Altering body-representation through non-naturalistic sounds: study protocol for an experimental study in a subclinical eating disorders sample

Sergio Navas-León
Universidad Loyola Andalucía

Luis Morales Márquez
Universidad Loyola Andalucía

Milagrosa Sánchez-Martín
Universidad Loyola Andalucía

Laura Crucianelli
Karolinska Institutet

Nadia Bianchi-Berthouze
University College London

Mercedes Borda-Mas
Universidad de Sevilla

Ana Tajadura-Jiménez (✉ atajadur@inf.uc3m.es)
University College London

Study protocol

Keywords: Auditory feedback, Body illusions, Body image disturbance, Perception, eating disorders, Multisensory integration, Sound

Posted Date: August 3rd, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1915001/v1

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Abstract

Background

Experimental research based on bodily illusions suggests that people with eating disorders (EDs) might have impairments in visual, interoceptive, proprioceptive, and tactile perception, potentially underpinning altered multisensory integration processes. Along this line, research indicates that people with EDs show abnormalities in integrating multisensory visuo-tactile signals, which might contribute to the development of body image disturbances in EDs. More recently, an altered integration of auditory signals related to body weight has been also shown for people with EDs. However, it remains unclear whether these impairments extend to any auditory signals, even if not related to body weight. To fill the gap, the present study will investigate whether participants with ED symptomatology and control participants differ in two auditory feedback tasks which will involve integration of auditory and proprioceptive cues using artificial non-naturalistic sounds. We will test two different body parts (i.e., fingers and waist) which have different levels of emotional saliency for people with EDs.

Methods

Recruitment will be through convenience sampling. The EDE-Q questionnaire will be administered as a screening tool to split the sample into participants with and without ED symptomatology. The strength of both illusions will be measured implicitly with estimations of body part position and size, and explicitly with self-report questionnaires. As a secondary aim, regression analysis will be carried out to test the predictive role of susceptibility for both illusions on ED symptomatology, interoceptive body awareness and sensory-processing sensitivity.

Discussion

Our study might contribute to our understanding of the aetiology of body image disturbances. The results may lay the ground for novel clinical interventions which aim to improve symptoms at the early stages of the illness.

Background

Body image disturbance (BID) is a clinical feature commonly associated with eating disorders (EDs) [1, 2]. BID is a multidimensional construct comprising two components: an attitudinal component (i.e., negative feelings and thoughts toward the body) and a perceptual component (i.e., inability to accurately estimate body size) [2]. Traditionally, the former has played a crucial role in cognitive-behavioral therapies whereas the latter has been largely overlooked [2, 3], and thus its relevance to clinical practice remains unclear[4]. Experimental evidence suggests that people with Anorexia Nervosa (AN) and Bulimia Nervosa (BN) overestimate the body size compared to control participants [4, 5]. Furthermore, the perceptual
component of BID in people with AN has been linked to poorer therapeutic outcomes, namely increased
cognitive, affective, and behavioral psychopathology [6, 7]. Importantly, neurobiological studies using
functional magnetic resonance imaging (fMRI) have associated impairments in the perceptual
component in people with AN with structural-functional brain abnormalities in areas involved in the
processing of body-related information (e.g., alterations of the precuneus or parietal cortex, among
others) [8, 9]. Taken together, this body of literature suggests that the perceptual component of BID is a
crucial clinical feature in EDs that requires more attention and must be targeted using specialized
treatments [4, 6].

The perceptual component of BID might be a contributing factor in the onset, maintenance, and relapse
of EDs, although evidence in this direction is still sparse [3]. However, recent developments in the field of
multisensory integration can fill this gap by uncovering the processes underlying the perception of one's
own body, and by implications shedding some light on the aetiological basis underlying perceptual
disturbances in body image [10]. Ongoing research in this field suggests that our body image is not static,
but it is continuously updated responding to the inputs that we receive from our body (i.e., visual, auditory,
or haptic signals, among others) [10, 11]. This idea is supported by studies using multisensory body
illusions (BIs), which have shown the malleability of body image, and overall mental body-
representations, in response to conflicting sensory inputs [11, 12]. In broad terms, these BIs could be
defined as any “psychological phenomenon in which the perception of one's own body importantly
deviates from the configuration of the physical one, e.g., in terms of size, location, or ownership” [13]. For
example, as a prototypical paradigm, the Rubber Hand Illusion (RHI) showed that it is possible to induce
participants to perceive a rubber hand as part of their body by touching a fake hand in synchrony with the
participant's own hand, which is out of view (visual-haptic-proprioceptive integration) [12]. Inspired by this
promising line of research, studies applying BIs to investigate the perceptual component of BID on people
with EDs are on the rise [14].

Mussap and Salton [15] used the RHI to evaluate the relationship between body image perception and ED
symptomatology. Their results suggest that participants with ED symptomatology were significantly
more susceptible to the RHI as compared to people without ED symptomatology. Thus, they concluded
that body image malleability could be a risk factor for developing EDs given the significant relationship
between the susceptibility to the illusion with ED symptomatology, such as bingeing and purging
behaviors. Along the same line, subsequent studies corroborated and extended these findings in ED
samples. For example, Eshkevari et al. colleagues [16] found that participants with ED experienced a RHI
even when the rubber hand and the participant's own hand were touched asynchronously (i.e., a condition
that does not lead to the illusion in healthy individuals) [16, 17]. In another key study, Keizer et al. [18]
used the Full Body Illusion to induce people with AN to feel as if a full-body avatar was their own body.
They reported that after removing visual feedback of the participant's own body, it was possible to reduce
the overestimation of participants' own body, with results lasting at least 2 hours and 45 minutes after
the illusion was induced. Overall, these findings show an increased sensitivity to visual information about
the body and a decrease attention to body somatosensory and proprioceptive information processing
[16–18]. However, studies in the field reveals that perceptual impairments relevant to BID may also be
non-visual, including other modalities such as haptic perception, interoception, or proprioception, among others [19, 20]. Accordingly, it is crucial to elucidate what aspect of perceptual processing of bodily information, including multisensory integration, is altered in EDs [20, 21].

