# Title: **Distorted body image influences body schema in individuals with negative bodily attitudes**

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## Abstract

There is now a considerable body of evidence to suggest that internal representations of the body can be meaningfully separated into at least two general levels; body image as a perceptual construct and body schema as a motor metric. However, recent studies with eating disordered individuals have suggested that there may in fact be more interaction between these two representations than first thought. We aimed to investigate how body image might act to influence body schema within a typical, healthy population. 100 healthy adult women were asked to judge the smallest gap between a pair of sliding doors that they could just pass through. We then determined whether these estimates were sufficient to predict the size of the smallest gap that they could actually pass through, or whether perceptual and attitudinal body image information was required in order to make these predictions. It was found that perceptual body image did indeed mediate performance on the egocentric (but not allocentric) motor imagery affordance task, but only for those individuals with raised body image concerns and low self-esteem; body schema was influenced by both the perceptual and attitudinal components of body image in those with more negative bodily attitudes. Furthermore, disparities between perceived versus actual size were associated with body parts that had larger variations in adipose/muscle-dependent circumference. We therefore suggest that it may be the affective salience of a distorted body representation that mediates the degree to which it is incorporated into the current body state.

***Keywords:*** perceptual body image; attitudinal body image; body schema; egocentric; allocentric

## 1. Introduction

Body image (BI) can be thought of as a multidimensional construct that embraces a person's conscious perception of their physical self, including the thoughts and feelings that result from that perception. One's BI is developed and maintained via complex interactions between socio-cultural, neurophysiological, and cognitive factors: it is central to our self-concept and influences our psychology and behaviour (Stice, 2002). Disturbed body image can lead to dramatic attempts by the individual to alter their appearance, for example through self-starvation in eating disorders such as anorexia nervosa (Stice, 2002) and excessive gym attendance and steroid use to increase muscle mass in those who experience muscle dysmorphia (DSM-5, 2013; Pope, Phillips & Olivardia, 2000).

### 1.1 Measuring body image

In an influential meta-analysis, Cash and Deagle (1997) consolidated the idea that body image comprises two independent modalities: i) a perceptual component that has to do with the accuracy with which a person can judge the dimensions of their own physical appearance, and ii) an attitudinal component which captures the feelings that a person has about their body size and shape. (More recent reviews exist, e.g., Skrzypek, Wehmeier & Remschmidt (2001), but arrive at essentially the same conclusion).

Measuring the attitudinal component of body image has been relatively straight-forward. Typically, psychometric tools are used to assess such attributes as body dis/satisfaction and attitudes to body shape and weight (Fairburn & Beglin, 1994; Evans & Dolan, 1993). However, measuring the perceptual component of body image has proved more challenging. A wide variety of methods have been tried, starting from image marking procedures (Askevold, 1975) and moveable calliper techniques (Slade & Russell, 1973), through body-distorting mirrors (Traub & Orbach, 1964) to distorting photograph and video techniques (Gardner & Moncrieff, 1988; Probst, Vandereycken & Van Coppenolle, 1995;

Shafran & Fairburn, 2002). Most recently CGI (computer generated imagery) technology has been used to create standard stimuli or even personalized 3D avatars that accurately reflect body mass index (BMI) dependent body shape change (Cornelissen et al., 2015; Mölbert et al., 2017).

With respect to eating disorders, while a small number of studies actually suggest that women with anorexia nervosa *under*-estimate their own body size (Meerman, 1983), or even show equivalent performance to healthy controls in size estimation tasks (Fernández, Probst, Meerman, & Vandereycken, 1994; Molbert, 2017), the majority of studies have found that patients with eating disorders overestimate their own visually perceived body size (see e.g. Gardner & Bokenkamp, 1996; Probst, Vandereycken, Van Coppenolle, & Pieters, 1995; Slade & Russell, 1973; Tovée, Benson, Emery, Mason, & Cohen-Tovée, 2003). This consensus that patients with eating disorders overestimate their body size has also found support in recent meta-analytic reviews (e.g., Gardner & Brown, 2014; Mölbert, Klein, Thaler et al., 2017).

This focus on visually perceived body size distortion, however, may be overly simplistic, as other distortions have been found across all forms of subjective bodily experience in eating disordered patients; from somato-tactile size distortions in the horizontal plane (Keizer, Smeets, Dijkermann et al., 2011; Keizer, Smeets, Dijkermann et al, 2012; Spitoni, Serino, Cotuqno et al., 2015), and disturbances of proprioception and kinesthetic processing (Eshkevari, Rieger, Longo et al., 2012; Guardia, Carey, Cottencin et al., 2013) through to altered interoceptive (Pollatos, Kurz, Albrecht et al., 2008) and extraroceptive sensitivity and awareness (Zucker, Merwin, Bulik et al., 2013), decreased multisensory integration (Case, Wilson & Ramachandran, 2012; Gaudio, Brooks & Riva, 2014; Keizer, Smeets, Postma et al., 2014) and deficits in sensorimotor/proprioceptive memory (Chieffi, Iavarone, La Marra, et al., 2015). Such findings challenge the notion that individuals with

EDs overestimate their body weight due to visual distortions alone, and suggest that other forms of body representation (such as body schema) should be similarly affected.

### 1.2 The body schema

The concept of a separate 'body schema' has been proposed to account for the apparent dissociation between perceptual (visual) body representations, and the configural metrics employed during movement (Dijkerman & de Haan, 2007; Gallagher, 2005; Paillard et al., 1983 & 1997; de Vignemont, 2010). The body schema, originally conceived by Head and Holmes (1911) as the postural schema, is a continuously updated spatial representation of the body, about which we are usually unaware. To quote Head and Holmes (1911):

> *"By means of perpetual alterations in position we are always building up a postural model of ourselves which constantly changes. Every new posture or movement is recorded on this plastic schema, and the activity of the cortex brings every fresh group of sensations evoked by altered posture into relation with it. Immediate postural recognition follows as soon as the relation is complete."* (p. 187)

In the contemporary view, the body schema is a central representation of the body's spatial properties, including the hierarchical arrangement of limb segments, the configuration of these segments in space, and the shape of the body surface (Haggard & Wolpert, 2005). Thus, the body schema tells us the position and configuration of the body as a volumetric object in space, which is critical to our ability to guide the movement of the body. However, while on-line afferent signals provide information relating specifically to body posture and limb configuration, there is no online sensory input that relates directly to the current lengths and widths of specific body-parts, which suggests the existence of a stored representation of the body's metric properties, from which the current body state must be inferred (Berlucchi & Aglioti, 2009; Longo, Azañón & Haggard, 2010; Longo, 2016).

One helpful way to visualize the components of such a complex representation is by analogy with the kinds of 3D models used when developing animated movies or computer games. Such models require three major components: i) a skeleton, or “rig”, which comprises a jointed set of bones where the animator specifies bone lengths, which would be an offline representation, ii) a polygonal “mesh” or 3D surface which captures the air/skin boundary and represents the shape of the flesh on the bones, which would also be offline, and iii) would be a dynamic online “pivot” representation of the joint angles and rotational position of limbs in relation to each other (See Figure 1a).

### 1.3 Distorted body schema and body image in anorexia

In light of research demonstrating the disturbed experience of body size in eating disorders, researchers have naturally asked whether the observed disturbances in body image representation in anorexia nervosa could also extend to the body schema. For example, Keizer et al. (2013) measured the perceived passability of a gap between two wooden partitions, which looked like a doorway (cf. Warren and Whang, 1987). They identified the largest aperture, *A*, at which participants just started to rotate their shoulders in order to walk through the gap, and computed the critical ratio, *A/S*, between *A* and participants’ shoulder width, *S*. Keizer et al. (2013) found this critical ratio to be larger for eating disordered patients, consistent with their false belief that their body size was also larger than reality. Guardia et al (2010) found a similar inflationary effect when eating disordered participants were asked to make perceptual ‘anticipatory’ motor judgements about the passability of a door-like aperture when viewed from a first person (egocentric reference frame) perspective, and furthermore; the magnitude of this increased passability ratio was positively correlated with the extent of the patient’s body and eating concerns. These results were replicated in a further study (Guardia et al., 2012) but importantly, when participants with EDs were asked to make the same motor imagery judgement from the point of view of the investigator nearby (i.e. a third person point of view; allocentric frame of reference), the passability ratio showed no inflationary effects. These authors suggested that overestimation of the size of a passable gap in women with anorexia may have been caused by overestimation within their own personal body schema. Intriguingly, Keizer et al. (2013) also had participants estimate their own shoulder widths, $S_{est}$, as a component of their body image. Not only was this estimate elevated in anorexic participants, compared to controls, but when the researchers substituted $S_{est}$ for $S$ in the critical $A/S$ ratio, they could no longer find a difference in $A/S_{est}$ between the anorexic and control participants. This finding suggests an alternative explanation: it may be the *stored* body size information that is disturbed in anorexia, and this distorted metric information is used in turn by action-related body schema representations, leading to their inflated aperture estimates. Interestingly, this idea has previously been put forward by Riva and Gaudio (2012) as a part of the “Allocentric Lock Hypothesis”, which posits that individuals with anorexia nervosa (AN) are no longer able to update perceptual, egocentric, information about their own body, and must therefore rely upon a stored and distorted ‘allocentric’ representation. While support for the idea of a specifically ‘allocentric lock’ has been equivocal, there is ample evidence to suggest that individuals with EDs are not able to optimally integrate incoming visual and proprioceptive/tactile/kinaesthetic information to update a current ‘online’ body percept (e.g., Keizer, Smeets, Dijkerman et al., 2011; Zucker, Merwin, Bulik et al., 2013) and may therefore be relying upon a stored and distorted body representation. Indeed, support for this idea also comes from functional imaging studies of participants with AN that have demonstrated increased connectivity in cortical somatosensory areas implicated in long-term spatial memory and the spatial representation of body size, and a corresponding decrease in connectivity in areas sub-serving visual memory functions and visual perception of the body (e.g. Favaro, Santonastaso, Manar et al., 2012).

### 1.4 Interactions between attitudinal and perceptual body image representations and the body schema?

Cornelissen et al. (2015) investigated perceptual body image in women with a history of anorexia and healthy controls. They asked participants to visually estimate their body size using CGI stimuli in a yes-no task together with the method of constant stimuli. Figure 1a illustrates their key findings. Control participants with a low BMI over-estimated their size and those with a high BMI under-estimated, a pattern which is consistent with a normal perceptual phenomenon called contraction bias (Poulton, 1989). In contrast, the women with a history of anorexia nervosa who had a low BMI were both extremely accurate at estimating visually presented body size and very sensitive to small changes in BMI. However, as BMI rose in this group, their body-size over-estimation rose dramatically in direct proportion to their increasing BMI. Critically, as is illustrated in Figure 1a, visual body size estimation in both groups also depended simultaneously on attitudinal factors indexed by performance on psychometric tasks measuring attitudes towards body shape, body size and eating habits. Neurologically, support for such interactivity between perceptual and attitudinal aspects of body image comes from a recent study by Preston & Ehrsson (2016) in which brain regions associated with affective body representation (such as the right anterior insular cortex and the anterior cingulate cortex) were demonstrated to be functionally connected to perceptual representation areas within the posterior parietal cortex, indicating that perceived body-size can directly influence attitudinal body image, even within healthy individuals.

