IRIS AperTO

UNIVERSITÀ DEGLI STUDI DI TORINO

AperTO - Archivio Istituzionale Open Access dell'Università di Torino

Body-scaled action in obesity during locomotion: Insights on the nature and extent of body representation disturbances

This is the author's manuscript

Original Citation:

Availability:

This version is available http://hdl.handle.net/2318/1658954 since 2018-01-24T01:51:22Z

Published version:

DOI:10.1016/j.jpsychores.2017.09.004

Terms of use:

Open Access

Anyone can freely access the full text of works made available as "Open Access". Works made available under a Creative Commons license can be used according to the terms and conditions of said license. Use of all other works requires consent of the right holder (author or publisher) if not exempted from copyright protection by the applicable law.

(Article begins on next page)

14 September 2026

Body-scaled action in obesity during locomotion: Insights on the nature and extent of body representation disturbances

Federica Scarpina[a,b,□], Nicola Cau[c], Veronica Cimolin[c], Manuela Galli[c,e], Gianluca Castelnuovo[b,f], Lorenzo Priano[a,d], Lucia Pianta[d,g], Stefania Corti[b], Alessandro Mauro[a,d], Paolo Capodaglio[g]

[a] "Rita Levi Montalcini" Department of Neuroscience, University of Turin, Turin, Italy [b] Psychology Research Laboratory, IRCCS Istituto Auxologico Italiano, Ospedale San Giuseppe, Piancavallo (VCO), Italy [c] Department of Electronics, Information and Bioengineering, Politecnico di Milano, Milan, Italy [d] Division of Neurology and Neuro-Rehabilitation, IRCCS Istituto Auxologico Italiano, Ospedale San Giuseppe, Piancavallo (VCO), Italy [e] IRCCS "San Raffaele Pisana", Tosinvest Sanità, Rome, Italy [f] Department of Psychology, Università Cattolica del Sacro Cuore, Milan, Italy [g] Research Laboratory in Biomechanics and Rehabilitation, Orthopedic Rehabilitation Unit, IRCCS Istituto Auxologico Italiano, Ospedale San Giuseppe, Piancavallo (VCO), Italy

ABSTRACT

Objective: Conscious perception of our own body, also known as body image, can influence body-scaled actions. Certain conditions such as obesity are frequently accompanied by a negative body image, leaving open the question if body-scaled actions are distorted in these individuals. Methods: To shed light on this issue, we asked individuals affected by obesity to process dimensions of their own body in a real action: they walked in a straight-ahead direction, while avoiding collision with obstacles represented by door-like openings that varied in width. Results: Participants affected by obesity showed a body rotation behavior similar to that of the healthy weighted, but differences emerged in parameters such as step length and velocity. Conclusion: When participants with obesity walk through door-like openings, their body parts rotation is scaled according to their physical body dimensions; however, they might try to minimize risk of collision. Our study is in line with the hypothesis that unconscious body-scaled actions are related to emotional, cognitive and perceptual components of a negative body image.

Keywords:
Action Body schema Body image Obesity 3D movement analysis

1. Introduction

For decades, it has been reported in the literature how difficulties in emotions, feelings and perceptions about one's own body [1–2],in other words, in body image[3], are implicated in body dissatisfaction and in maintaining healthy behavior [3–6] in obesity. However, this condition also has a dramatic impact on body proportions as well as on the subjective bodily experience; people affected by obesity overestimate [7–11] or underestimate [12–13] the physical dimensions of their bodies.

Critically, more recent studies suggest that an enlarged body might affect not only the subjective representation of bodily dimensions, meaning how people perceive the dimensions of their body parts, but also the perception of sensory bodily input; the perception of the intensity of peripheral pain [14–16], vibratory sensation and temperature [17],sense of satiety [18] and gastric motor functions [19] seem to be altered in obesity. Moreover, it was recently reported that people affected by obesity show alterations in the successful integration of multiple sensory input, such as audio-tactile stimuli [20] and audio-visual stimuli [21],anessential cognitive sensory process for successful actions in the environment. Consider the common behavior of walking: it results from a complex and unaware integration of different sources of information [22],suchas postural and sensory inputs related to the physical body size [23],dimensions and spatial position of possible obstacles [24],relationships between gait parameters and body proportions [25–26]. All of this information is processed and integrated together for a successful behavior. In other words, all these inputs are collapsed in the cognitive representation of body schema[3,27–31], which is a dynamic representation of one's own body [27–30] used to guide actions [6,31,32]. As suggested by several lines of research, the body schema arises from the integration of multisensory bodily inputs and, when it is impaired, incoherent sensorimotor action's representation can be observed [30–31]. Dijkerman and De Haan [31] specifically discussed the role of somatosensory processing, not only in the conscious perception and recognition of one's own body (i.e. the body image) [3], but also in the

construction of the body schema [31].For example, tactile input allows one “to localize and experience the various qualities of touch” on the surface of the body, as well as “to determine the position of different parts of the body with respect to each other, which provides fundamental information for action” [31].

Until now, body schema distortions in obesity have not generally been explored in literature. However we would hypothesize that enlarged body proportions, as well as aberrant sensory processing [14–21], might affect the body schema, with possible consequences for the generation of successful action.

The main aim of this work was to explore this hypothesis: it represents the first attempt to study a body action, requiring motion underpinned by entire body dimensions [33–34], in obesity. In this experimental task, participants walked towards a target, while avoiding collision with obstacles represented by door-like openings varying in width. The horizontal rotation of body parts is strictly determined by the opening dimensions [34] through which the participants have to pass: as our daily experience suggests, we rotate our body more when we have to pass through narrower openings than we do for larger openings, in order to preserve a safety margin between our body and the obstacles. This unconscious behavior is grounded on the body schema that processes the localization and the size of the body (provided by the bodily sensory input) with respect to external objects [33]. Given the features of this task, it represented a suitable way to provide a preliminary answer to the following question: is body schema affected in obesity?

Since the aforementioned results about the bodily perceptions in obesity [14–21] as well as about the estimation of body parts size [7–13], we can formulate two different predictions. If the participants affected by obesity perceive themselves as larger as their real body dimension (i.e. overestimation), they would start to rotate their body parts at relatively narrower openings. Otherwise, if they underestimate their body dimensions, they would start to rotate their body parts at relatively wider openings; in other words, they would not always rotate their body parts when they have to in order to pass safely through the aperture.

2. Materials and methods

2.1. Participants

The present study was performed in accordance with the Declaration of Helsinki and was approved by the Ethical Committee of the I.R.C.C·S Istituto Auxologico Italiano. All participants provided written informed consentbeforetakingpartin the study.

We recruited 18 female participants with obesity and 18 female normal weight participants. All participants were right-handed.

