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KEEPING IN TOUCH WITH OUR HIDDEN SIDE

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ABSTRACT

Previous studies have shown that the sensory modality used to identify regions of the body hidden from sight, but frequently viewed, influences the type of the body representation employed for reaching them with the finger. The question then arises as to whether this observation also applies to body regions which are rarely, if ever, viewed. We used an established technique for pinpointing the type of body representation used for the spatial encoding of targets which consisted of assessing the effect of peripheral gaze fixation on the pointing accuracy. More precisely, an exteroceptive, visually dependent, body representation is thought to be used if gaze deviation induces a deviation of the pointing movement. Three light-emitting diodes (LEDs) were positioned at the participants' eye level at -25 deg, 0 deg and +25 deg. Without moving the head, the participant fixated the lit LED before the experimenter indicated one of the three target head positions: topmost point of the head (vertex) and two other points located at the front and back of the head. These targets were either verbal-cued or tactile-cued and the participants had to reach them with their index finger. We analysed the accuracy of the movements directed to the topmost point of the head, which is a well-defined, yet out of view anatomical point. Based on the possibility of the brain to create visual representations of the body areas that remain out of view, we hypothesized that the position of the vertex is encoded using an exteroceptive body representation, both when verbally or tactile-cued. Results revealed that the pointing errors were biased in the opposite direction of gaze fixation for both verbal-cued and tactile-cued targets, suggesting the use of a vision-dependent exteroceptive body representation. The enhancement of the visual body representations by sensorimotor processes was suggested by the greater pointing accuracy when the vertex was identified by tactile stimulation compared to verbal instruction. Moreover, a control condition showed that participants were more accurate in indicating the position of their own vertex than the vertex of other people. Together, our results suggest that the position of rarely viewed body parts are spatially encoded by an exteroceptive body representation and that non-visual sensorimotor processes are involved in the constructing of this representation.

Key words: Body representations; Somatosensory target; Body image; Body schema

INTRODUCTION

Our daily experience shows that we can touch any part of our body with our hands. Remarkably, this includes touching regions that we rarely see (e.g., top of the head, back). This capacity provides evidence for the existence of internal body representations and for the access of the arm motor system to these representations.

Much of our knowledge on the control of pointing movements to regions of our body comes from studies in which subjects had to indicate with the index finger different positions on their contralateral arm hidden from view [1-6]. Generally, subjects point fairly accurately to these positions (errors $< \sim 2$ cm). As a key finding, studies show that the sensory modality used to locate such targets have an impact on the type of body representation used to encode their position [1,5,7]. Body positions identified by tactile stimuli would be encoded using an interoceptive, somatosensory-based, body representation if the eyes or head remain still between the stimulation and the response. On the other hand, body positions defined by auditory or verbal cues would be encoded in an exteroceptive, visually-based, body representation (see [8] for a review of different body representation taxonomies).

Visual calibration of proprioception is required for building coherent somatosensory body representations [9]. The question then arises as to whether somatosensory-based body representations are still used to locate body areas which are rarely viewed, even when defined by tactile stimulation. We addressed this issue by asking adult participants to touch with their index finger different points on their head (notably the vertex) indicated either verbally or by tactile stimulation. We used an established technique for pinpointing the type of body representation used for the spatial encoding of targets which consisted of assessing the effect of peripheral gaze fixation on the pointing accuracy [2,5,7]. The rationale for using this method is that the encoding of a target position is gaze-dependent when using an exteroceptive, visually-based, representation: in this case, the pointing errors are biased in the opposite direction to the gaze. For instance, with left fixation, subjects will usually point to the right of a target located straight-head [2,5,7]. Inversely, the spatial encoding of a target with an interoceptive body representation would be gaze independent: in this case, the pointing accuracy is not affected by gaze direction.

Clues exist in the literature suggesting that an exteroceptive body representation could be favoured over interoceptive representation for localising rarely viewed body positions identified by tactile stimulation. Indeed, studies have shown that coherent visual

representations, including of human bodies, can be built using partial visual information [10]. This opens the possibility of building a relatively accurate visual representation using available, yet incomplete visual feedback of the body. Vision of others' bodies [11] could contribute to this cognitive construction of body parts that remain out of view. On the basis of these psychophysiological findings, we hypothesized that the spatial positions of body areas which are rarely if ever viewed (e.g., the vertex) are encoded using an exteroceptive body representation, both when they are verbally or tactile-cued. Accordingly, we predicted that the accuracy with which individuals point to these body areas will be biased if gaze direction is deviated from straight-ahead.