It has previously been suggested by Smeets (1997), for example, that body size estimates may not be direct measurements of perceptual body image *per se*, but actually an indirect measure of bodily attitude. Statistically, this is equivalent to the idea that perceptual measures are really proxies for attitudinal measures and tap the same pool of variance. However, if Smeets' (1997) position was correct, then we should expect that hierarchical regression models of data from studies such as that illustrated in Fig. 1b, should render perceptual or psychometric measures as redundant, depending on the order of entry into the model. But this is not what the data show.

Another line of argument used by Smeets (1997) to conclude that body size estimation tasks should not be considered as visual perceptual tests, is that investigators, at that time, had tended only to compare the point of subjective equality (PSE) between eating disordered participants and healthy controls. They did not report the just noticeable difference (JND) or difference limen (DL). In classical psychophysics, the PSE is known to be sensitive to bias, and therefore any group differences in PSE reported in such studies could be attributable to bias alone. However, more recent research has rectified this problem, demonstrating differences in both PSE and DL when comparing participants who have eating disorders with healthy controls (Cornelissen et al., 2015; Cornelissen et al., 2017).

Finally, if Smeets' (1997) assertion was entirely correct, it is hard to explain why meta-analyses (e.g. Cash & Deagle, 1997; Skrzypek, Wehmeier & Remschmidt, 2001) have consistently found evidence that supports separable domains of perceptual versus attitudinal body image. In short, we argue that a complete picture of body image (i.e. one that maximizes variance explained), requires information about *both* participants' perceptual judgements *as well as* attitudinal information about how they feel about their body: it is a multidimensional construct. Given this level of interdependence between perceptual and attitudinal aspects of body image when estimating body size, a wider question naturally arises: in what ways might these two factors also interact with the body schema?

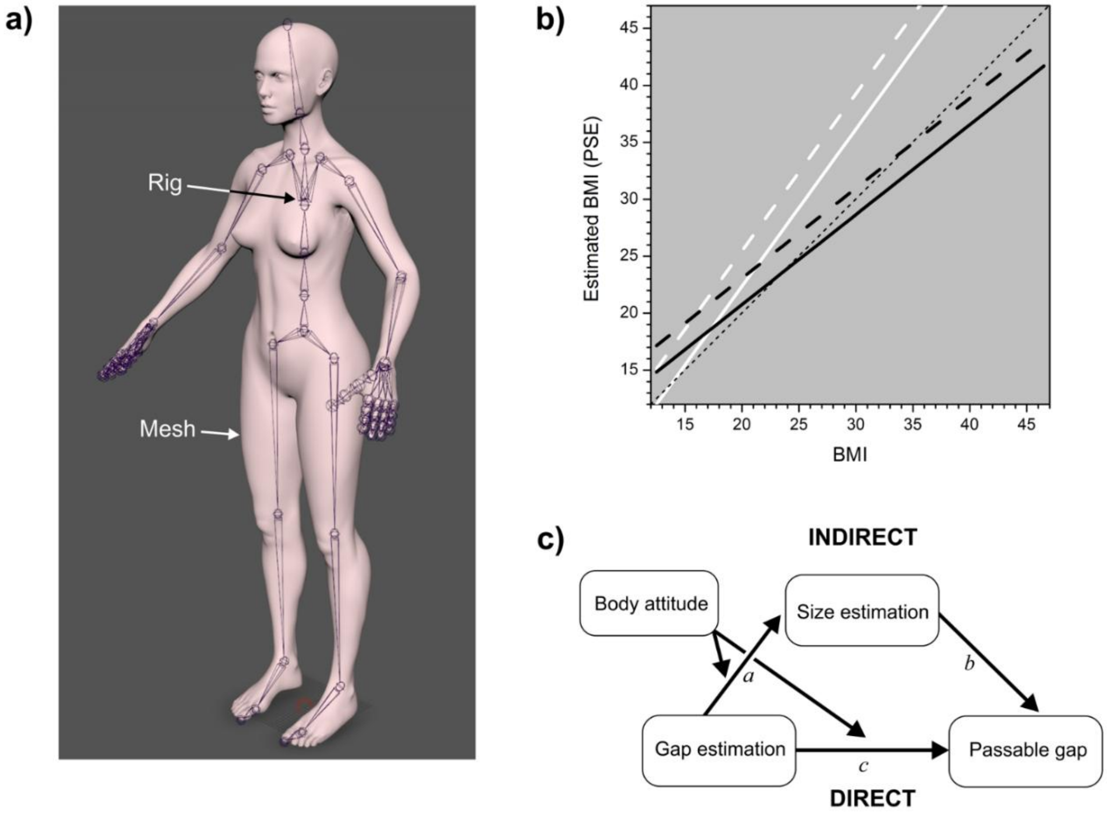

**Figure 1**

*(a) Illustrates the distinction between the body rig and body mesh as defined in animatable CGI models. (b) Shows the relationship between participants' BMI (x-axis) and their subjective estimate of body size (PSE) separately for women with a history of AN (white) and healthy controls (black). The impact of psychometric performance on these relationships is illustrated by the separate lines for each group: i.e. the data are plotted for PSYCH (a latent variable derived from a principal components analysis of questionnaires assessing attitudes to body shape, eating, depression and self-esteem) at + 1 SD, dashed lines, and – 1 SD, solid lines. (c) Conceptual form of a moderated mediation model. The direct path shows how performance in the gap estimation task predicts the size of a passable gap. The indirect path shows how this prediction may be partially or fully mediated by perceptual body image (i.e.*

*body size) judgements with the extent of the mediation being moderated by attitudinal aspects of body image.*

Unfortunately, neither Keizer et al. (2013) nor Guardia et al. (2012) analysed their data in a way that directly addresses this question either with respect to healthy controls or eating disordered individuals. Nevertheless, Guardia et al. (2010) did report positive correlations between attitudes to body shape and eating, and their equivalent to the critical $A/S$ ratio as well as between the critical $A/S$ ratio and body size estimation (BSE), computed across their whole sample of 25 anorexics and 25 controls. This suggests that there may be important patterns of interdependence between these three domains (i.e. perceptual and attitudinal body image and the body schema). In fact, a more recent study by Engel and Keizer (2017), which included measures of bodily attitudes and visual and tactile perceptual judgements, as well as motor affordances, found that individuals with current EDs did indeed have stronger negative body attitudes than healthy controls, or individuals who had completed ED treatment. Nevertheless, none of these authors carried out any further analyses that pitted critical $A/S$ ratio, BSE, affordance perception and body image attitudes against each other. Therefore, it is currently unknown under what circumstances these factors may or may not have influenced each other in these studies.

### 1.5 Current study

We argue that the eating disorders literature provides suggestive hints about how these three levels of representation may normally influence each other. Of particular interest is the observation of Keizer et al. (2013), described above, who substituted $S_{est}$ for $S$ in the critical $A/S$ ratio, and could no longer find a difference in $A/S_{est}$ between eating disordered and control participants. This strongly suggests that it might only be individuals with relatively high concerns about body shape/weight and eating who make use of their distorted perceptual body image during a motor imagery task: it seems that it may be the affective salience of the distorted *stored* body representation that mediates the degree to which it is incorporated into the current body state when making egocentric perceptual judgements. Accordingly, we decided to take advantage of individual differences in otherwise healthy women, who exhibit very wide variation across a spectrum of eating/body shape concerns (Luce, Crowther, & Pole, 2008; Mond et al., 2006), and use a correlational design with a sample size large enough to compute mediation/moderation analyses. In this way, we aimed to reveal the normal patterns of interdependence between the perceptual and attitudinal aspects of body image and the body schema in adult women.

Our strategy was to ask participants to make two kinds of egocentric judgements, both of which should be most sensitive to body size, shape and adiposity/muscle mass: i.e. the judgements should be heavily biased by the horizontal dimensions and girths of the body mesh in Fig. 1a, as compared to the largely vertical dimensions of the rig. For the first judgement, which indexes the body schema, participants carried out a task similar to that used by Guardia et al, (2010 & 2012) and Keizer et al., (2017); they were asked to estimate the smallest gap between a pair of moving sliding doors that they could just pass through without rotating their shoulders. This method was also previously used by Warren and Whang (1987) to determine whether or not such perceptual judgments differed between static and dynamic movement conditions. They measured large and small participants' critical *A/S* ratios to identify the phase transition from frontal walking to body rotation and compared these results with motor imagery or "passability" judgements made under both static and moving viewing conditions. Their conclusions were that: (i) critical *A/S* ratios were comparable between natural walking, and when participants made both static and moving passability judgements; (ii) at a bare minimum, passability can be accurately judged when participants are standing still and viewing the aperture to be judged with just one eye – i.e. they are merely imagining walking through the gap. The additional kinetic information available from real movement, together with binocular visual cues, are not necessary. Therefore, we would suggest that such a motor imagery task, in which participants are standing still, is appropriate for assessing egocentric body schema integrity (Guardia et al., 2010; Guardia et al., 2012; de Vignemont, 2010; Schwoebel & Coslett, 2005). In order to provide a 'baseline' of gap estimation ability, we also included a purely allocentric (non-body-related) control condition, in which participants were asked to make the same judgments for a yoga ball. Using a non-body-related object ensured that there were no possible interactions with attitudinal body image, or any confounds caused by bodily comparisons between participants' own bodies and a body-shaped exemplar.

For the second form of egocentric judgement, which indexes the visual perceptual (and possibly conceptual) aspect of body image, we asked participants to make both yes/no and method-of-adjustment decisions as to  whether a succession of CGI stimuli varying in BMI were either thinner or fatter than themselves. To index the attitudinal aspect of body image, we used a number of psychometric tasks that assess concerns about body shape and weight, eating habits, tendency towards feelings of depression and self-esteem.

Our first prediction was that we should be able to replicate the multidimensional nature of the body image representation as illustrated in Fig. 1b. Specifically, we predicted that psychophysical estimates of body size, indexing the body image, should best be predicted (i.e. maximum variance explained) by a linear combination of *both* participants' BMI and their psychometric performance.

Our second prediction was confirmatory and required us to obtain 3D body shape scan data from each participant. We predicted that participants' BMIs, their gap size estimates and the smallest aperture that they could actually pass through should all be highly correlated with each other and with latent variables from participants' 3D scan data that reflect horizontal/volumetric variability of the mesh (e.g. abdominal and limb girth and body volume) and not vertical variability of the rig (e.g., torso and limb segment length).

Our third and most important prediction, following the findings of Keizer et al. (2013), was that: i) aperture judgements in a motor imagery task should predict, statistically, the smallest gap that participants can actually pass through (i.e. the DIRECT path in Fig. 1c); ii) this prediction should be mediated at least in part by participants' perceptual body image; the size and shape they believe themselves to have (i.e. the INDIRECT path in Fig. 1c); iii) the extent of this mediation should be moderated by participant's attitudinal body image (i.e. Body attitude in Fig. 1c). Broadly speaking, therefore, we aimed to use information about three internal mental states\representations (assessed by the psychophysical and psychometric tasks), to predict an objective, external truth: the smallest gap between two doors into which a front facing participant could fit. To test these predictions required fitting a moderated mediation model. The goal of such models is to empirically quantify and test hypotheses about the contingent nature of the mechanisms by which X (predictor variable) exerts its influence on Y (outcome variable), and they are therefore directional (Hayes, 2015). Often with such analyses it is helpful to have an explicit temporal order for the events being modelled, for example from a longitudinal design, in order to match the directionality inherent in the model. Here, although the timeframe is tight, we suggest that this constraint of temporal order is (to some extent) met because participants need to predict when the sliding doors, which are constantly moving, will match the smallest gap they could walk through.

## 2 Method

The experimental procedures and methods for participant recruitment for this study were approved by the local ethics committee at *** *blinded* *** University.