The participants with obesity were recruited during the first weeks of a rehabilitation recovery in the IRCCS Istituto Auxologico Italiano – Ospedale San Giuseppe; they had been hospitalized in order to lose weight. Exclusion criteria for the study were: (1) psychiatric disturbance diagnosed by DSM-V criteria (except for Binge Eating Disorder) [35] and (2) any concurrent medical condition not related to obesity. For the healthy weight group, exclusion criteria were a body mass index (BMI) over 24.9 and no medical condition.

Means and standard deviations of demographic features and body dimensions are reported in Table 1. The two groups were comparable in terms of Age [the data are reported in years; $t(34) = 0.38$; $p = 0.7$], while the participants with obesity reported a significantly lower Years of Education than that of the healthy weight group [$t(34) = 6.7$; $p < 0.001$; $d = 2.5$]. As expected, the two groups differed significantly in their BMI [$t(34) = 16.04$; $p < 0.001$; $d = 5.33$]; moreover, participants with obesity showed a larger horizontal dimension of both shoulders [$t(33) = 5.67$; $p < 0.001$; $d = 1.95$] and pelvis [$t(33) = 10.18$; $p < 0.001$; $d = 3.94$])

Table 1
Demographic information, body dimensions and scores relative to psychological questionnaires on the presence of eating disorders as well as body image, divided by group. Means and standard deviations (in brackets). For the body parts drawing task, a negative error indicates an underestimation; a positive error, an overestimation of the actual dimensions.

	Group with obesity	Healthy weight group
Demographical details and body measures		
Age (years)	36 (8)	35 (9)
Education (years)	11 (2)	16 (2)
Body mass index (kg/(height in m2))	39.67 (4.72)	20.59 (1.81)
Shoulders – width (cm)	45.01 (2.51)	40.67 (1.89)
Pelvis – width (cm)	48.64 (3.72)	35.5 (3)
Eating disorder assessment		
Binge Eating Scale	14.5 (9.7)	4.1 (4.2)
Eating Disorder Inventory 2		
-Drive for the thinness	9.5 (6.5)	1.4 (2.5)
-Bulimia	3.5 (4.4)	0.2 (0.8)
-Body dissatisfaction	17.7 (7.7)	4.8 (6.1)
-Ineffectiveness	8.1 (6.9)	2 (3.7)
-Perfectionism	3 (3)	1.7 (1.6)
-Interpersonal distrust	6.1 (5.5)	1.6 (2)
-Interoceptive awareness	4.9 (6.1)	0.5 (1.5)
-Maturity fear	7.2 (6)	2.3 (2.5)
-Asceticism	5.6 (3.3)	2.3 (1.5)
-Impulsiveness	4.2 (4.6)	1 (2.2)
-Social insecurity	6.88 (5.09)	1.8 (2.4)
Body Uneasiness Test (BUT)		
A – Global severity index	2.1 (1.1)	0.6 (0.5)
A – Weight phobia	2.6 (1.4)	1.2 (0.9)
A – body image concerns	3 (1.4)	0.8 (0.7)
A – Avoidance	1.6 (1.2)	0.2 (0.3)
A – Compulsive self-monitoring	1.2 (0.9)	0.5 (0.6)
A – Depersonalization	1.6 (1.4)	0.1 (0.3)
A – Total score	12.3 (6.3)	3.69 (3.27)
B – Positive symptoms total	16.6 (7.6)	11.9 (8.8)
B – Distress index	2.9 (0.8)	1.6 (0.5)
B – Total score	19.9 (7.6)	13.6 (9.21)
Body part drawing task		
Shoulder Error (cm)	3.97 (6.77)	−0.23 (4.93)
Relative error[a]	−7.57 (13.57)	2 (11.95)
Pelvis Error (cm)	4.75 (17.94)	5.84 (7.5)
Relative error[a]	−7.68 (22.41)	11.35 (19.82)
Group with obesity		Healthy weight group

Formula: ((estimated size − actual size) / actual size) × 100. ° p value < 0.05.

compared to the healthy weight group.

Two self-rating questionnaires were administered, Eating Disorder Inventory 2 (EDI2) [36] and Binge Eating Scale [37]. Means and standard deviations are reported in Table 1. According to an Independent t-test Bonferroni-corrected ($p \leq 0.004$), the participants affected by obesity reported greater difficulties in regulation of impulsive tendencies, especially in eating (Impulsiveness) [$p < 0.001$]. Moreover, higher levels of Body Dissatisfaction [$p < 0.001$] were also present, suggesting a higher risk for disordered eating [36,38]. Reluctance to having close relationships (Interpersonal distrust) [$p = 0.002$] was consistent with the tendency to avoid sexual relationships (Asceticism) [$p < 0.001$] and they reported stronger social fears and insecurity (Social Insecurity) [$p = 0.001$], compared to the control group. According to the Binge Eating Scale [Levene Test $F = 17.68$; $p < 0.001$; $t(19.57) = 3.17$; $p = 0.005$; $d = 0.77$], our

sample reported higher numbers of behavioral, emotional and cognitive responses of an eating disorder compared to the control group.

2.2. Body image

We explored the body image through two different measures. The first was the self-questionnaire Body Uneasiness Test [39] that measures weight phobia, body image concerns, avoidance, compulsive self-monitoring, detachment and estrangement feelings towards one's own body (part A) and specific worries about specific body parts or functions (part B). The second measure adopted here was the body parts drawing task, in which participants are asked to draw a vertical line, representing the width of their shoulders and pelvis, on a panel placed in front of them. This task refers to the body image representation [1,31,33,40].Differences between the estimated dimension and the real dimension of the target body part was calculated for each participant, representing the error; as well as the relative error, meaning the error scaled in relation the physical extension of the body part.

The psychological assessment was conducted after the main experiment, in order to avoid any possible confounding effect of aware access to body representation.

2.3. Experimental task: body-scale task

This task was a modified version of Keizer et al. [33,41]. Each subject was evaluated in a fully instrumented movement laboratory, in order to measure the body-scaled action in terms of kinematic data. The 3D-movement acquisition was conducted using an optoelectronic system with passive markers (VICON, Oxford Metrics Ltd., Oxford, UK) for kinematic movement evaluation. The optoelectronic system performs a real-time processing of images from 6 fixed infra-red cameras (a sampling rate of 100 Hz) to extract the reflectance of passive markers (with a diameter of 15 mm) that are positioned on specific anatomical landmarks of the participants (Fig. 1).

In each trial, the participants walked 8 m towards a table placed behind an aperture. Five meters from the starting point, the participants walked through the aperture, which consisted of two grey movable wooden partitions (2 m in height and 1 m in width each). After each trial, the participants waited behind a screen while the experimenter prepared the set-up for the following trial.

We administered 18 trials consisting of 6 different aperture widths presented three times each, in a different randomized order for each participant. Aperture width (A) was determined for each participant, according to the actual pelvic width (P), and ranged from A/P = 1 to A/P = 2.0, in steps of A/P = 0.2.

