their everyday life. Participants will have to select one of three potential solutions to the operation, one being true and two being false.

Cognitive Performance – Visual Rotation Detection Task (VRDT): To perform the task, participants will be positioned 43cm from the screen to create a 50° x 40° visual field so the effect of distance on size estimation can be minimized.[27] The VRDT assesses short-term visual memory by measuring line and grating differences in the visual field.[33,57] All Gabor stimuli presentations will appear at a random orientation between 5 and 175 degrees to present rotation across the abscissa (Fig. 2A). The procedure will be as follows (Fig 2B): First, a base Gabor patch will be presented for 250ms. A fixation cross then will appear on the screen for 500ms and between stimulus presentations. After the base patch, visual noise made of four superimposed patches will appear with random orientations for 500ms. Then, the change grating will appear in a different orientation than the base grating. Participants will have to indicate if the change grating is rotated more towards the right (RIGHT key) or is rotated more towards the left (LEFT key) when compared to the base grating. In the end, participants will be presented with a screen asking about how confident they were that they responded correctly (4 = certainly correct, 3 = probably correct, 2 = probably incorrect, 1 = certainly incorrect). The block will last for 120 trials**.** The visual rotation detection task was designed in PsychoPy-2022.29.

Outcome-Neutral Criteria – Respiration and EMG: To ensure that the participant is actively engaging with the experimental conditions (DB and IHT), they will monitor their own bio-signals along with the researcher. These signals will be visualized using BIOPAC's *AcqKnowledge* software. For DB, average respiration rate will be observed to assess their engagement with the conditions. Participants will be considered as performing DB if a sharp visual peak emerges in the waveform during the inhale.[50,55] For IHT, EMG signals will be observed to assess if they are doing the IHT properly. IHT activity will be considered acceptable if bundles of electrical signals emerge during muscle constriction (i.e., ball squeeze).

Hypothesis 1: Interoceptive engagement will be responsible for perceptual advantage requiring accuracy as reflected in performance (Table 1).

H0: No difference in accuracy (*d'*) or response times across conditions.

H1: Given that the interoceptive system is mostly responsible for the maintenance of the body's internal state, we predict the highest accuracy (*d'*) with interoceptive engagement, then proprioceptive engagement when compared to control. The fastest response times on the VRDT are hypothesized to take place after interoceptive engagement, and then after proprioceptive engagement when compared to the arithmetic control.

Hypothesis 2: Interoceptive engagement will be responsible for perceptual advantage reflected in attention's mechanistic counterpart—P300 amplitude (Table 1).

H0: No difference in P300 amplitude across conditions.

H1: Given that the interoceptive system is mostly responsible for the maintenance of the body's internal state, we predict a larger P300 amplitude when detecting the visual stimuli during the VRDT after the interoceptive condition, than the proprioceptive condition with the smallest difference in the arithmetic control task.

Sampling Plan

For behavioral analyses, we decided to model power after our primary interest in how physiological engagement conditions affect performance outcomes. As such, we calculated effect sizes of discrimination on both an interoceptive and an exteroceptive task allowing us to choose the lowest effect size for the final sample size approximation. First, a study using Shamatha meditation, which involves attention to breathing, found lower discrimination thresholds after training [$F(1, 58) = 5.80$, $p = .019$, $\eta_p^2 = .09$.][58] The η_p^2 was converted into Cohen's f using the following formula: $f = \sqrt{(\eta p^2 / (1 - \eta p^2))}$ to equal 0.31. Using GPower 3.1 we computed an a priori ANOVA Repeated measures Within- Factors which was then run as follows: Effect size f: 0.31, error: 0.01, power: 0.95, groups: 1, measurements: 3, correlation among repeated measures: 0.5, non-sphericity correction: 1.[59] This resulted in a total sample size of n = 39.

To approximate the sample size for the exteroceptive engagement conditions, we used a previous study that found that bilateral knee extensions improved performance on the Stroop task which measures attention ($p < 0.05$, Cohen's $d = 0.75$).[29] This value was converted to Cohen's f using the formula $f = d/2$ to equal 0.375. Using GPower 3.1 we computed an a priori ANOVA Repeated measures Within-factors, which was then run as follows: Effect size f: 0.38, error: 0.01, power: 0.95, groups: 1, measurements: 3, correlation among repeated measures: 0.5, non-sphericity correction: 1.[59] This resulted in a total sample size of n = 27. Since the interoception study had the lowest effect size, we settled on n = 39 to calculate a proper behavioral effect.