### 2.1 Participants

To be eligible to take part in this study, participants had to be female (as assigned at birth), aged 18-35 and fluent in spoken English. Participants with a history of eating disorders were not excluded from the study, but this information was recorded (n=4). Accordingly, 100 women were recruited to an opportunistic sample of staff and students at *** *blinded* *** University and consented to take part in the study. Participant characteristics are reported in Table 1.

### 2.2 Measures

**Psychometric and anthropometric measures.** In order to assess the attitudinal component of participants' body image we administered a number of self-report questionnaires that measure body satisfaction, tendency towards depression, self-esteem, and attitudes towards body shape, weight and eating. The following questionnaires were used: (i) the Eating Disorders Examination Questionnaire (EDE-Q), which is a self-report version of the Eating Disorder Examination (EDE) interview (Fairburn & Beglin, 1994). The questionnaire contains four sub-scales; the Restraint subscale investigates the restrictive nature of eating, the Eating Concern subscale measures the preoccupation with food and social eating, the Shape Concern subscale measures dissatisfaction with body shape, and the Weight Concern subscale measures dissatisfaction with body weight. A global score of overall disordered eating behaviour is also calculated and frequency data on key behavioural features of eating disorders is provided. (ii) the 16-item Body Shape Questionnaire (BSQ) was used to measure body shape preoccupations (Evans & Dolan, 1993), (iii) the Beck Depression Inventory (BDI) was used to measure level of depression (Beck, Ward, Mendelson, Mock & Erbaugh, 1961), (iv) Rosenberg Self-Esteem (RSE) was used to measure their self-esteem (Rosenberg, 1965). Participants' Body Mass Index (BMI) was calculated from their weight and height measured with a set of calibrated scales and a stadiometer respectively. Lastly, the participant's body width was measured in the sagittal and coronal planes (with arms down and with arms across their chest).

Each participant had a 3D body scan. In a private booth, participants wore underwear only while their body shape was captured using a Size Stream Body Scanner (using scanner software v4.4). This device comprises a set of 14 infra-red depth sensors arranged around the body, each individually fixed to the rigid frame of the booth. Once in the scanner, participants adopted a standard pose while holding hand-rails to steady themselves. They were asked to exhale midway and not to move for ten seconds while the scan was completed. The circumferential inaccuracy of the system, using a test cylinder ~ 880mm tall, is less than +/- 5mm. The data generated by the scan, a large point cloud, were immediately stored off-line by the Size Stream Studio software, converted into a 30k polygon mesh from which a large number of biometric measurements are extracted automatically. From the set of outputs available, we selected 8 circumference and limb segment lengths (see Table 2), together with participants' height and total body volume for further analysis.

## 2.3 Psychophysical measurements

**2.3.1 Yes-no task:** In the yes-no task, participants were presented with a randomized sequence of images of a standard CGI female body model (for details of stimulus image generation, Cornelissen, 2016). Across the image set, BMI varied continuously from 12.5 to 44.5. On each trial of the task, one image was presented and participants were required to decide whether the body depicted was larger or smaller than they were. Stimuli were presented on a 19” flat panel LCD screen (1280w x 1024h pixel native resolution, 32-bit colour depth) for as long as it took participants to make a decision. At the standard viewing distance of ~60cm, the image frame containing the female body subtended ~26° vertically and ~8° degrees horizontally. Each participant first judged seven images covering the whole BMI range (from 12.5 to 44.5 in equal BMI steps) presented in two separate blocks. Each stimulus image appeared 10 times in each block, and the order of presentation was randomized. Based on the responses from each block, the participants’ point of subjective equality or PSE (the BMI they believe themselves to be) was calculated automatically by fitting a cumulative normal distribution. These two values were then averaged to give an initial estimate of the participant’s PSE. On the basis of this initial estimate, the program presented a further set of 21 images (spread over a range of 5 BMI units centred on the participant’s initial PSE, at a spacing of 0.25 units per image) for the participants to judge. Each image was presented ten times in randomized order. This final set of judgements allowed us to plot the full psychometric function (i.e. the proportion of ‘larger’ responses on the y-axis as a function of stimulus BMI on the x-axis) and use probit analysis off-line to calculate a definitive estimate of PSE as well as the difference limen or DL (that is how sensitive participants are to changes in BMI).

**2.3.2 Method of adjustment (MoA) task:** Participants used the method of adjustment to estimate their body size with the same stimulus set as for the yes-no task. Participants carried out 20 trials using the same display setup as for the yes-no task. On each of these 20 trials, the stimulus appeared on screen, and beneath the stimulus was a slider control (see Figure 2). The participant was asked to click on the slider control to move it from side to side. When the slider moved leftwards the BMI of the avatar reduced smoothly to a minimum of 12.5 and increased to a maximum of 44.5 when the slider moved rightward. The participant had to decide what body size of the stimulus best matched the body size they believed themselves to have, and then press a radio button, marked ‘Continue’, on screen that allowed the stimulus PC to log their response and initiate the next trial. At the start of each trial, the BMI of the avatar was set randomly to either its minimum, with the slider appearing at the leftmost extreme of its range of movement, or the maximum BMI, with the slider appearing at the rightmost extreme of its range of movement.

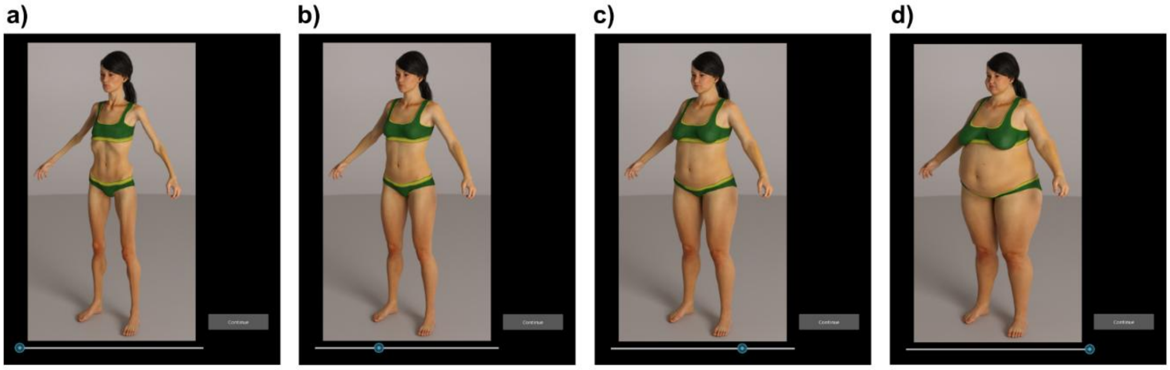

**Figure 2**.

*Body shape changes for the standard model stimulus as the slider control is moved from left to right through screenshots A, B, C & D.*

**2.3.3 The Aperture task:** In the current study, we used a motor imagery task in which participants were asked to judge the passability of a gap between two sliding wardrobe doors, each measuring 76.5cm x 222cm, viewed binocularly. The doors hung from castors whose wheels ran in tracks mounted on a wooden frame (298cm x 234cm). The doors could be opened and closed smoothly with a pulley system: the left door moved at the same speed as the right door, but in the opposite direction (net separation/closure speed was ~6.72cm/s). White fabric hung 95cm behind the aperture for a uniform background in order to minimize textural cues to aperture size. Participants stood at a fixed distance (2.2m) from the doors, facing them directly, and carried out two experimental conditions: (i) judging when the gap between the doors was just big enough for them to walk through, facing forward (“egocentric gap estimation”), (ii) judging when the gap between the doors was just big enough for a yoga ball (a control object measuring 58cm in diameter) to pass through without touching the doors (“allocentric ball estimation”). Each condition comprised 20 trials (i.e. 10 door opening trials and 10 door closing trials) and the order of conditions and trials within conditions was randomised. On each trial, the doors were either slowly opened or closed at the fixed rate by the pulley system. Participants were instructed to call out “stop” when they judged that the gap was just wide enough for them to walk through without turning their body or shoulders. A laser distance finder was used to measure the width of the gap between the two doors and this value recorded and the mean gap across 20 trials recorded as the passability judgement for that condition.

The minimum gap through which each individual could physically pass (smallest passable gap) was measured at the very end of the experimental session so as not to bias any other perceptual tasks; participants stood between the sliding doors, facing forward, with arms relaxed and hanging down at their sides. The doors were then closed and micro-adjusted until each door was just touching the skin corresponding to the smallest gap in the coronal plane that participants could just pass through.

### 2.4 Procedure

Participants began by completing the questionnaires, as described above, after which height, weight and body measurements were taken, and the 3D full body scan was obtained. This was then followed by the experimental tasks; the order in which the Aperture, MoA and yes-no tasks were completed was fully randomised.

### 2.5 Statistical analyses

#### 2.5.1 Body scan data.

We used the ‘Psych’ package (v 1.8.4) in R 3.5.1 to carry out a factor analysis with Varimax rotation and maximum likelihood estimation in order to identify significant latent variable(s) in 10 body scan measurements: 8 length and circumference measurements, height and total body volume. Next, we correlated these extracted components with participants’ actual BMI and smallest passable gap, expecting to observe sizable correlations with ‘mesh’ components but not with ‘rig’ components.

#### 2.5.2 Mediation models.

After presenting descriptive statistics, we present (moderated) mediation models to formally evaluate the model, illustrated in Fig. 1c, in R 3.5.1 (Michalak, 2016). The mediation analyses were conducted with the ‘psych’ package (v 1.8.4) with 10,000 bootstraps (Revelle, 2016). The moderated mediation analyses were run using Preacher and Hayes (2008) method in ‘lavaan’ v.0.6-3 (Rosseel, 2012) and also examined the index of moderated mediation (Hayes, 2015). Parameters in the moderated mediation model were estimated via Maximum Likelihood and inference was based on 10,000 bias-corrected bootstrap samples. The variables were centred prior to the moderated mediation analyses and we examine the parameter estimates at the means, as well as +/-1SD.

## 3. Results

### 3.1 Univariate statistics.

Table 1 below shows participants’ characteristics. Cronbach's alpha for the psychometric tasks RSE, BSQ, EDEQ and BDI were: 0.849, 0.944, 0.946 and 0.906 respectively.

