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Social Touch Somatotopically Affects Mental Body Representations

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Abstract—In pre-Covid days, many daily actions such as hand shaking or cheek kissing implied physical contact between our body and that of other people. With respect to touching an inanimate object (objectual touch), touching a person (social touch) concerns not only touching a human body, but also that this body belongs to a living person. This fundamental difference also may affect the way we figure our own movements and perceptions or, in other words, how we mentally represent our own body. To test this hypothesis, we asked 30 neurotypical participants to perform mental rotation of images representing hands, full bodies, and feet (an active cognitive task able to activate body representations without need of moving) in two tactile conditions: holding (one in each hand) either the thumbs of another person (social touch) or two plastic cylinders (objectual touch) of about the same circumference and size. Results showed that only mental rotation of hand images was affected by varying the tactile conditions, in that participants were faster during social than objectual touch. This suggests that the nature of hand-related tactile input (social or objectual touch) influences local (hand) and not global (body) mental representations of the body, and in a very somatotopic manner (hands but not feet). We interpret these findings with reference to the differentiation between sensorimotor (body schema) and visuospatial (body image) dynamics in the mental representation of our body. The present study shows that external social factors can affect the internal mental representations of one's own body.

Key words: body schema, body image, sensorimotor, motor cognition, mental imagery.

INTRODUCTION

Social interactions shape our behavior. After about two years of COVID-related social restrictions, we all look forward to start again shaking hands, kissing cheeks, hugging babies, and caressing beloved ones. To perform these actions, we need to know our body configuration and how to change it in order to comply with the social interaction's requirements. In other words, we cope with the requests of the social environment by accessing and manipulating the mental representation of our body, to successively guide our movements taking into account the body of the other person. This ability to activate and handle the mental representation of movements is classically defined "motor imagery", but it remains mostly at an introspective level. An objective way to measure some temporal aspects of motor imagery is provided by the mental rotation task which, interestingly, seems to be affected by social impairments (Conson et al., 2013). In addition, if participants are asked to identify the laterality of pictures of rotated body parts, their response times (RTs) vary as a function of the image orientation (Parsons, 1987), are affected by the current participant's posture (Ionta et al., 2007), and are associated with the activation of sensorimotor brain regions (Zapparoli et al., 2014). These are all signs that mental rotation of body parts share at least some properties with action planning (Jeannerod, 2001). Indeed the RTs required to align a rotated image to the upright position progressively increase for images presented from 0° to 180° and vice versa up to 360° (Munzert et al., 2009). Nevertheless, such an apparently linear relationship between image orientation and RT profile is, in fact, sensitive to several factors.

First, the nature of the images plays an important role, in that the influence of image orientation can vary between self- and other-body images (Zeugin et al., 2020), is larger for mental rotation of hands (Ionta et al., 2007; Zapparoli et al., 2014), faces (Ionta et al., 2010; Zeugin et al., 2017; Trebicky et al., 2018), and feet (Edwards et al., 2019; Scandola et al., 2019), but smaller for the mental rotation of body images (Devlin and Wilson, 2010; Perruchoud et al., 2016; Saetta et al., 2019). Second, physical constraints affect mental rotation in a specific manner, in that mental rotation of hands (not other images) is slower when participants' own hands are constrained with respect to when their hands are free (Moreau, 2013; Toussaint and Meugnot, 2013; Meugnot et al., 2014). Third, not only the quality of concurrent

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somatosensory input alters the temporal aspects of mental rotation (Schwoebel et al., 2001; Schmid and Coppieters, 2012), but also whether such somatosensory input derives from the interaction with an living or inanimate entity (Conson et al., 2011; Conson et al., 2015).

In sum, mental rotation depends on the nature of the images, is affected by physical constraints, and is differentially influenced by the interaction with living versus inanimate objects. On this basis, we hypothesized that constraining participants' hands through the interaction with living versus inanimate objects would differentially affect mental rotation of different types of images. To this aim, we asked 30 neurotypical volunteers to perform mental rotation of hand, body, and foot images while touching two different objects (one in each hand). The living objects were the thumbs of an experimenter (hereafter "social touch"). The inanimate objects were two plastic cylinders of same size (hereafter "objectual touch"). We predicted that only mental rotation of hand images would be differentially affected by social versus objectual touch. As control, no touch-related differences were expected for the mental rotation of body and foot images.