METHODS

Participants

27 right-handed participants (mean age: 23.8 ± 2.4 years, 14 women) with normal or corrected to normal vision volunteered for the experiment. Informed consent was obtained before the start of the experiment which conformed to the Declaration of Helsinki for experiments involving humans.

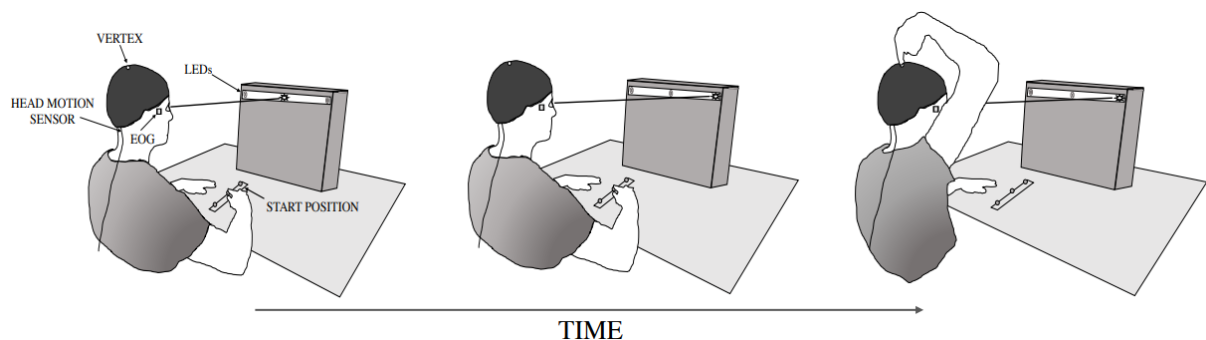


Figure 1. Schematic representation of the experimental set-up and procedure. The figure depicts the time course of a trial involving the middle starting position of the finger and a rightward gaze fixation. EOG: electro-oculography.

Experimental set-up

Before running the experiment, the experimenter marked the position of the vertex (i.e., the topmost point of the cranium [13]) on the stretch fabric cap worn by the participant. The vertex is located at the intersection point of the nasion-inion line and of the left and right tragus line. Then, the participant was seated in semi-darkness with the head vertical and aligned with the trunk. Light-emitting diodes (LEDs) were positioned eye level ~ 57 cm in front, at -25 deg (left),

0 deg (central) and +25 deg (right) with respect to the cyclopean eye (Fig. 1). These LEDs served to control gaze direction during the trials. Three small spheres, each 10 cm apart, were fixed on the table, in the participants' fronto-sagittal plane (the closest at 20 cm from the participants). These spheres served as starting positions for the right index finger. The view of the finger in its initial position helped maintain proprioception calibration during the movement initiation [9].

Data recordings

The endpoint position of the index finger on the head was recorded using a digitizing stylus (120 Hz, Polhemus Fastrak). Head position (i.e., X and Y coordinates) was tracked using a 2.5 cm electromagnetic sensor (120 Hz, Polhemus Fastrak) embedded in the cap at the back of the head. The position of the eyes was recorded by EOG (250 Hz, Coulbourn Instruments) and displayed on the computer screen. EOG recordings allowed to verify the participant's ocular behavior during the experiment. The few trials in which the participants failed to maintain their ocular deviation were deleted and repeated.

Experimental conditions

The task of the participants was to indicate different points on their head with the tip of the index finger. This task was performed with three gaze deviations (i.e., left, center, right), in two conditions (i.e., Verbal, Tactile) which differed according to the cue modality used to indicate these targets.

Verbal-cue condition

At the start of each trial, the experimenter verbally indicated one of the 3 finger starting positions (i.e., far, middle or close). Once in place, the participant sent the verbal message "ready". Then, the following lighting sequence of the fixation LEDs started. From 0 to 1.5 s: lighting of the central LED; from 2 to 10 s: lighting of either the left, central or right LED. The participant had to fix the lit LED without moving the head. After ensuring that the participant fixated the final lit LED by looking at the EOG signal, the experimenter indicated one of the 3 points of the head (hereafter referred to as the targets) that the participants had to reach immediately with the index finger.

