

Distorting the visual size of the hand affects hand pre-shaping during grasping

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Abstract Vision of the body is known to affect somatosensory perception (e.g. proprioception or tactile discrimination). However, it is unknown whether visual information about one's own body size can influence bodily *action*. We tested this by measuring the maximum grip aperture (MGA) parameter of grasping while eight subjects viewed a real size, enlarged or shrunken image of their hand reaching to grasp a cylinder. In the enlarged view condition, the MGA decreased relative to real size view, as if the grasping movement was actually executed with a physically larger hand, thus requiring a smaller grip aperture to grasp the cylinder. Interestingly, MGA remained smaller even after visual feedback was removed. In contrast, no effect was found for the reduced view condition. This asymmetry may reflect the fact that enlargement of body parts is experienced more frequently than shrinkage, notably during normal growth. In conclusion, vision of the body can significantly and persistently affect the internal model of the body used for motor programming.

Keywords Body representation · Body size distortion · Grasping · Vision · Somatosensory · Multisensory

Introduction

Converging evidence from animal and human studies suggests that the brain holds an inner representation of the body, based on the integration of concurrent visual and somatosensory information (e.g. Berlucchi and Aglioti 2009). One important but rarely discussed aspect of this internal representation is the physical size of body parts. Several experimental or pathological conditions, such as local anaesthesia or electrical stimulation (Gandevia and Phegan 1999; Paqueron et al. 2003), conflict between sensory modalities (de Vignemont et al. 2005; Lackner 1988), peripheral nerve lesions or limb amputations (Ramachandran and Hirstein 1998), can rapidly change this representation and produce surprising distortions of the perceived size of body parts.

What about the contribution of vision? It is well known that vision can significantly bias somatosensory perception. For example, in the so-called “rubber hand illusion”, watching a rubber hand being touched synchronously with one's own unseen hand causes the compelling impression that the touch is felt on the rubber hand, as well as some variable degree of perceived shift of the real hand towards the position of the fake hand (Botvinick and Cohen 1998). Visuo-tactile interference effects can indirectly show that the perceived position of an unseen limb may be biased towards that of a seen fake arm (Pavani et al. 2000). In addition, direct vision of a body part can modulate tactile discrimination at that skin location (Taylor-Clarke et al. 2004).

In the present paper, we investigated whether distorted visual input could influence the computation of the hand

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size, in such a way that even manual motor control would be affected. This issue is important given the influential, though controversial (Franz et al. 2009), claim that perceptual factors do not affect the motor system (Aglioti et al. 1995), and the recent report that rubber hand illusions do not influence pointing movements (Kammers et al. 2009). To investigate the specific case of body part size, we measured the maximum grip aperture (MGA) of the hand during grasping movements, while participants viewed their own grasping hand either at normal, enlarged or shrunken size. In this way, we could investigate whether the mismatch between altered vision and unaltered somatic input leads to a distorted representation of the body that could even influence the execution of elementary grasping actions.

If such an influence was present, we would predict that the parameters of grasping should change. Specifically, visual information about the enlargement of the hand would reduce the MGA, since it would not be necessary for the enlarged hand to open to the same degree as the normal hand in order to grasp an object of a given size. Conversely, if vision provides information that the hand is shrunken, an increased MGA would be required to grasp the object. Finally, recent work has shown that enlarged, but not shrunken, body parts can influence body representation (e.g. Pavani and Zampini 2007), raising the interesting possibility that our manipulations might also have asymmetric effects.

Methods

Subjects

Eight neurologically unimpaired participants (4 females and 4 males, mean age 26 years) were recruited as unpaid volunteers in accordance with the Declaration of Helsinki.

All participants were right-handed according to an informal interview, and had normal or corrected-to-normal vision.