EXPERIMENTAL PROCEDURES

Participants

Based on a previous pilot experiment, 30 neurotypical adults (24.9 ± 2.9 years) were enrolled in the experiment after signing a written informed consent. While the influence of gender on mental rotation is controversial (Sanchis-Segura et al., 2018; Guizzo et al., 2019), the effect of hand dominance on mental rotation is well established (Ionta and Blanke, 2009). Therefore, both women ($N = 22$) and men ($N = 8$) were enrolled in the study, but all of them were classified as right-handers according to the Edinburgh Handedness Inventory (Oldfield, 1971). The local Ethical Committee approved the experiment, which was performed in accordance with the Declaration of Helsinki 2013.

Stimuli

The hand images consisted of naturalistic pictures of an adult hand. The body images represented a front-facing person standing upright with the arms bended upwards at the level of the elbows. One hand of the body image was darker than the other one. The foot images showed a human adult foot (Fig. 1). All images varied in terms of laterality (left or right) and view (dorsum or palm/planum). Left-lateralized images were mirror-reversed images of the right-lateralized ones. For all images, the overall configuration (gender, age, ethnicity, etc.) and visual features (shape, size, luminosity, etc.) were the same. All images were oriented in one out of four clockwise orientations from the upright (0°, 90°, 180°, 270°). The upright orientation was defined as the fingers pointing upwards (0°). All images covered a visual angle comprised between 11° and 13° at a distance of about 60 cm.

Procedure

The experimental session comprised six blocks. Each block contained 64 images of only one image type (hand, body, foot). Images varied in terms of laterality (left, right), view (dorsum, palm/planum), and orientation (0°, 90°, 180°, 270°). The presentation of each image was randomly repeated twice for each participant. The six blocks differed in terms of type of touch (Fig. 2). According to a within-subject experimental design, while being presented with images, participants held one out of two objects in their hands. In three blocks (one for each image type), participants held the thumb of the experimenter's hands in each hand (social touch). In the other three blocks (also one for each image type) participants held a plastic cylinder in each hand (objectual touch). Both in the social and objectual touch conditions, participants' hands were hidden under a frame, therefore they were not visible to the participants. The presentation order of touch conditions and image types was counterbalanced across participants.

Participants sat in front of a table, on which a computer screen was placed on top of a custom-made frame (Fig. 2). Participants' hands were placed, and hidden, inside the frame with the elbows laying on the table and the whole forearms inside the frame. Inside the frame they held in each hand either the experimenter's thumb or a plastic cylinder. Image presentation was controlled by the E-Prime2 software (Psychology Software Tools Inc., Pittsburgh USA). At the beginning of each trial participants fixated a cross for 1000 ms. Then an image appeared (hand, body, foot) and participants judged as quickly and accurately as possible its laterality. In line with previous studies, for the body images participants indicated the laterality of the darker hand (Ionta et al., 2012; Perruchoud et al., 2016). Each image remained on the screen until the participant gave a response. Participants provided response verbally. A microphone was placed in front of the participant and recorded RT for each trial. RT was defined as the time between the image onset and the participant's response. Accuracy was manually encoded by a second experimenter. Before the experimental session, participants observed a subset of images in a training session. To avoid familiarization the images presented in the training session were shown to the participant in different orientations. Considering the relative ease of the task, during the training each participant could have been presented with up to three images for each category (hand, body, foot), without time limits to explore the image. Should participants not understand the task following the brief training, the training images were allowed to be repeated to ensure comprehension. During the training phase participants placed their hands under the box but they did not hold any object in their hands.

Data analysis

Trials with incorrect responses and/or RTs longer than 5000 ms or shorter than 500 ms were excluded from the analysis (Cooper and Shepard, 1975; Sekiyama, 1982; Parsons, 1987, 1987; Steggemann et al., 2011), with a

