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Running Head: Neural Bases of Body Image Distortion

Title: **Distinct contributions of Extrastriate Body Area and Temporoparietal Junction in perceiving one's own and others' body.**

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Abstract: The right temporo-parietal cortex plays a critical role in body representation. Here, we applied repetitive transcranial magnetic stimulation (rTMS) over right extrastriate body area (EBA) and temporo-parietal junction (TPJ) to investigate their causative role in perceptual representations of one's own and others' body. Healthy women adjusted size-distorted pictures of their own body or of the body of another person according to how they perceived the body (subjective task) or others perceived it (intersubjective task). In keeping with previous reports, at baseline, we found an overall underestimation of body size. Crucially, EBA-rTMS increased the underestimation bias when participants adjusted the images according to how others perceived their own or the participant's body, suggesting a specific role of EBA in allocentric body representations. Conversely, TPJ-rTMS increased the underestimation bias when participants adjusted the body of another person, either a familiar other or a close friend, in both subjective and intersubjective tasks, suggesting an involvement of TPJ in representing others' body. These effects were body-specific since no TMS-induced modulation was observed when participants judged a familiar object. Results suggest that right EBA and TPJ play active and complimentary roles in the complex interaction between the perceptions of one's own and other-people body.

Keywords: body image; eating disorders; temporoparietal junction; extrastriate body area; transcranial magnetic stimulation.

Introduction

The importance of having a slim body shape is a pervasive idea in Western societies leading to judge thinner women as more attractive (Brown et al. 2011). This sociocultural pressure for extreme thinness may affect the well-being of women and play a major role in the development of body image disturbance in eating disorder (ED) patients (Rivadeneyra, Ward & Gordon, 2007; Fernandez & Pritchard, 2012; Mele, Cazzato & Urgesi, 2013). Body image disturbance is thought to be a multifaceted phenomenon, likely to depend on perceptual, affective, and behavioural components (Thompson, 2004). The perceptual component refers to the mental representation of one's own body and often denotes body distortion, such as body size overestimation. On the other hand, the affective component of body image disturbance comprises negative attitudes and emotions towards one's own body, which in turn can also affect how people behave, leading them, for instance, to avoid situations in which the body becomes the focus of attention.

Several neuroimaging studies have tried to evaluate the neural correlates of one or multiple components of body image disturbance in healthy and ED women (e.g., Friederich et al., 2010; Miyake et al., 2010; Mohr et al., 2010). Miyake et al. (2010) investigated the neural correlates of body image perception in patients with anorexia nervosa (AN) or bulimia nervosa (BN) and in healthy women, examining the cerebral responses to presentation of morphed pictures of the participant's and another woman's body. In response to distorted fat body pictures, as compared to undistorted, the authors reported increased activation of the amygdala, prefrontal cortex and right fusiform gyrus in all groups of participants. In a similar vein, Uher and colleagues (2005) presented adult AN, BN, and healthy women with line drawings resembling female bodies. Both groups of ED patients exhibited lower activation in the inferior parietal lobule compared to healthy controls. This effect was even stronger in participants with AN as compared to those with BN. Furthermore, the authors found weaker activation for AN than BN patients in the *extrastriate body area* (EBA), an area of the lateral occipito-temporal cortex that is selectively involved in visual perception of human bodies (Downing et al., 2001; Urgesi et al., 2004, Urgesi, Calvo-Merino et al., 2007; Urgesi, Candidi et al., 2007; Costantini et al., 2011; Moro et al., 2008). In keeping with these findings, Suchan et al. (2010; 2013) documented structural and functional alterations of EBA in AN patients, which might be related to their altered body perception (Urgesi et al., 2012, 2013). Thus, mounting evidence points to EBA as a critical area of a neural network whose alteration may underlie body image distortions in ED patients.

Although these studies provide valuable information about the neuronal underpinnings of body image disturbance, several questions still remain unanswered. For instance, body image concerns not only how our own body subjectively appears to ourselves, but also how we believe it appears to others. As a consequence, body image distortion may also involve brain regions specialized in the intersubjective representation of the body, which refers to the ability to perceive one's own body as other people see it. Neuroimaging studies indicate that the right temporoparietal junction (TPJ) is involved in high-order processing of self-other relationship, such as theory of mind (Lawrence et al., 2006; Saxe & Wexler 2005), empathy (Jackson et al., 2006; Lamm, Batson & Decety, 2007), perspective-taking (Ruby & Decety, 2003), self-other distinction (Tsakiris, Costantini & Haggard, 2008; Uddin et al., 2006). Hence, the right TPJ might be specifically involved in telling apart self- and other-related representations, enabling the, possibly uniquely, human capacity to infer about others' affective and cognitive mental states (Saxe, 2006).

Disturbances in intersubjective representations of one's own body image may importantly contribute to body distortion in ED. Jansen and collaborators (2006) found that healthy controls rate themselves as more attractive as compared to how they are rated by other people, suggesting a positive 'self-serving bias' in body image. Conversely, the attractiveness ratings of their own body in ED individuals were comparable to those provided by other people, suggesting that ED patients might lack such 'self-serving' bias. Self-serving biases or positive illusions have been described for several cognitive domains in healthy individuals and are supposed to be useful for maintaining mental health and protecting from depression (Taylor & Brown, 1994). Therefore, while a positive body-image bias may be normal and protective in healthy individuals, the lack of it can contribute to body disturbances in ED (Alleva et al., 2013). Investigating the psychological processes and the neural mechanisms of how healthy and ED people perceive their own body in relation to others may contribute to the evaluation of body image disturbances in the manifestation of ED. Furthermore, this is also important for informing prevention and treatment models in women at risk of developing an ED.

The aim of the present study was to investigate the neural mechanisms of perceptual distortions for one's own or another person's body by means of repetitive transcranial magnetic stimulation (rTMS). The rTMS technique provides the unique opportunity of studying causal relationship between brain structures and behavior in healthy individuals, allowing to selectively interfere with a given brain area and investigate the effects on behavior; thus establishing whether the targeted area necessarily participates to a given function. Here, we applied such an approach to stimulate the neural areas that are activated by body perception and are possibly involved in body image disturbances. We used an off-line rTMS protocol to inhibit neural activity in EBA and TPJ and then we tested the stimulation effects on the subjective and intersubjective representations of the body. This rTMS protocol was combined with a new digital computer-based assessment method, namely the Body Image Revealer (BIR) (Mian & Gerbino, 2009), which was developed for clinical assessment of body image distortion in ED patients.

In two rTMS experiments, two groups of young women (University students) with no sign or history of ED were presented with size-distorted pictures (either shrunk or enlarged) of i) their own body; ii) the body of another familiar individual; and iii) of a familiar, non-corporeal object. In Experiment 1, we investigated the possible distortions of *Self*-body perception induced by rTMS interference with neural activity of EBA and TPJ. Using the "up" or "down" arrow keys of the computer keyboard, participants were requested to increase or decrease, respectively, the width of the image of their own body until it corresponded to: a) how they perceive it (subjective task); b) how others perceive it (intersubjective task). It is worth noting that, while in the subjective task the subject of perception corresponded to the target model ('I see me'), the intersubjective task was characterized by incongruence between the subject and the target of the perception ('Others see me').

Subjective and intersubjective perceptual representations differed for source of knowledge that was used to construct them, since we get evidence of our own body-figure mainly by looking at our mirror reflection or by looking pictures, while others have direct perception of our body figure (see Figure 1). They also differ for the perspective that is assumed in the perceptual representation, which is egocentric or allocentric in subjective and intersubjective representations, respectively.

An opposite pattern, however, occurs when we represent the body of other individuals: in this case, subjective perceptual representations, in which a subject perceives his/her own body, requires an allocentric perspective, since we must represent how the other subject takes evidence of his/her body figure. Conversely, people have direct perceptual evidence of the body of another person, and thus they assume an egocentric perspective with regards to the intersubjective representation of it. To control for these effects, in the control condition of experiment 1 we asked our participants to adjust the body image of a familiar woman according to a subjective ('how she sees herself') or intersubjective ('how I see her') perceptual representation. This allowed us to adopt a factorial manipulation of the object of the perceptual representation (Self vs. Other body) and of its subjective or intersubjective nature. The interaction between these two factors also allowed controlling for the role of representational perspective; that is egocentric (i.e., the point of view of the participant) in the subjective self-body task and in the intersubjective other-body task, and allocentric (i.e., the point of view of others) in the intersubjective self-body task and in the subjective other-body task. Crucially, in Experiment 1 we also tested whether the intersubjective representation of the body was influenced by the affective relationship with others and, thus, we asked two different groups of participants to adjust the body of a friend or a familiar woman (without friend relationship). Moreover, in Experiment 2, a familiar object (i.e., coke bottle) was presented to test whether any perceptual distortion was specific to bodily-related information or also extended to non-corporeal objects. Finally, an additional control experiment was conducted to investigate the influence of the distortion level from which participants start to adjust their own and others' body image and the object picture. The task procedure in this experiment was identical to the other experiments, except that the body/object distortion levels presented at the beginning of the trials varied randomly rather than being at fixed positive or negative extremes. Crucially, by means of self-report questionnaires we further investigated the cognitive strategies adopted during the tasks, thus checking whether participants were actually assuming different representational perspectives (i.e., perceptual vs. metacognitive) when they judged self and other's body-targets according to subjective or intersubjective perspective.