These points were described and named as follows: the topmost point of the head (top, i.e., vertex), the mid-distance between the eyes and the topmost point of the head (front) and

the mid-distance between the rearmost and the topmost points of the head (back). Without moving the eyes or the head, the participants had to touch, as accurately as possible, the target with the tip of their index finger.

Tactile-cue condition

This condition was similar to the Verbal-cue condition. Instead of verbally identifying the targets, the experimenter touched the targets using a Semmes-Weinstein monofilament (caliber: 6.65; force: 4.38 N). To this end, the experimenter held the filament perpendicularly above the target before descending it until the filament bowed upon contact with the head. Immediately after the tactile stimulation, the participants had to touch with their finger where they felt they had been touched on their head. The use of the monofilament ensured that the sensory stimulation evoked by the touches was similar across gaze and cue conditions, and across participants.

In both conditions, the participants were instructed not to rush their response. Standing behind the participants, the experimenter slipped a digitalizing stylus under the index to record the middle of the touched area on the head. Then, the experimenter touched 4 other points of the head with the stylus. The third of which was the actual vertex, while the others were nearby random positions on the head. Touching the head at random positions diminished the possibility of the participants obtaining error feedback about their pointing accuracy. Questioned after the experiment, all participants confirmed that they did not realize that the third position touched by the stylus on their head corresponded to the actual target position. Only trials using the vertex as the target were analyzed. The use of the front and back targets, and of the different starting positions minimized the risk of participants implementing stereotyped pointing responses to the vertex. For this reason, the front and back targets were not defined precisely.

For each Cue and Gaze condition, 12 trials used the vertex target, 2 trials used the front target and 2 trials used the back target. The order of presentation of the targets and of the fixation LED was pseudorandom. 14 participants started the experiment with the Tactile-cue condition. Prior to each experimental condition, participants performed a series of 7 familiarization trials comprising all combinations of ocular fixation with the front and back targets (i.e., 6 trials) and 1 trial using the top target and the central fixation.

Others (control condition)

The identification of the vertex of other people can be thought of as being exclusively based on visual representations [1]. It is therefore possible to assess the accuracy with which one

localizes the vertex on the basis of a (hypothetically pure) visual representation by asking participants to indicate the vertex of other people. In a control condition, the participants located with their index finger the vertex of 6 adult volunteers (aged between 21 and 56 years) wearing a black fabric cap. During the test, the volunteers were seated, eyes closed, in a lighted room with the head vertical and aligned with the trunk. The experimenter positioned the tip of the digitizing stylus at the point of the head indicated by the participants. The participants were then asked to move around the seated volunteer and were allowed to correct the position of the stylus, before the experimenter marked its position. Then, in the absence of the participants, the actual vertex position of the volunteers was also marked on the cap before this and the participants' perceived vertex positions were recorded using the stylus. This control condition was performed either before or after the Verbal-cue or Tactile-cue conditions.

Data analyses

The effect of Gaze and Cue-target conditions on pointing accuracy was assessed by computing the radial error, which was defined as the 2D euclidean distance between the finger end position and the actual vertex position. Previous studies have shown that gaze direction had a greater impact on pointing movements in the medio-lateral direction than in the antero-posterior direction when subjects have their head aligned with the trunk [2,5,7]. Pointing accuracy was then further analyzed by computing the lateral (X coordinates) and longitudinal (Y coordinates) errors. These errors were respectively defined as the signed distance between the perceived and the actual vertex positions in both X and Y coordinates. Positive lateral errors indicated that the participants perceived the vertex to the right of the actual vertex. Positive longitudinal errors indicated that the vertex was perceived in front of the actual vertex.

The variability (i.e., standard deviation of the mean) in estimating the vertex position was computed for each Cue-target condition. This variable provides an estimate of the reliability of the representation used to locate the vertex when identified by either tactile or verbal cues.

The continuous recording of the head position indicated that the participants succeeded in minimizing head movements during the trials. Notably, looking at a peripheral target had no effect on the lateral head position as indicated by the results of one way ANOVAs which did not show significant effect of Gaze on the lateral positions of the head measured at the lighting of the fixation LED and at the time the touched position was measured ($p > 0.05$ for both cue-target conditions). On average (all Cue-target and Gaze conditions), the participants moved their head by 0.12 ± 0.27 cm in the transverse plane between the recordings of the perceived

and of the actual vertex positions (recordings separated by 2.6 s, on average). To cancel out the effect of these small head movements on the assessment of the participants' performance, prior to the error calculation, we subtracted X (medio-lateral) and Y (antero-posterior) head displacements measured between the two recordings, from the X and Y coordinates of the measured vertex position.