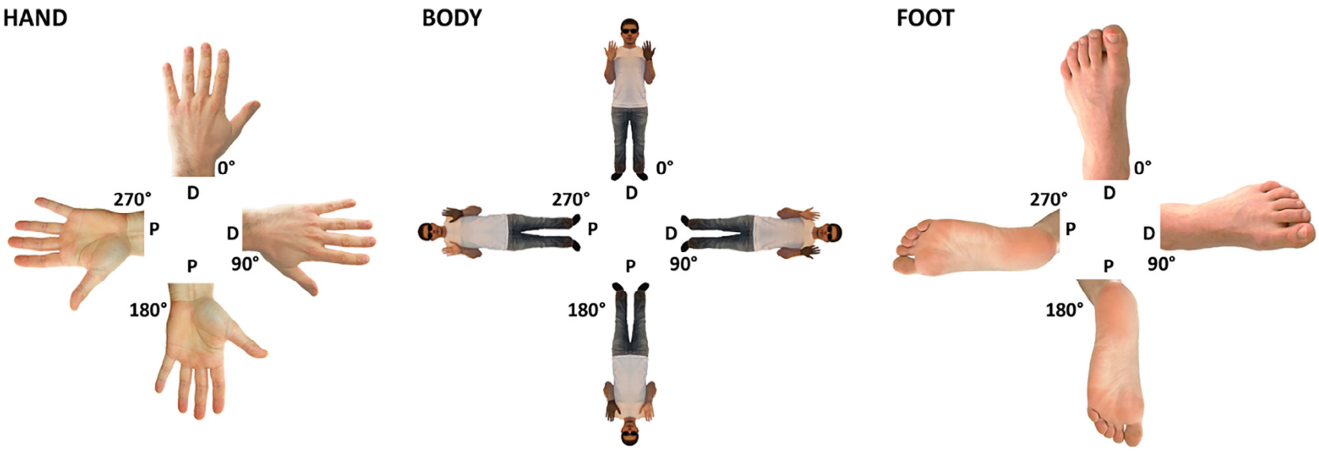

Fig. 1. Stimuli. The hand/foot/body images represented a human adult hand/body/foot from the dorsum (D) or the palm/planum (P) view. One hand of the body images was darker than the other one. All images were presented in four orientations (0°, 90°, 180°, 270°), and showed left- and right-lateralized images. For illustration purposes, figure shows only left-lateralized images.

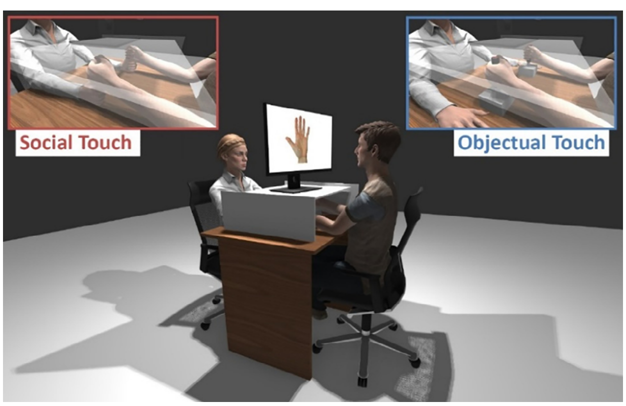

Fig. 2. Experimental setup. Graphical reproduction of the experimental setup. Participants (right avatar) sat in front of the experimenter (left avatar). Both the participant and experimenter placed their (hidden) hands and forearms under a frame. A computer screen was placed on top of the frame, to show the experimental images. Under the frame, in each hand, the participant could hold either the experimenter's thumbs (social touch) or two plastic cylinders (objectual touch). For illustrational purposes figure shows the plastic cylinder as joystick-shaped objects. The participant's body posture remained the same during both the social and objectual touch conditions.

total trial loss of 8.9%. The resulting distributions of RT as a function of the experimental factors were normally distributed according to the Kolmogorov-Smirnov test for normality, and were therefore entered in a 5-way repeated measures ANOVA with touch (social, objectual), image (hand, body, foot), laterality (left, right), view (dorsum, palm/planum), and orientation (0°, 90°, 180°, 270°) as within-subject experimental factors. The confidence interval for the ANOVA was set at 95% (significance level: $p = 0.05$). The partial eta squared (η^2p) was used to establish the effect size of all significant main effects and interactions deriving from the ANOVA. The confidence interval for the significant effects was set at 99% and its lower (CI_{low}) and upper (CI_{high}) limits were calculated for the effect size of each significant main effect and interaction. The significance levels for the post-hoc tests of the significant effects were Bonferroni-corrected for multiple comparisons. For statistical analysis the STATISTICA software (StatSoft Inc., Tulsa, US) was used.