For EEG analyses, an a priori power analysis for a one-way repeated measures ANOVA at 0.95 power via GPower 3.1 determined n = 21 as sufficient to find a true effect.[60] An experiment examining the effect of a visual detection task, similar to one proposed here, found no evidence of learning on vernier stimuli before and after training about peak amplitude of the P300 (166ms: $F(1,15) = 3.327$, n.s.).[33] The F value was converted into Cohen's f using an online calculator with the following specifications (F value: 3.327, CI: 90%, numerator degrees of freedom: 1, denominator degrees of freedom: 15) for a Cohen's f of 0.37. A

GPower 3.1 computation (A priori: ANOVA: Repeated measures, within factors) was then run as follows: (Effect size f: 0.37, error: 0.01, power: 0.95, groups: 1, measurements: 3, correlation among repeated measures: 0.5, non-sphericity correction: 1).[59] This resulted in a total sample size of 28. With both the behavioral and EEG power analyses taken together, this experiment will use a total sample of 39.

Analysis Plan

Response Times

Conscious visual detection will be assessed by response time differentials between stimulus presentation and participant response (i.e. button press). Stimulus discrimination will be assessed via d' and C based on signal detection theory. The clockwise (CW) orientations are considered signal present because they are easier to detect than counter-clockwise orientations (CCW).[61] In a 2x2 matrix this is illustrated as follows: If the orientation value in degrees in the base grating is lower than the changed grating, the rotation is considered clockwise (CW). Here, responses are scored as RIGHT (Hit) and LEFT (False Alarm). If the orientation value in degrees in the base grating is higher than the changed grating, the rotation is considered counter-clockwise (CCW). Here, responses are scored as RIGHT (Miss) and LEFT (Correct Rejection). Response time will be calculated by subtracting the time of stimulus presentation from the time of the proper keypress response. Because response times are not normally distributed, as they do not contain negative values, a Kruskal-Wallis H test will be run on the values. Next, Mauchly's Test of Sphericity will test the assumption of equal variance. If the sphericity assumption is violated, Greenhouse-Geisser corrections will be used before proceeding with post-hoc t-tests supplemented with Tukey correction. Potential confounds like the MAIA, KSS, and LF/HF HRV ratio will be explored.

Performance accuracy

Perceptual performance is assessed using signal detection theory (SDT). SDT formulates *d'* (d prime) as a measure of accuracy, and C as a measure of decision criterion for response bias.[62] In essence, d' is our ability to discriminate two states of the world (two Gaussian distributions of signal v. noise).[62,63] C, the decision criterion is not a fixed boundary, but it is under the observer's control, therefore it can change.[62,64] This moveable dimension of SDT allows individuals to vary in their ability to properly detect stimuli. For example, when C bisects the two bimodal Gaussians (signal v. noise) in SDT, a division is created. This division then creates four sections out of the overlapping Gaussians: hits, misses, false alarms, and correct rejections.[65] Shifting of the criterion can change signal detection rates as the division happens at higher or lower ends of the distribution. For example, a more conservative C would shift to the right, leading to lower correct responses, but also lower incorrect responses. d' and C scores will be calculated from raw Hit, Miss, False Alarm, and Correct Rejection data using a custom R pipeline. Once these measures are calculated, Shapiro-Wilks tests will be set at a confidence level of 0.05 to inform us about the data. If the normality assumption is not violated, repeated measures ANOVA will be run between the three conditions on the measure of d'. Next, Mauchly's Test of Sphericity will be run to test the assumption of equal variance. If the sphericity assumption is violated, Greenhouse-Geisser corrections will be used before proceeding with post-hoc t-tests supplemented with Tukey correction. If the normality assumption is violated, a Kruskal-Wallis H test will be run between the groups on the measure of d' with post-hoc Wilcoxon-signed rank tests supplemented with Tukey correction. Potential confounds like the MAIA, KSS, and LF/HF HRV ratio will be explored.