Table 1. Descriptive statistics for age, actual BMI, questionnaire responses, psychophysical and aperture estimation tasks (n=100)

| | *M* | *SD* | Range | |
|---|---|---|---|---|
| | | | Actual | Potential |
| Participant characteristics | | | | |
| Age (years) | 22.35 | 4.65 | 18.00 – 35.00 | |
| BMI (weight/height$^2$) | 22.97 | 4.15 | 15.83 – 38.62 | |
| Depression and self-esteem | | | | |
| BDI | 12.19 | 8.91 | 0.00 – 47.00 | 0 – 63 |
| RSE | 18.19 | 4.30 | 8.00 – 28.00 | 0 – 40 |
| Eating and body shape concern | | | | |
| EDEQ Eating concern | 0.97 | 0.97 | 0.00 – 4.20 | 0 – 6 |
| EDEQ Restraint | 1.44 | 1.32 | 0.00 – 5.00 | 0 – 6 |
| EDEQ Shape concern | 2.59 | 1.54 | 0.00 – 6.00 | 0 – 6 |
| EDEQ Weight concern | 2.03 | 1.51 | 0.00 – 5.40 | 0 – 6 |
| EDEQ Global | 1.76 | 1.20 | 0.06 – 4.58 | 0 – 6 |
| BSQ | 44.97 | 17.20 | 19.00 – 87.00 | 16 – 96 |
| Psychophysical performance | | | | |
| Yes-No (BMI units) | 23.82 | 4.38 | 16.02 – 41.50 | |
| MoA (BMI units) | 24.38 | 5.14 | 17.03 – 41.86 | |
| Aperture task | | | | |
| Estimated gap size (cm) | 52.64 | 8.47 | 31.55 – 87.60 | |
| Estimated ball size (cm) | 69.12 | 8.68 | 34.80 – 96.10 | |
| Smallest passable gap (cm) | 45.78 | 3.49 | 39.20 – 59.80 | |
| Estimated – Smallest passable gap (cm) | 6.86 | 7.84 | -8.10 – 38.30 | |

Note: BDI = Beck Depression Inventory, RSE = Rosenberg Self-Esteem Scale, EDEQ = Eating Disorders Examination Questionnaire with subscales, BSQ = Body Shape Questionnaire

### 3.2 Body image data.

We used PROC REG in SAS v9.4 (SAS Institute, North Carolina, USA) to carry out ordinary least squares multiple regression of estimated BMI (from the yes-no and MoA tasks) on actual BMI and included as covariates the psychometric variables: BSQ, EDEQ, BDI and RSE. All variables were centred by converting them to z-scores, and separate analyses were run for the MoA and yes-no tasks. The models were optimized by running both forward and backward selection, retaining only explanatory variables that were significant at $p<.05$. The final model for MoA explained 67% of the variance in estimated BMI and showed statistically significant main effects for actual BMI ($\beta = 0.67$, $t = 10.1$, $p < .001$, 95%CI = 0.54 – 0.80) and BSQ ($\beta = 0.25$, $t = 3.8$, $p < .001$, 95%CI = 0.12 – 0.38), but no significant interaction. The final model for the yes-no task explained 56% of the variance in estimated BMI and showed statistically significant main effects for actual BMI ($\beta = 0.48$, $t = 6.3$, p < .001, 95%CI = 0.33 – 0.64) and BSQ ($\beta = 0.40$, $t = 5.2$, $p < .001$, 95%CI = 0.25 – 0.55), but no significant interaction. Both of these results replicate the findings of Cornelissen et al. (2015) who showed that body size was predicted by a linear combination of perceptual and attitudinal body image.

### 3.3 3D body scan data

The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy (which indicates the degree of diffusion in the pattern of correlations) was 0.81 suggesting an acceptable sample. Two factors had an Eigen value greater than Kaiser's criterion of one, and they explained 79% of the variance. The scree plot showed an inflexion, i.e. Cattel's criterion which also justified retaining two factors. Parallel analysis and the Velicer MAP test also suggested two factors as illustrated in Figure 3.

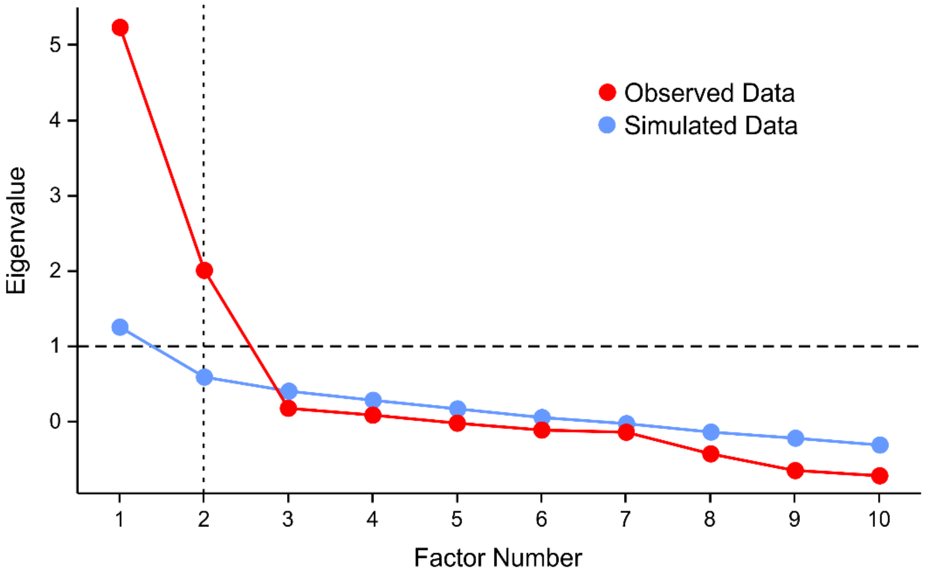

Figure 3: *Scree plot including parallel analysis. Factors 1-2 have larger eigenvalues based on the observed data than when based on simulated data.*

The overall root mean square off-diagonal residual was 0.04, indicating that the factor structure explained most of the correlations. The factor loadings are shown in Table 2, and we have blanked out values less than 0.4 for clarity. Factor 1 loaded primarily onto circumference measures, and is referred to as mesh. Factor 2 loaded primarily onto lengths, and is referred to as rig.

Table 2: Factor loadings from a factor analysis with rotation of the 3D body scan data (<.4 not shown)

| | Factor 1 (Mesh) | Factor 2 (Rig) |
|---|---|---|
| Chest bust circ | 0.91 | |
| Waist abdominal circ | 0.90 | |
| Hip circ | 0.90 | |
| R arm bicep circ | 0.86 | |
| R leg thigh circ | 0.87 | |
| Total volume | 0.97 | |
| R inseam leng | | 0.93 |
| R arm leng | | 0.75 |
| R leg leng | | 0.83 |
| Height | | 0.85 |

NB: Circ = circumference; Leng = Length; R = Right

Table 3 shows the correlation matrix between the two factors and participants' actual BMIs as well as the smallest gap they could pass through (Actual gap). It confirms that these two measures were both substantially and significantly correlated with the factor representing horizontal "mesh" circumferences, but not with the latent variable representing "rig" limb segment lengths. (Note the 95% confidence intervals for the correlations between BMI and Factors 1 and 2 as well as smallest passable gap (Actual gap) and Factors 1 and 2 did not overlap with one another). These finding are important, because they confirm that both perceptual body size and body schema judgements are related to body features that vary primarily on adipose and muscle mass and not the length of limb segments.

Table 3: Pearson correlations between participants' actual BMI, smallest passable gap and the two factors. Values in square brackets indicate the 95% confidence interval for each correlation.

| Variable | BMI | Actual gap | Factor 1 (Mesh) |
|---|---|---|---|
| Actual gap | .76** | | |
| | [.65, .84] | | |
| Factor 1 (Mesh) | .96** | .79** | |
| | [.93, .97] | [.70, .86] | |
| Factor 2 (Rig) | -.11 | .24* | .02 |
| | [-.32, .10] | [.03, .43] | [-.20, .23] |

* = *p*<.05; ** = *p*<.01; *** = *p*<.001

### 3.4 Mediation models.

The model in Fig. 1c was tested first for mediation alone with *both* the yes-no task and MoA as mediators. The total variance explained by this model was 53%. There was evidence of significant mediation (*ab* path: 0.27, 95%CI: 0.12 to 0.41), whereby the direct path, *c*, from gap estimation to smallest passable gap was substantially reduced from β=.38 to β=.11, after accounting for the mediators via the indirect path. Quantitatively, this means that a shift of 8.47cms (one SD) in gap estimation, predicts a shift of 1.33cm in smallest passable gap, of which 0.94 cm is attributable to the psychophysical tasks. To be sure that we were fitting an optimal model at this stage, we also compared a mediation model in which the positions of passable gap and gap estimation were swapped, so that path *c* in Fig. 1c now had passable gap pointing to gap estimation. This alternative model only explained 18% of the total variance and showed no evidence of mediation. This alternative model represents a substantially poorer fit to the data; it explained one third as much variance as the model in Fig. 1 c. Therefore, it was rejected as a viable alternative (see supplementary materials for more details).

Sequentially testing the yes-no task and MoA, rather than combining them into a single model showed that each acted a mediator, respectively: 95%CI's: 0.11 to 0.36 and 0.1 to 0.4. Substituting participants' gap estimation based on their own body for ball estimation, showed no significant mediation effect, respectively: 95%CI's: -0.16 to 0.16 and -0.14 to 0.24. This suggested that any mediation effects we observed were specific to body representations.

We next tested whether body image concern (i.e. the average of BSQ and EDEQ scores) moderated the relationship between gap estimation and smallest passable gap (i.e. the direct path). There was no evidence for such a moderation (B=-.002+/-.004, $t(96)= -.493$, $p=.623$ ). Next, we tested whether body image concern moderated the mediation effects (i.e. the indirect path) of the yes-no task and MoA. In both cases, we found no overall evidence for moderated mediation across the full range of body image concern (respectively: index of moderated mediation: 0.002+/-0.003, $Z=.586$, $p= .558$ and index of moderated mediation: 0.004+/-0.004, $Z= 1.03$, $p=.303$). However, in both cases, we did find that in the 1SD above group, i.e. those with high body image concern, there was evidence for an indirect effect via yes-no task/MoA respectively (yes-no task: $\beta= 0.088$+/-0.038, $Z=2.336$, $p= .019$, 95%CI: 0.014 to 0.164; MoA: $\beta=0.104$+/-0.05, $Z=2.098$, $p= .036$, 95%CI: 0.011 to 0.209). In contrast, in the remaining groups (means, 1SD below) there was no evidence for such indirect effect $p$'s >.12). This suggests that the mediation effect is driven by those with higher body image concern as opposed to lower body image concern, consistent with Keizer et al. (2013). See Fig. 4 (red circles for BI).

When examining depressive symptoms, we first tested whether depressive symptoms moderated the relationship between gap estimation and actual width (i.e. the direct path). There was no evidence for such a moderation (B=-.001+/-.005, *t*(96)= -.195, *p*=.846). Next, we tested moderated mediations (i.e. the indirect path) separately for the yes-no task and MoA, with depressive symptoms (BDI) as moderator. In both cases, we found no overall evidence for moderated mediation – i.e. depressive symptoms did not change the level of mediation (respectively: index of moderated mediation: 0.002+/-0.005, *Z*=.398, *p*= .690 and index of moderated mediation: -0.006+/-0.005, *Z*= -1.011, *p*=.312). However, with the yes-no task, the mediating paths were of roughly equal strength and statistically significant across the three levels of depressive symptoms (all *p*<.05, see Fig.4, green triangle for BDI) – i.e. this is equivalent to saying that strong mediation occurred irrespective of the level of depressive symptoms. With MoA, the mediating paths were statistically significant for those with low (-1SD) and average depressive symptoms (*p*<.01) but not for those scoring high on depressive symptoms (+1SD) (*p*=.209, see Fig.4, green triangles for BDI).

When examining self-esteem, we found that self-esteem moderated the relationship between gap estimation and actual width (B=-.027+/-.012, *t*(96)= -2.33, *p*=.022). A simple slope analysis showed a positive slope for those low in self-esteem (one SD below the mean, β=.237+/-.051, *p*<.0001), but not for those high in self-esteem (one SD above the mean, β=.003+/-.077, *p*=.97). Finally, we tested moderated mediations separately for the yes-no task and MoA, with self-esteem (RSE) as moderator. For both the yes-no task and MoA, we found evidence for moderated mediation, the index of moderated mediation was statistically significant. (Respectively: index of moderated mediation: -0.032+/-0.012, *Z*=-2.742, *p*= .006 and index of moderated mediation: -0.024+/-0.012, *Z*= -1.982, *p*=.047; see Fig.4, blue squares for RSE). The mediating paths were statistically significant for those with low (-1SD) and average scores of self-esteem (all *p*<.05), but not those with high self-esteem (+1SD) (all *p*>.4, Fig. 4). This suggests that the overall mediation pattern is driven by those with lower self-esteem as opposed to those with higher self-esteem. In conclusion, in our sample of typical -healthy women, we found evidence for the perceptual body image mediating performance in an imaginary action, but only for those participants with low self-esteem and raised body image concerns.