RESULTS

Touch-related effects

The ANOVA showed the significant main effect of touch [$F(1,15) = 15.8$; $p < 0.001$; $\eta^2p = 0.51$; $CI_{low} = 0.03$; $CI_{high} = 0.74$] and 2-way interaction between touch and image [$F(2,30) = 3.4$; $p < 0.05$; $\eta^2p = 0.18$; $CI_{low} = 0$; $CI_{high} = 0.45$]. The main effect of touch was explained by the shorter RTs obtained in the social touch (1307.8 ms) than the objectual touch condition (1403.0 ms). The touch by image interaction showed that the RT difference between social and objectual touch was significant for the hand images but not for the body and foot images (Fig. 2). In particular, mental rotation of hand images was faster ($p < 0.01$) in the social touch condition (1349.9 ms) than the objectual touch condition (1553.8 ms). Conversely, for the body and foot images, the RTs obtained in the social (body = 1294.6 ms; foot = 1278.9 ms) and objectual touch conditions (body = 1392.7 ms; foot = 1298.5 ms) were not significantly different (all $p_s > 0.05$) (See Fig. 3).

Other effects

Additional findings generally confirmed well-established evidence of the impact of image laterality, view, and orientation on mental rotation. Accordingly the ANOVA showed the significant main effects of laterality [$F(1,15) = 8.0$; $p < 0.01$; $\eta^2p = 0.35$; $CI_{low} = 0$; $CI_{high} = 0.65$], view [$F(1,15) = 39.1$; $p < 0.001$; $\eta^2p = 0.72$; $CI_{low} = 0.25$; $CI_{high} = 0.85$], and orientation [$F(3,45) = 9.5$; $p < 0.001$; $\eta^2p = 0.39$; $CI_{low} = 0.08$; $CI_{high} = 0.57$], as well as the significant

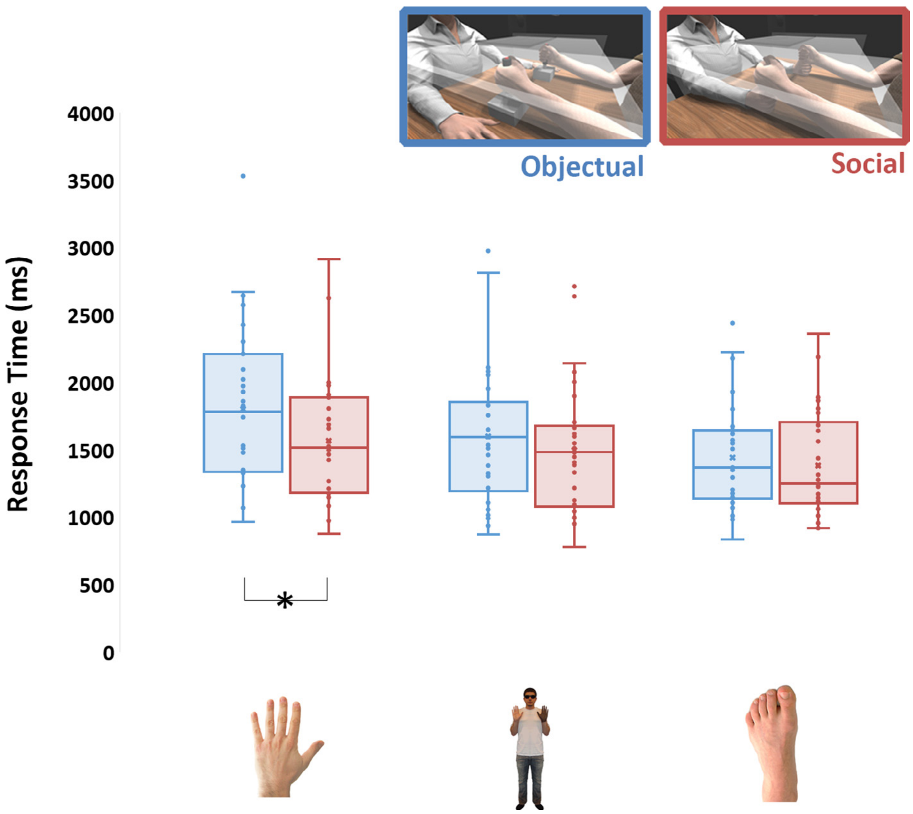

Fig. 3. Touch by image interaction. Social touch determined longer mental rotation of hand images with respect to objectual touch. No touch-related difference was found in the mental rotation of body and foot images. Asterisks represent significant differences. Error bars represent the 95% confidence interval.