Importantly, despite the growing body of literature pointing to the importance of auditory cues on body perception in healthy individuals and various clinical populations [22], there is a lack of investigation about auditory-driven body perception in EDs [23]. Along this line, Tajadura-Jiménez et al. [24] found that people’s perceptions of their own body weight can change depending on the frequency spectra of their footsteps sounds (see work on the so-called ‘footsteps illusion’; Tajadura-Jiménez et al. [24]). Among the main findings, participants reported their bodies as being thinner when hearing the higher frequencies of their footsteps sound (vs. a low frequency condition) [24]. Critically, in the ED field, to the best of our knowledge, only two studies have investigated the multisensory integration of auditory signals with other sensory signals. In the first study, Chirico et al. [23] used the ‘sound-induced flash illusion’, in which a single flash is presented together with several auditory beeps, to show that temporal discrimination processing of visuo-auditory stimuli was impaired in patients with AN, as compared to healthy controls. In the second study, considering the above-mentioned literature indicating a stronger influence of external sensory signals on processing bodily information, Tajadura-Jiménez et al. [25] hypothesised that participants with high-ED symptomatology and participants with AN would experience an enhanced ‘footstep illusion’ compared with those with low-ED symptomatology and control participants. This is in line with the previous hypothesis suggesting an overreliance of exteroception in people with EDs [16–18]. Contrary to expectations, they found that the AN group and the high-EDs risk group reported their body as wider/heavier in the ‘High-Frequency’ condition compared to the ‘Control-condition’. Tajadura-Jiménez et al. [25] suggested that these abnormalities in multisensory integration of proprioceptive and auditory signals may explain the difficulties in updating bodily information in light of novel and sometimes surprising sensory signals, which might potentially contribute to the development of BID in EDs. However, it still remains unclear whether these impairments are specific to natural auditory signals related to body weight, which is an emotionally-salient aspect in people with EDs, or whether they correspond to a general impairment related to the monitoring and integration of any auditory signals in relation to one’s own body [25].

Given the lack of research, the primary aim of this study is to elucidate the link between body perception and non-naturalistic auditory information in participants with subclinical ED symptomatology, as compared to participants without ED symptomatology, using two BIs. To this end, as the primary objective, we will expose participants to artificial non-naturalistic sounds which do not contain information on body size but have been found to elicit changes in the perceived size of a finger in healthy populations in the so-called ‘auditory Pinocchio’ illusion [26]. In the study first reporting this illusion, it was found that when healthy participants pulled the tip of their right index finger with their left hand and an ascending pitch sound was presented concurrently, the participants both felt and judged their finger to be longer than when the pull was combined with a descending pitch or a constant pitch sound [26]. This illusion builds on the well-known association between changes in pitch and changes in height or size (for a review see [27]). This illusion focuses on a body part (finger) that is not emotionally salient, reducing
therefore ‘contamination’ by cognitive processes [28]. Nevertheless, given the clinical relevance of studying emotionally salient body parts as they play an essential role in BID [4], and in order to extend the aforementioned research [25], we will adapt the ‘auditory Pinocchio’ illusion to a body part that is particularly salient from the emotional point of view for the majority of EDs, namely the waist. We expect that the illusion also occurs for the waist (horizontal position) as for the finger (vertical position) since besides the correspondence with height, pitch is also associated to physical size (at least in the visual domain): static high and low pitches are respectively associated to smaller and larger visual size [29], and ascending and descending pitches are respectively associated to growing and shrinking size [30].

Based on the recent evidence suggesting deficits in multisensory integration mechanisms in this population [23, 25], we hypothesize that participants with subclinical ED symptomatology compared to people without ED symptomatology will present unusual patterns of results, that is, the perceived finger elongation or shrinking waist will not necessarily occur in the ascending pitch condition (or not only in that condition). The results will shed light on whether these impairments are linked to auditory signals related to body weight/size (e.g., footsteps) or are linked to any auditory signals [25]. Nonetheless, an alternative hypothesis is that participants with subclinical ED symptomatology will experience the illusion for the finger (not emotionally salient stimuli), replicating previous research (see [26]) but not for the waist (emotionally salient). In that case, the experience of the illusion will not be linked to the nature of the auditory signals (natural sound vs. artificial sound), but to the emotional salience of the body part (finger vs. waist). A third alternative hypothesis could be that people with ED symptomatology will show a stronger experience in both BIs, especially for the body part that is more emotionally salient (waist), than control individuals [28]. These potential results will provide further support for the traditional hypothesis for a stronger influence of external sensory signals, leading to stronger BIs in people with EDs [16–18].

Our approach holds the potential to provide experimental evidence supporting the development of novel therapies, which can target specifically the aforementioned distortions in the perception of sensory body signals, and ultimately BID (e.g., Riva et al. [31]).