Drift-diffusion Modeling

Drift diffusion modeling (DDM) is a method of simulating decisions in a two-choice discrimination task.[66] In essence, DDM assumes that decisions are made by a noisy process that accumulates information over time from an initial starting point (z) toward two response criteria, or boundaries (α and 0).[66] This is also known as an accumulator process. The rate at which information is acquired is called the drift rate (v).[66] Because of noise via within-trial variability (s), processes with the same drift rate do not always end at the same time leading to response time distributions, and do not end at the same boundary, producing errors.[66] When the accumulator reaches one of these boundaries, a decision is made. Of note, it is the boundary that is reached first that determines the decision being made. Response time is therefore the amount of time it takes the accumulator to reach a decision boundary. DDM is used to model the decision-making process in determining whether the changed grating is rotated more towards the right (RIGHT key) or is rotated more towards the left (LEFT key) when compared to the base grating. Since DDM can also include measures of confidence, they are included here as parameters.[67] HDDM will be used in Python to model this process.[68]

Electrophysiological Analysis

EEG event-related potential (ERP) analysis will be used to objectively assess the detection of visual stimuli. Participants will be equipped with a 64-electrode EasyCap attached to a BrainAmp system. Visual detection will be assessed through ERP analysis in MNE Python. Preprocessing includes bad channel rejection by visual inspection. Here, we will remove flat channels and channels contaminated by unusual high-amplitude variations/very high-frequency noise over the whole acquisition time course. Next, we will use bandpass filtering (0.1-40Hz) and data epoching by event (stimulus presentation, right click, left click). Then, we will employ bad epoch rejection by visual inspection where we will remove epochs contaminated by very high-amplitude/very high-frequency noise. Using independent component analysis (ICA; Infomax, 136 iterations on epochs, 54 PCA components) non-neural components will be determined by visual inspection based on their spatial distribution, power spectrum, and variance over epochs. These will be removed from the signal. Next, we will employ bad channel interpolation and re-referencing to the common average. With the analysis pipeline, we will start by plotting evoked objects. Then we will display combined scalp topography plots. After, global field power will be computed and plotted. Finally, we will extract wave peaks and latencies, leading to ERP visualization.

Heart Rate Variability

To assess the role of affect on perception, heart rate variability (HRV) will be used as a proxy for the emotional state.[48] Since it was found that the ratio of low-to-high frequency HRV was associated with positive affect, the HRV ratio will be calculated to be explored later as a potential confound in performance. Preprocessing of the raw cardiac time series will follow the standard preprocessing guidelines: a 0.5 highpass Butterworth filter and powerline noise removal. R-peak detection will be conducted using the native Neurokit2 algorithm.[70] The RR peak time series will be then interpolated. Frequency domain features will be calculated using the Welch decomposition. This procedure yields the power in two different bands, mainly low frequency (LF) between 0.04 and 0.15Hz and high frequency between 0.15 and 0.4Hz (HF). After, the ratio can be calculated as LF/HF.

Limitations

One study limitation concerns the difficulty of completely isolating the interoceptive, proprioceptive, and exteroceptive processes. For example, diaphragmatic breathing (DB) engages some proprioceptive processes such as the movement of the spine, ribs, and clavicle. Isometric handgrip (IHT) engages some exteroceptive processes, such as the sensation of the stress ball on the palm of one's hand.

Another limitation lies in the treatment of potential confounds. Since our primary interest deals with the difference between groups, we opted to base power analyses and subsequent sample size estimates on repeated-measures within-subjects ANOVA. As such, we inherently assume the possible confounds (MAIA, KSS, and LF/HF HRV Ratio) are of secondary importance by opting to not use them as covariates in a preregistered ANCOVA or ANCOVA-like GLM (e.g. mixed-model approach). Instead, we chose to collect data on these confounds and explore them in exploratory, non-preregistered phenotyping of the sample and/or analysis. Additionally, potential sequence effects cannot be delineated. Although we mitigated this issue by counter-balancing the block order and by administering the Karolinska Sleepiness Scale, we nevertheless stay cautious about the wash-out periods between exposures and the potential for effects of fatigue.