In order to stress the implicit nature of the task, we followed the instructions from Keizer et al. [33]. Thus, participants were led to believe that they were completing a recognition memory test. At the start of each walking trial, they explored a complex visual pattern and were instructed to memorize it. At the end of the walking trial, they were asked to recognize the memorized pattern between two possible figures and to indicate their choice with the index finger of the right hand for a couple of seconds in order to allow the system to record the movements. A fake marker was placed on the participants' right hand index finger and a camera was placed on the top of the table. At the end of the task, participants completed a questionnaire in which they were asked to describe the experiment: all participants confirmed they believed it was a memory task. Moreover, most of them reported noticing the panels were horizontally moved across trials.

3. Analyses

3.1. Body image

An independent t-test was conducted in order to identify possible differences between groups in BUT scores and in errors in the body parts drawing task.

3.2. Experimental task: body-scale task

Starting from the XYZ coordinates of each marker, the measurements were computed using SMARTAnalyzer software (BTS SMARTAnalyser, Italy) and Matlab (Mathworks, USA) software providing kinematic quantities and indices, as follows:

- -Step length in mm, defined as the longitudinal distance from one foot strike to the next, normalized to the subject's height and calculated from RANK and LANK markers;
- -Step duration in seconds, defined as the time between two consecutive heel strikes of the same foot;
- -Mean velocity in m/s, represented by the mean velocity of progression calculated from the S marker;
- -Shoulder Range of Motion (ROM) in degrees, computed between the vector from RSHO and LSHO and medio/lateral axes of the laboratory. This parameter was defined as the difference between its maximum and minimum value, representing the shoulder excursion on the transversal plane;
- -Pelvic ROM in degrees: the pelvis angle computed between the vector from E and W and medio/lateral axes of the laboratory. This parameter was defined as the difference between its maximum and minimum value, representing the pelvis excursion on the transversal plane.

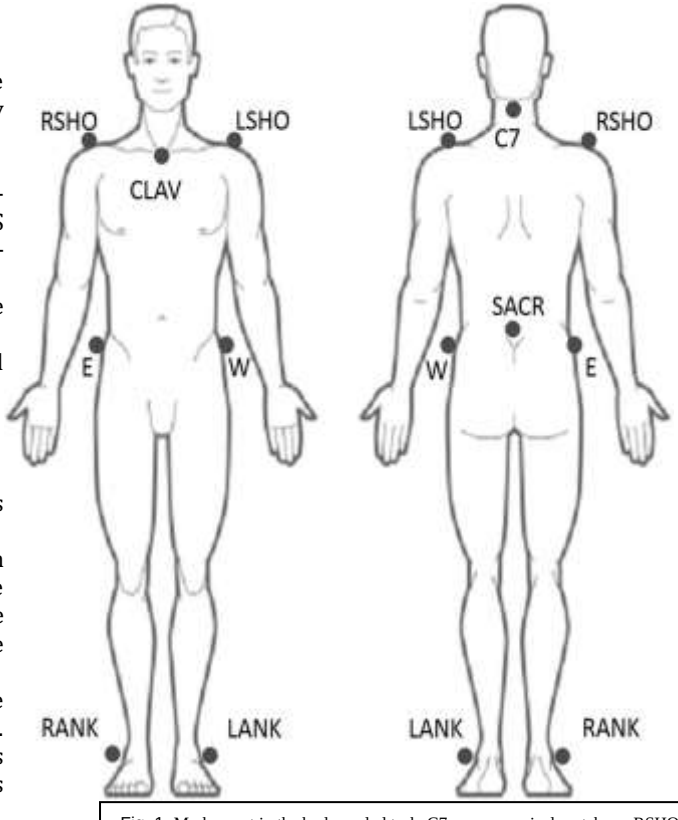

Fig. 1. Markers set in the body-scaled task. C7: seven cervical vertebrae; RSHO/LSHO: right/left acromion; CLAV: clavicle; RANK/LANK: right/left lateral malleolus; SACR: sacrum; E and W: the larger point of the pelvis respectively on the right and left side of the participant.

The path walked by the participants was divided into two zones, according to the analysis of the shoulder rotation angle: the reaching zone (from the starting point to the change of shoulder rotation angle, according to the method explained below) and the crossing zone (from the end of the reaching zone to the baseline of the shoulder rotation angle, after the two panels). In particular, the crossing zone started when the shoulder rotation pattern was statistically different from the reaching zone, according to Chebyshev theorem, setting a threshold of 10%, which corresponded to an interval of confidence of (μ_REACH ±3.2 σ_REACH), where μ_REACH and σ_REACH were the mean and the standard deviation in the reaching zone [42–43]. If > 10% of the sample frames in the phase of crossing were located in the area shown in dotted texture in Fig. 2,the movement strategy of the subject was considered significantly different from the path of the reaching zone. In the reaching zone, the shoulder's ROM was lower compared to the one calculated in correspondence of the crossing zone where the subject had to turn the upper part of his body to pass through the space between the two panels.