----------------------------------Please Insert Figure 1 about here ---------------------------------

We tested only female participants given the higher incidence of ED among women, as compared to men, and the high vulnerability of women to suffer from dysfunctional body images. In all experiments, the tasks were performed in a baseline session (no-rTMS) and after rTMS of right EBA (EBA-rTMS) and TPJ (TPJ-rTMS). We focused on right hemisphere areas, since previous studies have reported higher selectivity for body stimuli in the right than left EBA (Aleong & Paus, 2010; Downing, Wiggett & Peelen, 2007; Downing, Chan et al., 2006; Downing, Peelen et al., 2006). In a similar vein, the critical role of the right TPJ in various aspects of social cognition has been documented by several studies (for a comprehensive review see: Decety & Lamm, 2007). In line with previous reports (Vocks et al., 2007; Jansen et al., 2006), at the baseline assessment, we expected to find an underestimation bias during judgments of the body image, but not for object. Furthermore, we expected that, given the critical role in EBA in the visual perception of body-related information, independently from the individual's identity (Hodzic, Kaas et al., 2009; Hodzic, Muckli et al., 2009), inhibiting activity in this area would increase perceptual errors in evaluating the size of both one's own and or the other person's bodies. On the other hand, given the role of TPJ in self-other distinction (Uddin et al., 2006; Heinisch, Krüger & Brüne, 2012), we expected that disrupting activity in the right TPJ may affect differentially the perception of one's own or the other person's body, and especially for the intersubjective component of body image. Finally, we anticipated that rTMS over EBA and TPJ would only affect the judgements related to body images, but not those related to non-corporeal objects.

Methods

Participants

A total of sixty-six female participants were recruited from the student population of the University of Udine and from the local community by word of mouth. Two groups of sixteen healthy women participated in Experiment 1 (Group 1, aged 20-26 years; Group 2, aged 19-29 years); a further group of seventeen healthy women aged 19-23 years (Group 3) participated in Experiment 2. Finally, a group of seventeen healthy women aged 20-27 years (Control Group, Group 4) participated in the additional control experiment. None of the participants took part in more than one experiment. Participants were naïve as to the purposes of the experiment and information about the experimental hypothesis was provided only after the experimental tests were completed. All participants, but two women respectively from Group 2 and Group 4, were right-handed as ascertained by means of a Standard Handedness Inventory (Briggs & Nebes, 1975). They were all native Italian speakers. All participants reported normal or corrected to normal vision and they were all in good health, free of psychotropic or vasoactive medication, with no past history of psychiatric or neurological disease and with no contraindication to TMS (Rossi et al., 2009). Moreover, at the end of the experiment participants completed a series of self-report standard clinical scales, namely the Body Shape Questionnaire (BSQ-34, Cooper et al., 1987), the Eating Disorder Inventory (EDI-2, Garner, 1984) and the Body Attitude Test (BAT-20, Probst et al., 1995). This allowed us to eventually exclude participants showing positive symptoms of ED or body image disturbance (no participant was excluded for this criterion). Furthermore, we estimated participants' body mass index (BMI) from self-report measures of weight (Kg) and height (cm). The participants' demographics and self-report questionnaire scores for the four groups separately are reported in Table 1. Participants of the four groups were matched for age

[F(3,61) = 0.631, p = 0.598; η_p^2= 0.03], weight [F(3,61) = 0.479, p = 0.369; η_p^2= 0.04], height [F(3,61) = 0.808, p = 0.494; η_p^2= 0.038] and BMI [F(3,61) = 1.84, p = 0.149; η_p^2= 0.083]. Participants gave their written informed consent and the procedures were approved by the ethics committee of the Scientific Institute (IRCCS) “E. Medea” and were in accordance with the ethical standards of the 1964 Declaration of Helsinki.

----------------------------Please Insert Table 1 about here -----------------------------

Body distortion technique

We adopted a digital computer-based optical distortion method, namely Body Image Revealer (BIR) (Mian & Gerbino, 2009), aiming at assessing body image distortion in women. Such a procedure has high ecological validity since it simulates in an experimental and controlled setting the experience of looking at our own body in the mirror. In a first step, we took a picture with a digital camera (Canon PoweShot A400 camera in portrait orientation and with the automatic flash setting) of: i) the participant’s body, ii) the body of a young female University employee who was familiar to all participants (Experiment 1, Group 1) or the body of a paired friend (Experiment 1, Group 2), iii) a coke bottle (Experiment 2). All pictures were taken from a frontal perspective. The camera was set at 4.5 m distance from the person and at 1.5 m from the bottle, and the zoom setting was adjusted so that 2 m in height for the body pictures and 22 cm in height for the bottle filled the vertical dimension of the picture. The pictures of the participants’ and model woman’s body were taken while they were standing in front of a gray wall in a standardized pose (standing upright, with the arms spread horizontally and the feet closed adjacent to the wall), so that the picture showed the participant’s whole body. The size of the pictures was 768 × 583 pixels and they were displayed on the screen of a laptop computer using the BIR distortion program to scale the picture along the horizontal axis. The software is designed to jointly and realistically manipulate different body parts (shoulder, chest, belly, hips and thighs) leaving the surrounding environment unchanged, but it can be also used for manipulation of other objects. The face was also presented to improve the ecological validity of the test and to reinforce the self- vs. other's body identification during task performance.

At the beginning of each trial the picture was shown with maximal distortion level at the lower (slimmer) or upper (larger) extreme. By pressing the 'up' or 'down' key, participants could adjust the width of the body/object model, thus making it to appear larger or narrower. The range of possible distortion was set at ± 50% (see Figure 2)**.** A value of 0% indicates the original model size; negative values indicate a distortion towards a slimmer figure and positive values indicate a distortion towards a larger figure with respect to the actual size of the model. Each key-press corresponded to a distortion change of ±1%. Participants could adjust the degree of distortion of the picture as much as they wanted, increasing or decreasing the level of distortion until they confirmed their choice by pressing the 'Enter' key when they thought that the current adjustment represented the best answer to the task question. No time limits were given for responding, but participants were invited to respond on the basis of their first impression, avoiding to recursively wonder about their choice. The dependent variable was the difference between the models' real size and the participants' response. The value (in %) corresponding to the final level of distortion for the body (body distortion score, BDS) or the object (object distortion score, ODS) models was automatically saved on a computer for offline analysis.

-----------------------------------Please Insert Figure 2 about here ---------------------------------

Task procedure

During the experimental session, participants sat at 57 cm in front of a 15-inch LCD monitor (resolution: 1.024 × 768 pixels; refresh frequency: 60 Hz). Stimuli appeared at the center of the monitor on a black background and subtended a 13.5° × 17.94° region. In Experiment 1, participants were asked to adjust the image of their body accordingly to two tasks. One task assessed the participant's subjective representation of her owns body (*Self-body)* by asking her to adjust the image answering to the question: 'How do you see yourself?' The other task assessed the intersubjective component of body representation by asking the participant: 'How do others see you?' The two tasks were also performed by asking participants to adjust another woman's body image accordingly to a subjective ('How does she see herself?') or intersubjective perceptual representation ('How do you see her?'). Participants assigned to Group 1 performed the tasks on the body image of a familiar woman (a well-known University employee; BMI: 20.08 kg/cm^2; age: 32 years); the body image of the same individual was presented to all the participants of Group 1. Conversely, Group 2 was composed of 8 couples of friends; both of them performed the subjective and intersubjective tasks for their body image and for that of their paired friend on the same day. This way, the same stimulus served as 'self-body' image for one participant and as 'other-body' image for the other participant of each pair. Finally, in Experiment 2, in order to control that any rTMS effects were specific for body images and did not generalize to non-bodily objects, we asked participants to adjust a picture of a well-known object, i.e. a Coke bottle. As for the previous experiments, participants performed the tasks by answering to the following questions: 'How do you see it?' for the subjective task and 'How do others see it?' for the intersubjective task. During the experimental session, two blocks of 6 trials were presented for each task and model in each stimulation condition (no-rTMS, EBA, TPJ) for a total of 144 trials in Experiment 1 and 72 trials in Experiment 2. Block order was balanced according to a Latin square procedure (ABBA). This way, the order of tasks (subjective and intersubjective) for both experiments and that of the body-target (Self, Other) in Experiment 1 was counterbalanced across participants. Furthermore, the initial distortion level of the image presented at the beginning of each trial (either -50% slimmer or +50% larger) was randomized in each block.

Transcranial Magnetic Stimulation

Off-line rTMS was applied with a Magstim Rapid stimulator (Magstim Co., Whitland, UK) connected with an eight-shaped air-cooled coil (outer diameter of each wing, 7 cm). Participants performed the behavioral tasks soon after 15 min of low frequency (1 Hz; 900 pulses) rTMS. In different sessions, the coil was positioned over the right EBA and TPJ, while a no-rTMS condition, in which participants performed the tasks without rTMS, served as baseline. Since we used an off-line paradigm in which rTMS is delivered before performing the task, no auditory or tactile sensorial effects can influence performance in either rTMS or no-rTMS conditions. Thus, as our design was aimed at dissociating the effects of EBA- and TPJ-rTMS, we chose a no-rTMS control condition (rather than, e.g., vertex rTMS) in order to ensure having a clear estimation of baseline performance in the tasks. The location of the primary motor cortex "hot spot" for activating muscles of the right hand was determined prior to the main experiment. This was achieved by trial and error exploration relative to its typical location, with single-pulse TMS applied at a low rate <0.2 Hz. The rMT was defined as the lowest stimulus intensity able to evoke 5 of 10 motor-evoked potentials with amplitude of at least 50 μV. The rMT values ranged from 45% to 75% (57.44 ± 2.03 %) of the maximum stimulator output in Group 1, from 45% to 70% (56.94 ± 2.25 %) in Group 2 and from 43% to 70% (57 ± 1.64 %) in Group 3, with no significant differences among the three groups [$F(2,46) = 0.019$, $p = 0.981$; $\eta_p^2 = 0.001$]. During rTMS of both right EBA and