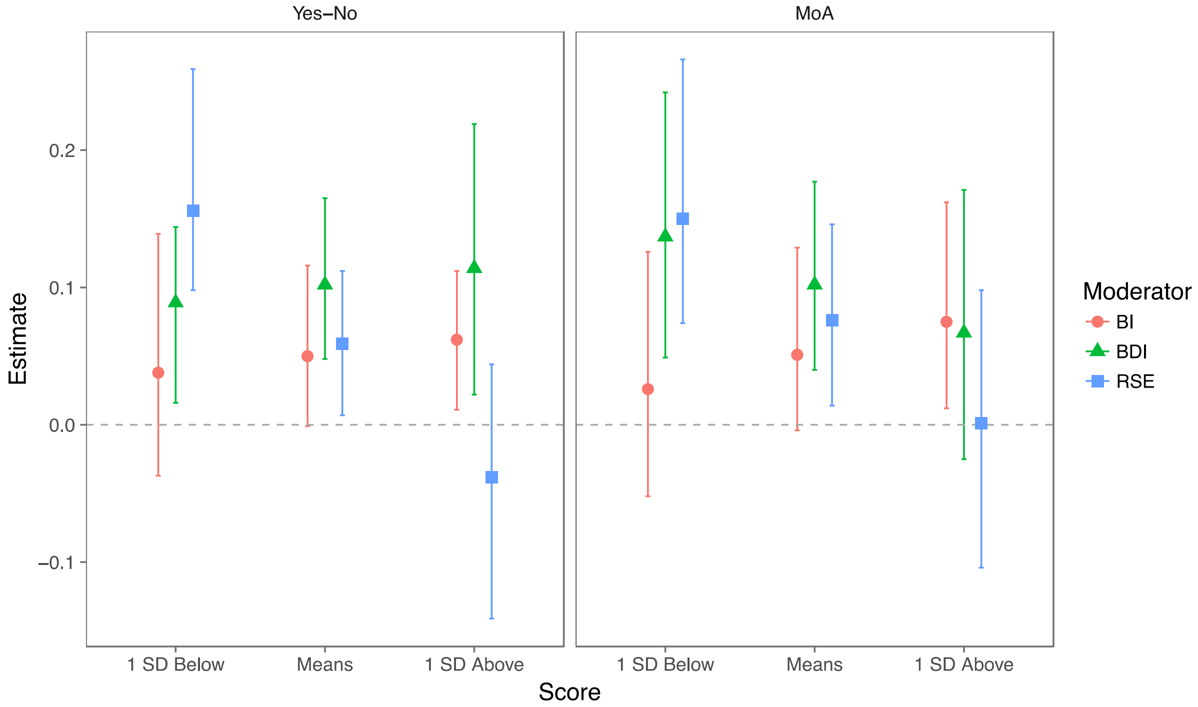

**Figure 4:** *Plots of the beta weights for the indirect pathway (a × b) in the moderated mediation models. The data are shown separately for models with the yes-no and MoA tasks as mediators and the three moderator variables BI (i.e. the mean of the BSQ and EDEQ) in red circles, BDI (green triangles) and RSE (blue squares) at +/- 1 SD and their respective means. The error bars represent 95% CI and are based on bias-corrected accelerated bootstrapping (10,000 bootstraps), hence their asymmetry.*

### 3.5 Accuracy versus strategy?

The moderated mediation analysis showed clear evidence of individual variation, and this is consistent with interdependence between representational levels being used differently by different individuals. However, this analysis cannot exclude the possibility that variation in the accuracy of body/gap size estimation may have contributed. If this were true, then we might expect to see correlations between accuracy in the aperture task and the MoA as a function of actual passable gap size. However, if individual variation is related primarily to how different individuals combine representational information to predict the size of the smallest gap they can pass through, then we should not expect to see such correlations.

To address this, we calculated percentage error in the MoA and aperture tasks for every trial: i.e. (MoA BMI – Actual BMI) / Actual BMI × 100 and (Estimated gap – Actual gap) / Actual gap × 100, respectively. Note, we did not include the yes-no task in this analysis because it is linked to a task dependent contraction bias effect (Cornelissen et al., 2017), which would mean that percentage error in this task and actual passable gap will always be correlated: we would never be able to detect a null relationship.

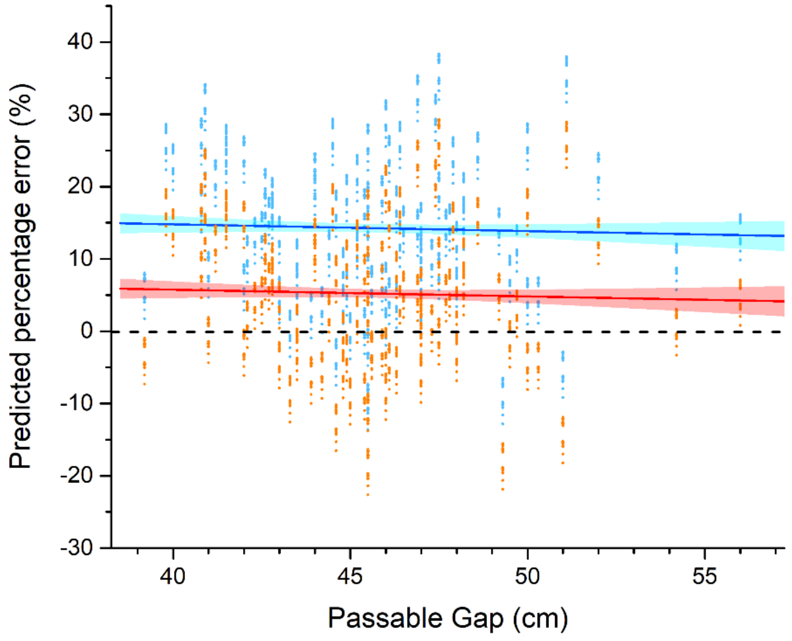

**Figure 5**

*Plots of the predicted percentage error in the aperture task (dark cyan dots with blue regression line) and MoA task (orange dots with red regression line) as a function of passable gap size. In each case the regression lines are accompanied by their 99% confidence bands.*

We used PROC MIXED in SAS v9.4 (SAS Institute, North Carolina, USA) to predict percentage error from: i) Task (i.e. MoA versus Aperture task) and ii) Actual passable gap size in a linear mixed effects model. We included both participants and individual trials as random effects for the intercepts in the model. We found a significant main effect of Task ($\beta = 9.04$, $F(1,3624) = 455.5$, $p<.001$, 95%CI = 8.21 – 9.87) but no effect of passable gap size ($\beta = -0.093$, $F(1,3624) = 0.09$, $p=.76$, 95%CI = -0.70 – 0.52), nor any interaction between the two. Fig. 5 shows very clearly that participants' errors in the two tasks were independent of smallest passable gap. The LSmeans for percentage error were 14.24% (95%CI = 11.92 – 16.56) for the Aperture task and 5.20% (95%CI = 2.89 – 7.52) for MoA. In short, participants systematically over-estimated both their body size in the MoA by about ~5% (consistent with Cornelissen et l., 2017) and the Aperture task by ~15%, as if they had all achieved close to the same criterion level for each task, yet neither pattern of over-estimation was related to smallest passable gap size. Therefore, these results suggest that the moderated mediation analysis should best be interpreted to reflect variation in the strategies that participants used to achieve criterion performance, rather than variation in accuracy *per se*. Specifically, individuals with high self-esteem and low body image concerns could predict smallest passable gap size directly – they needed no other information, to achieve a given level of performance. Conversely, individuals with low self-esteem and raised body image concerns appeared to use a combination of the direct estimate of gap size and a distorted estimate of current body metrics in order to achieve the same criterion.

## 4. Discussion

There is now a considerable body of clinical and experimental evidence to suggest that internal representations of the body can be separated into at least two general levels. First, the body image, which underlies perceptual and attitudinal judgments about the body and is a cognitive representation that integrates stored knowledge and experiences. Second, the body schema, a holistic representation which is used in the control of movement and is constructed primarily from proprioceptive input (e.g., Gallagher 1986; Paillard 1991, 1999). Here, inspired by observations from patients with eating disorders, we investigated how these two representational schemes may interact in a normal population, at least in one particular context, that of making motor imagery ‘affordance’ judgements. We asked healthy adult women to judge the smallest gap between a pair of sliding doors that they could just pass through. We then asked whether these estimates were sufficient to predict the size of the smallest gap that they could *actually* pass through, or whether additional information from their attitudinal and/or perceptual body image was required in order to make these predictions.

Our first study aim was met, in that we replicated Cornelissen et al. (2015) by showing that perceptual body image judgements, indexed by BMI, were predicted by a linear combination of participants’ actual BMI and their attitudes about their body shape and weight. In the context of the main research question, our analysis of the 3D body scan data also confirmed that judgements about body image and the passability of gaps are related only to those body shape components belonging to horizontal properties of the body “mesh” and not the vertical properties of the “rig”. This finding is important empirically, because it explicitly links body image (indexed by BMI), gap estimation and actual passable gap size to a common and specific subset of body shape measures: those which are highly associated with changes in adiposity and muscle mass (Wells, Treleaven & Cole, 2007; Wells, Cole, Bruner, & Treleaven, 2008). Finally, our moderated mediation analysis suggested that a complex pattern of interdependence between these representational domains exists, because perceptual body image information was required to predict smallest passable gap size – it had a mediating role – but only for those individuals who have elevated concerns about their body shape and/or those with reduced self-esteem. Moreover, these interactions are specific to self-referential (egocentric) judgements about the body, because no such inter-relationships could be found for equivalent allocentric judgements made for an inanimate object, i.e. a yoga ball. The implications of these findings are two-fold. First, these results suggest that it may only be individuals without higher psychological concerns about body shape/weight and normal levels of self-esteem who are able to update current body state information to guide movement of the body, as is usually conceived. For those who do have such concerns, it appears that the strength of the emotional salience or valence of the false beliefs about their over-sized body (or more specifically, body parts that are more susceptible to large and/or rapid changes in adiposity/muscle mass) which accompany these concerns serves to moderate the degree to which this distorted perceptual body image is weighted when determining the current body-state, or prevents sensory/proprioceptive/kinaesthetic information from updating the stored body representation used by the body schema for programming egocentric body movement. The second implication is that the apparently anomalous behaviour of women with anorexia nervosa reported by Keizer et al. (2013) is not qualitatively different from that seen in otherwise healthy women who happen to have higher self-reported body image concerns and low self-esteem.