The effect of Gaze and of Cue-target conditions was tested using 3 Gaze (left, center, right) x 2 Cue-target (verbal, tactile) repeated measures analyses of variance (ANOVAs). We also compared the mean errors (radial, lateral, longitudinal) measured while the participants gazed at the central LED in both the Verbal-cue and Tactile-cue conditions with those measured in the Others control condition. These data were submitted to separate one-way ANOVAs with three levels (i.e., tactile, verbal, others). The alpha level was set at 0.05 for all statistical contrasts. Significant effects were further analyzed using Newman-Keuls post-hoc tests. Note that additional ANOVAs, not reported here, did not show significant Gender main or interaction effects on the 3 types of errors (all $p > 0.05$).

RESULTS

Radial error

As a first salient finding, the amplitude of the radial error significantly differed according to the type of cue indicating the vertex ($F_{1,26} = 28.29$; $p < 0.001$; $\eta^2_p = 0.27$, Fig. 2A). The radial error was smaller in the Tactile-cue (1.04 ± 0.44 cm) than in the Verbal-cue (1.38 ± 0.57 cm) conditions. The ANOVA did not reveal significant effect of Gaze ($F_{2,26} = 0.13$; $p > 0.05$) or significant interaction Cue-Target x Gaze ($F_{2,26} = 0.42$; $p > 0.05$).

The variability of the radial error was significantly different between the two Cue-target conditions ($F_{1,26} = 27.94$; $p < 0.001$; $\eta^2_p = 0.26$; Fig. 2B). This variability was smaller when the participants indicated their vertex position in the Tactile-cue (0.70 ± 0.28 cm) than in the Verbal-cue (0.88 ± 0.30 cm) conditions.

Lateral error

The participants perceived their vertex to the left of its actual position with right gaze fixation (-0.15 ± 0.48 cm) and to the right with left gaze fixation (0.11 ± 0.48 cm). This bias was confirmed by the ANOVA which revealed a significant effect of Gaze on the lateral error ($F_{2,26}$

= 4.20; $p < 0.05$; $\eta_p^2 = 0.10$, Fig. 2C) and by the post-hoc comparison which showed a significant difference between left and right gaze fixations ($p < 0.05$). The perceived vertex position in the gaze-centered condition did not significantly differ from that measured in gaze-deviated conditions (both $p > 0.05$). Importantly, the perceived lateral position of the vertex did not significantly differ between the Verbal-cued and the Tactile-cued target conditions ($F_{1,26} = 3.42$; $p > 0.05$) and the interaction Gaze x Cue-target was not significant ($F_{2,26} = 0.03$; $p > 0.05$).