TPJ, we set the stimulator output at an intensity of 90% of the individual rMT. Although there is no clear relation between the intensities needed to stimulate the motor and visual cortices, we set the stimulation intensity on the basis of the rMT since this is considered as a safety procedure to reduce the possible discomfort and adverse effects of rTMS (Rossi et al., 2009) and diffusion of neural alteration to distant sites (Speer et al., 2003). Hence, we decided to estimate the rMT on the safe side by recording from the dominant hand (with left hemisphere stimulation in most participants), which was expected to provide lower and more reliable rMT values as compared to non-dominant hand muscles. The coordinates in the Talairach space (Talairach & Tournoux, 1988) of the stimulation sites for right EBA were: $x = 52$, $y = -72$, $z = 2$ and were taken from previous rTMS studies on the role of right EBA in visual body perception (Urgesi et al. 2004, Urgesi, Calvo-Merino et al., 2007; Urgesi, Candidi et al., 2007). The coordinates for right TPJ were: $x = 63$, $y = -50$, $z = 23$ and were taken from a previous rTMS study on the role of right TPJ in maintaining a coherent sense of the body (Tsakiris et al., 2008). The scalp positions corresponding to these areas (see Figure 3) were identified for each participant with the SofTaxic Optic neuronavigation system (Electro Medical Systems, Bologna, Italy; www.softaxic.com). Skull landmarks (nasion, inion, and two preauricular points) and 60 points providing a uniform representation of the scalp were digitized by means of a Polaris Vicra optical tracking system (Northern Digital, Inc., Waterloo, Ontario, Canada). The SofTaxic Otpic system allowed us to automatically estimate the coordinates in standard space from an MRI-constructed stereotaxic template and to monitor on-line the position of the coil focus over the target positions during stimulation. The coil was placed over and securely held tangentially to the scalp by means of a coil holder with the handle pointing backward. Immediately after the end of the rTMS train over right EBA and right TPJ, participants performed the two tasks for each model. Performing the different tasks had a maximal duration of about 10 min in Experiment 1 and 5 min in

Experiment 2, thus being within the time limit of the estimated effects of a 15-min, 1-Hz rTMS stimulation protocol (Chen, 1997). A rest of at least 60 min was allowed before proceeding to the next stimulation condition. This ensured us that any residual effect of rTMS had faded away (Avenanti et al., 2012; Marini & Urgesi, 2012). The order of the three stimulation conditions was balanced between subjects. No painful sensations or adverse effects during rTMS were reported or noticed, and no participants asked to interrupt the stimulation protocol for any major discomfort induced by the facial muscular twitches evoked by rTMS.

----------------------------------Please Insert Figure 3 about here ---------------------------------

Post-experimental manipulation check

To verify that the participants of Group 1, Group 3 were familiar with the model woman or object, respectively, at the end of the experimental session we asked them to position the computer mouse along a 100 mm Visual Analogue Scale (VAS) to provide a series of judgments on the model. Participants of Experiment 1 were requested to report: i) ‘How well do you know her personally?’ (0 = I do not know her at all/ 100 = I know her very well); and ii) ‘How often have you seen her so far’ (0 = I have never seen her before / 100 = I have often seen her). In addition, participants estimated the age, weight and height of the model woman. According to the mean VAS values, participants of Group 1 reported to have previously seen the university employee with a mean value of 70.94 (± 5.35), but to know her personally with a mean value of 13.63 (± 3.73). Furthermore, they correctly estimated her weight (53.19 ± 1.1 kg vs. 54 kg, $t(15) = -0.74$, $p = 0.47$), height (1.64 ± 0.01 m vs. 1.64 m, $t(15) = -0.6$, $p = 0.56$) and age (33.44 ± 1.16 years vs. 32 years, $t(15) = 1.24$, $p = 0.23$). Thus, as compared to the friend pairs of Group 2, who know each other very well and had every day contact since they were university colleagues, participants of Group 1 had visual familiarity with the model and demonstrated to know very well her body appearance, but had only limited personal contact. VAS ratings on the Coke bottle were collected from each participant at the end of the Experiment 2 using the following questions: i) 'How well do you know this bottle?' (0= I do not know it at all/ 100 = I know it very well); and ii) 'How often have you seen this bottle so far?' (0= I have never seen it before / 100 = I have often seen it). According to the mean familiarity VAS, participants from Experiment 2 reported to have had common everyday life experience with the coke bottle (46.71 ± 7.54) and to know it with a mean VAS score of 55.29 (± 7.72).

Control experiment

With the aim to ascertain whether participants' judgments were influenced by using a fixed maximal distortion (-50% slimmer or 50% fatter) at the beginning of each trial, we performed an additional control experiment using similar methods as in Experiment 1 and 2 but varying randomly the initial distortion level of the image presented at the beginning of each trial (from -20% to -50% slimmer or from 20% to 50% fatter). In different blocks, participants adjusted the image of their own body, of the body of a familiar woman (a well-known café employee; BMI: 20.32 kg/cm^2; age: 26 years) and of a coke bottle. As for the previous experiments, two blocks of 6 trials were presented for each task and model (Self/Other/Object) in no-TMS stimulation condition for a total of 72 trials. Block order was counterbalanced across participants. Furthermore, post-experimental manipulation checks about familiarity with the model woman and object (Coke bottle) were performed as in the previous experiments. Control participants reported to have previously seen the model with a mean value of 32.24 (± 6.05), but to know her personally with a mean value of 18.53 (± 4.24). Furthermore, they correctly estimated her weight (57.47 ± 1.13 kg vs. 56 kg, $t(16)$ =

1.3, $p = 0.213$), height (1.67 ± 0.01 m vs. 1.66 m, $t(16) = 0.49$, $p = 0.628$) and her age (26.41 ± 0.58 years vs. 26 years, $t(16) = 0.708$, $p = 0.489$). Therefore, in keeping with the judgements of Group 1 participants in Experiment 1, participants of the control experiment had visual familiarity with the model, but had only limited personal contact. Furthermore, according to the mean familiarity scale for the Coke bottle, control participants reported to have had common everyday life experience with the coke bottle (69.12 ± 5.53) and to know it with a mean score of 68.65 (± 7.01). Finally, to verify whether participants were spontaneously taking the perspective of another person according to task instructions, control participants were requested to provide a series of judgments (on a VAS scale ranging from 0: 'nothing at all' to 100: 'very much') on the cognitive strategy used during the subjective and inter-subjective tasks for their own and other's body images. The aim of this questionnaire was to unfold to what extent participants based their subjective and intersubjective judgements 1) on their own perceptual representation, thus performing the tasks according to how they see their own and other's body ('Strongly basing my judgments on the perception I have about *my/her* body') or 2) on metacognitive representation, thus trying to take the perspective of the other individual and putting themselves in the other woman's shoes to imagine how she sees the participant's body or her own body in front of a mirror ('Putting myself in the other person's shoes and imaging how she sees *my body from an external point of view/her body in front of a mirror*').

Data Handling

Statistical analyses were calculated with Stat Soft STATISTICA 8.0 (StatSoft Inc, Tulsa, Oklahoma). The BDS % or ODS % values were averaged for each individual across the trials of subjective and intersubjective tasks, for each target (Self vs. Other body, in Experiment 1; non-corporeal object, in Experiment 2) and each stimulation condition (12 trials per cell).

Trials associated with erroneous key presses (0.2%) were excluded from the analysis. In keeping with previous studies using similar body distortion techniques (e.g., Legenbauer et al., 2011), preliminary analyses including the initial distortion level (slimmer/larger) showed more negative BDS and ODS values when the initial picture depicted slimmer than larger distortion levels [all *F-values* > 19.724 and all *p-values* < 0.001]. However, this 'anchor effect' did not interact with stimulation site or other factors of the design and therefore was not included in further analyses [all *F*-values < 2.084 and all *p*-values > 0.168]**.** In Experiment 1, we tested whether stimulation of right EBA and TPJ, as compared to the no-rTMS condition, affected BDS when participants had to adjust not only their image, but also the image of another woman, who was either a familiar university employee or a paired friend. Thus, we performed a full-factor 4-way mixed-model ANOVA including rTMS condition (no-rTMS, EBA, TPJ), body-target (Self, Other) and type of judgments (subjective, intersubjective) as within-subjects factors and group (familiar woman, friend) as between-subjects factor. In Experiment 2 we tested whether the ODS values for the coke bottle were modulated by EBA- and TPJ-rTMS, as compared to the no-rTMS condition. Thus, we performed a 3×2 repeated-measure ANOVA with rTMS condition (no-rTMS, EBA, TPJ) and type of judgment (subjective, intersubjective) as within-subjects factors. In the control experiment, we tested the effects of variation of distortion level at the beginning of the trials and compared the results of the control group to that of Group 1 and Group 3 in the no-rTMS condition of Experiment 1 and 2, respectively, where a fixed initial distortion level was used. Thus, BDS scores were analysed by means of a 2×2×2 mixed-model ANOVA with body-target (self, other) and type of judgments (subjective, intersubjective) as within-subjects factors and group (Group 1, Control group) as between-subjects factor. Furthermore, a 2×2 mixed-model ANOVA with type of judgments (subjective, intersubjective) as within-subjects factors and group (Group 3, Control group) as between-subjects factor was performed on the

ODS. Finally, self-report questionnaires scores about perspective-taking strategies were analysed by means of a 2×2×2 repeated-measure ANOVA with body-target (Self, Other), type of judgments (subjective, intersubjective) and strategy (perceptual, metacognitive) as within-subjects factors. The source of all significant interactions was analyzed using the Duncan post-hoc test. A significance threshold of $p < 0.05$ was set for all effects. All data are reported as Mean (*M*) and Standard Error of the Mean (*s.e.m.*). Finally, we calculated, for each condition, a measure of the change of BDS and ODS as the difference between the individual values after rTMS of EBA and TPJ, on the one hand, and the corresponding values in the no-rTMS condition. The BDS and ODS change indexes were correlated, using Pearson correlations, with individual BMI values, age and scores of the psychological measures (BSQ-34, EDI-2, BAT-20). Separate analyses were conducted for each experiment. This allowed us to account for the potential contribution of BMI, age and body image disturbances and ED-related clinical dimensions to the experimental findings. Bonferroni correction procedure was used to correct for multiple analyses (17 variables were correlated with the BDS or ODS change indexes).