### 4.1 Prior research: emotionally valent stimuli and body image *or* body schema

Previous research has demonstrated interactions between body image and affective states such as self-esteem (Hoffmeister et al., 2010) as well as with pain, which has both separable nociceptive and cognitive/emotional components (Woo, Roy, Buhle, & Wager, 2015). For example, having induced the rubber hand illusion, Ehrsson et al. (2007) showed that threats of pin pricks to a rubber hand could induce neural patterns of anxiety which were very similar to those measured for threats to a real hand. Moreover, the magnitude of these neural responses was correlated with the strength of participants' ownership of the hand. In patients with chronic hand pain, Lorimer, Parsons and Spence (2008) showed that visual distortion of the body image, modulated both the level of pain experienced, and the extent of tissue swelling evoked by movement. Impressively, these effects were bi-directional; optical magnification of the limb increased pain and swelling while minification reduced them. When Schwoebel et al. (2001) asked patients with chronic unilateral arm pain to decide on the laterality of images of hands presented at different orientations, reaction times in this imaginary mental rotation task, were systematically slower for the painful arm compared to the unaffected arm, consistent with pain having an influence on the body schema. Finally, the defensive peri-personal space, or 'safety margin' surrounding the body, which Moseley, Gallace & Spence (2012) suggest is maintained by the same 'body matrix' that integrates homeostatic, somatotopic and body-centred spatial information, has also been shown to be influenced by affective state; individuals reporting higher trait anxiety scores also demonstrate larger safety margins for the same stimuli (Sambo & Iannetti, 2013; de Vignemont & Iannetti, 2015).

In short, there have been previous reports of emotionally valent stimuli having an influence on, or being influenced by, either the body image or the body schema. However, outside of the clinical domain, to our knowledge, the current study is the first time that the interactions between body schema, perceptual body image and, critically, attitudinal body image have been observed and quantified.

### 4.2 Experimental manipulations separating the body schema from the body image

Beyond neurological and neuropsychological studies of patients, task dependent effects on bodily illusions have previously supported the notion that the body schema is functionally separable from the body image (Dijkermann & de Haan, 2007; Kammers, van der Ham, & Dijkerman, 2006). For example, during the rubber hand illusion (RHI; Botvinick & Cohen, 1998), participants are shown a rubber hand that has the same posture and orientation as their own visually occluded hand, but which is displaced medially or laterally with respect to their own hand. When the rubber hand and the participant’s hand are stroked synchronously, the participant experiences a multisensory conflict of seeing a touch that is felt at a different location. The conflict is resolved through a perceptual shift whereby the felt position of the participant’s own hand appears to migrate towards that of the rubber hand. This is thought to occur through a process of visual capture, whereby proprioceptive information encoded earlier in time is over-written by current visual and tactile information, and the rubber hand is incorporated into the participants’ own body image (Ehrsson, Spence & Passingham, 2004; Ehrsson, Holmes & Passingham, 2005). In contrast, if participants are also asked to make ballistic pointing movements to indicate the positions of the unseen stimulated and non-stimulated finger tips, their performance is very accurate (Kammers, de Vignemont, Verhagen & Dijkerman, 2009), and it was suggested that these movements, thought to be supported by the body schema, are refractory to the RHI, and therefore dissociable from responses dependent on the body image.

Clearly, it is possible to use short-term experimental manipulations of bodily illusions in healthy participants to provide results that mirror the findings from patients. However, in more recent research Kammers et al. (2010) have demonstrated that the body schema can also be influenced by the RHI if the amount of stimulation of the participants' hands and the rubber hand is manipulated, and hand postures are changed to facilitate grasping rather than pointing. Under these circumstances manipulating the grip aperture of the rubber hand leads not only to a perceptual illusion (body image distortion) but also altered grasping responses (body schema distortion). A similar result was also reported by Newport, Pearce & Preston (2010) using a digitally presented real-time version of the RHI to induce the illusion of supernumerary limbs. Participants were able to incorporate multiple representations of the same limb into the body image, and when an offset representation of the hand was seen to stroke a paintbrush synchronously with the unseen real hand, pointing errors revealed a remapped limb position in which the perceived real hand location was remapped towards the location of the offset limb; the illusion also affected body schema.

Such studies demonstrate that body image and body schema are not as 'dissociable' as initially thought, although these short-term intervention studies do not demonstrate how the two systems may normally be expected to interact with each other in the steady state, over the longer term, and this was the focus of the current study. Moreover, what may be revealed in the short-term as a result of experimental manipulation may not necessarily hold true for the long term. Indeed, an increasing number of studies and reviews have suggested that there are direct inter-relationships between differing representations of the body, and that there may in fact be a common long-term representation underlying both action *and* bodily experiences (e.g. Alsmith, 2009; Berlucchi et al., 2010; Bermudez, 2005; Moseley et al., 2012; de Vignemont, 2010). Pitron and de Vignemont (2017, p.116) discuss this singular 'fusion' model, and compare it to two alternatives. The first, the 'independent model', posits "… two distinct functionally defined representations of the enduring properties of the body, a long-term body schema for action and a long-term body image for perception, that work independently of each other". The second, the 'co-construction model', proposes " … two distinct functionally defined representations of the enduring properties of the body, a long-term body schema for action and a long-term body image for perception which can interact and reshape each other". Pitron and de Vignemont (2017) argue the case for a Bayesian version of the co-construction model, and we would argue in turn that such an interaction model is a good fit to our current findings, with the addition of a moderator role for attitudinal body image. Further, we would suggest that the putative mechanism responsible for the distortions observed in both the body image and body schema of individuals with EDs may be the inability to fully integrate current sensory input that is in conflict with a distorted long-term representation that holds higher emotional/affective salience.

### 4.3 Limitations

A central assumption of this study is that the gap estimation task indexes the body schema because it can be treated as a visuomotor imagery task: participants need to predict when the sliding doors, which are constantly moving, will match the gap they would have to walk through. In support of this assumption, there are several lines of evidence demonstrating that the same cognitive / neural representations are used for motor imagery and motor execution. For example, there is substantial overlap between the brain areas that are activated by both actual and imagined movement (Bakker et al., 2008; Hanakawa et al., 2003; Roth et al., 1996), even in patients with complete spinal cord injury (Alkhadi, Brugger, Boenderkamer et al., 2005). With a human-computer interface, motor imagery can be used to drive a computer cursor, for example, with neural signal strengths matching those of real motor execution (Miller et al., 2010). Furthermore, studies of patients with parietal cortex lesions (Sirigu et al. 1996) and healthy controls in virtual reality (Decety et al., 1995) have shown that the durations of imagined and actual movements are constrained in similar ways by the timing and accuracy requirements of the tasks that participants performed (Guardia, 2012). However, it should be noted motor imagery and motor execution cannot be considered entirely equivalent: conditional Granger causality and graph-theoretic analyses of fMRI data revealed greater causal connection for execution than imagery, suggesting wider network involvement for the former (Gao, Duan & Chen, 2011). Nevertheless, it appears that motor execution and motor imagery have sufficient kinematic properties and neural processes in common (Hesslow, 2012) for us to assume that the gap estimation task is a valid and appropriate way to assess body schema integrity (Guardia et al., 2012).

From an empirical point of view, if the aperture task *cannot* be treated as a motor imagery task, then the only realistic alternative would be to consider it as a third way for participants to estimate their body size as part of their perceptual body image. If this were true, then the gap estimations would be equivalent to the yes-no and method of adjustment tasks; they would all, in effect, be proxies for each other. If this was the case, then it should not matter for the mediation analysis whether gap estimates are the main predictor, and the yes-no / method of adjustment task the mediator, or vice versa, (i.e. the roles of mediator and predictor should be interchangeable). We therefore sought evidence of mediation for this ‘reversed’ mediation model which had either the yes-no task or method of adjustment as the main predictor for actual gap size and gap estimation as the mediator variable in these relationships. However, there was no statistical support for either case: i) yes-no task as predictor, gap estimation *ab* path: 0.04, 95%CI: -0.005 to 0.15, and ii) method of adjustment task as predictor, gap estimation *ab* path: 0.03, 95%CI: -0.002 to 0.10. Furthermore, if anticipatory gap estimation were merely another form of perceptual size estimation task, we would also expect to see size errors of a similar magnitude between the two tasks, but this is not the case. Errors on the motor imagery (gap estimation) task were three times the size of those seen in the PSE tasks, which is in keeping with previous literature examining the difference between depictive and metric methods of body-size estimation (e.g. Longo & Haggard, 2012; Mölbert, Klein, Thaler, et al., 2017). We believe that this lack of symmetry, and the fact that it is not possible to use the mediator and predictor variables interchangeably within the mediation model, taken together with the literature reviewed above, is consistent with the view that our aperture task can legitimately be treated as a motor imagery task to index the body schema.

Additionally, we asked participants to judge the passability of a yoga ball in the aperture task in order to independently assess participants' accuracy in the aperture task using a non-body-related stimulus for purely allocentric judgements that prevented comparisons with another bodily exemplar, and to provide a 'baseline' of gap estimation ability for the mediation models. Our prime concern was to exclude the possibility that individual variation in gap estimates might be attributable to some generic process making some people more accurate than others in all psychophysical tasks. To the extent that the yoga ball and gap estimation data were dissociated from each other, we can confidently exclude a generic error mechanism as a strong confound in the results. However, as we did not include a further allocentric, body-related, condition, then strictly speaking, inferences cannot be made as to whether our findings (or those of Guardia et al., 2010 and Keizer et al., 2013) relate specifically to participants' *own* bodies, or their perception of bodies more generally. Nevertheless, the results of Guardia et al. (2012), in which participants were asked to make passability judgements for both themselves and a third person, suggest that body overestimation affects judgments about the capacity for action only when they concern the individual's own body.

In conclusion, we demonstrate that information related to perceptual body image can also influence performance on a simulated motor task. Moreover, the degree to which distorted perceptual body image influences performance on egocentric (but not allocentric) motor imagery tasks, such as judging the smallest passable gap one can fit through, is contingent upon individual differences relating to body image concerns and reduced self-esteem. This has important implications for the treatment of EDs, and future work would benefit from experimentally manipulating these domains separately, perhaps in a virtual reality setting.

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## References

Alkadhi, H., Brugger, P., Boendermaker, S.H., Crelier, G., Curt, A., Hepp-Reymond, M-C. & Kollias, S.S. (2005). What disconnection tells about motor imagery: evidence from paraplegic patients. *Cerebral Cortex*, *15(1)*, 131-140. Doi: 10.1093/cercor/bhh116

Alsmith, A. J. (2009). Acting on (bodily) experience. *Psyche*, *15(1)*, 82–99. Doi: 10.1016/j.concog.2017.06.006

APA (2013). *Diagnostic and statistical manual of mental disorders: DSM-5*. Arlington, VA: American Psychiatric Association.

Askevold, F. (1975). Measuring body image: Preliminary report on a new method. *Psychotherapy and Psychosomatics, 26*, 71–77. Doi: 10.1159/000286913

Bakker, M., De Lange, F., Helmich, R., Scheeringa, R. & Bloem, B. (2008). Cerebral correlates of motor imagery of normal and precision gait. *NeuroImage*, 41, 998–1010. Doi: 10.1016/j.neuroimage.2008.03.020

Beck, A. T., Ward, C. H., Mendelson, M., Mock, J. & Erbaugh, J. (1961). An inventory for measuring depression. *Archives of General Psychiatry, 4,* 561-571. Doi: 10.1001/archpsyc.1961.01710120031004

Berlucchi, G. & Aglioti S.M. (2010). The body in the brain revisited. Experimental Brain Research, 200: 25. Doi: 10.1007/s00221-009-1970-7.

Bermudez, J. L. (2005). The phenomenology of bodily awareness. In: D. Woodruff Smith, A. Thomasson (Eds.), *Phenomenology and philosophy of mind*. Oxford: Clarendon Press, pp. 295–316.

Botvinick, M., Cohen, J. (1998). Rubber hands 'feel' touch that eyes see. *Nature*, 391(6669), 756. Doi: 10.1038/35784

Case, L.K., Wilson, R.C. & Ramachandran, V.S. (2012) Diminished size–weight illusion in anorexia nervosa: evidence for visuo-proprioceptive integration deficit. *Experimental Brain Research, 217(1):* 79–87. Doi: 10.1007/s00221-011-2974-7.