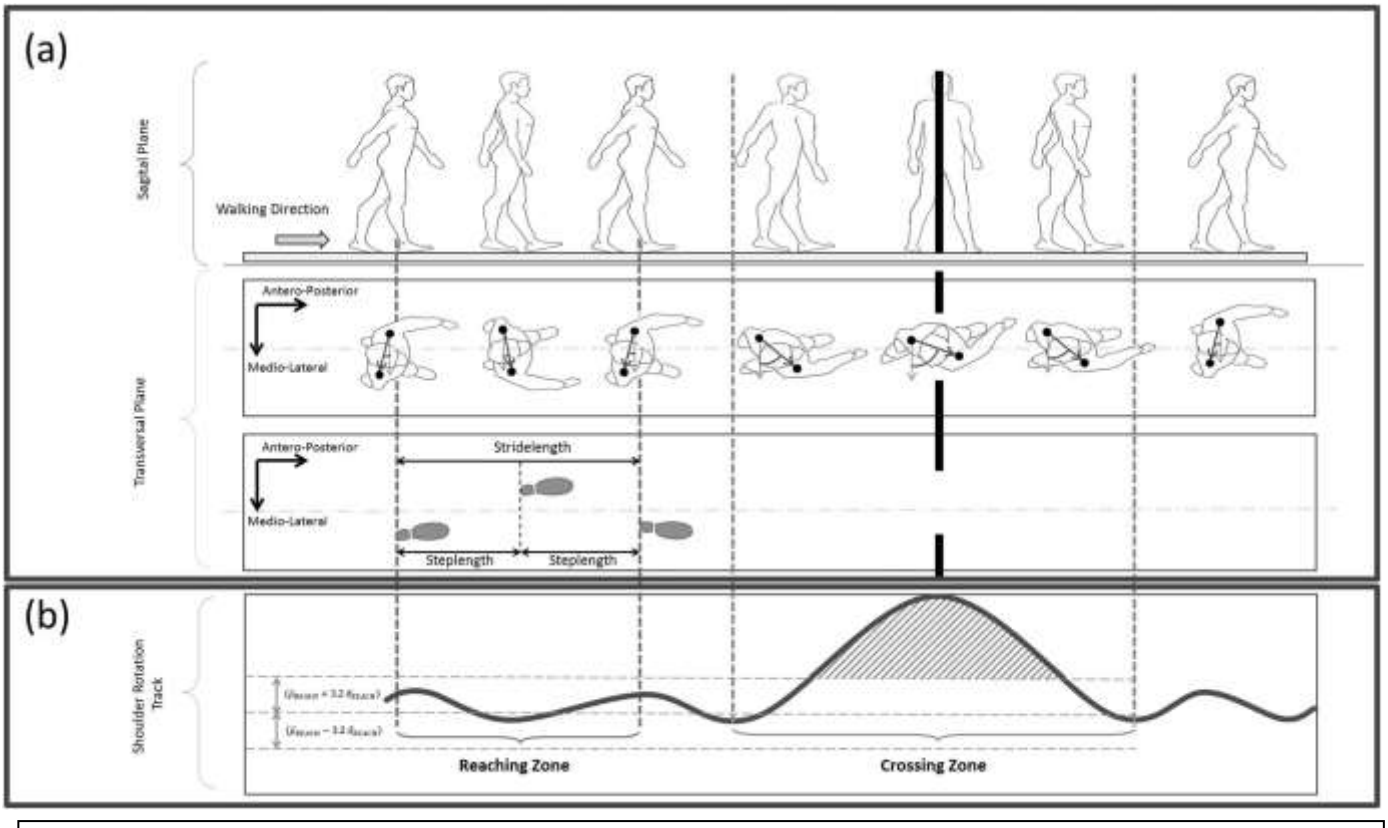

Fig. 2. Representation of reach space and cross space during the body-scaled task. (a) Shoulders vector Vs laboratory reference vector, step and stride lengths in the transverse plane. (b) The typical shoulder angle pattern. In the reaching zone, the shoulder's ROM is lower compared to that one calculated in correspondence of the crossing zone, where the subjects have to turn the upper part of their body to pass through the narrow space between the two panels

For each parameter, trials in which each participant's value was out of the range of two SD of the group's mean were excluded from the analysis. Overall, we removed 3.66% of trials relative to the reaching zone, and 3.75% of trials relative to the crossing zone. Secondly, for each aperture, the value of the three repetitions was collapsed. Mixed repeated measures analysis of variance was performed with Group (patients with obesity versus healthy weight group) as the betweensubjects factor and Aperture (six A/P values: 1.0; 1.2; 1.4; 1.6; 1.8; 2) as the within-subjects factor. If the interaction was significant, a Bonferroni-corrected post-hoc estimated marginal means comparison was applied.

About the crossing space, the A/Pcrit was defined as the widest aperture for which a participant rotated her shoulders in at least two out of three trials. An independent t-test was performed in order to find any difference in this value between groups. Since the two groups were significantly different in terms of Education and BMI, the analyses were run introducing these variables as covariates. Where not expressly indicated, their introduction did not lead to different results. As such, we report the main analysis without covariates. Moreover, since the two groups reported a significant difference in the physical dimensions of the Shoulders, the latest was introduced as covariate in the analyses; again, no difference emerged in the results. As such, we report the main analysis without covariates.

4. Results

4.1. Body image

The participants with obesity showed a negative conscious body image representation in almost all the measured psychological dimensions (part A), with an alteration of body perception and a greater impact of body uneasiness on their life (part B) compared to the healthy weight group (Table 1) [$p < 0.006$]; also, the sum of the scores relative to part A [$p < 0.001$] and part B [$p = 0.036$] was higher for the group affected by obesity than it was for the healthy weight group. The two groups showed no difference in the error score for the estimation of

shoulders [t(33) = 1.19, p = 0.06] or of the pelvis [t(33) = 0.14; p = 0.88] (Table 1). Summarizing, the group of participants with obesity suffered from eating disorders, and reported a negative body image in terms of emotions, cognitions and perceptions.

4.2. Body action task

Means and standard deviations for each parameter are reported in Table 2.

4.2.1. Reaching zone The participants with obesity showed a shorter Step Length [F(1, 34) = 5.44; p = 0.026; η^2 = 0.13] compared to the healthy weight group. Aperture did not show any significant interaction with Step Length [F(5, 170) = 1.08; p = 0.37]. Secondly, a lower Step Duration was found [F (1, 33) = 18.28; p < 0.001; η^2 = 0.357] without any interaction with the factor Aperture [F(5, 165) = 1.52; p = 0.18]. No difference emerged between groups for Shoulders ROM [F(1, 32) = 3.83; p = 0.059], accompanied by no significant interactions with Aperture [F(5, 160) = 1.05; p = 0.38]. Considering the Pelvis ROM, no main effect of the between factor Group [F(1, 32) = 0.25; p = 0.61] emerged from the analyses

Table 2
Body-scaled task: means and standard deviations in brackets are reported for each index, divided by group

	Group with obesity	Healthy weight group
Demographical details and body measures		
Age (years)	36 (8)	35 (9)
Education (years)	11 (2)	16 (2)
Body mass index (kg/(height in m2))	39.67 (4.72)	20.59 (1.81)
Shoulders – width (cm)	45.01 (2.51)	40.67 (1.89)
Pelvis – width (cm)	48.64 (3.72)	35.5 (3)
Eating disorder assessment		
Binge Eating Scale	14.5 (9.7)	4.1 (4.2)
Eating Disorder Inventory 2		
-Drive for the thinness	9.5 (6.5)	1.4 (2.5)
-Bulimia	3.5 (4.4)	0.2 (0.8)

p value ≤ 0.05

However, the analysis showed a trend towards significance for the interaction between Group and Aperture [$F(1, 160) = 2.31$; $p = 0.046$; $\eta^2 = 0.067$]. However, Bonferroni-corrected estimated marginal mean comparisons showed no significant difference between groups for each aperture [$p \geq 0.63$], confirming that this trend was a misleading artifact.

4.2.2. Crossing zone

Considering the variable Mean Velocity, the participants with obesity were significantly slower than healthy ones [$F(1, 33) = 15.99$; $p < 0.001$; $\eta^2 = 0.32$]. As suggested by the significant interaction for Aperture and Group [$F(5, 165) = 6.5$; $p < 0.001$; $\eta^2 = 0.16$] and by the Bonferroni-corrected estimated marginal mean comparisons, they were slower when crossing all apertures [$p \leq 0.022$], except for the middle aperture measuring 1.2 [$p = 0.09$]. The two groups were comparable in relation to the Shoulders ROM [$F(1, 34) = 0.08$; $p = 0.77$]. However, the significant interaction between Group and Aperture [$F(5, 170) = 6.17$; $p < 0.001$; $\eta^2 = 0.154$] and the successive Bonferroni-corrected estimated marginal mean comparisons indicated that participants with obesity showed a higher ROM in the apertures measuring 1 [$p = 0.037$], 1.8 [$p = 0.045$], and 2 [$p = 0.027$] compared to the healthy weight group. No other significant difference was found [$p \geq 0.059$] (Fig. 3).