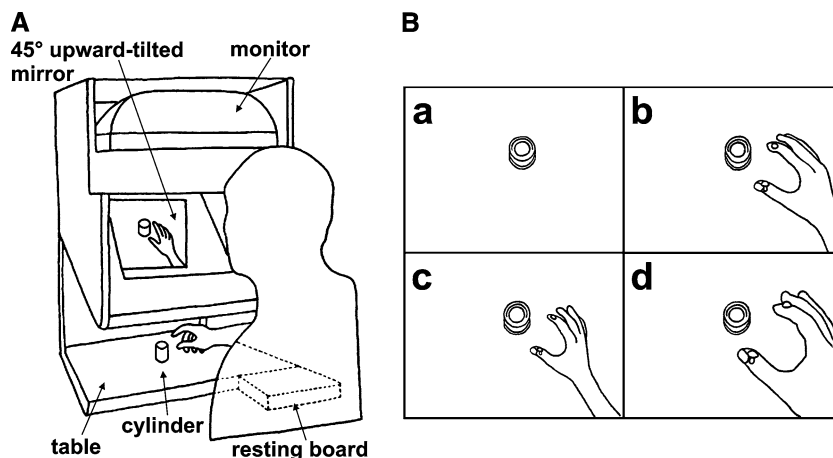
Apparatus

Participants sat at a table (645 × 470 mm), in a dimly lit room, with their right hand resting on a board (Fig. 1a). They looked towards a 45° upward-tilted mirror, suspended 180 mm above the table. The mirror completely prevented participants from directly seeing the table and their own hands throughout.

Participants were asked to firmly grasp, without lifting, with a right hand precision grip (i.e. using the thumb and the index finger), a plastic cylinder (diameter 40 mm, weight 60 g), centrally positioned on the table and uniformly illuminated by three halogen lamps fixed behind the mirror. A digital video camera (NV-GS17, Panasonic), invisible to the subject, acquired real-time images of the table from the participants' perspective through a 45° downward-tilted mirror fixed behind the upward-tilted mirror (Fig. 1a). These images were sent to a video-mixer (MXPro, Videonics), which extracted the hand from the visual scene and superimposed it on a fixed picture of the table and the target sent through an alternative video channel. This composed image was then sent to a CRT 22-inch colour monitor (SyncMaster-1200nf, Samsung) suspended face down over the upward-tilted mirror, so that the participants could visually monitor online (the actual delay of the video system was 94 ms), their own grasping movements superimposed on the fixed image of the target cylinder.

An optoelectronic motion analyser (SMART system, BTS, sampling rate of 120 Hz, accuracy < 0.2 mm) recorded the 3D spatial position of two markers fixed on the participants' right thumb and index fingers, throughout. The maximum distance between the thumb and the index finger (MGA) and the time at which the MGA occurred (TMGA) were then computed offline for each trial.

Fig. 1 **a** Schematic sketch of the experimental apparatus. **b** Line drawing of the visual feedback given to participants in the no-hand condition (*a*), the real size hand condition (*b*), the shrunken hand condition (*c*) and the enlarged hand condition (*d*). The cylindrical shape represents the object to be grasped



Experimental design and procedure

Participants performed the grasping task under four different visual feedback conditions (Fig. 1b): no-vision (NV), real size hand (RH), shrunken hand (SH) and enlarged hand (EH). Under the NV condition, participants could only see the picture of the target sent through the alternative video channel but received no visual feedback from their movements (open-loop grasping). Under the RH condition, participants could see both the target and their grasping hand at real size. Under the SH and the EH conditions, the image of participants' hand was, respectively, shrunk or enlarged by zooming out or in with the video camera (magnification factor 0.65 and 1.35, respectively), while the picture of the target sent through the alternative video channel was kept constant.

In a single experimental session consisting of seven blocks (comprising 10 grasping actions each, for a total of 70 trials), we tested both the direct effect of the distorted visual feedback on grasping (exposure blocks) and any after-effect of the visual distortions in the open-loop grasping (post-exposure blocks).

In blocks 1 and 2 (pre-exposure blocks), the baseline measures for the RH and NV conditions were collected, respectively. Blocks 3 and 6 consisted of either the EH or SH conditions, in alternate order across participants, each followed by a NV condition (post-exposure blocks 4 and 7). In block 5, participants again performed the task under the RH condition, as a wash-out from any adaptation following the previous exposure to the visual distortion of the hand, before being exposed to the opposite distortion.