We expect the results to offer a better understanding of the mechanisms underlying BID but also to provide an additional way to potentially identify people at risk of developing EDs. As Mussap and Salton [15] noted, one explanation for individual differences in response to cognitive-behavior therapies may reflect differences in pre-existing levels of body-image flexibility (i.e., ability to openly perceive thoughts or sensations concerning the body without acting on or changing them) [15]. This line of reasoning is in accordance with a recent meta-analysis (N = 62) which indicated that higher body-image flexibility is associated with lower levels of body-image problems and ED symptomatology [32]. Thus, body-image flexibility may arise as a key psychological construct that may be enhanced during psychological interventions [32]. In that case, both BIs (affecting finger and waist mental representations) could be useful as a proxy indicator for identifying participants who will be most responsive to CBTs, as those with heightened body-image flexibility. However, given the lack of research, there is a need to test whether increases in body-image flexibility predict reductions in ED symptomatology and BID [32]. To target these potential effects, as a secondary objective, we hypothesized that the susceptibility to both BIs will predict ED symptomatology and other key psychological constructs such as interoceptive body awareness (i.e.,
the ability to identify, access, understand, and respond appropriately to the patterns of internal signals) [15–16] and sensory-processing sensitivity (i.e., the tendency to process stimuli and information more strongly and deeper than others [33]).

Material And Methods

The ethics committees of the University of Loyola and of Junta de Andalucía have approved the present study, which will be performed in accordance with the ethical standards in the 1964 Declaration of Helsinki and its later amendments. All participants will provide informed consent to take part in the study.

Participants

The experiment will be conducted individually in a quiet laboratory room [see Additional file 1, section A]. A young adult female sample will be chosen due to the higher prevalence of EDs in this population [34]. Thus, the sample will comprise young adult women in the 18–24 age range. Participants will be recruited through public advertisements and social media posts (convenience sampling) and they will be paid or compensated with grade points for their time. To split the sample into participants with and without ED symptomatology, the Spanish Eating Disorder Examination Questionnaire (S-EDE-Q) [35]) will be administered since it is considered the “gold standard” for assessment of ED pathology [36] (see Table 1 for more details). The pre-screening will allow to form two groups of similar size: once the desired participant sample size has been reached for one of the groups, only participants falling into the other group defined for the study will be invited to take part. The S-EDE-Q have demonstrated good psychometric properties in young female adults in Spain [35]. A global EDE-Q score ≥ 2.8 has been shown to provide an optimal trade-off between sensitivity and specificity when it is used for screening in primary care [45].
Table 1
Overview of study measures and data collection timepoints.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Description</th>
<th>Baseline</th>
<th>Experiment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demographic data</td>
<td>Participants’ age. In addition, BMI will be calculated with the following formula: BMI = weight (kg)/ (height (m)^2) following the World Health Organization’s criterion [46].</td>
<td></td>
<td>X</td>
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<tr>
<td>Information consent</td>
<td>Written informed consent.</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>S-EDE-Q†</td>
<td>To assess body EDs psychopathology. Self-administered questionnaire composed of 28 items using 7-point Likert scales ranging from 0 (not at all) to 6 points (markedly). Four subscales are measured, including dietary restraint, shape concerns, weight concerns, and eating concerns. The score ranges from 0 and 6 points. Participants will be grouped according to this global index score. As in Mond et al. [37], we will use a cut-off point ≥ 2.8 as clinically significant.</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>HSPS‡</td>
<td>To assess the tendency to process stimuli and information more strongly and deeply than others (sensory-processing sensitivity). Self-administered questionnaire composed of 27 items using 7-point Likert scales ranging from 0 (not at all) to 6 points (markedly). Six subscales are measured, including sensitivity to overstimulation, aesthetic sensitivity, low sensory threshold, fine psychological discrimination, harm avoidance. Higher scores indicate higher sensitivity level.</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>MAIA§</td>
<td>To measure interoceptive body awareness. Self-administered questionnaire composed of 32 items using 6-point Likert scales ranging from 0 (never) to 5 points (always). Six subscales are measured, including noticing, not-distracting, not-worrying, attention regulation, emotional awareness, self-regulation, body listening and trusting. The scores range from 0 to 160 points. Higher scores indicate higher interoceptive awareness.</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Auditory trials</td>
<td>Presented in four conditions: an anchor task (20 trials); a practice task (3 trials); an experimental block (30 trials) and a questionnaire block (3 trials).</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Estimation of body position (finger/waist)</td>
<td>To assess estimation of location or position of fingertip/knuckle (allowing to calculate the estimated finger length can be calculated) and waist width after each auditory experimental trial.</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Measure</td>
<td>Description</td>
<td>Baseline</td>
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<tr>
<td>Confidence task</td>
<td>It has been found that the reliability of perception might be linked to subjective rather than objective accuracy [40]. Previous studies using BIs report that confidence was not accompanied by increases in objective accuracy (i.e., [41, 42]). Therefore, to assess the reliability of their estimations, after each auditory experimental trial, the feeling of confidence with the estimation of body part position will be explicitly assessed by asking the participants: “From one to seven, how confident are you of your estimation?” (7-point Likert scale)</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Body feelings questionnaire (finger/waist) [26]</td>
<td>To assess subjective feelings about their finger/waist after the trials (susceptibility to the illusion). Participants will respond to a questionnaire containing 7-point Likert-type response items ranging from 1 (strongly disagree) to 7 (strongly agree) (Finger: 14 items; Waist: 13 items). In addition, a range of figures representing finger/waist will be presented. Each figure shows a whole hand/trunk selectively shrunk or elongated. Participants will be asked to choose one of the figures to describe the subjective feeling of the size of their finger/waist when listening to the sound. [see S2 Additional file and S3 Additional file for more details]</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Body visualizer task [43]</td>
<td>To assess the ability to accurately estimate body size (body size discrepancy) as well as the effects of sound feedback on perceived body size. Participants will adjust the weight related dimension of the body of a 3D avatar displayed on the screen to correspond to their perceived body size. Accuracy will be calculated according to the formula (estimated/actual body size) x 100 also-called body perception index (BPI)[44]. Specifically, a negative value represents an underestimation, whereas a positive value represents an overestimation.</td>
<td>X</td>
<td>X</td>
</tr>
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</table>