Results

Experiment 1

The visual inspection of the results suggested that participants tended to adjust both self and others' body pictures as slimmer than their actual dimensions (Figure 4). This was confirmed by the significance of the intercept [$F(1,30) = 22.691$, $p < 0.001$; $\eta_p^2 = 0.431$], showing that the BDS was significantly different from 0%, thus suggesting an overall bias towards the underestimation of body stimuli. The underestimation bias, however, was stronger for Other (-7.62 ± 1.44%) than for Self (-3.28 ± 1.18%) pictures, as shown by the significant main effect of body-target [$F(1,30) = 10.922$, $p = 0.002$; $\eta_p^2 = 0.267$]. The main effects of rTMS condition [$F(2,60) = 1.96$, $p = 0.15$; $\eta_p^2 = 0.061$], type of judgments [$F(1,30) = 1.851$, $p = 0.184$; $\eta_p^2 = 0.058$] and group [$F(1,30) = 0.06$, $p = 0.809$; $\eta_p^2 = 0.002$] were not significant, thus ruling out any non-specific effects of rTMS, type of judgments or group. Interestingly, the 2-way interaction between rTMS condition × body-target showed a trend toward significance [$F(2,60) = 2.95$, $p = 0.06$; $\eta_p^2 = 0.09$], further qualified by a significant 3-way interaction of rTMS condition × body-target × type of judgments [$F(2,60) = 4.758$, $p = 0.012$; $\eta_p^2 = 0.137$]. Figure 4 shows results from this 3-way interaction. Post-hoc comparisons revealed that, when participants were judging their own body image, for the subjective self-body judgments, no modulation was observed after both EBA- (-3.42 ± 1.35%) and TPJ-rTMS (-3 ± 1.31%) as compared to the no-rTMS condition (-3.14 ± 1.02%; all $ps > 0.501$). On the contrary, intersubjective self-body judgments were affected by rTMS over EBA (-4.14 ± 1.5%), because participants adjusted their image as slimmer in this condition as compared to the TPJ-rTMS (-3.26 ± 1.34%; $p = 0.034$) and no-rTMS (-2.72 ± 1.21 %; $p = 0.001$) conditions. This effect was selective for EBA-rTMS, since no differences were observed between the TPJ-rTMS and no-rTMS conditions ($p = 0.206$). On the other hand, when participants were judging the other person's body, post-hoc comparisons revealed that TPJ-rTMS (-8.48 ± 1.78%) impacted on subjective other-body judgments, increasing the underestimation bias with respect to EBA-rTMS (-7.14 ± 1.56%; $p = 0.002$) and no-rTMS conditions (-5.99 ± 1.56%; $p < 0.001$). However, the effect of TPJ-rTMS was not selective, since interfering with right EBA significantly increased the underestimation bias of subjective other-body judgments with respect to no-rTMS condition ($p = 0.004$). Furthermore, rTMS over TPJ (-9.14 ± 1.72%) specifically increased the underestimation bias for the intersubjective other-body judgments with respect to EBA-rTMS (-7.47 ± 1.45 %; $p < 0.001$) and no-rTMS conditions (-7.51 ± 1.41%; $p < 0.001$). This effect was selective for TPJ stimulation, since no difference was observed between EBA-rTMS and no-rTMS conditions (p = 0.925).

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The effects of rTMS on BDS were the same when participants had to perform the tasks with respect to a familiar person or a friend, as the 4-way interaction of rTMS condition × type of judgments × body-target × group was not significant [$F(2,60) = 0.152$, $p = 0.859$; $\eta_p^2 = 0.005$]. No other interaction with Group was significant, suggesting that participants did not differ in their ability to adjust their own body or the body of another woman depending on their social relationship with the other person (familiar woman vs. friend) and ruling out any spurious effect due to between-groups differences. Finally, the remaining effects were all non-significant with F-values < 2.37 and all p-values > 0.102.

No significant correlation was found between the BDS change indexes and the BMI, age and psychological measures for any type of judgments and body-target (-0.304 < all *rs* < 0.253). In a similar vein, the BDS change indexes were not related to the level of familiarity with the model person (i.e. familiar women) reported by the participants of Group 1 (-0.494 < all *r*s < 0.321).

To sum up, no effects of EBA- and TPJ-rTMS were obtained for the judgments of how the participants perceive their own body (subjective self-body judgments). In contrast, we found that rTMS of EBA increased the bias to underestimate how other individuals perceive the participant's body (intersubjective self-body judgments) and how the other woman perceives her own body (subjective other-body judgments). Interestingly, stimulation of TPJ affected both subjective and intersubjective judgments related to the representation of another person's body, but did not affect the representation of one's own body.

Experiment 2

In Experiment 2 we investigated whether rTMS over EBA and TPJ may distort the subjective and intersubjective representations of non-corporeal objects. Visual inspection of the results showed that a slight underestimation bias was present for the bottle image, but this was not confirmed statistically since the intercept was non-significant [$F(1,16) = 1.072$, $p = 0.316$; $\eta_p^2 = 0.063$], suggesting that the ODS values did not differ significantly from 0%. Furthermore, in striking contrast with the results of Experiment 1, the ANOVA on ODS revealed no significant effect of rTMS condition [$F(2,32) = 0.100$, $p = 0.905$; $\eta_p^2 = 0.006$] and type of judgments [$F(1,16) = 3.609$, $p = 0.076$; $\eta_p^2 = 0.184$] or their interaction [$F(2,32) = 0.676$, $p = 0.516$; $\eta_p^2 = 0.041$], suggesting that ODS values for both tasks were comparable in the EBA-, TPJ-, and in no-rTMS conditions (see Figure 5). Finally, there was no correlation between BMI, age and psychological measures (EDI-2, BSQ-34, BAT-20) and the ODS change index, both in the subjective ($-0.347 < \text{all } r\text{s} < 0.303$) and in the intersubjective ($-0.210 < \text{all } r\text{s} < 0.367$) judgments. There was no correlation between the ODS change index and the mean familiarity VAS about the coke bottle ($-0.323 < \text{all } r\text{s} < 0.391$).

In conclusion, Experiment 2 demonstrates that rTMS over EBA and TPJ did not interfere with the subjective and intersubjective representation of external objects, suggesting that these two brain regions are specifically involved in processing body-related information.

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Control Experiment

In keeping with the results of Experiment 1, the significance of the intercept [$F(1,31) = 13.801$, $p < 0.001$; $\eta_p^2 = 0.308$] showed that BDS in the control experiment was significantly different from 0%, thus suggesting an overall bias towards the underestimation of body stimuli. Furthermore, the main effects of body-target [$F(1,31) = 3.117$, $p = 0.087$; $\eta_p^2 = 0.091$], type of judgments [$F(1,31) = 0.805$, $p = 0.376$; $\eta_p^2 = 0.025$] and group [$F(1,31) = 0.981$, $p = 0.033$; $\eta_p^2 = 0.031$] were not significant, thus ruling out any non-specific effects of body-target, type of judgments or group. Crucially, the 2-way interaction of body-target × type of judgments resulted significant [$F(1,31) = 6.27$, $p = 0.018$; $\eta_p^2 = 0.168$]. Post-hoc comparisons revealed that, when participants were judging their own body image, no difference was observed between the two tasks (subjective task: -2.85 ± 1.14%; intersubjective task: -2.08 ± 1.14%, $p = 0.245$). On the contrary, when participants were judging the other woman's body, post-hoc comparisons revealed higher underestimation bias during the intersubjective (-5.65 ± 1.26%) than the subjective task (-4.06 ± 1.4%, $p = 0.026$). Crucially, modulation of BDS was comparable when participants had to perform the tasks with respect to a random or fixed distortion intervals, as the 3-way interaction of type of judgments × body-target × group [$F(1,31) = 0.089$, $p = 0.767$; $\eta_p^2 = 0.003$] or the other interactions with group (F-values < 2.814 and all p-values > 0.103) were not significant.

The 2-way type of judgments x group mixed-model ANOVA on ODS revealed neither a significant intercept [$F(1,32) = 2.195$, $p = 0.148$; $\eta_p^2 = 0.064$] nor significant effects of group and type of judgments [all F-values < 2.692 and all p-values > 0.111]. Thus, the distortion level (fixed vs. random) at the beginning of each trial did not affect the subjective and intersubjective representations of non-corporeal objects.