The two groups did not show differences in terms of Pelvis ROM [$F(1, 33) = 0.25$; $p = 0.61$]. A significant interaction between Group and Aperture was found [$F(5, 165) = 15.03$; $p < 0.001$; $\eta^2 = 0.31$]. Bonferroni-corrected comparisons indicated that the participants with obesity showed a larger ROM for the aperture measuring 1.0 [$p < 0.001$] and smaller ROM for the aperture measuring 1.2 [$p = 0.01$] compared to the healthy weight group, with no other significant difference [$p \geq 0.33$] (Fig. 4).

About A/Pcrit, no significant difference emerged between groups [$t(34) = 0.51$; $p = 0.61$].

5. Discussion

The aim of our study was to report preliminary evidence about body schema distortions in obesity. We present an experiment in which we contrasted the performance of a cohort of women affected by obesity to a healthy-weight comparable group in an ecological task, in which participants had to rotate their body in order to pass through different apertures, varying in width.

According to our results, the individuals affected by obesity showed a body rotation behavior similar to that of healthy weight participants, as suggested by the results relative to the pelvis and shoulders rotation as well as by the A/Pcrit. However, differences could be observed in terms of speed and step length, in line with previous studies [44–50]. Thus, the various components of the body schema might be variously affected in obesity.

The absence of any difference in body rotation behavior between the two groups stands out as a counterintuitive result in light of previous findings by Keizer et al. [33]. According to this previous study, a negative body image "does affect actions as well as cognition", assuming that body image and body schema influence each other [31–32]. For instance, female individuals affected by Anorexia Nervosa [33] act as if they are larger than they really are, in line with their cognition and emotion, instead of their real physical dimensions. Following this hypothesis, in obesity, a negative impact of the perceptual component of the body image on actions might result in a larger rotation of body parts, as individuals with obesity would picture themselves as larger than their real body dimension (overestimation of body dimensions). Otherwise, if the range of motion been found shallowed, we might have assumed a dissociation between a negative body image and an optimistic body action. In this case, we would hypothesize that individuals with obesity represent themselves as thinner than their real body dimension (underestimation). The current results mirror a different, third scenario in the body scaled-action, in which the participants showed a body rotation similar to that of the healthy weight group, despite a negative body image. They acted as if they were completely aware of their body dimensions. This result reflects the adequate level of accuracy reported in the body parts drawing task, in line with previous studies on the size estimation of the whole body [2] and of body parts [7,50].

On the other hand, the differences reported in speed and step length suggest that the locomotor body schema[26] is biased in obesity. The locomotor body schema refers to the perception of kinematic parameters emerging from an interplaying "between a priori notions about inherent dynamics of multi-joint limb motion

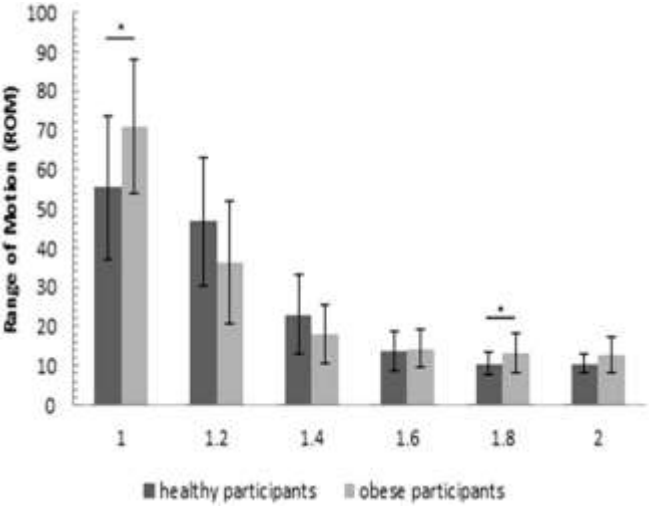

Fig.3.ShoulderROMincm(y-axis)incrossingzoneofthebody-scaledtask,meansandstandarddeviations(inbars)forhealthyweightparticipants(darkgreycolumns)andparticipantswithobesity(lightgreycolumns),reportedforeachaperture(x-axis).*p<0.05.

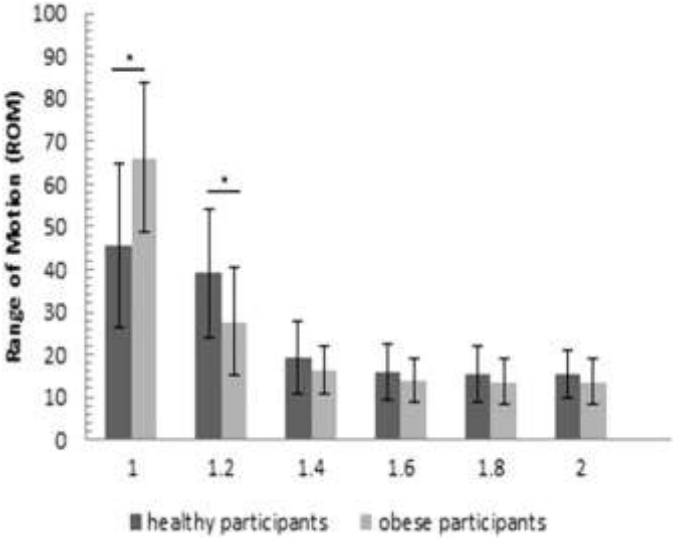

Fig.4.PelvicROMincm(y-axes)inthecrossingspaceofthebody-scaledtask,meansandstandarddeviations(inbars)forhealthyweightparticipants(darkgreycolumns)andforparticipantswithobesity(lightgreycolumns)reportedforeachaperture(x-axes).*p<0.05.

and proprioception" of body proportions [26]. Most interestingly, in our sample of participants with obesity, the locomotor body schema is affected independently from the BMI: the lower velocity and the shorter length step recorded in our sample appear to be unrelated to the higher body mass. This result appears in line with that reported by Gills et al [50]; in their manuscript the authors reported that BMI was not correlated with velocity of walking when individuals affected by obesity crossed through obstacles; however, as the authors claimed in their manuscript, only stationary obstacles were adopted. We extended this result, since in our experiment the dimensions of obstacle were scaled according to each individual's pelvis dimensions. This result might be interpreted as a strategy minimizing risk [52]. Individuals affected by obesity may adopt a walking strategy to minimize fatigue, specifically when they are required to walk at faster speeds [46], or to maintain biomechanical stability [47,49]. Interestingly, it was reported in the literature that walking parameters change after body mass loss: individuals increased stride length and walking velocity in the self-selected velocity [48], specifically when the obstacles were far away from the body [49]. Following the hypothesis of a strategy minimizing risk adopted during the task, we would hypothesize that individuals affected by obesity did not alter their walking kinematics because it would increase their risk of losing trunk stability and, consequently, of falling. On the other hand, if they did not change their shoulders motion, not only would the risk of losing stability decrease, but also the cost would be to bump lightly the obstacle. Indeed, overall, adults with obesity have reduced ankle, knee, and hip range of motion [52]. Furthermore, other factors, such as the established negative body image, as well as fear of falling [53–54] or injuring [56], might influence this strategy. Individuals with obesity might walk at a slow pace, taking small steps, guided by their emotions and cognitions instead of their physical potentialities. Further investigation is required, but the current result points out the influence of a negative body image on at least some components of the body schema.