**Abbreviations.** † Spanish Version of the Eating Disorder Examination Questionnaire[35]; ‡ Spanish version of the Highly Sensitive Person Scale[38]; § The Multidimensional Assessment of Interoceptive Awareness [39].

**Note.** Body weight will be measured to the nearest 0.1 kg/% by means of a calibrated digital body fat scale (Sinocare CW 286). The Body feelings questionnaire will be directly built into Google Form and completed on a 10.1” Android tablet (Lenovo M10).

[INSERT Table 1 AROUND HERE]
current use of psychotropic drugs (e.g. antidepressants) or intake of recreational synthetic or natural drugs; e) inability to understand Spanish; f) inability to provide consent; g) out of age range; h) pregnant status.

Inclusion criteria will be: a) normal (or corrected) auditory acuity; b) sex: women; ; Exclusion criteria: a) lifetime history or presence of any significant brain injury, neurological condition, auditory pathology; b) lifetime history or presence of a mental illness. In addition, to assure that participants with EDs do not participate in the study, only women with BMI in the healthy range (between 18.5-24.9) according to the World Health Organization (WHO) [46] will be included; c) lifetime history of underweight or overweight; d) current use of psychotropic drugs (e.g. antidepressants) or intake of recreational synthetic or natural drugs; e) inability to understand Spanish; f) inability to provide consent; g) out of age range; h) pregnant status.

**Stimuli and apparatus**

Auditory stimuli for both Experiment 1 (finger) and 2 (waits) will be generated through Audacity software and presented via closed headphones (Sennheiser HDA300) with high passive ambient noise attenuation (>30 dBA). The auditory stimuli will consist of pure tones (2000 ms duration, 44.1-kHz sample rate) of increasing ('ascending' tone: 700 to 1200 Hz), decreasing ('descending' tone: 700 to 200 Hz) or constant ('constant' tone: 700 Hz) frequency, as in Tajadura-Jiménez et al. [26] and Nava and Tajadura-Jiménez [47]. An additional auditory stimulus, presented in the anchor task at the beginning of the experiment, will consist of a pure tone of constant frequency ('anchoring' tone: 250 ms duration, 700 Hz). A 10 ms onset/offset ramp will be added to the auditory stimuli to prevent clipping. Prior to completing both experiments, participants will adjust the volume on the headphones to a comfortable level. Figure 1 and Figure 2 show a schematic diagram and a detailed description of each experimental setup. Both experiments will be run on a HP 15S-fq4027ns Intel Core i5 laptop.  Body visualizer task will be completed on a 1920x1080 pixel resolution computer screen (AOC e2270swn led 21.5") (see the S1 section A). For Experiment 1, we will use a vernier calliper (DEXTER; Range: 150mm; Graduation: .001”/.02 mm) (see the S1 section B). For Experiment 2, we will use a paediatric stadiometer  (ADE MZ10028-1; Range: 100 cm; Graduation: 1 mm) (see the S1 section B).

**General experimental procedure**

Table 1 shows an overview of study measures and data collection time points and Figure 1 shows a schematic representation of the experimental procedure. After reading the information sheet and signing the information consent, participants will complete the S-EDE-Q. Participants eligible to take part will be invited to the lab at Loyola Andalucia University. The experimental procedures will be implemented, and all data will be collected, by a postgraduate Ph.D. researcher trained by senior members of the research team. After reading the information sheet and signing the information consent, demographic data (age and BMI) will be collected. Later, participants will complete the Multidimensional Assessment of
Interoceptive Awareness Scale (MAIA) and the Highly Sensitive Person Scale (HSPS). The same participants will complete both Experiments 1 and 2.

**Figure 1.** Schematic depiction of experimental procedure and timeline of events for participants with subclinical eating disorders symptomatology and healthy controls. R = Randomized order.

Prior to the experiments, participants will be asked to remove any jewellery from their hands and verbal and written instructions about the tasks will be given to them. Before each experiment, anthropometric data (in centimetres, thereafter ‘cm’) will be collected (finger length and waist width). Next, participants will be accommodated in the experimental setup and equipped with the pressure sensor (fixed with rubber bands) and the headphones. First, participants will be asked to complete the “anchor” task, which consists of pressing and pulling their right index fingertip with their left hand (in Experiment 1) or pressing and pulling out their waist with their index fingertips (in Experiment 2) twenty times, an action that triggers the ‘anchoring’ tone on each occasion (as in [26]). Note that during this task, participants will not be exposed to the ‘ascending’ or ‘descending’ tones. The “anchor” task uses a standard tone to facilitate participants pair the motor action and the production of a sound [26]. Having completed the “anchor” task, participants will be asked to complete a practice task, one trial for each feedback condition. Later, participants will be asked to complete the experimental block.