On each trial, participants grasped the target with their right hand following a go-signal from the experimenter. Afterwards, they put their hand back to the resting board. Each trial lasted about 3 s with an inter-trial interval of about 10 s, during which the experimenter checked the position of the target and relocated it at the starting position, if necessary. Participants were given a brief training session under the RH condition in order to ensure that they could accomplish the grasping task properly.

Results

Data were analysed offline. A few (2.8%) trials with unstable marker tracking were excluded from the analysis.

In order to compensate for the different hand size of the participants, the values of MGA measured for each participant were normalised to the participant's maximum possible grip aperture. These resulting values, actually ratios expressing fractions of the absolute MGA, were used for the analysis. For the sake of completeness, mean values of the normalised MGA \pm SD, here reported, are followed by

the original values of MGA in square brackets. A preliminary *t* test showed that the normalised MGA measured for the two blocks performed under the RH condition, namely the baseline and wash-out, was stable (0.79 ± 0.07 [99 ± 13 mm] vs. 0.76 ± 0.05 [95 ± 8 mm], $t_7 = 1.52$, $p = \text{n.s.}$). Therefore, data from these two blocks were collapsed for further analysis. A mixed-model two-way analysis of variance (ANOVA) with Experimental Block as a seven-level within-subjects factor and Block Order as a two-level (EH or SH distortion first) between-subjects factor was performed separately on MGA and TMGA. The ANOVA on MGA showed a significant main effect of Experimental Block ($F[5,30] = 5.33$, $p < 0.001$, $p\eta^2 = 0.47$). This effect was mainly due to the EH exposure block that showed a significant reduction of MGA (0.73 ± 0.06 [91 ± 12 mm]) as compared to the RH situation (0.77 ± 0.05 [97 ± 10 mm]; $t_7 = 3.12$, $p < 0.05$) (Fig. 2a). No effect of Block Order or interaction was found.

On average, the decrease of MGA started from the fourth trial of exposure to the EH, and was carried over to the following open-loop session (NV baseline = 0.8 ± 0.07 [101 ± 14 mm]; EH post-exposure = 0.74 ± 0.06 [93 ± 13 mm]; $t_7 = 5.47$, $p < 0.001$) (Fig. 2c). By contrast, there was no difference between the SH (0.78 ± 0.05 [98 ± 9 mm]) and the RH exposure blocks (0.77 ± 0.05 [97 ± 10 mm]) or between the SH post-exposure (0.78 ± 0.05 [98 ± 11 mm]) and the NV baseline (0.8 ± 0.07 [101 ± 14 mm]) blocks.