Optimization of Code, Visualizations, and Setup: Pilot Data

To optimize the setup and EEG analysis pipelines, one participant (n=1) was run through a full-montage pilot. This included electrophysiological recordings with the BIOPAC MP160 system (respiration belt and

EMG sensors) and the EEG EasyCap throughout the entirety of the experiment. To optimize task code and behavioral analysis pipelines a behavioral-only pilot was run on six participants (n=6). This pilot involved participants engaging in the conditions and completing the visual detection task of 80 trials per condition without the EEG or BIOPAC M160 (EMG, Respiration) montage. This pilot sample consisted of men (33%) and women (67%) with different levels of education completed: Bachelor (16.7%), Master (33.3%), and Ph.D. (50.0%). Ages ranged from 22 to 36 (M = 29.83, SD = 4.79). Laterality indices ranged from 75 to 100 (M = 87.50, SD = 9.35), indicating that the sample was right-handed. General anxiety scores ranged from 4 to 17 (M = 8.83, SD = 5.04), indicating that on average the sample was below the anxiety cutoff for inclusion criteria (< 9). Two participants scored higher than the inclusion criteria allowed (> 9); however, for purposes of the pilot these participants still ran through the protocol, and their data was included.

Outcome variables of average response time, average confidence, d', and C were assessed for normality assumptions. Shapiro-Wilk tests found that response time for diaphragmatic breathing (W = .809, p = .07), isometric handgrip task (W = .910, p = 0.44), and math (W = .969, p = .889) were normally distributed. Furthermore, d' scores for diaphragmatic breathing (W = .876, p = .25), isometric handgrip task (W = .977, p = 0.94), and math (W = .941, p = .669) were normally distributed. C criterion response scores were normally distributed for diaphragmatic breathing (W = .875, p = .245) and isometric handgrip task (W = .873, p = .238), but not for the math condition (W = .969, p = .012; Supp. Fig 1). Normality was further confirmed for average confidence ratings in both diaphragmatic breathing (W = .831, p = .110) and math (W = .954, p = .772) conditions, but not for isometric handgrip (W = .719, p = .009). As such, Friedman's tests were run on C criterion $\chi^2(2) = 3$, p = 0.22, W = .25 [95% CI: -0.2, 0.44] and confidence ratings $\chi^2(2) = .666$, p = 0.72, W = .056 [95% CI: -0.46, 0.26] neither revealing significant differences between groups. Repeated measures ANOVA were run on average response time (F(2, 10) = 1.36, p = 0.30, $\eta^2 = .12$) and d' scores (F(2, 10) = 0.095, p = 0.91, $\eta^2 = .011$), neither revealing significant differences between conditions. Because the sample was underpowered, there are no conclusions we can make from the data. However, the purpose of such a pilot was to optimize our setup and code, leading to usable and visualizable data.

Data Availability

The data and the preprint will be made available at https://osf.io/k8nzd/.

Code Availability

All analysis codes for behavior and electrophysiology along with the visual detection task can be found here: https://gitlab.uliege.be/poc/body-anchoring-and-perceptual-moderation.

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Author Contributions

LDF: Conceptualization, funding acquisition, methodology, coding, visualization, writing – original draft, project administration, data curation, investigation

SM: Coding (EEG pipelines), writing - review & editing

PAB: Writing - review & editing, methodology for confidence ratings

AD: Conceptualization, methodology, supervision, resources, visualization, writing - review & editing, project administration, data curation, funding acquisition

Competing Interests

The authors declare no competing interests.