The analysis of the self-report questionnaire values revealed that the main effect of body-target, the 2-way interactions of body-target × strategy and that of type of judgments × strategy were all significant [all F-values > 4.384, all p-values < 0.053] and further qualified by a significant 3-way interaction of body-target × type of judgments × strategy [$F(1,16) = 21.916$, $p < 0.001$; $\eta_p^2 = 0.578$]. Figure 6 shows the results of this 3-way interaction. Post-hoc comparison revealed that when participants were requested to adjust size-distorted images of their own body no difference was observed between the subjective and the intersubjective tasks for both the perceptual (75.71 ± 5.36 vs. 62.65 ± 8.69, p = 0.294) and metacognitive strategies (42.06 ± 6.35 vs. 58.53 ± 7.88, p = 0.169). However, for subjective self-body judgments, participants used more a perceptual (75.71 ± 5.36) than a metacognitive strategy (42.06 ± 6.35, p = 0.016); to the opposite, no difference was observed between the two strategies when participants performed the self-body intersubjective task (62.65 ± 8.69 vs. 58.53 ± 7.88, p = 0.723). Interestingly, when participants adjusted the body image of another person, they reported to base judgments on their own perceptual experience more during the intersubjective than the subjective task (76.18 ± 5.15 vs. 32.06 ± 7.75, p = 0.003). On the contrary, participants reported to engage in metacognitive strategy more when they had to perform the subjective than the intersubjective (67.94 ± 6.36 vs. 34.71 ± 7.72, p = 0.017) other-body task. Furthermore, they reported greater use of the metacognitive than perceptual strategy during the other-body subjective task (67.94 ± 6.36 vs. 32.06 ± 7.75, p = 0.012); to the opposite, during the other-body intersubjective task participants reported to base their judgments more on perceptual than metacognitive strategy (76.18 ± 5.15 vs. 34.71 ± 7.72, p = 0.005).

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Discussion

The present study tested whether interfering with activity of EBA and TPJ in the right hemisphere prevents healthy women from correctly processing different components of their body image; namely how one's own body is perceived by the subject (subjective task) or by another individual (intersubjective task). One point of novelty of our study is that we investigated the neural bases of body image distortions by focusing not only on the representation of the participant's body, but also on the representation of another person's body. Participants were asked to adjust size-distorted pictures (either shrunk or enlarged) of the body of themselves or of another woman. Furthermore, to control for any unspecific biases in size estimation, in a second experiment participants were asked to adjust distorted pictures of an object, namely a Coke bottle. Additionally, a control experiment was carried out to check whether the initial distortion level for each trial might affect our results at baseline condition without stimulation and to confirm that participants were engaging different cognitive operations according to subjectivity and perceptual perspective.

We used a new computer-based assessment method that allowed us to present the model bodies or object as slimmer or larger with respect to their real appearance and to quantify how accurately participants adjusted the size of the displayed picture with or without interferential stimulation over EBA and TPJ. The main findings of the study were the following.

In Experiment 1, we found that interfering with right EBA activity by means of rTMS altered the intersubjective evaluation of one's own body; that is the way participants judge their body to be perceived by others. Furthermore, EBA-rTMS interfered with the subjective judgment of others' body image, i.e. the way participants judge another woman to perceive her own body. Therefore, interference with neural activity in right EBA affected the two tasks requiring an allocentric representation of either the participant's or the other model's body. Conversely, interferential rTMS over right TPJ selectively affected both subjective and intersubjective judgments when the target was another woman's body, but did not alter own body perception. The effect of rTMS over TPJ was the same when participants judged a body of a familiar person or that of a close friend. Thus, interference with neural activity in TPJ affected the two tasks requiring the representation of the other model's body, independently from subjectivity, perceptual perspective and social relationship. Furthermore, in Experiment 2, we found that these TMS effects were not generalized in any perceptual judgments, instead of being specific for body-related judgments, as rTMS over right EBA and TPJ did not alter the way participants perceive the shape of a coke bottle or judge how others perceive it. Finally, the control experiment not only demonstrated that the type of random vs. fixed distortion interval at the beginning of each trial did not affect our findings at baseline condition, but also that participants provided different size estimations according to subjectivity and body-target. Furthermore, these findings were strengthened by self-report questionnaires about perspective-taking strategies in which we found dissociation between the use of perceptual and metacognitive perspectives depending on type of judgments and body-targets. We will now consider each major finding and its implications in turn.

Body size underestimation bias in healthy women

In the baseline condition, without brain stimulation, when participants were asked to adjust the size of their own body image, they showed an underestimation bias for both subjective and intersubjective judgements. This result replicates the findings by Vocks and co-authors (2007), which also reported that healthy controls underestimate their body size. This effect might be ascribed to a 'self-serving bias', so that healthy individuals tend to represent themselves as thinner than how they actually are, and seems functional for preventing negative feelings and attitudes toward one's own body image (Jansen et al., 2006). However, participants from Experiment 1 showed a strong underestimation bias also for the other woman's body, which was even stronger than that for their body. Instead, no significant bias was found for the Coke bottle in Experiment 2. The fact that such underestimation bias concerns also the perception of the size of others' body, but not of external objects, is in accordance with the results of Mohr and co-authors (2007), who found a greater underestimation bias for another person's body than for the participant's own body. Their results are in keeping with our findings and show a tendency to perceive others as thinner than ourselves, which may likely contribute to body dissatisfaction in healthy women through unfavourable social comparison processes (Trampe, Stapel & Siero, 2007). It is worth noting that Mohr and colleagues (2007) also reported that unilateral presentation of self-body images into the left visual hemifield, which is projected first to the right hemisphere, resulted into an overestimation bias in women, but not in men. Conversely, no difference between men and women were noticed for non-corporeal objects (coke bottle), suggesting a selective role of right hemisphere areas in body image distortion in women.

An important finding of this study is that body size underestimation was found for both subjective and intersubjective representation of one's own and other's body, but not for non-corporeal objects, thus suggesting that it reflects general perceptuo-affective processes that are independent from the perspective and the target of the representation. Similar underestimation in the four tasks was not due to the use of self-referential heuristics according to which participants always judged their own and others' body on the basis of their direct perceptual experience (of their body). Indeed, when we inquired participants of the control experiment about the strategy used in the tasks, they reported to have changed the perceptual vs. metacognitive strategy according to whether they were judging their own or other's body. In particular, during self-body subjective and other-body intersubjective tasks participants reported to adjust the body image on the basis of their perceptual experience rather than on metacognitive processes. Conversely, during other's body subjective task, participants reported to put themselves in the woman's shoes and to imagine how she sees herself in front of a mirror rather than to base their judgments on the their own 'perceptual information. On the contrary, self-body intersubjective judgements involved the contribution of both perceptual and metacognitive strategies at the same extent.

In a similar vein, the analysis of the baseline BDS revealed that when participants were judging their own body image, no difference was observed between the two types of judgments. On the contrary, when participants were judging the other woman's body, higher underestimation bias was found for the intersubjective than the subjective task. All together, these results suggest that, not , participants tended to judge their own body image on the basis of their direct perceptual experience also when asked to report others' perspective, thus leading to comparable estimations in the subjective and intersubjective self-body task, although the relative weight of the perceptual strategy was stronger in the subjective than intersubjective self-body task. Conversely, the representation of others' bodies shows more clear modulation according to whether the participants assume a subjective vs. intersubjective perspective.

Role of EBA in body image distortion

In Experiment 1 we found that, when participants judged how others perceive their body, inhibition of right EBA selectively altered performance as compared to both right TPJ-rTMS and no-rTMS conditions. In particular, the underestimation effect increased after right EBA stimulation, showing an increase of the perceptual error in this condition. In the same vein, when participants adjusted the picture of another woman's body with respect to how they thought it appears to others, interfering with EBA activity increased the underestimation bias as compared to the no-rTMS condition. These results demonstrated that interfering with EBA activity leads to a change in perceiving a body from an allocentric perspective, both when the body belongs to oneself or to another person. Thus, EBA may be involved in basic aspects of body perception that affects the perceptual components of body representation. In keeping with this claim, previous studies have shown that right EBA, as compared to left EBA, is more activated by allocentric than egocentric views of human bodies and body parts (Chan, Peelen & Downing, 2004; Saxe, Jamal & Powell, 2006). The opposite pattern has been found in left EBA (Chan et al., 2004). Whereas this dissociation of responses between left and right EBA was interpreted as reflecting self-other distinction, the present results that rTMS over right EBA impairs the representation of both self- and other-body when viewed from an allocentric view suggests that perceptual perspective, rather than body identity, is the critical factor modulating the involvement of EBA in body perception.

Supporting evidence that EBA response to human bodies is dependent on the adopted visual perspective comes from an electroencephalographic study of body representation abilities (Arzy et al., 2006). Arzy and colleagues (2006) asked healthy participants to judge the laterality of a coloured hand on a schematic front- or back-facing human figure. In one condition, the participants were instructed to imagine that the human figure was their mirror reflection and to make the laterality judgement on the basis of direct perception of the figure. In another condition, participants were instructed to imagine being in the position of the figure and to make the laterality judgement from the perspective of the human-like figure. Using evoked potential mapping and distributed linear inverse solution techniques, the authors found that EBA and TPJ were activated in both conditions, but the spatial and temporal distribution of the activations depended on whether the task required or not the assumption of an external viewpoint. Thus, the interference induced by EBA-rTMS on how others perceive our body and their own bodies may reflect the specific role of EBA in coding allocentric body representations.

On the other hand, the results of our study clearly show that the involvement of EBA is not depending on the identity of the body, since its stimulation affected the allocentric representation of both self- and other-body image. Results from fMRI studies comparing EBA activations for viewing self-body images with respect to viewing images of others' body are still controversial. Hodzic and colleagues (2009) found no difference in right EBA, but a stronger response to self than others' bodies in left EBA and in the right Fusiform Body Area (FBA), which is considered a part of the 'core brain region of person perception' (Downing & Peelen, 2011). On the other hand, Vocks al. (2010) reported small, but significant, activation increases in response to one's own body as compared to the body of an unknown other in right EBA and FBA. Hence, while most studies reported no difference in EBA and FBA in response to images of one's own and others' body, some studies reported modest changes in one or both of these regions. These differences may be explained by the fact that the role of EBA is in creating a basic, perceptual representation of the shape and posture of the body and its parts (Peelen & Downing, 2007), which may then be used by other brain regions, such as the anterior inferotemporal cortex (see Kriegeskorte et al., 2007), in order to process specific information on body identity. On this account, EBA may contribute to code body identity by differentiating between individuals with different body shapes, but it does not explicitly represent person identity and is thus not directly involved in the visual discrimination of self vs. others' bodies.