2-way interaction between view and orientation [$F(3,45) = 12.1$; $p < 0.001$; $\eta^2p = 0.45$; $CI_{low} = 0.12$; $CI_{high} = 0.61$], 3-way interaction between laterality, view, and orientation [$F(3,45) = 3.8$; $p < 0.02$; $\eta^2p = 0.2$; $CI_{low} = 0$; $CI_{high} = 0.41$], and 4-way interaction between image, laterality, view, and orientation [$F(6,90) = 2.6$; $p < 0.02$; $\eta^2p = 0.15$; $CI_{low} = 0$; $CI_{high} = 0.28$]. The main effect of laterality showed significantly faster responses for right-lateralized (1270.6 ms) than left-lateralized images (1440.2 ms). The main effect of view indicated shorter RTs for dorsum-view (1248 ms) than palm/planum-view images (1462.8 ms). The main effect of orientation was driven by the significantly slower performance (all $p_s < 0.05$) with images presented at 180° (1477.1 ms) with respect to 0° (1333.9 ms), 90° (1319.2), and 270° (1291.5), which did not significantly differ among them.

The Bonferroni-corrected comparisons for the 2-way interaction between view and orientation showed that mental rotation of dorsum-view images was more sensitive to image orientation than palm/planum-view images. In particular, in the dorsum view, images at 180° were mentally rotated more slowly (1466.3 ms) than the other orientations (0° = 1161.9 ms; 90° = 1212.8 ms; 270° = 1151 ms; all $p_s < 0.001$). Conversely the difference in speed for mentally rotating palm/planum-view images presented at different orientations was not statistically significant.

The Bonferroni-corrected for the 3-way interaction between laterality, view, and orientation further illustrated that the larger sensitivity to orientation (modulation of RTs) for dorsum-view images was present for both left- and right-lateralized images. Conversely, for palm/planum view images, the left-lateralized ones seemed more sensitive to orientation (larger modulation of RTs) than the right-lateralized ones.

These effects were further detailed by the Bonferroni-corrected comparisons for the 4-way interaction between image, laterality, view, and orientation. In particular, it seemed that, for each view separately, the influence of orientation was similar for left- and right-lateralized images of hands. Conversely, both for body and foot images, the influence of orientation was similar among left- and right-lateralized images presented from the dorsum view, while it was different for palm/planum view images. For palm-view body images, RTs for right-lateralized images seemed to be monotonically modulated by orientation, while the effect of orientation was less straightforward for left-lateralized body images. For planum-view foot images, RTs for left-lateralized images seemed to generally decrease as a function of orientation, while for right-lateralized images RTs seemed less dependent on orientation.

In sum, these effects confirmed that mental rotation is influenced by the type of image (Ionta et al., 2012), view (Ionta and Blanke, 2009), laterality (Ionta et al., 2007), orientation (Zeugin et al., 2017), and that the relative flattening of the RT profile hint at a weaker influence of image orientation on mental rotation (Zacks et al., 2002; Jola and Mast, 2005; Devlin and Wilson, 2010). All these effects have been extensively described in previous studies and will not be further discussed here (See Fig. 4).

DISCUSSION

The present study shows that the nature of hand-related tactile perception (social or objectual) somatotopically affects the mental representation of the perceiver's body. This was reflected in the faster RTs required for mentally rotating hand images in the social touch condition, with respect to the objectual touch one. No touch-related differences were found in the mental rotation of body and foot images. These results support the peculiarity of social touch with respect to objectual