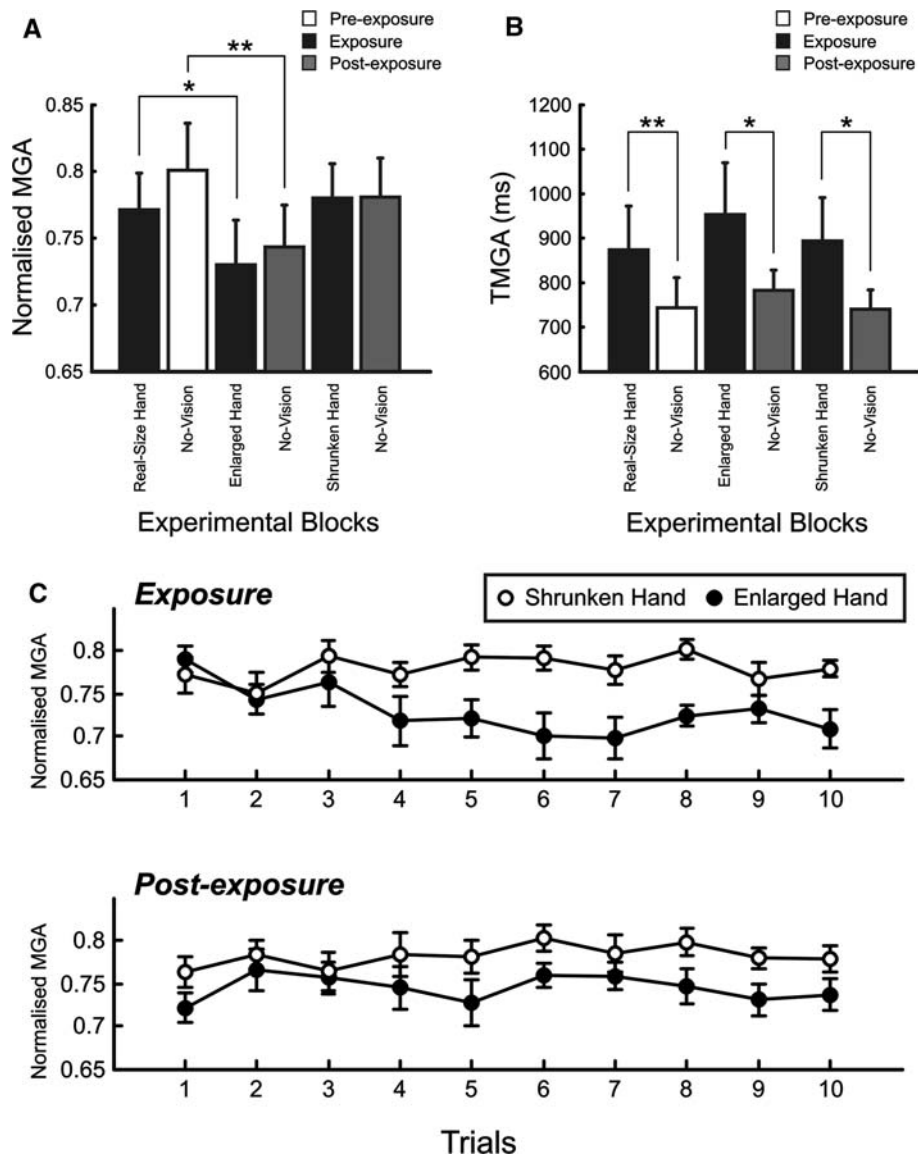
Inspection of individual participants' data showed that after the EH condition all participants produced a smaller MGA on average, with a 4% mean decrease in MGA as compared to the RH condition. However, only five out of eight participants showed increased MGA with the SH condition, and the group as a whole showed only a small increase in MGA (2%) as compared to RH.

The ANOVA on TMGA showed a significant effect of the factor Experimental Block ($F[5,30] = 5.32$, $p < 0.05$, $p\eta^2 = 0.47$) without any effect of Block Order or interaction. The MGA occurred significantly earlier for blocks without visual feedback as compared to blocks with visual feedback (Fig. 2b). In particular, differences between the NV baseline and the RH exposure blocks (744 ± 125 vs. 873 ± 170 ms; $t_7 = 4.06$, $p < 0.01$), the EH exposure and post-exposure blocks (953 ± 216 vs. 782 ± 85 ms; $t_7 = 2.60$, $p < 0.05$) and the SH exposure and post-exposure blocks (893 ± 183 vs. 740 ± 81 ms; $t_7 = 2.32$, $p = 0.053$) were found.

Discussion

When grasping an object, the brain has to coordinate information about the size of the object and the shape and size of

Fig. 2 **a** Mean normalised MGA measured for the six experimental conditions. Error bars are the 95% confidence intervals. Connecting lines indicate significant pairwise comparisons between experimental conditions (* $p < 0.05$; ** $p < 0.01$). **b** Mean TMGA measured for the six experimental conditions. Error bars are the 95% confidence intervals. **c** Time course of MGA. Mean normalised MGA as a function of the sequence number of trials separately for exposure (upper row) and post-exposure (lower row) to the shrunken hand (white dots) and to the enlarged hand (black dots). Error bars are the 95% confidence intervals



the grasping hand: together, these factors determine how much the hand has to be opened for grasping (Gentilucci 2002; Jeannerod et al. 1995). The latter factor is part of our taken-for-granted, internal model of the body (Berlucchi and Aglioti 2009). The perception of one’s own body size is relatively stable, and generally changes only over the developmental timescale, although recent experimental and neurophysiological studies show that current sensory input also contributes to perceived body part size (e.g. Gandevia and Phegan 1999; Paqueron et al. 2003).