The procedure and materials of each of the experimental blocks is described in next sections and in Figures 1 and 2. In brief, in the experimental block each experimental tone (‘ascending’, ‘descending’, ‘constant’), will be presented ten times. The order in which the tones are presented will be counterbalanced across participants following a within-subject design. After the experimental block is completed, participants will be asked to repeat the task of pulling their right finger (Experiment 1) or waist sides (Experiment 2) while listening to a tone for three more trials, one trial for each feedback condition, with the presentation order randomized across participants. Participants will be asked to complete a body feelings questionnaire after each feedback condition (questionnaire block) [see S2 Additional file and S3 Additional file for more details]. Additionally, for Experiment 2, a baseline and post-experiment body size discrepancy measure will be collected. The full experimental procedure will take approximately 120 minutes with a 5-minute rest interval between both experiments. After completing the study, a debriefing session will be carried out.

**Experiment 1 procedure: Finger**

First, the length of the index finger of the participant’s right hand will be measured by the experimenter using a vernier calliper from the proximal crease at the base of the finger to the tip of the finger. Next, participants will be required to complete an "anchor" task. In this task, participants will be asked to press and pull out their right index fingertip with their left hand twenty times, an action that will trigger the ‘anchoring’ tone on each occasion. After completing the anchor task, participants will complete a practice task, one trial for each feedback condition.
In each practice trial, participants are required to stare straight at the red fixation point and complete the simple action of pressing and pulling their right index fingertip with their left hand while keeping the right index finger in a fixed position (straight against the plastic panel and metal bar, see Figure 2). One of the three experimental tones ('ascending,' 'descending,' or 'constant') is triggered by the pressing/pulling action. Participants are instructed to continue pressing and pulling their fingers until the sound is no longer audible and, once the sound stops, to relax their left hand while continuing to grasp their right finger with the left hand. They will be then asked to estimate the position of their right fingertip and knuckle by having the experimenter adjust the two visible points on the ruler clips. This adjustment will be done as follows: First, the experimenter will move the top clip downwards at a continuous speed until the participant indicates that the visual point on the clip has reached the fingertip position with a "Stop" signal. Following a similar procedure, the experimenter will move the bottom clip upwards at a continuous speed until the participant indicates that the visual point on the clip has reached the knuckle position with a "Stop" signal.

Additionally, for each estimation (fingertip and knuckle), the feeling of confidence with the estimations made will be assessed.

The experimenter will use the measurements on the back of the ruler to record the fingertip and knuckle positions, rounding to the nearest 0.5 cm. After each trial, the clips are relocated. After completing the practice task, the experimental block will begin. Participants will repeat the task for thirty trials. Each experimental tone will be presented ten times. The order of trials will be randomized across participants. Participants will be given the opportunity to rest after each 10 trials.

After the experimental block, participants will be asked to repeat the task for three more trials (one for each sound condition, their order randomized across participants), in order to collect self-report measures (questionnaire block). After each trial, participants will complete a questionnaire that assesses their subjective experience during the task [see S2 Additional file].

**Experiment 2 Procedure: Waist**

First, to assess the degree of baseline body size discrepancy participants will complete the Body Visualizer task. The initial 'weight' of the avatar will be set to match the participant's ±25%. Participants will be instructed to adjust the avatar's body's 'weight' dimension. Whether the initial weight was +25% or -25% will be counterbalanced over two repeats, one after the other, and which together allows calculating the degree of body size discrepancy for each condition, by averaging the two responses. Later, the experimenter will measure the width of the participant's waist using a paediatric stadiometer. Specifically, the location of the waist will be “the minimum horizontal circumference around the body at waist height” in line with the ‘Standard Terminology Relating to Body Dimensions for Apparel Sizing’ [48].

Subsequently, participants will be first required to complete an "anchor" task. In this task, participants will be asked to press and pull out their waist twenty times, an action that will trigger the 'anchoring' tone on
each occasion. After completing the anchor task, a practice task will be presented, one trial for each feedback condition.

In each practice trial, participants are required to look straight at the red fixation point in the middle of the table and complete the simple action of pressing and pulling their waist with both hands while keeping them fixed to their waist (see Figure 3). One of the three experimental tones ('ascending,' 'descending,' or 'constant') is triggered by the pressing and pulling action. Participants are instructed to continue pressing and pulling their hands until the sound is no longer audible and, once the sound stops, to relax both hands (while keeping touching their waist). They will then be asked to determine the width of their waist by having the experimenter adjust the two visible points on the ruler clips. As a paradigmatic example, this adjustment will be done as follows: as in Keizer et al. [19], first, the experimenter will move both clips closer together at a continuous speed until the participant indicates that the clips have reached the perceived waist width position with a "Stop" signal. Similarly, the starting point of the aperture width (A) will be set at A = 2.0 x W (W = waist width in cm). This will be repeated while the clips are closed, and while the experimenter pressed and pulled them apart. The initial position of the clips will be counterbalanced across the trials. For both conditions we will collect waist width estimation measurements. Similarly, for each condition, the feeling of confidence with the estimation will be assessed and an average score will be obtained.

As in the finger experiment, the experimenter will use the measurements on the back of the ruler to record the position of the clips, rounding to the nearest 0.5 cm. After completing the practice task, the experimental block will begin. They will repeat the task for thirty trials. Each experimental tone will be presented ten times. The order of the trials will be randomized among participants. Participants will have an opportunity to rest after each 10 trials.