Previous works investigated the interaction between body image and body action by assessing the perception of aperture passability [23,57,58] Individuals were asked to estimate the chance to pass through different apertures. This passability judgment, based on a mental simulation [57], might be affected by a negative body image [57,58]. In our task, we stressed the implicit nature of the body-scaled action, avoiding any prior judgements before acting [33,41]. Moreover, we measured the on-line behavior of our participants, since spatial judgments might be influenced by different factors, such as effect of body weight on the perception of distance [59], as well as high-level cognitive deficits, described in individuals with obesity [60–62].

In the present study, we tested the behavior of female individuals. The different distribution of adipose tissue between males (android shape) and female (gynoid shape) [63–65] implies different postural stability and balance [66]. Furthermore, males and females, not only with obesity but also of healthy weight [67], report a different body image. Thus, the generalization of the present results independently from gender needs to be carefully evaluated.

An argument could be made that in the present experiment, the horizontal dimension of pelvis was used as a reference in order to scale the relative aperture width for each participant. Of course, the dimension of this part was significantly different between the two groups: thus, for female individuals affected by obesity, the pelvis represented the largest part compared to the shoulders; however, for healthy participants, the shoulders were larger than the pelvis. If we hypothesize that individuals determine their body rotation on the widest part of their body when crossing an aperture, in our experiment the body target would be different between groups (pelvis for the group with obesity; shoulder for the healthy group). A priori, we decided to scale the aperture referring to the pelvis, since both the clinical experience and the literature indicated that pelvis is enlarged in obesity more than other body parts. Considering this objective information as matter of fact, we adopted a more conservative strategy referring to the pathological group (people affected by obesity) than the healthy-weight group during the preparation of our experimental set-up. In fact, if the shoulders would be adopted as target, the aperture would scale referring to the largest body parts for the healthy individuals, but not for the participants affected by obesity (according to our results, in our sample, the pelvis was larger than the shoulders). Otherwise, if we had scaled the apertures referring to the largest body parts for each individual, the target would be different between participants, affecting the reliability of the experiment. Generally, previous studies in the field of obesity have focused on the range of motion of hip [52], pelvis [46], waist [47], and not shoulders, also when the performance was matched with healthy participants: this fact is due to the role of these body parts in determining the movement of individuals with larger body mass [46–49,52]. Finally, from a psychological point of view, pelvis (and not shoulders) is a sensitive body part in terms of negative emotions and feelings about size and shape [11,40,68]; thus, if body schema and body image interact [31–32], the emotional meaning related to specific body parts in the individual's experience would be taken in account. Future studies might clarify if scaling the aperture according to different body parts (not only in terms of physical extensions, but also in terms of psychological and emotional constraints) in the same individuals would affect the body motion.

In conclusion, studying the experience of an enlarged body size in obesity is still in the infancy stage. Future research could assess the role of emotion, cognition and perception (i.e. the body image) on body schema in obesity; it can simultaneously establish the efficacy of a rehabilitative approach based on multiple sensory inputs and their integration. Obesity is a growing global health issue, but since its complexity links medical, neuropsychological and psychopathologic dimensions, all these components have to be considered in the light of the possible outcome on more efficient interventions in rehabilitation and fall prevention [69].

References

[1] G. Cafri, J.K. Thompson, Measuring male body image: a review of the current methodology, Psychol. Men Masculinity 5 (1) (2004) 18–29, http://dx.doi.org/10. 1037/1524-9220.5.1.18.

[2] M.B. Schwartz, K.D. Brownell, Obesity and body image, Body Image 1 (1) (2004) 43–56.

[3] F. De Vignemont, Body schema and body image—pros and cons, Neuropsychologia 48 (3) (2010) 669–680, http://dx.doi.org/10.1016/j.neuropsychologia.2009.09.022.

[4] G. Riva, M. Bacchetta, G. Cesa, S. Conti, G. Castelnuovo, F. Mantovani, E. Molinari, Is severe obesity a form of addiction? Rationale, clinical approach, and controlled clinical trial, Cyberpsychol. Behav. 9 (4) (2006) 457–479, http://dx.doi.org/10. 1089/cpb.2006.9.457.

[5] G. Castelnuovo, G.M. Manzoni, P. Cuzziol, G. Cesa, C. Tuzzi, V. Villa, et al., TECNOB: study design of a randomized controlled trial of a multidisciplinary telecare intervention for obese patients with type-2 diabetes, BMC Public Health 10 (2010) 204, http://dx.doi.org/10.1186/1471-2458-10-204.

[6] M. Cernelic-Bizjak, Z. Jenko-Pražnikar, Impact of negative cognitions about body image on inflammatory status in relation to health, Health Psychol. 29 (3) (2014) 264–278, http://dx.doi.org/10.1080/08870446.2013.844807.

[7] R.M. Gardner, V. Gallegos, R. Martinez, T. Espinoza, Mirror feedback and judgments of body size, J. Psychosom. Res. 33 (1989) 603–607.

[8] D.M. Garner, P.E. Garfinkel, H.C. Stancer, H. Moldofsky, Body image disturbance in anorexia nervosa and obesity, Psychosom. Med. 38 (1976) 327–336.

[9] J.K. Collins, P.J.V. Beaumont, S.W. Touyz, J. Krass, P. Thompson, T. Philips, Variability in body shape perception in anorexic, bulimic, obese, and control subjects, Int. J. Eat. Disord. 6 (1987) 633–638, http://dx.doi.org/10.1002/1098-108X (198709)6:5<633::AID-EAT2260060506>3.0.CO;2-U.

[10] A. Docteur, I. Urdapilleta, C. Defrance, J. Raison, Body perception and satisfaction in obese, severely obese, and normal weight female patients, Obesity 18 (2010) 1464–1465, http://dx.doi.org/10.1038/oby.2009.418.

[11] F. Scarpina, G. Castelnuovo, E. Molinari, Tactile mental body parts representation in obesity, Psychiatry Res. 220 (3) (2014) 960–969, http://dx.doi.org/10.1016/j.psychres.2014.08.020.

[12] C. Bell, S.W. Kirkpatrick, R.C. Rinn, Body image of anorexic, obese, and normal females, J. Clin. Psychol. 42 (1986) 431–439.

[13] G. Valtolina, Body-size estimation by obese subjects, Percept. Mot. Skills 86 (1998) 1363–1374.