An open question is why we did not find any modulation of the distortion effect for subjective judgments of one's own body after rTMS over either right EBA or right TPJ. A possible account is that providing subjective judgements on our body might be an over-practiced task that we repeatedly do in everyday life looking at our body through a mirror or directly from an egocentric perspective. Thus, this ability may be hard to be affected by a short-lasting modulation of neural activity in EBA or TPJ. Furthermore, it is possible that our stimulation protocol was not optimal to target precisely EBA and TPJ focuses in all participants, since we used average coordinates from previous studies rather than individual's functional or structural scans to localize them. Nevertheless, although we cannot exclude that this might have reduced stimulation efficacy, we found that both EBA- and TPJ-rTMS had selective and dissociated effects on other body size estimation tasks. An alternative account for the absence of EBA- and TPJ- TMS effects on subjective self-body judgments is that asking participants to adjust their body image may also recruit other brain areas processing different kinds of interoceptive and exteroceptive bodily signals. Thus, beside the role of EBA in visual processing of human bodies, it is plausible that other brain structures, such as the right anterior insula, for instance, which is thought of as a convergence zone where interoceptive and exteroceptive signals are integrated (Craig, 2010), may have been engaged during subjective judgments of self body image, thus masking the effect of rTMS over EBA. The effects of EBA inhibition on body image perception converge with several pieces of evidence on the sensitivity of right lateral occipitotemporal cortex to body size distortions, especially in healthy females (Mohr et al. 2010; Aleong & Paus, 2010). Interestingly, a number of recent findings suggest that processing of body-related information in EBA might be altered in patients with ED (Castellini et al., 2013; Miyake et al., 2010; Wagner et al., 2003; Uher et al., 2005; Suchan et al., 2010, 2013). For example, Mohr and colleagues (2011) have recently found that whereas EBA activity in healthy women varied when body images of distorted size were presented, no size-dependent modulation was found in BN patients. Furthermore, Vocks et al. (2011) found that after cognitive-behavioural therapy, which involved body image exposure, EBA activation in response to their own body pictures was reduced in ED. Taken together, these findings suggest that disturbances in the visual processing of body-related information, especially of body size and shape, in ED patients might be related to neural alterations of EBA.

Role of TPJ in self-other body representation

Previous studies have shown that right TPJ is involved in multisensory coding of the human body and self (Blanke et al., 2002, 2004; Leube et al., 2003; Berlucchi & Aglioti, 1997; Schwoebel et al., 2005), in the visual processing of human bodies (Vaina et al., 2001;

Beauchamp et al., 2002; Grossman & Blake, 2002) and in visuospatial perspective-taking (Maguire et al., 1998; Vallar et al. 1999; Ruby & Decety, 2003; Vogeley & Fink, 2003). Here, we ascertained its active role in maintaining a coherent perceptual representation of another person's body from both allocentric and egocentric perspectives (required, respectively, by the subjective and intersubjective tasks).

Recently, Tsakiris and colleagues (2008) used rTMS to interfere with right TPJ during inducement of the so-called rubber hand illusion (Botvinick & Cohen, 1998). Feeling touch on one's hand, while it is hidden from view, and viewing a synchronous tactile stimulation on a fake hand result into the illusory feeling that the rubber hand is perceived as one's own hand. This effect normally does not occur if touch is felt and seen on non-body objects. Tsakiris and colleagues showed that inhibitory TMS over right TPJ increases the illusory sense of ownership for a non-body object during synchronous visuo-tactile stimulation, suggesting that this area underlies a sort of test-for-fit discrimination of which sensory events pertain to one's own body and which do not. These results suggest that TPJ may be specifically linked to self-other distinction. In a similar vein, Uddin and colleagues (2006) demonstrated a selective impairment of self-other face discrimination when rTMS was applied over the right inferior parietal lobule, in close proximity to the location of TPJ, during a perceptual task involving discrimination between self- and other-familiar faces. In the present study, we found that rTMS over right TPJ selectively modulated the representation of another person's body but not of the participant's own body. Thus, our data suggest that right TPJ is necessary to correctly represent other persons' body and, therefore, alterations of its activity may affect the way we perceive others. It is important to note here that these altered representations of other persons' body may, in turn, influence our own body image through an upward social comparison process (Cattarin et al., 2000; Friederich et al., 2007).

Recent data suggest that ED patients may suffer from an altered ability to represent the body in relation to others. Urgesi and colleagues (2011) tested mental imagery related to body representation (vs. external object) in BN and binge eating disorder (BED) patients by means of the same disembodied task used by Arzy et al. (2006), which requires to mentally rotate one's body in space to imagine oneself to be in the position of a sketched human figure. They found that BN patients, but not BED patients, presented a significant impairment in mental transformation of the body as compared to mental rotation of a non-body stimulus. The authors suggested that the impaired mental body transformation abilities of BN patients might reflect the altered functioning of the temporoparietal cortex in BN patients (Uher et al., 2005).

Conclusions

In conclusion, our data indicate that right EBA and TPJ are actively involved in maintaining accurate subjective and intersubjective representations of one's own and other person's body. In particular, while the right EBA seems crucial for representing our and other persons' body from an allocentric perspective, independently from identity, the right TPJ is actively involved in representing the body of others independently of the perspective that is assumed. These results suggest that dysfunction of these two critical brain regions in the temporoparietal and lateral occipitotemporal cortices of the right hemisphere may be associated with different components of body image disturbance. Future studies, however, are needed to prove the specific link between neurofunctional alterations of these regions and body image disturbances in patients with different types of ED. In particular, one critical question regards the direction of the effects of interferential stimulation of right EBA and TPJ, which induced an even greater underestimation bias as compared to baseline. As participants showed a size underestimation bias for both their own and other's bodies but not for non-corporeal objects, not only self-serving bias, but also more general perceptuo-affective processes, still selective for the body, may explain the tendency to underestimate body size. The effects of EBA/TPJ-rTMS on these processes may be twofold: 1) on the one hand, they can provide basic perceptual input and alteration of this perceptual input may shift body mage toward more ideal, thin figures (Cazzato, Mele & Urgesi, 2014); 2) on the other hand, they can play a crucial role in specific body size representation, with right hemisphere areas showing a bias toward body size overestimation (at least in women; see Mohr et al., 2007). In both these possibilities, which are not mutually exclusive, interferential stimulation of right EBA/TPJ is expected to exacerbate body underestimation bias, as it did in the present study. Thus, further psychological and neuroscientific studies are needed to study how EBA and TPJ in the left and right hemispheres contribute to body size estimation. What our study shows is a differential contribution of these two brain regions to subjective and intersubjective representations of self's and other's body. An important conclusion form our data is that, when studying neural mechanisms and dysfunction of body perception, it is critical to consider the complex interaction between subjective and intersubjective representations of one's own body and of the body of others, because the way we perceive ourselves influences the perception of others and the way we perceive others, in turn, affects our self-perception. Such interaction might be critical in the genesis, maintenance and treatment of ED.

Conflict of Interest Statement

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Figure Captions

Figure 1: Schematic illustration of subjective and intersubjective perceptual judgments in Experiment 1. In four different tasks, participant was requested to increase or decrease respectively the width of one's own body picture (Self body-target, on the left side) until it corresponded to: a) the way she perceives herself, thus taking an egocentric perspective in the representation of her own body in which the subject and the object of the representation is the same person (subjective self-body task); b) the way others perceive the participant's body, thus taking an allocentric perspective in the representation of her own body in which the subject and the object of the representation are different persons (intersubjective self-body task). Crucially, introducing the body of another woman (Other body-target, on the right side), we asked participant to adjust the pictures according to how: c) the other woman perceives her own body, thus taking an allocentric perspective in the representation of another model's body in which the subject and the object of the representation is the same person (subjective other-body task); d) participant perceives the other woman's body, thus taking an egocentric perspective in the representation of another model's body in which the subject and the object of the representation are different persons (intersubjective other-body task). The schematic illustration shows that, whereas the subjective tasks recall the every-day situation of being in front of a reflective medium, the intersubjective tasks rely upon the direct visual perception of a person who is different from the subject of the perception. The direction of the source of visual information likely used for comparison with the picture to be adjusted is indicated by continuous arrows for subjective judgments and dashed arrows for intersubjective judgments.

Figure 2: Examples of veridical (original = 0) and distorted (slimmer = -50/fatter = +50) pictures of a person.

Figure 3: Stimulation sites plotted on the lateral view of a standard brain. The rTMS stimulation sites were identified on the basis of Talairach coordinates reported by previous rTMS studies on visual body perception (Urgesi et al. 2004, Urgesi, Calvo-Merino et al., 2007; Urgesi, Candidi et al., 2007) and in maintaining a coherent sense of the body (Tsakiris, Costantini & Haggard, 2008). Mean Talairach coordinates of the stimulation sites were located on the right hemisphere and were as follows: EBA: ($x = 52$, $y = -72$, $z = 2$) and TPJ: ($x = 63$, $y = -50$, $z = 23$).

Figure 4: Effects of rTMS on mean BDS (%) for the adjustments of self- and other-body pictures as a function of rTMS condition (no-rTMS, EBA, TPJ) and type of judgements (subjective, intersubjective). *Error bars* indicate standard errors mean over participants. $^*p < 0.05$.

Figure 5: Effects of rTMS on mean ODS (%) for the adjustments of a familiar, non-corporeal object (coke bottle) as a function of rTMS condition (no-rTMS, EBA, TPJ) and type of judgements (subjective, intersubjective).