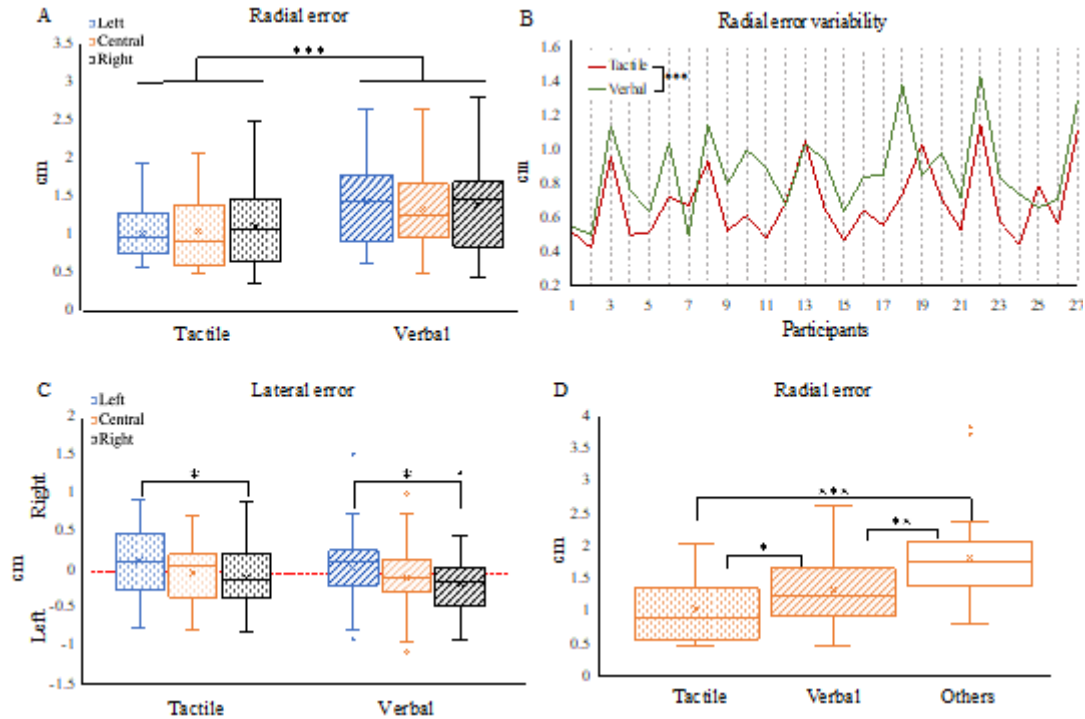


Figure 2: Boxplots of radial [A] lateral [C] errors measured in the different Cue-target and Gaze conditions and of radial errors [D] in the Tactile-cue condition and in the Verbal-cue and Others conditions (both with centered-gaze fixation). The cross represents the mean, the horizontal line represents the median. The lower and upper edges of the box correspond respectively to the 1st and the 3rd quartiles. The length of the whiskers represent the ranges of the bottom 25% and top 25% of the data values, excluding outliers which are represented by individual dots (i.e., data at least 1.5 times the interquartile range from the edge of the box). [B] Variability of the radial error in the Tactile-cue and Verbal-cue conditions. * $p < 0.05$; ** $p < 0.005$; *** $p < 0.001$.

Longitudinal error

The longitudinal error was not significantly different between the Verbal-cue and Tactile-cue conditions ($F_{2,26} = 0.0007$; $p > 0.05$) or between the different gaze fixations ($F_{2,26} = 0.79$; $p > 0.05$). The interaction Gaze x Cue-target was also not significant ($F_{2,26} = 0.49$; $p > 0.05$).

Perceived self versus others vertex position

Radial error

Participants were more accurate in indicating the position of their own vertex than the vertex of other people. This was confirmed by the one-way ANOVA (Others, Tactile, Verbal) which showed a significant effect of Condition on the radial errors ($F_{2,26} = 15.27$; $p < 0.001$; $\eta^2_p = 0.39$, Fig. 2D). Post-hoc comparison revealed that the radial error significantly differed between each condition. The radial errors were greatest in the Others condition (1.83 ± 0.71 cm) and smallest in the Tactile-cue conditions (1.03 ± 0.46 cm). As it can be seen in Fig. 2d, two participants were identified as outliers in the boxplot of the radial errors in the Others condition. To ensure that the larger radial error in the Others condition was not due to these participants, we performed another ANOVA without them. The significant effect of condition was preserved ($F_{2,24} = 13.09$; $p < 0.001$; $\eta^2_p = 0.37$) as well as all pairwise comparisons (all $p < 0.05$).

Lateral and longitudinal errors

The ANOVA revealed a significant effect of Condition on the lateral error ($F_{2,26} = 4.05$; $p < 0.05$; $\eta^2_p = 0.14$). The Post-hoc analyses showed that the lateral error in the Others condition (-0.29 ± 0.45 cm) was significantly greater than in the Tactile-cue condition (0.01 ± 0.35 cm, $p < 0.05$), but not significantly different to the Verbal-cue condition (-0.13 ± 0.48 cm, $p > 0.05$).

The longitudinal error did not significant differ ($F_{2,26} = 1.50$; $p > 0.05$) between Tactile-cue (-0.02 ± 1.06 cm), Verbal-cue (0.10 ± 1.35 cm), and Others conditions (0.51 ± 1.16 cm).