After the experimental block, participants will be asked to repeat the task for three more trials (one for each sound condition, their order randomized across participants) in order to collect self-report measures (questionnaire block). After each trial, participants will complete a questionnaire that assesses their subjective experience during the task [see the S3 Additional file]. In addition, to assess the degree of post-experiment body size discrepancy, participants will complete the Body Visualizer task. They will repeat the task for three trials, one trial for each feedback condition. The order of the trials will be randomized among participants.

**Data analysis plan**

IBM SPSS Statistics version 28.0 will be used for data inspection, descriptive and inferential statistics. All the analysis will be done by one of the investigators and it will be cross-checked by a second investigator. For transparency purposes, data derived from this study will be available in our OSF project.

**Data inspection**
To ensure methodological rigour, prior to running the main analyses, data will be screened for normality through Shapiro-Wilk tests, QQ plots, histograms and values of skewness and kurtosis. Besides, we will examine the generated dataset to ascertain any patterns of missing data, outliers and aberrant response patterns (e.g., deviate from the typical responses).

**Data management**

*Estimation of body position/size and confidence task*

For both experiments, data from the 10 repetitions for each condition will be averaged. As a rule of thumb, for participants with one trial per condition excluded, data for that trial will be replaced by the mean value of the other nine trials for that condition (as in [26]). Conversely, participants with more than one trial per condition excluded, will be excluded from all analyses. Overall, data from trials exceeding three standard deviations from the mean group value will be excluded.

For Experiment 1, we will collect measures for estimated knuckle position and fingertip position, as well as level of confidence with each estimation. In addition, for each trial, the estimated knuckle position will be subtracted from the estimated fingertip position in order to calculate the estimated finger length (as in [26]). For Experiment 2, we will collect waist width estimations, as well as level of confidence with each estimation. For each trial, we will estimate the perceived waist width by averaging the two responses given by the participant (i.e., for the opening and closing aperture).

For each participant a total of 12 summary scores will be calculated \[(\text{knuckle position} + \text{fingertip position} + \text{finger length} + \text{waist width limits}) \times (3 \text{ feedback conditions: 'ascendent', 'constant', 'descendent'})\]. Similarly, a total of 12 summary scores for the confidence task will be calculated \[(\text{confidence knuckle position} + \text{confidence fingertip position} + \text{confidence finger length} + \text{confidence perceived waist width limits}) \times (3 \text{ feedback conditions: 'ascendent', 'constant', 'descendent'})\].

Data from Presentation® software (Version 18.0, Neurobehavioral Systems, Inc., Berkeley, CA, [www.neurobs.com](http://www.neurobs.com)) will be recorded into a file in UTF-8 format. The file will be organized and imported into Microsoft Excel 2021 and subsequently into IBM SPSS Statistics version 28.0. Data generated associated with the anchor tasks and practice tasks will be disregarded.

*Body feelings questionnaire*

Per participant, a total of six questionnaires will be filled \[(\text{Experiment 1} + \text{Experiment 2}) \times (3 \text{ feedback conditions: 'ascendent', 'constant', 'descendent'})\]. Due to automation of the Google form, filled data will be recorded into the Google drive as sheets in ‘comma separated value’ (csv) format. All subject-related data will be stored in an anonymous manner by using research identification numbers/codes that uniquely identify each user and will furthermore be password-protected to ensure the privacy of the participants. The sheets will be organized and imported into Microsoft Excel 2021 and subsequently into the statistical software IBM SPSS Statistics version 28.0. By default, we don’t expect missing values.
Body visualizer task

The degree of body size discrepancy will be hand-coded by the experimenter into a data sheet. Per participant, a total of four summary estimations will be calculated \([(\text{baseline body size discrepancy}) + (\text{post-experiment body size discrepancy} \times 3 \text{ feedback conditions: 'ascendent', 'constant', 'descendent'})]\) according to the BPI index (see Table 1 for more details).

Descriptive statistics

For the final sample, data will be expressed and pulled as means and standard deviations for parametric data whereas median and interquartile range will be used for non-parametric data. Additionally, skewness, and kurtosis for the continuous variables and frequency counts and percentages for the categorical variables will be reported. Cronbach’s \(\alpha\) for each questionnaire will be reported for each questionnaire.

Sample size calculation

Given the well-known challenges in pre-screening and recruiting people with subclinical ED symptomatology in the healthy population, a compromise power analysis was performed to determine the minimum number of participants that would generate reliable findings. Compromise power analysis represents a novel concept in statistics, which can be determined using the G*Power software package [49-51]. It is applicable in uncontrollable situations (e.g., working with samples affected by diseases and/or attrition), or when N is too small to satisfy conventional levels of alpha (\(\alpha\)) and beta (\(\beta\)) (1-power) [49-51]. As both were the case in our situation, we used this method to determine the number of participants we would need for our study, as well as for the study’s statistical power. Following Lakens [50] recommendations, besides justifying sample restrictions, a compromise power analysis should also report a justification of the expected effect size and the desired ratio of Type I and Type II errors (\(q=\beta/\alpha\)).

Regarding the effect size, based on previous literature on the topic (i.e., [15,52], we expected moderate and large effect sizes for the power analysis described below. On the other hand, it is commonly assumed that the error ratio \(q\) is equal to four; considering most studies are designed to have 80% power (\(\beta\) equal to 0.20) and \(\alpha < 0.05\) [53-56]. However, in compromise power analysis is preferably to set \(q = 1\), balancing an equal Type I and Type II error risks \(\beta/\alpha\) since both are considered equally serious[49-51]. As Faul et al. [49] noted, the benefit of balanced Type I and Type II error risks often offsets the costs of violating significance level conventions.