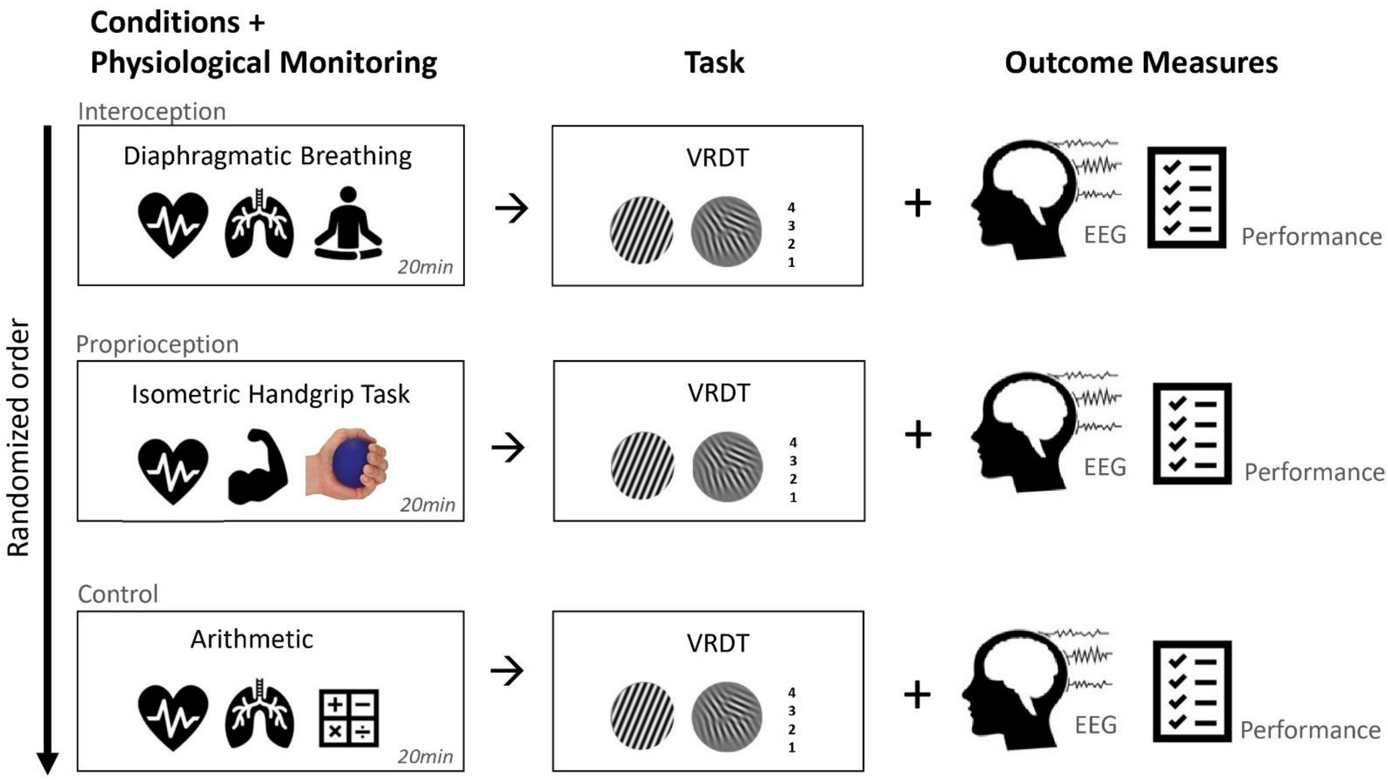

Figure 1. ***Design and Procedure*****.** Participants will perform a visual rotation detection task (VRDT) under three conditions (interoception, proprioception, and control) while EEG, EMG, and respiration data will be monitored. In the Interoception condition, participants will perform diaphragmatic breathing for 20 minutes. After, they will complete a detection task of 120 stimulus presentations. In the Proprioception condition, they will perform an isometric handgrip task (IHT) by squeezing a stress ball in both hands for 20 minutes. After, they will complete a detection task of 120 stimulus presentations/trials.