Cash, T. F. & Deagle, E. A. (1997). The nature and extent of body image disturbances in anorexia nervosa and bulimia nervosa: a meta analysis. *International Journal of Eating Disorders, 22*, 107-126. Doi: 10.1002/(SICI)1098-108X(199709)22:2<107::AID-EAT1>3.0.CO;2-J

Chieffi, S., Iavarone, A., La Marra, M., Messina, G., Villano, I., Ranucci, S., Messina, A., Piombino, L., Dalia, C. & Monda, M. (2015). Memory for proprioceptive targets in bulimia nervosa. *Journal of Psychiatry, 18*, 297. Doi: 10.4172/2378-5756.1000297.

Cornelissen, P. L., Johns, A., & Tovée, M. J. (2013). Body size over-estimation in women with anorexia nervosa is not qualitatively different from female controls. *Body Image, 10(1)*, 103-111. Doi: 10.1016/j.bodyim.2012.09.003

Cornelissen, K. K., Bester, A., Cairns, P., Tovée, M. J., & Cornelissen, P. L. (2015). The influence of personal BMI on body size estimations and sensitivity to body size change in anorexia spectrum disorders. *Body Image, 13*, 75-85. Doi: 10.1016/j.bodyim.2015.01.001

Cornelissen, K. (2016). *What does it mean to have distorted body image in anorexia nervosa?* Doctoral thesis, Newcastle upon Tyne, UK: Northumbria University.

Cornelissen, K.K., McCarty, K., Cornelissen, P.L. & Tovée, M.J. (2017) Body size estimation in women with anorexia nervosa and healthy controls using 3D avatars. Scientific Reports, 7(1), 15773. DOI: 10.1038/s41598-017-15339-z.

Decety, J. & Jeannerod, M. (1995). Mentally simulated movements in virtual reality: does Fitts's law hold in motor imagery? *Behavioural Brain Research*, *72*, 127–134. Doi: 10.1016/0166-4328(96)00141-6

Dijkerman, H. C. & de Haan, E. H. (2007). Somatosensory processes subserving perception and action. *The Behavioral and Brain Sciences*, *30*, 189–201. Doi: 10.1017/S0140525X07001641

Ehrsson, H.H., Spence, C. & Passingham, R.E. (2004). That's my hand! Activity in premotor cortex reflects feeling of ownership of a limb. *Science*, *305*, 875–877. Doi: 10.1126/science.1097011

Ehrsson, H.H., Holmes, N.P. & Passingham, R.E. (2005). Touching a rubber hand: Feeling of body ownership is associated with activity in multisensory brain areas. *Journal of Neuroscience*, *25*, 0564–10573. Doi: 10.1523/JNEUROSCI.0800-05.2005

Ehrsson, H.H., Wiech, K., Weiskopf, N., Dolan, R.J. & Passingham, R.E. (2007). Threatening a rubber hand that you feel is yours elicits a cortical anxiety response. *Proceedings of the National Academy of Sciences*, *104(23)*, 9828–9833. Doi: 10.1073/pnas.0610011104

Engel, M.J. & Keizer A. (2017). Body representation disturbances in visual perception and affordance perception persist in eating disorder patients after completing treatment. *Scientific Reports, 23;7(1),* 16184. Doi: 10.1038/s41598-017-16362-w.

Eshkevari, E., Rieger, E., Longo, M.R., Haggard, P. & Treasure, J. (2012) Increased plasticity of the bodily self in eating disorders. *Psychological Medicine, 42(4):* 819–828. doi:10.1017/S0033291711002091.

Evans, C., & Dolan, B. (1993). Body Shape Questionnaire: derivation of shortened "alternate forms". *International Journal of Eating Disordoers, 13*, 315-321. Doi:10.1002/1098-108X(199304)13:3<315::AID-EAT2260130310>3.0.CO;2-3

Fairburn, C. G. & Beglin, S. J. (1994). Assessment of eating disorders: interview or self-report questionnaire? *Eating Disorders, 16(4),* 363-370. Doi: 10.1002/1098-108X(199412)16:4<363::AID-EAT2260160405>3.0.CO;2-#

Fairburn, C.G., Cooper, Z., & Shafran, R. (2003). Cognitive behaviour therapy for eating disorders: A "transdiagnostic" theory and treatment. *Behaviour Research and Therapy, 41*, 509-528. Doi: 10.1016/S0005-7967(02)00088-8

Farrell, C., Lee, M., & Shafran, R. (2005). Assessment of body size estimation: a review. *European Eating Disorders Review, 13*, 75-88. Doi: 10.1002/erv.622/

Favaro, A., Santonastaso, P., Manara, R., Bosello, R., Bommarito, G., Tenconi, E. & Di Salle, F. (2012). Disruption of visuospatial and somatosensory functional connectivity in anorexia nervosa. *Biological Psychiatry, 72(10)*, 864-70. Doi: 10.1016/j.biopsych.2012.04.025.

Fernández, F., Probst, M., Meermann, R., & Vandereycken, W. (1994). Body size estimation and body dissatisfaction in eating disorder patients and normal controls. *International*

*Journal of Eating Disorders, 16*, 307–310. Doi: 10.1002/1098-108X(199411)16:3<307::AID-EAT2260160313>3.0.CO;2-P

Gallagher, S. (1986). Body image and body schema. *Journal of Mind and Behaviour*, *7,* 541–554.

Gallagher, S. (2005). *How the body shapes the mind*. New York: Oxford University Press.

Gao, Q., Duan, X. & Chen, H. (2011). Evaluation of effective connectivity of motor areas during motor imagery and execution using conditional granger causality. *Neuroimage, 54*, 1280-1288. Doi: 10.1016/j.neuroimage.2010.08.071

Gaudio, S., Brooks, S.J. & Riva, G. (2014). Nonvisual multisensory impairment of body perception in anorexia nervosa: A systematic review of neuropsychological studies. *PLoS One, 9(10):* e110087. Doi: 10.1371/journal.pone.0110087.

Gardner, R.M., & Moncrieff, C. (1988). Body image distortion in anorexics as a non-sensory phenomenon: A signal detection approach. *Journal of Clinical Psychology*, *44,*101-107. Doi: 10.1002/1097-4679(198803)44:2<101::AID-JCLP2270440203>3.0.CO;2-U

Gardner, R.M., & Bokenkamp, E.D. (1996). The role of sensory and nonsensory factors in body size estimations of eating disorder subjects. *Journal of Clinical Psychology*, *52,* 3-15. Doi: 10.1002/(SICI)1097-4679(199601)52:1<3::AID-JCLP1>3.0.CO;2-X

Gardner, R. M. & Brown, D. L. (2014). Body size estimation in anorexia nervosa: a brief review of findings from 2003 through 2013. *Psychiatry Research, 219*, 407-410. Doi: 10.1016/j.psychres.2014.06.029

Gledhill, L. J., Cornelissen, K. K., Cornelissen, P. L., Penton-Voak, I. S., Munafò, M. R., & Tovée, M. J. (2016). An interactive training programme to treat body image disturbance. *British Journal of Health Psychology, 22(2)*, 60-76. Doi: 10.1111/bjhp.12217

Guardia, D., Carey, A., Cottencin, O., Thomas, P. & Luyat, M. (2013). Disruption of spatial task performance in anorexia nervosa. PLoS One, 8(1), e54928. Doi: 10.1371/journal.pone.0054928.

Guardia, D., Lafargue, G., Thomas, P., Dodin, V., Cottencin, O., et al. (2010). Anticipation of body-scaled action is modified in anorexia nervosa. *Neuropsychologia*, *48*, 3961–3966. Doi: 10.1016/j.neuropsychologia.2010.09.004

Guardia, D., Conversy, L., Jardri, R., Lafargue, G., Thomas, P., et al. (2012). Imagining one's own and someone else's body actions: Dissociation in Anorexia Nervosa. *PLoS ONE*, 7(8): e43241. Doi:10.1371/journal.pone.0043241

Haggard, P. & Wolpert, D.M. (2005). Disorders of body scheme. In: Freund, H.J., Jeannerod, M., Hallett, M., Leiguarda, R. (Eds.), *Higher-Order Motor Disorders*. New York: Oxford University Press.

Hanakawa, T., Immisch, I., Toma, K., Dimyan, M.A., van Gelderen, P. & Hallett, M. (2003) Functional properties of brain areas associated with Motor execution and imagery. *Journal of Neurophysiology*, *89*, 989-1002. Doi: 10.1152/jn.00132.2002.

Hayes, A. F. (2015). An Index and Test of Linear Moderated Mediation. *Multivariate Behavioral Research*, *50*(1), 1–22. Doi: 10.1080/00273171.2014.962683

Head, H. & Holmes, H. G. (1911–1912). Sensory disturbances from cerebral lesions. *Brain*, *34*, 102–254. Doi: 10.1016/S0140-6736(01)64640-3

Hesslow, G. (2012). The current status of the simulation theory of cognition. *Brain Research*, *1428*, 71-79. Doi: 10.1016/j.brainres.2011.06.026

Hoffmeister, K., Teige-Mocigemba, S., Blechert, J., Klauer, K.C. & Tuschen-Caffier, B. (2010). Is implicit self-esteem linked to shape and weight concerns in restrained and unrestrained eaters? *Journal of Behaviour Therapy and Experimental Psychiatry*, *41*, 31–38. Doi: org/10.1016/j.jbtep.2009.08.009

Kammers, M.P.M., van der Ham, I.J., Dijkerman, H.C. (2006). Dissociating body representations in healthy individuals: differential effects of a kinaesthetic illusion on perception and action. *Neuropsychologia*, *44(12)*, 2430–2436. Doi: 10.1016/j.neuropsychologia.2006.04.009

Kammers, M.P.M., de Vignemont, F., Verhagen, L. & Dijkerman, H.C. (2009). The rubber hand illusion in action. *Neuropsychologia*, *47(1)*, 204–211. Doi: 10.1016/j.neuropsychologia.2008.07.028

Kammers, M.P.M., Kootker, J.A., Hogendoorn, H. & Dijkerman, H.C. (2010). How many motoric body representations can we grasp? *Experimental Brain Research*, *202*, 203-212. Doi: 10.1007/s00221-009-2124-7

Keizer, A., Smeets, M. A. M., Dijkerman, H. C., van den Hout, M., Klugkist, I., van Elburg A. & Postma, A. (2011). Tactile body image disturbance in anorexia nervosa. *Psychiatry Research*, *190(1)*, 115-20. Doi: 10.1016/j.psychres.2011.04.031

Keizer, A., Smeets, M.A.M., Dijkerman, H.C., van Elburg, A. & Postma, A. (2012). Aberrant somatosensory perception in Anorexia Nervosa. *Psychiatry Research,* 200(2), 530–537. Doi: doi: 10.1016/j.psychres.2012.05.001.

Keizer, A., Smeets, M. A. M., Dijkerman, H. C., Uzunbajakau, S. A., van Elburg, A., & Postma, A. (2013). Too fat to fit through the door: first evidence for disturbed body-scaled action in anorexia nervosa during locomotion. *Plos One*, *8*(5), e64602 Doi: 10.1371/journal.pone.0064602

Keizer, A., Smeets, M.A.M., Postma, A., van Elburg, A. & Dijkerman, H.C. (2014). Does the experience of ownership over a rubber hand change body size perception in anorexia nervosa patients? *Neuropsychologia, 62,* 26-37. doi: 10.1016/j.neuropsychologia.2014.07.003.