Based on the above, a sample size of 40 participants was estimated as acceptable. For that purpose, four power analysis were carried out. The first analysis was based on statistical tests for t-test (two independent groups; two-tailed). The power was evaluated as a function of an expected large effect size (\(d = 0.80\)), sample size (\(N = 20\) per group), and an error–probability ratio (\(\beta/\alpha\)) of 1. The outcome yielded an 80% chance of finding a statistically significant difference (thus \(\alpha < 0.1\)). The second analysis was based on statistical F test (ANOVA: Repeated measures, within-between interaction) (number of groups = 2; number of measurements = 3). The power was evaluated as a function of an expected large effect size
(η2 = 0.14), sample size (N = 20 per group), and an error–probability ratio (β/α) of 1. The outcome yielded an 99% chance of finding a statistically significant difference (thus α < 0.05). The third analysis was based on a correlational bivariate model (N = 40; r = 0.50; per group; q = 1). The outcome yielded an 93% chance of finding a statistically significant difference (thus α < 0.06). The fourth analysis was based on multiple linear regression (number of predictors: 3) (sample size = 40; f2 = 0.30; q = 1). The outcome yielded an 89% chance of finding a statistically significant difference (thus α < 0.1). All our analysis will have, at least, an 80% of finding a statistically significant difference which is considered a convention for general use in the psychology field [53-56]  

Statistical analyses

**Primary aim: altered body perception and auditory feedback**

**Baseline measures**

To determine differences between the groups, analyses will be performed with a Student's t-test paired comparison (for normal distribution) or Wilcoxon tests (for non-normal distribution) for ED symptomatology (Eating Disorder Examination Questionnaire, EDE-Q), interoceptive body awareness (Multidimensional Assessment of Interoceptive Awareness, MAIA), sensory-processing sensitivity (Highly Sensitive Person Scale, HSPS) and body size discrepancy (Body visualizer tool).

**Experiment 1 and Experiment 2**

For the estimations of body part position/size, confidence task and items from the body feelings questionnaires we will follow a 2 x 3 ANOVA within-between interaction repeated-measures design (see Table 2). Specifically, we will use non-parametric ANOVAs on aligned rank (ART) data, suitable for ordinal data, using the R package ARTool [57]. The ANOVAs will involve a group factor with 2 levels (subclinical EDs and controls) and a feedback condition factor with 3 levels ('ascendent', 'constant', 'descendent'). Prior the analysis, assumptions of independence, normality and sphericity will be checked. As in Tajadura-Jiménez et al. [25], we will include the degree of body size discrepancy as covariate in case of significant baseline differences. Appropriate post-hoc tests will be conducted in case of significant differences.

For body size discrepancy, we will follow a 2 x 3 ANOVA within-between interaction repeated-measures design (see Table 3). The ANOVAs will involve a group factor with 2 levels (subclinical EDs and controls), a time factor with two levels (baseline and post-experiment) and a feedback condition factor with 3 levels ('ascendent', 'constant', 'descendent').
Table 2. ANOVA 2 x 3 design.

<table>
<thead>
<tr>
<th>Feedback Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Group</strong></td>
</tr>
<tr>
<td>Subclinical EDs</td>
</tr>
<tr>
<td>Controls</td>
</tr>
</tbody>
</table>

The degree of body size discrepancy as covariate will be included in case of significant baseline differences. Similarly, assumptions of independence, normality and sphericity will be checked and post-hoc tests will be conducted if appropriate.

Table 3. ANOVA 2 x 2 x 3 design.

<table>
<thead>
<tr>
<th>Baseline</th>
<th>Experiment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Feedback condition</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Group</strong></td>
<td>Ascendent</td>
</tr>
<tr>
<td>Subclinical EDs</td>
<td>Subclinical EDs Post-experiment Ascendent</td>
</tr>
<tr>
<td>Controls</td>
<td>Controls</td>
</tr>
<tr>
<td>Baseline</td>
<td>Post-experiment Ascendent</td>
</tr>
</tbody>
</table>

**Secondary aim: testing predictors**

Only outcomes showing significant bivariate correlations with the predictor will be included in the final multivariate logistic regression model and these selected variables will be forced into the model using enter method. For these bivariate correlations, we will use Spearman’s Rho for non-parametric data and Pearson’s r product-moment correlation coefficient for parametric data. Prior to the analysis we will check for multicollinearity, homoscedasticity, normality of the residuals as well as independence/variance of the residuals and any bias influencing the model. If these assumptions do not hold, then non-linear regression analysis will be used.