Figure 6: Mean VAS during self-report questionnaire about perspective-taking for the adjustments of self- and other-body pictures as a function of type of judgements (subjective, intersubjective) and strategy (perceptual, metacognitive). ***Error bars*** **indicate standard errors mean over participants.** $^*p < 0.05$**.**

Table 1: Mean and Standard Error of Mean (S.E.M., in brackets) of participants' demographic and self-report questionnaire scores for the **four** study groups separately. Notes: BMI, Body Mass Index; EDI-2, Eating Disorder Inventory-2; BAT, Body Attitude Test; BSQ, Body Shape Questionnaire.

	Experiment 1		Experiment 2	**Control Experiment**
	Group 1 (*n* =16)	Group 2 (*n* = 16)	Group 3 (*n* =17)	**Group 4 (*n* =17)**
Age	21.56 (0.38)	21.13 (0.68)	20.88 (0.26)	**22 (0.58)**
Weight (kg)	59.69 (2.55)	57.94 (2.15)	58.29 (1.94)	**62.35 (1.65)**
Height (m)	1.70 (0.01)	1.66 (0.01)	1.68 (0.02)	**1.67 (0.02)**
BMI (kg/cm^2)	20.71 (0.75)	20.75 (0.66)	20.76 (0.61)	**22.44 (0.43)**
EDI-2				
Drive for thinness	2.06 (1.04)	3.38 (1.22)	2.76 (1.19)	**1.12 (0.36)**
Bulimia	0.75 (0.34)	0.69 (0.3)	0.94 (0.28)	**1.12 (0.36)**
Body dissatisfaction	7.94 (1.74)	7.13 (1.6)	6.12 (1.34)	**7.94 (1.72)**
Interoceptive awareness	1.19 (0.54)	1.94 (0.36)	1.47 (0.48)	**1.29 (0.33)**
Ineffectiveness	1.75 (0.73)	4.94 (1.17)	2.76 (0.66)	**2.94 (0.7)**

Maturity fears	5.44 (1.17)	4.25 (0.94)	4.88 (0.57)	**2.12 (0.61)**
Perfectionism	1.94 (0.41)	3.5 (0.71)	3.18 (0.55)	**2.35 (0.79)**
Interpersonal distrust	1.50 (0.61)	4.94 (1.16)	2.29 (0.68)	**4.35 (1.03)**
Asceticism	1.38 (0.59)	2.63 (0.4)	1.53 (0.54)	**0.53 (0.23)**
Impulse regulation	1.06 (0.35)	2 (0.56)	0.88 (0.39)	**0.88 (0.33)**
Social insecurity	2.31 (0.51)	5.94 (0.96)	2.53 (0.47)	**3.06 (0.56)**
BAT-20				
BAT 1 (max 35): Appreciation of body size	7.44 (1.82)	9.19 (1.38)	6.65 (1.43)	**12.12 (1.15)**
BAT 2 (max 25): Lack of familiarity	8.31 (1.29)	8.69 (0.97)	5.76 (0.7)	**7.53 (0.74)**
BAT 3 (max 20): General dissatisfaction	7.19 (1.07)	7.69 (0.98)	6.35 (0.95)	**8.71 (0.75)**
BAT total (max 80)	22.94 (3.79)	25.56 (2.66)	18.76 (2.93)	**28.35 (2.37)**
BSQ total (max 204)	71.25 (8.01)	78.75 (7.23)	68.88 (6.5)	**80.76 (4.16)**

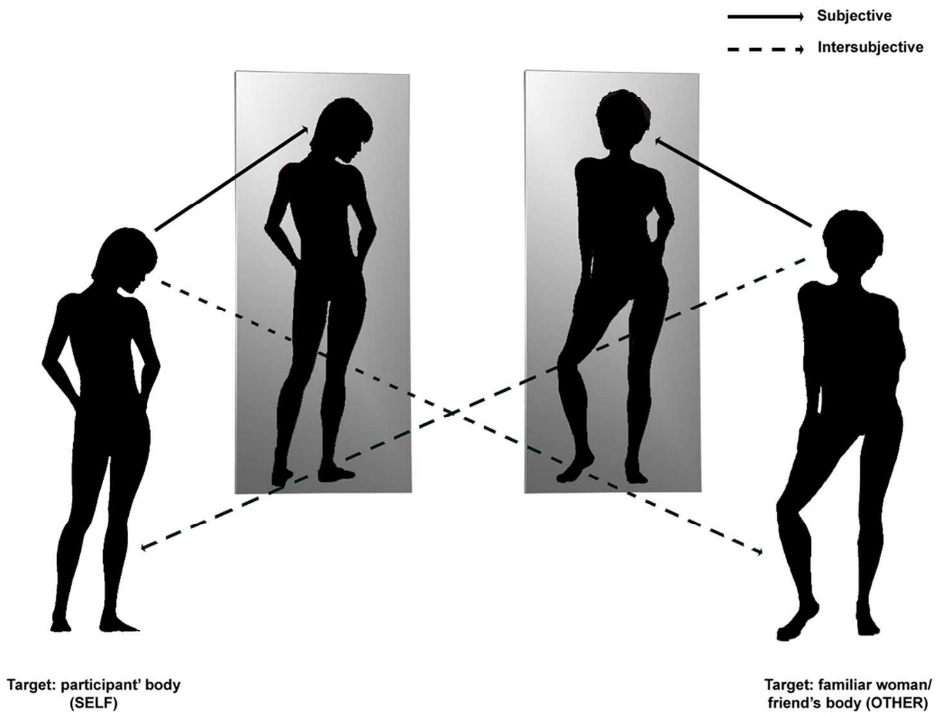

Figure 1: Schematic illustration of subjective and intersubjective perceptual judgments in Experiment 1. In four different tasks, participant was requested to increase or decrease respectively the width of one's own body picture (Self body-target, on the left side) until it corresponded to: a) the way she perceives herself, thus taking an egocentric perspective in the representation of her own body in which the subject and the object of the representation is the same person (subjective self-body task); b) the way others perceive the participant's body, thus taking an allocentric perspective in the representation of her own body in which the subject and the object of the representation are different persons (intersubjective self-body task). Crucially, introducing the body of another woman (Other body-target, on the right side), we asked participant to adjust the pictures according to how: c) the other woman perceives her own body, thus taking an allocentric perspective in the representation of another model's body in which the subject and the object of the representation is the same person (subjective other-body task); d) participant perceives the other woman's body, thus taking an egocentric perspective in the representation of another model's body in which the subject and the object of the representation are different persons (intersubjective other-body task). The schematic illustration shows that, whereas the subjective tasks recall the every-day situation of being in front of a reflective medium, the intersubjective tasks rely upon the direct visual perception of a person who is different from the subject of the perception. The direction of the source of visual information likely used for comparison with the picture to be adjusted is indicated by continuous arrows for subjective judgments and dashed arrows for intersubjective judgments.
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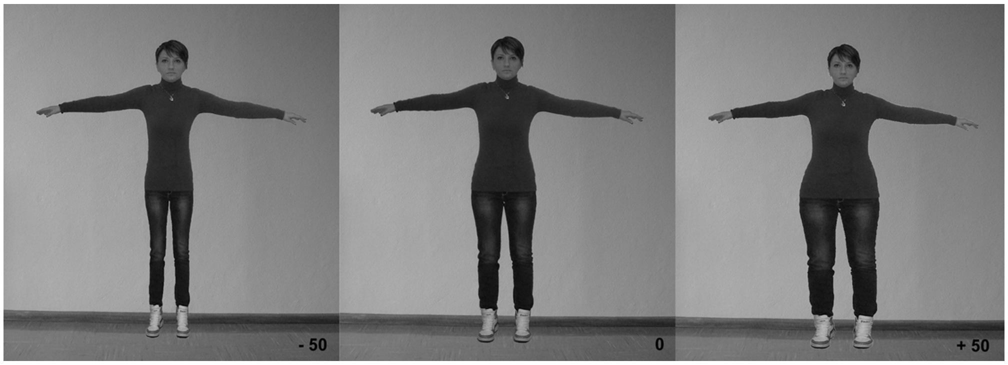


Figure 2: Examples of veridical (original = 0) and distorted (slimmer = -50/fatter = +50) pictures of a person.
150x53mm (300 x 300 DPI)