Longo, M. R., Azañón, E., & Haggard, P. (2010). More than skin deep: body representation beyond primary somatosensory cortex. *Neuropsychologia, 48(3),* 655-68. Doi:10.1016/j.neuropsychologia.2009.08.022

Longo, M. R. (2016). Distorted body representations in healthy cognition. *The Quarterly Journal of Experimental Psychology, 218,* 1-37. Doi: 10.1080/17470218.2016.1143956

Longo, M.R. & Haggard, P. (2012). Implicit body representations and the conscious body image. *Acta Psychologica, 141(2),* 164-168. Doi: 10.1016/j.actpsy.2012.07.015

Luce, K.H., Crowther, J.H., & Pole, M. (2008). Eating Disorder Examination Questionnaire (EDE-Q): Norms for Undergraduate Women. *International Journal of Eating Disorders*, *41(3)*, 273–276. Doi: 10.1002/eat.20504

Meermann, R. (1983). Experimental investigation of disturbances in body image estimation in anorexia nervosa patients, and ballet and gymnastics pupils. *International Journal of Eating Disorders*, *2*, 91–100. Doi: 10.1002/1098-108X(198322)2:4<91::AID-EAT2260020416>3.0.CO;2-Z

Michalak, N. (2016). Reproducing Hayes's PROCESS Models' results in R, [blog post]. Retrieved from https://nickmichalak.blogspot.co.uk/2016/07/reproducing-hayess-process-models.html

Miller, K.J., Schalk, G., Fetz, E.E., den Nijs, M., Ojemann, J.G. & Rao, R.P.N. (2010). Cortical activity during motor execution, motor imagery, and imagery-based online feedback. *Proceedings of the National Academy of Sciences, 107(15)*, 4430-4435. Doi: 10.1073/pnas.0913697107

Moseley, G.L., Gallace, A. & Spence, C. (2012). Bodily illusions in health and disease: Physiological and clinical perspectives and the concept of a cortical ‘body matrix’. *Neuroscience & Biobehavioral Reviews, 36(1)*, 34-46. Doi: 10.1016/j.neubiorev.2011.03.013

Mölbert, S.C., Klein, L., Thaler, A., Mohler, B.J., Brozzo, C, Martus, P., Karnath, H-O., Zipfel, S. & Giel, K.E. (2017). Depictive and metric body size estimation in anorexia nervosa and bulimia nervosa: A systematic review and meta-analysis. *Clinical Psychology Review*, *57*, 21-31. Doi: 10.1016/j.cpr.2017.08.005.

Mölbert, S.C., Thaler, A., Mohler, B.J., Streuber, S., Romero, J., Black, M.J., Zipfel, S., Karnath, H-O., Giel, K.E. (2017). Assessing body image in anorexia nervosa using biometric self-avatars in virtual reality: attitudinal components rather than visual body size estimation are distorted. *Psychological Medicine*, Doi: 10.1017/S0033291717002008

Mond, J.M., Hay, P.J., Rodgers, B., & Owen, C. (2006). Eating Disorder Examination Questionnaire (EDE-Q): Norms for young adult women. *Behaviour Research and Therapy*. *44*, 53–62. Doi: 10.1016/j.brat.2004.12.003.

Newport, R., Pearce, R., & Preston, C. (2010). Fake hands in action: embodiment and control of supernumerary limbs. *Experimental Brain Research, 204(3)*, 385-95. Doi: 10.1007/s00221-009-2104-y.

Paillard, J., Michel, F. & Stelmach, G. (1983). Localisation without content: a tactile analogue of "blind sight". *Archives of Neurology, 40*, 548-551. Doi: 10.1001/archneur.1983.04050080048008

Paillard, J. (1991). Knowing where and knowing how to get there. In: Paillard, J. (ed) *Brain and space*. Oxford: Oxford University Press, pp. 461–481.

Paillard, J. (1997) Divided Body Schema and Body Image in Deafferented Patients. In: Brain and Movement: Int. Symp. Motor Control. St.-Petersburg - Moscow (Abstract). In: V.S. Gurfinkel & Yu. S, Levik (Eds). Institute for Information and Transmission problems RAS Moscow.

Paillard, J. (1999). Body schema and body image: a double dissociation in deafferented patients. In: Gantchev GN, Mori S, Massion J (eds) *Motor control, today and tomorrow*. Sofia: Academic Publishing House, pp. 197–214.

Pitron, V. & de Vignemont, F. (2017). Beyond differences between the body schema and the body image: insights from body hallucinations. *Consciousness and Cognition*, *53*, 115-121. Doi: 10.1016/j.concog.2017.06.006

Pollatos, O., Kurz, A., Albrecht, J., Schreder, T., Kleeman A.M., Schöpf, V., Kopietz, R., Wiesmann, M. & Schandry, R. (2008). Reduced perception of bodily signals in anorexia nervosa. *Eating Behaviors, 9(4):* 381-388. Doi: 10.1016/j.eatbeh.2008.02.001.

Pope, H., Phillips, K., & Olivardia, R. (2000). *The Adonis complex*. New York: Free Press.

Poulton, E.C. (1989). *Bias in Quantifying Judgements*. Hove, UK: Erlbaum.

Preacher, K. J., & Hayes, A. F. (2008). Asymptotic and resampling strategies for assessing and comparing indirect effects in multiple mediator models. *Behavior Research Methods, 40*(3), 879–891. Doi: 10.3758/BRM.40.3.879

Preston, C. & Ehrsson, H.H. (2016). Illusory obesity triggers body dissatisfaction responses in the insula and anterior cingulate cortex. *Cerebral Cortex, 26(12),* 4450–4460. Doi: 10.1093/cercor/bhw313.

Probst, M., Vandereycken, W., Van Coppenolle, H., & Pieters, G. (1995). Body size estimation in eating disorder patients: Testing the video distortion method on a life-size screen. *Behaviour Research and Therapy*, *33*, 985-990. Doi: 10.1016/0005-7967(95)00037-X

R Development Core Team. (2008). *R: a language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing.

Revelle, W. (2016). psych: Procedures for personality and psychological research. *R Package*.

Riva, G. & Gaudio, S. (2012). Allocentric lock in anorexia nervosa: New evidences from neuroimaging studies. *Medical Hypotheses*, *79*, 113-117. Doi: 10.1016/j.mehy.2012.03.036.

Rosenberg, M. (1965). *Society and the adolescent self-image*. Princeton, NJ: Princeton University Press.

Rosseel, Y. (2012). lavaan: An R package for structural equation modeling. *Journal of Statistical Software*, *48*, 1–36. Doi: 10.18637/jss.v048.i02

Roth, M., Decety, J., Raybaudi, M., Massarelli, R., Delon-Martin, C., et al. (1996). Possible involvement of primary motor cortex in mentally simulated movement: A functional magnetic resonance imaging study. *Neuroreport*, 7, 1280-1284.

Sambo, C.F. & Iannetti, G.D. (2013). Better safe than sorry? The safety margin surrounding the body is increased by anxiety. *Journal of Neuroscience,* 33(35), 14225–14230. Doi: 10.1523/JNEUROSCI.0706-13.2013.

Schwoebel, J., & Coslett, H. B. (2005). Evidence for multiple, distinct representations of the human body. *Journal of Cognitive Neuroscience, 17*, 543–553. Doi: 10.1162/0898929053467587

Shafran, R., & Fairburn, C. G. (2002). A new ecologically valid method to assess body size estimation and body size dissatisfaction. *International Journal of Eating Disorders*, *32*, 458–465. Doi: 10.1002/eat.10097

Sirigu, A., Duhamel, J.R., Cohen, L., Pillon, B., Dubois, B., et al. (1996). The mental representation of hand movements after parietal cortex damage. *Science*, *273*, 1564–1568. Doi: 10.1126/science.273.5281.1564

Skrzypek, S., Wehmeier, P.M., & Remschmidt, H. (2001). Body image assessment using body size estimation in recent studies on anorexia nervosa. A brief review. *European Child & Adolescent Psychiatry, 10*, 215-221. Doi: 10.1007/s007870170010

Slade, P., & Russell, G. (1973). Awareness of body dimensions in anorexia nervosa: cross-sectional and longitudinal studies. *Psychological Medicine*, *3*, 188-199. Doi: 10.1017/S0033291700048510

Smeets, M.A.M., (1997) The rise and fall of body size estimation research in anorexia nervosa: a review and reconceptualization. *European Eating Disorder Reviews,* (5), 75-95. Doi: 10.1002/(SICI)1099-0968(199706)5:2<75::AID-ERV190>3.0.CO;2-A

Spitoni, G.F., Serino, A., Cotugno, A., Mancini, F., Antonucci, G. & Pizzamiglio, L. (2015). The two dimensions of the body representation in women suffering from Anorexia Nervosa. *Psychiatry Research, 15;230(2),* 181-8. doi: 10.1016/j.psychres.2015.08.036.

Stice, E. & Shaw, H. E. (2002). Role of body dissatisfaction in the onset and maintenance of eating pathology. A synthesis of research findings. *Journal of Psychosomatic Research, 53,* 985-993. Doi: 10.1016/S0022-3999(02)00488-9

Tovée, M.J., Benson, P.J., Emery, J.L., Mason, S.M., & Cohen-Tovée, E.M. (2003). Measurement of body size and shape perception in eating-disordered and control observers using body-shape software. *British Journal of Psychology, 94,* 501-516. Doi: 10.1348/000712603322503060

Traub, A.C., & Orbach, J. (1964). Psychophysical studies of body-image: 1. The adjustable body-distorting mirror. *Archives of General Psychiatry, 11(1)*, 53-66. Doi: 10.1001/archpsyc.1964.01720250055007

Treasure, J., Claudino, A. M. & Zucker, N. (2010). Eating disorders. *The Lancet, 375*, 583-593. Doi: 10.1016/S0140-6736(09)61748-7

de Vignemont, F. (2010). Body schema and body image – pros and cons. *Neuropsychologia, 48*, 669-680. Doi: 10.1016/j.neuropsychologia.2009.09.022

de Vignemont, F. & Iannetti, G.D. (2015). How many peripersonal spaces? *Neuropsychologia, 70,* 327-334. Doi: 10.1016/j.neuropsychologia.2014.11.018

Warren, W., H. & Whang, S. (1987). Visual guidance of walking through apertures: body-scaled information for affordances. *Journal of Experimental Psychology: Human Perception and Performance, 13*(3), 371-383. Doi: 10.1037/0096-1523.13.3.371

Wells, J.C., Treleaven, P., & Cole, T.J. (2007). BMI compared with 3-dimensional body shape: the UK national sizing survey. *The American Journal of Clinical Nutrition*, *85*, 419-425. Doi: 10.1093/ajcn/85.2.419

Wells, J.C.K., Cole, T.J., Bruner, D., & Treleaven, P. (2008). Body shape in American and British adults: Between-country and inter-ethnic comparisons. *International Journal of Obesity*, *32*, 152–159. Doi: 10.1038/sj.ijo.0803685

Woo, C.W., Roy, M., Buhle, J.T. & Wager, T.D. (2015). Distinct brain systems mediate the effects of nociceptive input and self-regulation on pain. *PLOS Biology, 13(1)*, e1002036. Doi: 10.1371/journal.pbio.1002036

Zucker, N.L., Merwin, R.M., Bulik, C.M., Moskovich, A., Wildes, J. & Groh J. (2013). Subjective experience of sensation in anorexia nervosa. *Behaviour Research and Therapy, 51(6),* 256-265. Doi: 10.1016/j.brat.2013.01.010