In the present work, we show that such a stable representation of body part size can be significantly affected by distorted visual feedback from the body. While it was previously shown that distorted vision can influence tactile perception (Taylor-Clarke et al. 2004), here we show that the influence of vision also has an influence on action parameters such as the MGA. Therefore, the pre-shaping

component of grasping likely involves not only the visual representation of the object size, but also a volumetric representation of the moving hand. Our results show that this representation is at least partly visual in origin.

Even more surprisingly, we found that the effect exerted by the vision of the enlarged hand on MGA carried over to the following post-exposure situation in which subjects performed grasping movements without any visual feedback of the hand. The after-effect that follows this adaptation is even resistant to somatosensory afferent feedback from ongoing movements, which usually elicits rapid adaptation of motor control (Dewhurst 1967). Taken together, these findings suggest that distorted visual input leads to an altered size of the hand in an internal representation of the physical properties of one’s own body, which would be somewhat resistant to the mismatching somatosensory input.

The analysis of TMGA only revealed that the MGA was attained earlier for movements performed without vision of the hand than with the visible hand, regardless of any visual distortion. This finding may be akin to the faster TMGA observed during grasping performed under impoverished visual conditions of the target (Berthier et al. 1996; Schettino et al. 2003), and suggests that this kinematic parameter is also modulated by the overall vision of the moving hand. The lack of effect of hand size on TMGA is in line with previous results showing that timing of grasping movements, including reaction times, movement times, and acceleration/velocity parameters, mostly depends on the non-spatial characteristics of the target (e.g. weight, coefficient of friction) rather than on the spatial characteristics (e.g. size, shape, and orientation; see Glover 2004 for a review of the influence of a wide variety of visual and cognitive information on the parameters of grasping).

Although the participants were not explicitly told about the different experimental conditions, they all spontaneously reported that, on different trials, the image of their hand was either enlarged or shrunken. Furthermore, some of them even claimed that during both the exposure and the following post-exposure EH conditions they surprisingly felt their right hand bigger than usual. These reports are reminiscent of the pathologic perceived expansion of the entire body or of single body parts (i.e. *hyperschematia*) which may be experienced following different pathological conditions (Bonnier 1905; Coleman 1933; Lippman 1952; Lukianowicz 1967; Mauguire and Courjon 1978; Sanguineti et al. 1983; Todd 1955), reduced sensory input or cutaneous stimulation (Gandevia and Phegan 1999; Paqueron et al. 2003) or cortical stimulation (Blanke et al. 2004).

However, a novel finding of the present paper is that any altered representation of body part size was not simply reported as a ‘strange feeling’ but also affected motor behaviour. In contrast, somatic illusions and motor control were dissociated in other studies. For example, in a recent experiment, Moseley and co-workers (2008) could bias subjective pain perception when patients affected by chronic pain executed pantomimes under distorted vision of their hand, although no effect on the amplitude movement was observed. Apart from other methodological differences, it is likely that the lack of motor effect in that experiment was due to the kind of movement requested. Since Moseley et al.’s participants did not make grasping movements, the kinematics of action might have been less affected by a visual distortion of hand size. Clearly, the distinctive feature of grasping is that the size of the hand must be matched to the size of the target object (Jeannerod et al. 1995).

Our results also contrast with purely perceptual distortions of perceived body part spatial position that may follow peripheral nerve lesions, amputations (Ramachandran

and Hirstein 1998) or local anaesthesia (Gandevia and Phegan 1999; Paqueron et al. 2003). A number of studies have explicitly investigated whether somatic illusions also affect motor control. They have generally produced conflicting answers to this question. For example, visual exposure to a rubber hand, which can affect the perceived position of the real hand, biases the endpoint of slow reaching movements (Holmes et al. 2006) but leaves unaltered the kinematics of ballistic pointing movements (Kammers et al. 2009). In contrast, our study found consistent effects on action control, at least for body part enlargement. We suggest that this difference may occur because grasping requires matching volumetric information about hand size to information about object size. In contrast, pointing responses require only positional information: neither the size of the hand nor the size of the target forms part of the formal description of the pointing task.