For each experiment, we will conduct multiple linear regression analysis on the entire sample to explore the predictive role of body-image flexibility (estimation of body position/size measures as inputs) on different outcomes such as ED symptomatology (Eating Disorder Examination Questionnaire, EDE-Q), interoceptive body awareness (Multidimensional Assessment of Interoceptive Awareness, MAIA) and sensory-processing sensitivity (Highly Sensitive Person Scale, HSPS).
Conclusions

Accumulated evidence points towards the need for a better understanding of what aspect of perceptual processing of bodily information, including multisensory integration, is altered in EDs [20, 21]. Addressing this issue holds the potential to lay the ground for novel therapeutic interventions targeting the perceptual component of BID, which has been identified as a core feature of ED symptomatology [5]. To target this outstanding question, the present research project will provide critical knowledge about the link between body perception and non-naturalistic auditory information in individuals with ED symptomatology using two BIs with different levels of emotional saliency for people with EDs. The potential significance and impact of this study are noteworthy since it is still unclear whether the abnormalities in integrating auditory signals are specific to natural auditory signals related to body size or whether they extend to a general impairment related to any auditory signals. Furthermore, given that EDs treatments and body image-directed interventions still yield modest therapeutic outcomes [58, 59], it is crucial to be able to identify possible predictors of individuals at high risk of developing EDs, who may potentially be targeted by specific preventive intervention such as body-image flexibility. An early identification of such individuals might be the best way to reduce the incidence of EDs, as we know that EDs have a very negative prognosis and high level of relapses. From a clinical perspective, this study might pave the wave for the development of novel therapeutic approaches for BID in EDs.

Abbreviations

AN
Anorexia Nervosa.
BMI
Body Mass Index.
BN
Bulimia Nervosa.
BID
Body Image Disturbance.
BIs
Body Illusions.
EDs
Eating Disorders.

Declarations

Ethics approval and consent to participate

This study has been approved by the Research Ethics Committee of the Autonomous Region of Andalucía (code: 2354-N-20) and Ethics Committee of the University of Loyola Andalucía. The data collection in this study follows the ethical standards laid down in the 1964 Declaration of Helsinki and its
later amendments. The ethics commission will be notified in case of any amendments to the study protocol. Prior to participation, written informed consent is obtained from all participants after a comprehensive explanation of the study procedures. The informed consent form can be requested from the corresponding author.

Consent for publication

Not applicable

Availability of data and materials

The datasets generated and/or analysed during the current study will be available in the Open Science Framework.

Competing interests

None to declare.

Study status

Pilot studies and recruitment/data collection began in June 2022.

Funding

This work was supported by the Spanish Agencia Estatal de Investigación project grant “MAGIC outFIT” I+D+i /PID2019-105579RB-I00, funded by the Spanish Agencia Estatal de Investigación (MCIN/AEI/10.13039/501100011033/), and by the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement No 101002711). SNL was supported by the FPU program from the Spanish Ministerio de Educación, Cultura y Deporte (FPU20/00089). The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript. The authors have no conflict to declare.

Authors' contributions

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication. Conceptualization: SN, LM, MS, AT; Methodology: SN, LM, MS, AT; Writing–Original Draft Preparation: SN; Writing, Review and Editing: SN, LM, MS, LC, NB, MB, AT; Supervision: AT; Funding Acquisition: AT, MS. AT is the chief investigator on this study. LM, MS, LC, NB and MB are co-investigators. This study will contribute towards SN’s Doctor of Philosophy thesis. All authors read and approved the final manuscript.

Acknowledgements

None to declare.
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Figures

Figure 1

Schematic depiction of experimental procedure and timeline of events for participants with subclinical eating disorders symptomatology and healthy controls. R = Randomized order.
Figure 2

Experiment 1 experimental setup, extracted from Tajadura-Jiménez et al. [26]. a) A vertical plastic panel (39x15 cm) will be attached on the bottom and right side to a vertical metal bar (2 x 2 x 50 cm). Participants will sit in front of the panel, with their right hand pressed and pulled out against it and their fingertip pointing upwards. A black cloak will be tied to the participant's neck; the other side of the cloak will be attached to the top of the panel to block the participant from seeing her own hand. b) To detect the participant's finger pulling action and trigger the auditory stimulation, a force-sensitive resistor (FSR; 4 mm-diameter active sensing area) will be attached to the right index fingertip. The FSR will be connected to a computer via an Arduino microcontroller. Presentation® software (Version 18.0, Neurobehavioral Systems, Inc., Berkeley, CA, www.neurobs.com) will be employed for stimulus delivery and response recording. c) A slide bar will be used to collect participants' estimates of their fingertip and knuckle position. This apparatus consists of a ruler fixed on the right side of the metal bar, parallel to it. The ruler will be blacked out on the side facing the participant. Two horizontal clips will be mounted on the ruler, each of them with a red dot which will serve as visual points that the participant uses to mark their felt fingertip and knuckle positions. The two horizontal clips on the ruler will be initially positioned at the heights of 10 cm and 50 cm. A red fixation point will be fixed on the top centre of the plastic panel (over the cloak). Permission to reproduce the figure from: CC BY 4.0
Figure 3

Experiment 2 experimental setup. **a)** The participants will sit in front of a table, with both hands pressed and pulled out against their waist. A black cloak will be tied around the participant's neck; the other side of the cloak will be attached to the bottom of the table to prevent the participant seeing their body. **b)** Similarly to Experiment 1, to detect the task of pressing and pulling out the participant's waist and activate the auditory stimulation, a force-sensitive resistor will be placed on one finger. The FSR will interface to a computer through an Arduino microcontroller. Likewise, Presentation® software version 18.0 will be used for stimulus delivery and response recording. **c)** A horizontal ruler will be used to collect the participants' estimates of their waist width. The ruler will be located on the table. The ruler will be dark on the side facing the participant. Two horizontal metal clips will be mounted on the ruler, each with a red dot that will serve as visual points that the participant will use to mark their waist position. A red fixation point will be placed on the middle of the table.

**Supplementary Files**

This is a list of supplementary files associated with this preprint. Click to download.

- 2.Additionalfile1.docx
- 2.Additionalfile2.docx
- 2.Additionalfile3.docx