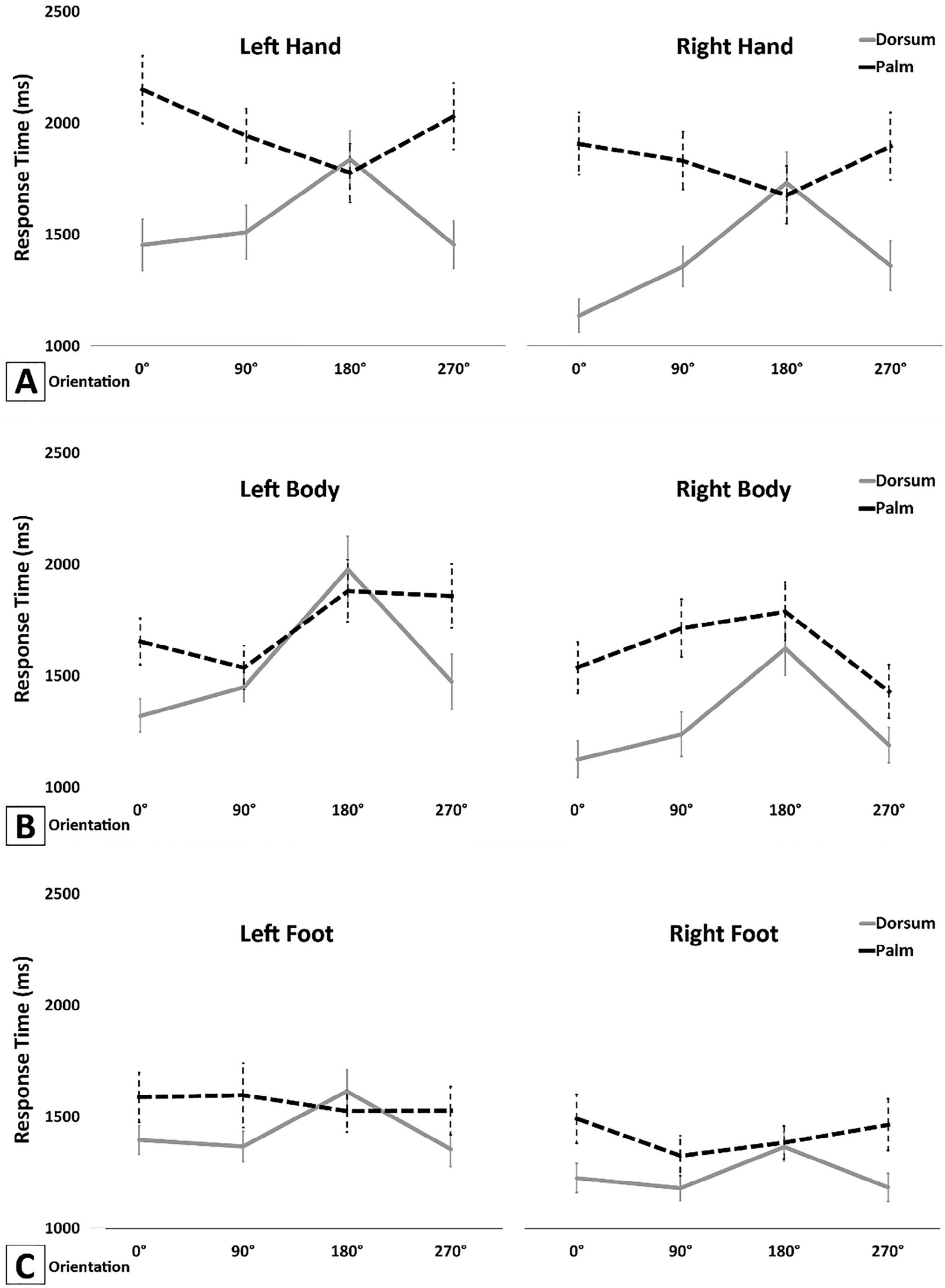

Fig. 4. Image by laterality by view by orientation interaction. For all dorsum-view images the influence of image orientation was large. For palm/planum-view images the influence of orientation was straightforward for hand images, mixed for body images, and small for foot images. Error bars represent the 95% confidence interval.

touch, in that social touch would somatotopically affect the mental representation of one's own body.

The 2-way interaction between touch and image showed that touch-related differences in mental rotation were significant only for hand images, not for body and foot images. This finding indicated that social touch had a greater impact on mental rotation of hand images with respect to body and foot images. On this basis, we propose that the social versus objectual nature of tactile inputs plays a relatively more specific role in creating and manipulating local representations of the body (hands), with respect to global ones (not body) and in a somatotopically specific manner (not feet). This finding can be explained by the differentiation between sensorimotor and visual strategies in mental spatial transformations (Zacks and Michelon, 2005), extending to the psychological constructs of body schema and body image (Gallagher, 1986).