Classical neurology proposed the existence of a *superficial* and a *postural* body schema (Head and Holmes 1911). Our results suggest that the body representation also includes a plastic *size schema*, which plays a critical role in guiding object-oriented actions. Previous studies assimilated body part size information to a body structural representation (e.g. Corradi-Dell’Acqua et al. 2008), showed its independence from the spatial representation of extrapersonal objects (Sposito et al. 2010), but did not consider how this information was used for action. Our data suggest that the information about the body size can be used unconsciously, as typically maintained by the classical notion of the *postural body schema*, for action execution and is based not only on somatosensory, but also on ongoing visual input. According to a recent taxonomy of somatosensory processing put forward by Longo and colleagues, the computation of body part size would be part of a higher order system of sensory perception, called *somatosensation*, that would be critical for the processing and integration of multisensory information related to the body, that would include the PPC as a critical neural substrate (Longo et al. 2009). Such multisensory input from the body would then affect both early somatosensory processing, possibly via feedback projections to unimodal somatosensory cortex (e.g. Schaefer et al. 2007; Taylor-Clarke et al. 2004) and action planning and execution,¹ as shown by the present experiment.

Interestingly, in the present experiment, an effect on MGA was found following enlarged, but not shrunken

¹ Intriguingly, our results are reminiscent of the dynamic modulation of body representation induced by the repetitive use of external tools (Maravita and Iriki 2004) that can subsequently affect the kinematics of movement of the trained arm (Cardinali et al. 2009). Critically, in our experiment, the mere vision of altered hand size would be sufficient to modify the internal body model for action.

vision of the hand that only induced a trend for increased MGA in some participants. First, this evidence rules out the hypothesis that our effects with the EH situation may be due to any mere perceptual, size constancy effect or illusory size mismatch between the image of the object (which does not change in size) and that of the hand, or to the small change in the apparent spatial location of hand introduced by the experimental manipulations. Although these spatial and perceptual factors may have played a role in modulating the MGA, it is unlikely that they were responsible for our effects: Given that these factors were opposite in the EH and SH conditions, they should have produced not only the observed reduction of MGA in the EH situation but also an increased MGA in the SH condition.

The overall asymmetry between enlargement and shrinkage also recalls the predominance of enlargement over shrinkage in conditions such as epilepsy and migraine (Mauguiere and Courjon 1978; Podoll and Robinson 1999), local anaesthesia and cutaneous stimulation (Gandevia and Phegan 1999). Similarly, recent experiments showed that tactile sensitivity of the index finger can be modulated by an illusory elongation, but not shrinkage, of the finger induced by muscle vibration (de Vignemont et al. 2005). Furthermore, the rubber hand illusion can be induced by showing to the participants a real size or enlarged, but not reduced vision of their own hand (Pavani and Zampini 2007).

The asymmetry between EH and SH effects may, firstly, take into account the typical asymmetry in the size of the retinal image usually subtended by one's own body parts in daily life. For example, while the retinal image of the thumb consistently expands when the hand gets closer to the eyes, it cannot shrink below about 2° of visual angle given the limited extension of the forearm. Therefore, any smaller image of the hand must belong to extrapersonal space, and not to our own body. Secondly, a shrunken view of the hand could possibly reduce the feeling of ownership (see, e.g., discussion in Moseley et al. 2008), thus any visual information specifying hand shrinkage would be less easily attributed to one's own body, and would not then be taken into account for motor programming.

In conclusion, the vision of a distorted image of a body part can be taken into account for motor programming. This transfer of a somatic illusion to motor control may critically depend on the critical role of body part size information in grasping actions. Our findings could also have practical implications, e.g., they could be potentially exploited in motor rehabilitation of neurological patients, where the vision of an enlarged hand could perhaps increase the effectiveness of visuomotor training.

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