[14] M. Peltonen, A.K. Lindroos, J.S. Torgerson, Musculoskeletal pain in the obese: a comparison with a general population and long-term changes after conventional and surgical obesity treatment, Pain 104 (3) (2003) 549–557, http://dx.doi.org/10. 1016/S0304-3959(03)00091-5.

[15] H.C. Hitt, R.C. McMillen, T. Thornton-Neaves, K. Koch, A.G. Cosby, Comorbidity of obesity and pain in a general population: results from the southern pain prevalence study, J. Pain 8 (5) (2007) 430–436, http://dx.doi.org/10.1016/j.jpain.2006.12. 003.

[16] T.J. Somers, A.A. Wren, F.J. Keefe, Understanding chronic pain in older adults: abdominal fat is where it is at, Pain 152 (1) (2011) 8–9, http://dx.doi.org/10.1016/ j.pain.2010.09.022.

[17] G. Miscio, G. Guastamacchia, A. Brunani, L. Priano, S. Baudo, A. Mauro, Obesity and peripheral neuropathy risk: a dangerous liaison, J. Peripher. Nerv. Syst. 10 (4) (2005) 354–358, http://dx.doi.org/10.1111/j.1085-9489.2005.00047.x.

[18] J.F. Gautier, K. Chen, A.D. Salbe, D. Bandy, R.E. Pratley, M. Heiman, et al., Differential brain responses to satiation in obese and lean men, Diabetes 49 (2000) 838–846.

[19] M.I. Park, M. Camilleri, Gastric motor and sensory functions in obesity, Obes. Res. 13 (2005) 491–500, http://dx.doi.org/10.1038/oby.2005.51.

[20] X. Wan, C. Spence, B. Mu, X. Zhou, C. Ho, Assessing the benefits of multisensory audiotactile stimulation for overweight individuals, Exp. Brain Res. 232 (2014) 1085–1093, http://dx.doi.org/10.1007/s00221-013-3792-x.

[21] F. Scarpina, D. Migliorati, P. Marzullo, A. Mauro, M. Scacchi, M. Costantini, Altered multisensory temporal integration in obesity, Sci Rep 6 (2016) 28382, http://dx. doi.org/10.1038/srep28382.

[22] B. De Gelder, M. Tamietto, G. van Boxtel, R. Goebel, A. Sahraie, J. van den Stock, B.M. Stienen, L. Weiskrantz, A. Pegna, Intact navigation skills after bilateral loss of striate cortex, Curr. Biol. 18 (24) (2008) R1128–9, http://dx.doi.org/10.1016/j. cub.2008.11.002.

[23] J.K. Stefanucci, M.N. Geuss, Big people, little world: the body influences size perception, Perception 38 (12) (2009) 1782–1795, http://dx.doi.org/10.1068/p6437.

[24] T. Higuchi, K. Imanaka, A.E. Patla, Action-oriented representation of peripersonal and extrapersonal space: insights from manual and locomotor actions, Jpn. Psychol. Res. 48 (3) (2006) 126–140, http://dx.doi.org/10.1111/j.1468-5884.2006. 00314.x.

[25] N. Dominici, E. Daprati, D. Nico, G. Cappellini, Y.P. Ivanenko, F. Lacquaniti, Changes in the limb kinematics and walking-distance estimation after shank elongation: evidence for a locomotor body schema? J. Neurophysiol. 101 (3) (2009) 1419–1429, http://dx.doi.org/10.1152/jn.91165.2008.

[26] Y.P. Ivanenko, N. Dominici, E. Daprati, D. Nico, G. Cappellini, F. Lacquaniti, Locomotor body scheme, Hum. Mov. Sci. 30 (2) (2011) 341–351, http://dx.doi.org/ 10.1016/j.humov.2010.04.001.

[27] H. Head, H.G. Holmes, Sensory disturbances from cerebral lesions, Brain 34 (1911) 102–254.

[28] J. Paillard, Body schema and body image: a double dissociation in deafferented patients, in: G.N. Gautchev, G.N. Mori, S.J. Massion (Eds.), Motor Control, Today and Tomorrow, Academic Publishing House, Sofia, 1999, pp. 197–214.

[29] S. Gallagher, How the Body Shapes the Mind, Oxford University Press, Oxford, New York, 2005.

[30] S. Gallagher, J. Cole, Body image and body schema in a deafferented subject, JMB 16 (4) (1995) 369–389.

[31] H.C. Dijkerman, E.H. de Haan, Somatosensory processes subserving perception and action, Behav. Brain Sci. 30 (2) (2007) 189–201, http://dx.doi.org/10.1017/ S0140525X07001392.

[32] A. Sedda, F. Scarpina, Dorsal and ventral streams across sensory modalities, Neurosci. Bull. 28 (3) (2012) 291–300, http://dx.doi.org/10.1007/s12264-012-1223-9.

[33] A. Keizer, M.A. Smeets, H.C. Dijkerman, S.A. Uzunbajakau, A. van Elburg, A. Postma, Too fat to fit through the door: first evidence for disturbed body-scaledaction in anorexia nervosa during locomotion, PLoS One 8 (5) (2013) e64602, http://dx.doi.org/10.1371/journal.pone.0064602.

[34] W.H. Warren, S. Whang, Visual guidance of walking through apertures: body-scaled information for affordances, J. Exp. Psychol. 13 (1987) 371–378.

[35] American Psychiatric Association, Diagnostic and Statistical Manual of Mental Disorders, 5th ed., American Psychiatric Publishing, Arlington, VA, 2013.

[36] D.M. Gamer, Eating Disorder Inventory-2 Professional Manual, Psychological Assessment Resources, Odessa, 1991.

[37] J. Gormally, S. Black, S. Daston, D. Rardin, The assessment of binge eating severity among obese persons, Addict. Behav. 7 (1) (1982) 47–55, http://dx.doi.org/10. 1016/0306-4603(82)90024-7.

[38] K.A. Beals, M.M. Manore, Behavioral, psychological, and physical characteristics of female athletes with subclinical eating disorders, Int. J. Sport Nutr. Exerc. Metab. 10 (2) (2000) 128–143.

[39] M. Cuzzolaro, G. Vetrone, G. Marano, P.E. Garfinkel, The Body Uneasiness Test (BUT): development and validation of a new body image assessment scale, Eat. Weight Disord. 11 (1) (2006) 1–13.

[40] M.A.M. Smeets, I. Klugkist, S. van Rooden, H. Anema, A. Postma, Mental body distance comparison: a tool for assessing clinical disturbances in visual body image, Acta Psychol. 132 (2009) 157–165, http://dx.doi.org/10.1016/j.actpsy.2009.03. 011.

[41] A. Keizer, S.E. De Bruijn, M.A. Smeets, H.C. Dijkerman, A. Postma, Walking through apertures: do you know what you are doing during body-scaled action? Perception 42 (5) (2013) 583–585, http://dx.doi.org/10.1068/p7484. [42] C. Vercellis, Business Intelligence, McGraw-Hill, Milano, 2006.