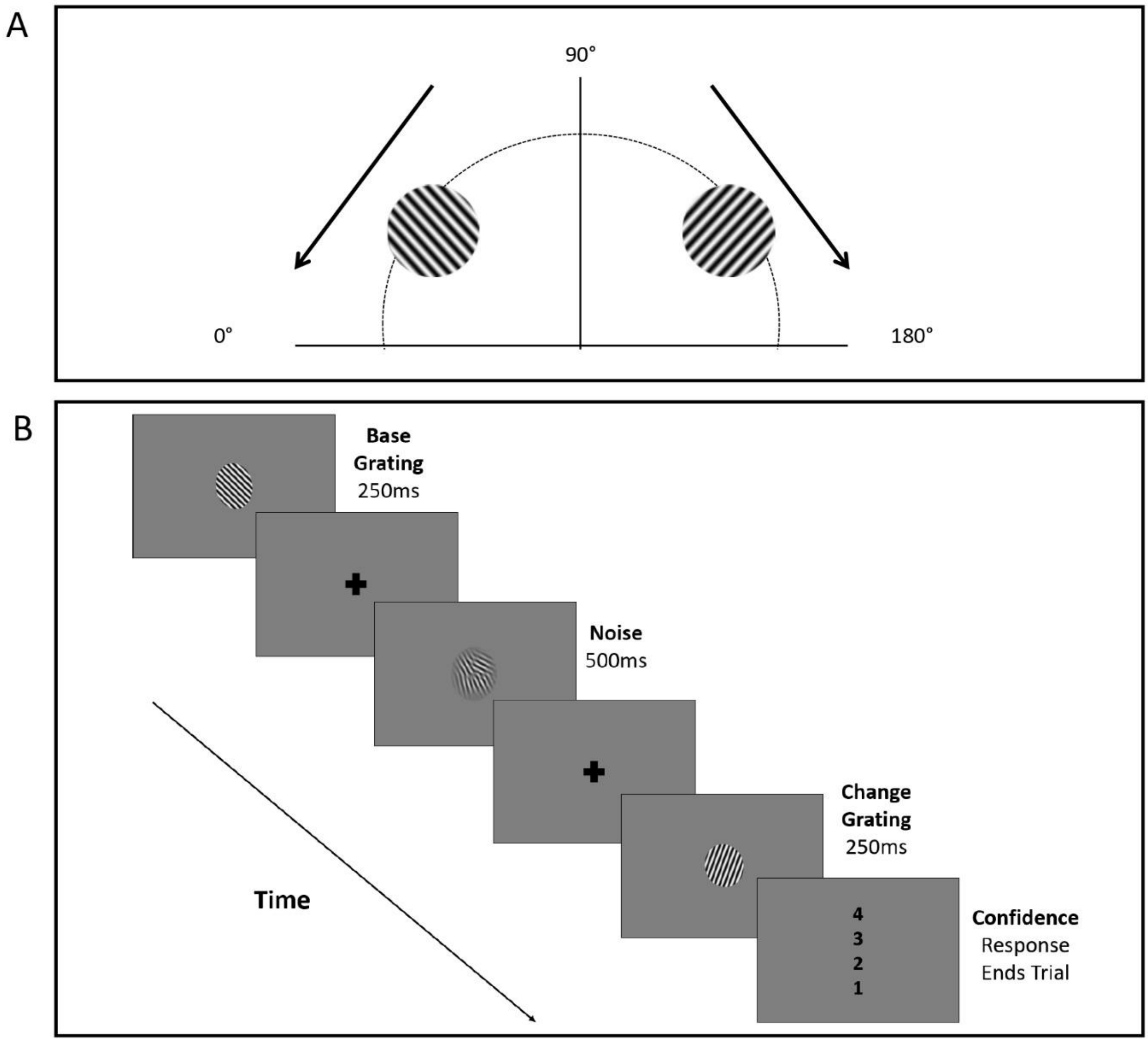

Figure 2. ***Visual Rotation Detection Task (VRDT) Design***. *Stimulus Presentation (A*): All Gabor patches in the VRDT are presented at a random interval (5°-175°) prevented from flipping across the abscissa. *Procedure (B)*: First, a base Gabor patch is presented for 250ms. A fixation cross then appears on the screen for 500ms and appears between stimulus presentations. After the base patch, visual noise made of four superimposed patches with random orientations will appear for 500ms. Then, the change grating will appear in a different orientation than the base grating. Participants will have to indicate if the change grating is rotated more towards the right (RIGHT key) or is rotated more towards the left (LEFT key) when compared to the base grating. In the end, participants will be presented with a screen asking about how confident they were that they responded correctly (4 = certainly correct, 3 = probably correct, 2 = probably incorrect, 1 = certainly incorrect). The block lasts for 120 trials**.**