Previous evidence showed that mental rotation of hand images is influenced by proprioceptive input (Sirigu and Duhamel, 2001; de Lange et al., 2006; Ionta et al., 2007; Ni Choisdealbha et al., 2011). This influence is even augmented when the proprioceptive input is combined with tactile input concerning touching oneself (self-touch), with respect to touching an inanimate object (Conson et al., 2011). However, with respect to touching an inanimate object, during self-touch at least two events are happening at the same time. Not only the participant is touching a person, but this person is her/himself. It is therefore difficult to disentangle whether the effects attributed to self-touch are specifically bound to self-directed touch or can be more generally associated with touching ''a'' person. The present study shows that already touching another person (social touch) is enough to affect mental rotation, with respect to touching an inanimate object (objectual touch). We note that participants kept the same posture in both the social and objectual touch conditions and that the shape and size of the two objects (thumbs, plastic cylinders) were very similar. It is therefore likely that the differential performance in mental rotation of hand images between the two tactile conditions was not due to postural or proprioceptive differences. On this basis, we propose that the main factor to influence mental rotation was the *nature* of the tactile interaction: social versus objectual.

The 4-way interaction showed that image orientation differentially affected mental rotation of different images/views, with the relatively largest effect for hand images, intermediate for body images, and smallest for foot images. The magnitude of dependency of RT from image orientation has been considered a sign that mental spatial transformations share at least some sensorimotor properties with physical actions (Jeannerod, 2001; Petit et al., 2003). Together with the observation that the brain network active during mental rotation of hand images includes mainly sensorimotor regions (de Lange et al., 2006; Zapparoli et al., 2014; Perruchoud et al., 2018), the larger influence of orientation on mental representations of hand images supports that the mental representations of images of tactilely-relevant body parts (participant's hands), but not tactilely non-relevant ones (participant's feet), activate sensorimotor simulation mechanisms (Lotze and Halsband, 2006). In addition, we found that the influence of orientation on mental rotation of body and foot images was less straightforward with respect to hand images, especially for palm/-planum view images. This finding suggests that global (body images) and somatotopically irrelevant local (foot images) representations of the body are based more strongly on visuospatial mechanisms. This latter effect has been consistently reported in previous behavioral studies (Devlin and Wilson, 2010; Ionta et al., 2012) and is in line with brain imaging data showing that the brain network involved in mental rotation of body images comprises mainly visual and associative brain regions (Blanke et al., 2005; Perruchoud et al., 2016). On this basis, we propose that regardless the nature of touch, image orientation's influence on mental rotation of hand images is greater with respect to body and foot images because (i) the mental representation of local and tactilely-relevant body parts (hand images) rely to a greater extent upon sensorimotor simulations than body of foot images, and (ii) therefore are more sensitive to the biomechanical constraints reflected by more awkward orientations (Lust et al., 2006; Steenbergen et al., 2007). This interpretation fits the distinction between sensorimotor and visuospatial mental spatial transformations. During sensorimotor transformations, the relationship between the spatial coordinates of the environment and the observer remains the same, and the coordinates of the hand are mentally transformed (mental simulation of hand movement). In case of visuospatial transformations the relationship between the coordinates of the environment and the coordinates of the self are modified (mental simulation of perspective change) to determine the localization of an object (Zacks and Michelon, 2005). Despite the use of one or the other strategy is usually triggered by the type of image to mentally process, it is also possible that participants switch or mix the two strategies as a function of contextual factors (Wilson et al., 2004; Mercier et al., 2008; ter Horst et al., 2012). We interpret the differential influence of image orientation on mental rotation of hand images (relatively stronger) and body images (relatively weaker) as evidence that the strategy to mentally manipulate local bodily representations (hand) comprised a contextually stronger sensorimotor component, while the strategy used to manipulate global body representations (body) included a contingently larger influence of visuospatial aspects.