[43] R.A. Johnson, Probabilità e statistica per Ingegneria e Scienze, Pearson, London, 2007.

[44] L. Vismara, M. Romei, M. Galli, A. Montesano, G. Baccalaro, M. Crivellini, G. Grugni, Clinical implications of gait analysis in the rehabilitation of adult patients with "Prader-Willi" Syndrome: a cross-sectional comparative study ("Prader- Willi" Syndrome vs matched obese patients and healthy subjects), J. Neuroeng. Rehabil. 4 (2007) 14, http://dx.doi.org/10.1186/1743-0003-4-14.

[45] V. Cimolin, L. Vismara, M. Galli, F. Zaina, S. Negrini, P. Capodaglio, 61. Effects of obesity and chronic low back pain on gait, J. Neuroeng. Rehabil. 8 (55) (2011), http://dx.doi.org/10.1186/1743-0003-8-55.

[46] Z.F. Lerner, W.J. Board, R.C. Browning, Effects of obesity on lower extremity muscle function during walking at two speeds, Gait Posture 39 (2014) 978–984.

[47] S.V. Gill, The impact of weight classification on safety: timing steps to adapt to external constraints, J. Musculoskelet. Neuronal Interact. 15 (2015) 103–108.

[48] P. Devita, P. Rider, T. Hortobagyi, Reductions in knee joint forces with weight loss are attenuated by gait adaptations in class III obesity, Gait Posture 45 (2016) 25–30.

[49] S.V. Gill, M.K. Walsh, J.A. Pratt, N. Toosizadeh, B. Najafi, T.G. Travison, Changes in spatio-temporal gait patterns during flat ground walking and obstacle crossing one year after bariatric surgery, Surg. Obes. Other Relat. Dis. 12 (2016) 1080–1085, http://dx.doi.org/10.1016/j.soard.2016.03.029.

[50] S.V. Gill, G. Hicks, Y. Zhang, J. Niu, C.M. Apovian, D.K. White, The association of waist circumference with community walking ability in knee osteoarthritis: the osteoarthritis initiative, Osteoarthr. Cartil. 25 (2017) 60–66.

[52] R.C. Browning, R. Kram, Effects of obesity on the biomechanics of walking at different speeds, Med. Sci. Sports Exerc. 39 (9) (2007) 1632–1641, http://dx.doi.org/ 10.1249/mss.0b013e318076b54b.

[53] A.P. Hills, E.M. Hennig, N.M. Byrne, J.R. Steele, The biomechanics of adiposity–structural and functional limitations of obesity and implications for movement, Obes. Rev. 3 (2002) 35–43.

[54] D.G. Bruce, A. Devine, R.L. Prince, Recreational physical activity levels in healthy older women: the importance of fear of falling, J. Am. Geriatr. Soc. 50 (1) (2002) 84–89, http://dx.doi.org/10.1046/j.1532-5415.2002.50012.x.

[56] F.C. Martin, D. Hart, T. Spector, D.V. Doyle, D. Hararu, Fear of falling limiting activity in young-old women is associated with reduced functional mobility rather than psychological factors, Age Ageing 34 (3) (2005) 281–287, http://dx.doi.org/ 10.1093/ageing/afi074.

[57] D. Guardia, G. Lafargue, P. Thomas, V. Dodin, O. Cottencin, M. Luyat, Anticipation of body-scaled action is modified in anorexia nervosa, Neuropsychologia 48 (13) (2010) 3961–3966, http://dx.doi.org/10.1016/j.neuropsychologia.2010.09.004.

[58] D. Guardia, M. Metral, M. Pigeyre, I. Bauwens, O. Cottencin, M. Luyat, Body distortions after massive weight loss: lack of updating of the body schema hypothesis, Eat. Weight Disord. 18 (3) (2013) 333–336, http://dx.doi.org/10.1007/s40519- 013-0032-0.

[59] M. Sugovic, P. Turk, J.K. Witt, Perceived distance and obesity: It's what you weigh, not what you think, Acta Psychol. 165 (2016) 1–8, http://dx.doi.org/10.1016/j. actpsy.2016.01.012.

[60] E. van den Berg, R.P. Kloppenborg, R.P. Kessels, L.J. Kappelle, G.J. Biessels, Type 2 diabetes mellitus, hypertension, dyslipidemia and obesity: a systematic comparison of their impact on cognition, Biochim. Biophys. Acta 792 (5) (2009) 470–481, http://dx.doi.org/10.1016/j.bbadis.2008.09.004.

[61] C. Prickett, L. Brennan, R. Stolwyk, Examining the relationship between obesity and cognitive function: a systematic literature review, Obes. Res. Clin. Pract. 9 (2) (2015) 93–113, http://dx.doi.org/10.1016/j.orcp.2014.05.001.

[62] A. Singh-Manoux, S. Czernichow, A. Elbaz, A. Dugravot, S. Sabia, G. Hagger-Johnson, et al., Obesity phenotypes in midlife and cognition in early old age: the Whitehall II cohort study, Neurology 79 (8) (2012) 755–762, http://dx.doi.org/10. 1212/WNL.0b013e3182661f63.

[63] D.D. Stallone, A.J. Stunkard, T.A. Wadden, G.D. Foster, J. Boorstein, P. Arger, Weight loss and body fat distribution: a feasibility study using computed tomography, Int. J. Obes. 15 (11) (1991) 775–780.

[64] R.I. Harik-Khan, R.A. Wise, J.L. Fleg, The effect of gender on the relationship between body fat distribution and lung function, J. Clin. Epidemiol. 54 (4) (2001 Apr) 399–406.

[65] R. Vettor, G. De Pergola, C. Pagano, P. Englaro, E. Laudadio, F. Giorgino, W.F. Blum, R. Giorgino, G. Federspil, Gender differences in serum leptin in obese people: relationships with testosterone, body fat distribution and insulin sensitivity, Eur. J. Clin. Investig. 27 (12) (1997) 1016–1024.

[66] F. Menegoni, M. Galli, E. Tacchini, L. Vismara, M. Cavigioli, P. Capodaglio, Genderspecific effect of obesity on balance, Obesity 17 (10) (2009) 1951–1956, http://dx. doi.org/10.1038/oby.2009.82.

[67] S. Grogan, Body image, Understanding Body Dissatisfaction in Men, Women, and Children, 2nd ed., Taylor & Francis e-Library, New York, 2008.

[68] E. Molinari, Body-size estimation in anorexia nervosa, Percept. Mot. Skills 81 (1995) 23–31.

[69] S. Corna, V. Aspesi, N. Cau, F. Scarpina, N. Gattini Valdés, L. Brugliera, V. Cimolin, P. Capodaglio, Dizziness and falls in obese inpatients undergoing metabolic rehabilitation, PLoS One (2017) e0169322, http://dx.doi.org/10.1371/journal.pone. 0169322.