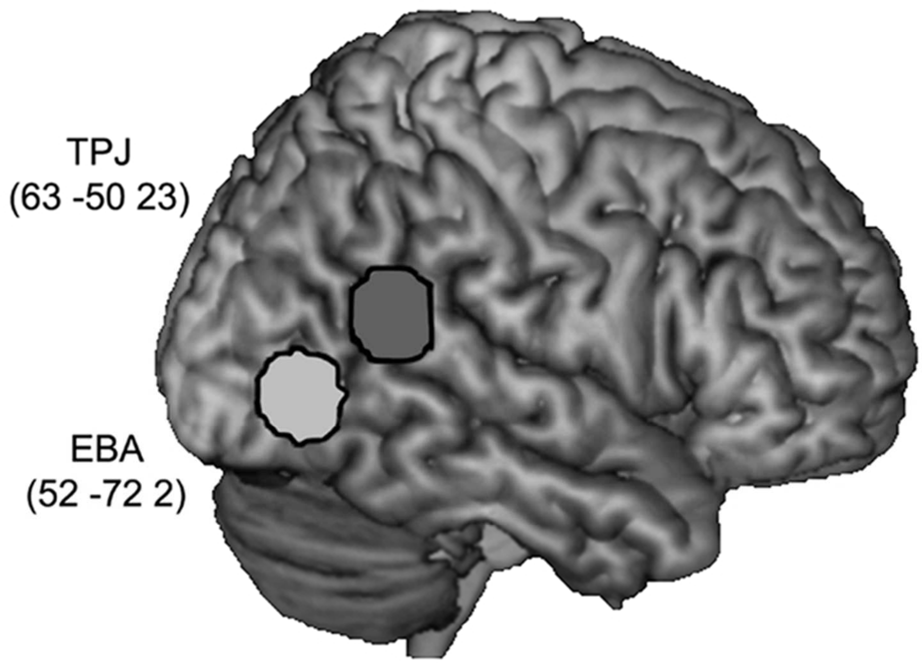
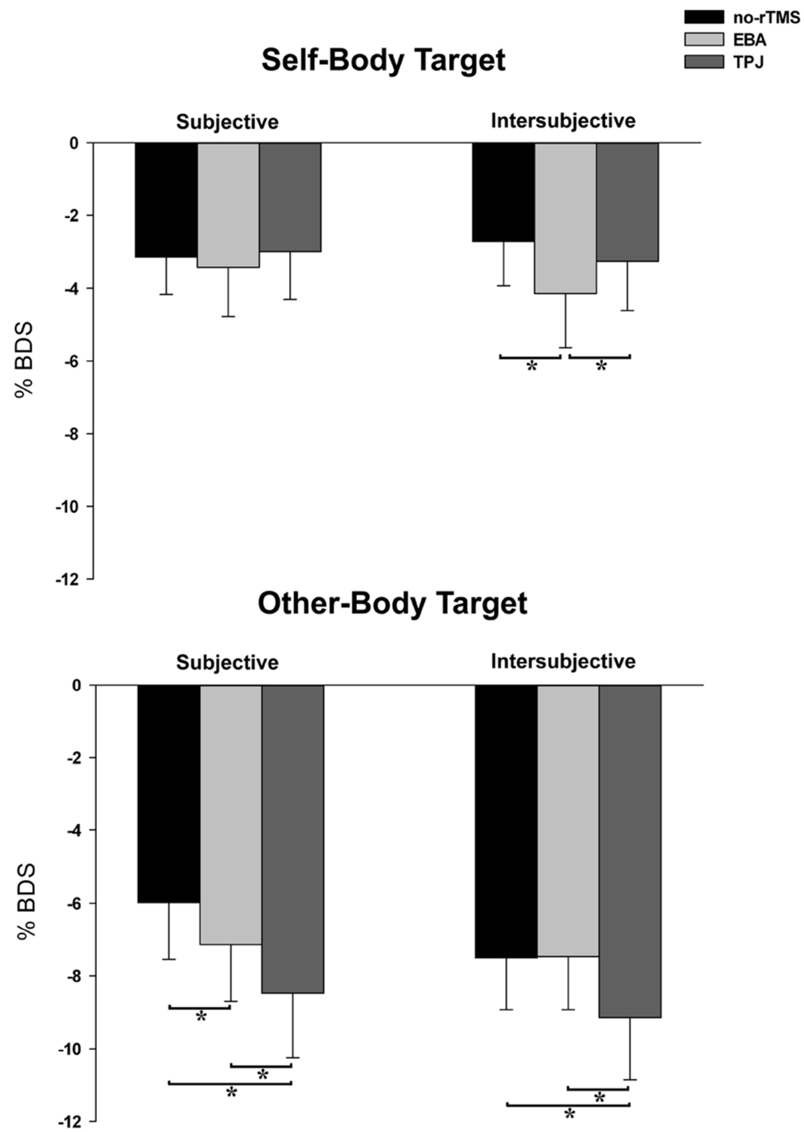


Figure 3: Stimulation sites plotted on the lateral view of a standard brain. The rTMS stimulation sites were identified on the basis of Talairach coordinates reported by previous rTMS studies on visual body perception (Urgesi et al. 2004, Urgesi, Calvo-Merino et al., 2007; Urgesi, Candidi et al., 2007) and in maintaining a coherent sense of the body (Tsakiris, Costantini & Haggard, 2008). Mean Talairach coordinates of the stimulation sites were located on the right hemisphere and were as follows: EBA: (x = 52, y = -72, z = 2) and TPJ: (x = 63, y = -50, z = 23).
60x47mm (300 x 300 DPI)



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86x118mm (300 x 300 DPI)

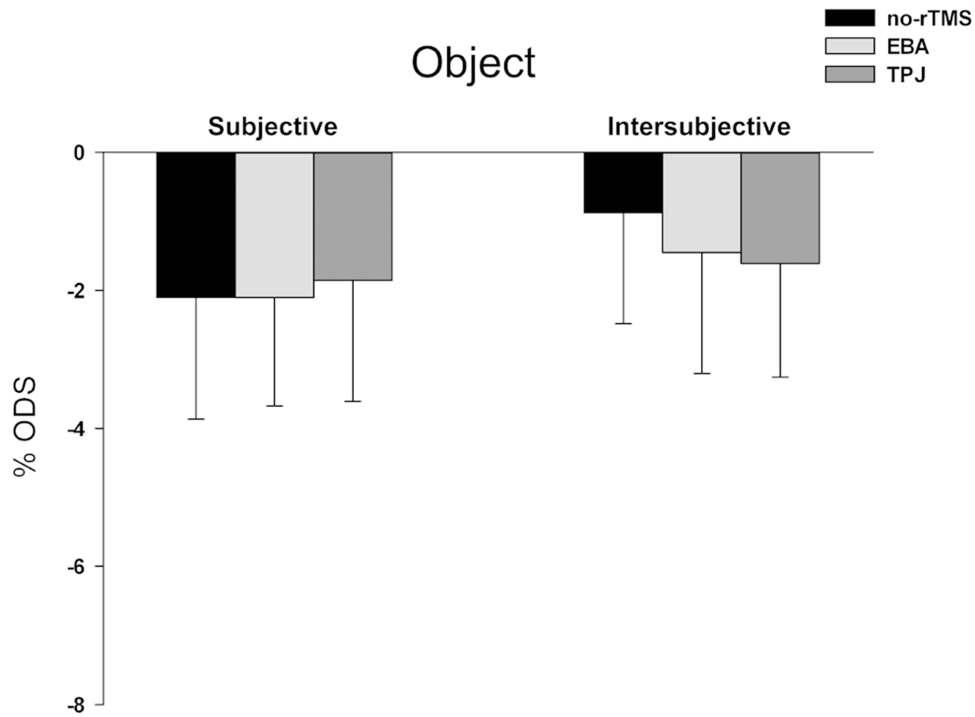

Figure 5: Effects of rTMS on mean ODS (%) for the adjustments of a familiar, non-corporeal object (coke bottle) as a function of rTMS condition (no-rTMS, EBA, TPJ) and type of judgements (subjective, intersubjective).
86x62mm (300 x 300 DPI)

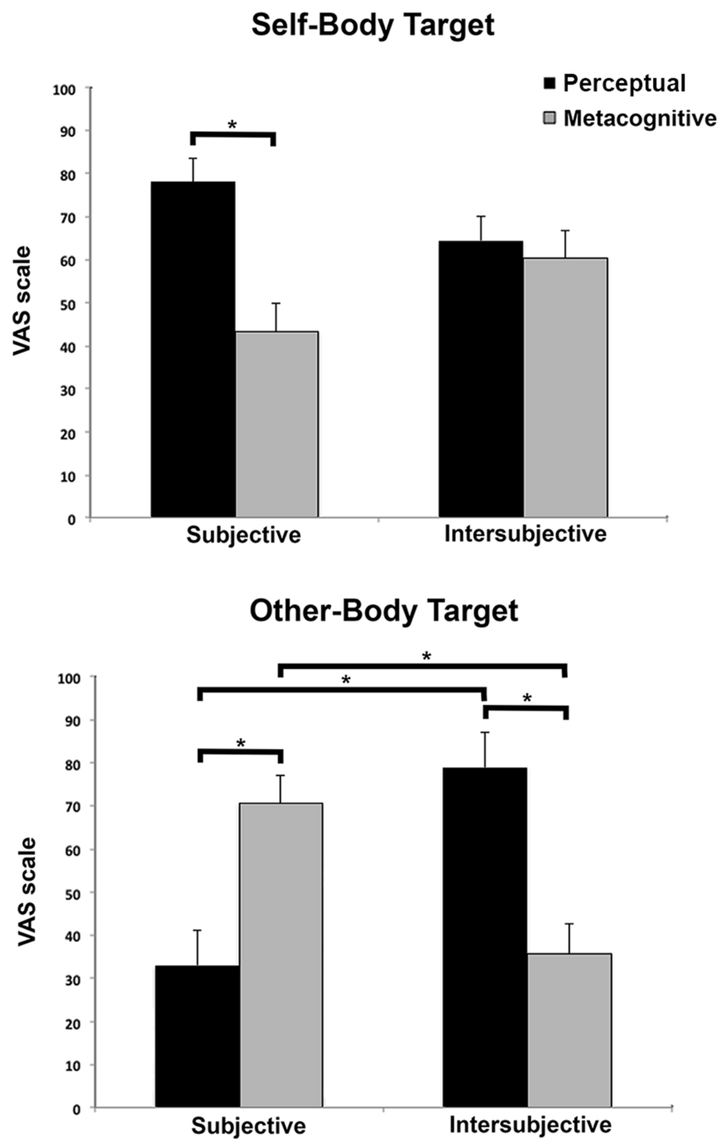

Figure 6: Mean VAS during self-report questionnaire about perspective-taking for the adjustments of self- and other-body pictures as a function of type of judgements (subjective, intersubjective) and strategy (perceptual, metacognitive). Error bars indicate standard errors mean over participants. *$p < 0.05$.
80x122mm (300 x 300 DPI)