The differential weight of sensorimotor and visuospatial aspects in the mental representations of the body links to the distinction between body *schema* and body *image*. Classically the body schema identifies the online representation of the somatosensory information about one's own body (Head, 1920). It represents the reference frame used to plan, monitor, and control body configurations and movements (Berlucchi and Aglioti, 1997), exploits previous somatosensory experience to create mental representations of the usual sensorimotor configurations of the body, and uses such representations to evaluate the current states of the body (Sainburg et al., 1993; Ghez et al., 1995). Conversely, the body image refers to the pictorial aspects of the body (Schilder, 1935) and strongly relies on previous visual experience (Adame et al., 1989; Adame et al., 1991), including the mental representation of the appearance of one's own body seen from the outside (Gardner and Moncrieff, 1988). In typical conditions, the relationship between body schema and body image is balanced, but their mutual exchange can be affected by contextual factors (Gallagher and Cole, 1995). In particular, if one source of information becomes less unreliable, it is possible to switch from the body schema to the body image as reference frame (Ionta et al., 2016; Scandola et al., 2019). In this framework, we propose that social touch had a larger influence on local representations of tactilely-relevant body parts (hand) because participants relied more on a sensorimotor strategy to perform mental rotation of hands, exploiting the body schema as reference frame, as reflected by the large impact of image orientation on mental rotation of hands. Conversely, for more global (body images) or local but context-dependent tactilely irrelevant local (foot images) representations of the body, we propose that participants relied on a more visuospatial strategy, therefore using the body image as reference frame, as reflected by the small influence of image orientation and the absence of touch-related differences in mental rotation of body and foot images.

Why is mental rotation of hand images more influenced by social touch than objectual touch? We interpret this effect in terms of different affordances linked to living beings versus inanimate objects. By affordance we refer to the implicit properties automatically attributed to an object, including how the object can be used or manipulated (Gibson, 1977). In the present study, we propose that the knowledge that the thumbs held by the participants belonged to a real person (social touch) activated the affordance that the participants' own hands were less free to move in the social touch condition, with respect to the objectual touch condition when they were holding the more easily movable wooden joysticks. This interpretation relies on evidence that the experimental immobilization of an otherwise healthy limb results in physiological modifications at the muscular level (Seki et al., 2001), impairs follow-up motor performance (Moisello et al., 2008), and is associated with decreased neural firing in somatosensory and motor regions of the human brain (Facchini et al., 2002; Kaneko et al., 2003; Huber et al., 2006). Limb immobilization not only affects physiological and kinematic aspects of real movements, but also it can impact the temporal characteristics of imagined movements, including those implied in mental rotation of hands (Toussaint and Meugnot, 2013). In particular, the temporary immobilization of one hand affects the mental rotation of images depicting the immobilized hand, and not the free hand nor other body-unrelated images, such as numbers (Meugnot et al., 2014). This latter observation is in line with evidence that limb immobilization does not affect visuospatial mental transformations and, actually, it can drive a shift to a visuospatial strategy for the mental rotation of images that normally would recruit a sensorimotor strategy (Toussaint and Meugnot, 2013). Such a shift can be attributed to the fact that when the somatosensory input normally used to build an appropriate representation of one's own body becomes less reliable, a visual strategy is implicitly considered more efficient and takes place automatically (Wilson et al., 2004; Mercier et al., 2008; ter Horst et al., 2012). In this framework, we propose that the affordances associated with the social touch condition induced the impression of a limited freedom to move the hands, which affected tactilely-relevant local mental representations of the body based on sensorimotor components and using the body schema as reference frame (hands), but did not affect global (body) and context-dependent tactilely irrelevant local (foot) body representations based on visuospatial aspects and using the body image as reference frame (body). Conversely, the affordances associated with the objectual touch condition did not affect the impression of potentially move the hands and therefore did not differentially impact the mental rotation of body and foot images.

Even if touch-mediated experiences derive from external stimulations, they can be related to the activation of inner individual processing in the context of emotional processing (Burleson and Quigley, 2021) and social interactions (Tang et al., 2020). In this vein, it could be speculated that the differentiation between affordances related to social versus objectual touch might reflect the influence of historical and cultural factors on motor, cognitive, social developments (Solovieva and Quintanar, 2021), including possibly a more crucial role of hand-related social touch in human communication, emotional processing, and intellectual experience (Cascio et al., 2019; Lew-Williams et al., 2019; Smirni et al., 2019) with respect to body- or foot-related tactile experience.

In sum, the present study demonstrates that the nature of tactile interaction (social or objectual) somatotopically affects the mental representation of one's own body. Touch-relevant local representations of the body (hands) were sensitive to the difference between social and objectual touch. This indicates the activation of a predominantly sensorimotor strategy to mentally represent and manipulate hands, using the body schema as reference frame. Contextually, global and tactilely-irrelevant representations of the body (body and foot images) were not differentially influenced by social and objectual touch. This suggests the activation of a more visuospatial strategy to mentally represent and manipulate the full body, using the body image as reference frame. These findings open new scenarios for the understating of the influence of external social factors on the internal mental representations of our body.

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