DISCUSSION

Previous studies have shown that the sensory modality used to identify regions of the body influences the type of the body representation employed for reaching them with the finger [1,5]. More specifically, identifying the body areas with an auditory and tactile cue respectively prompts the use of an exteroceptive (visually-based) and interoceptive (somatosensory-based) body representations when the eyes and head remain stationary. This scenario appears to be less straightforward when the target consists in a rarely, if ever, viewed area of the body, as in the present study. Indeed, when pointing to the tactile-cued vertex, our participants presented gaze-dependent errors: they pointed to the right of the vertex when fixating to the left, and vice versa (i.e., same directional biases as in previous studies using visual targets or auditory-cued targets on the arm [e.g., 5]). In agreement with our hypothesis, these effects of gaze direction on the

finger endpoint position are consistent with the predominantly use of an exteroceptive body representation. One interpretation for this novel finding could be that visual body representations are used to localize body parts that cannot be identified through visual-somatosensory integration. We shall focus much of our discussion on the bases of this interpretation.

Whilst the targets used in previous studies were generally located on the contralateral arm [1-6], our participants had to indicate the position of their vertex with the tip of their finger. The peculiarity of this body location is that it is rarely, if ever, viewed on ourselves. Our results therefore lead to the paradox that the spatial position of a tactile stimulation on a part of the body that is regularly viewed would be encoded through a somatosensory-based representation [1,3,5] while the position of a touch on a rarely viewed body part would be encoded through a visually-based representation (present results). This apparent paradox could be resolved by considering that the intrinsic and extrinsic body representations are co-constructed [12] and that the weight given to each representation is context-dependent.

An accurate somatosensory mapping of the body space requires cross sensory calibration [15]. For sighted persons, this calibration is principally achieved through vision [9,12]. The possibility to regularly see our upper limbs and therefore refresh their somatosensory mapping through vision could enhance the reliability of the intrinsic body representation for encoding the spatial position of tactile stimuli on the arm. The reliability of the intrinsic body representation for locating hidden parts of the body such as the vertex, appears hampered by the impossibility to co-register their positions with somatosensory and visual inputs. The lack of visual calibration could also have an exacerbated detrimental effect for localizing body areas with little density of somatosensory receptors, as is the case for the top of the head [14].

In this context, an extrinsic body representation appears most suitable for coding the vertex position. Seeing ourselves from a first or a third (e.g., through a mirror) perspective, and seeing someone else's body [11] would be fundamental to constructing what has been referred to as the long-term visual body representation (for a review, see [12]). This body representation could also benefit from the capacity of the brain to construct coherent consolidated representations, or to re-actualise them, on the basis of partial visual information [10].

Furthermore, sensorimotor-derived processes could also be involved in the construction of visual body representations [16]. For instance, sensorimotor experience gained during a

lifetime could have a key role in enhancing the spatial resolution of the visual representation of the vertex. Putting on a sweatshirt or a hat, or washing your hair are examples of sensorimotor activities that might improve the visual representation of this unseen body area. This idea is supported by the fact that our participants showed smaller radial and lateral errors when indicating the position of their own vertex, than the vertex of other people. It seems reasonable to assume that the task of localizing the vertex on another person's head is essentially based on visual representations (see [1]). Our results therefore further stress the importance of non-visual sensorimotor processes for constructing body representations, including those of visual origin. This is in line with the proposal that intrinsic and extrinsic body representations are co-constructed [12].

The enhancement of visual body representations by sensorimotor processes is also suggested by the greater pointing accuracy showed by the participants when their vertex was identified by tactile stimulation compared to verbal instruction (i.e., smaller radial error associated with smaller variability). Previous studies have reported improved position sense with tactile stimulation [4,6]. Our results indicate that this finer spatial resolution of the somatosensory mapping (which could be short-lived) can benefit visually-based extrinsic body representations. The interdependence between somatosensory-based and visually-based body representations is also revealed in the so-called rubber hand illusion [17]. This illusion arises from the simultaneous brushing of the hand of the subject, which is hidden from view, and of a facsimile of a human hand viewed in front of the subject. After a few minutes of exposure to this somato-visual context, the subjects perceive the fake hand as being the real hand, consistent with a close link between visual and somatosensory body representations.

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REFERENCES

- [1] A. Sirigu, J. Grafman, K. Bressler, T. Sunderland, Multiple representations contribute to body knowledge processing: evidence from a case of autotopagnosia, *Brain*. 114 (1991) 629–642. <https://doi.org/10.1093/brain/114.1.629>.
- [2] A. Blangero, Y. Rossetti, J. Honoré, L. Pisella, Influence of gaze direction on pointing to unseen proprioceptive targets, *Adv. Cognit. Psychol.* 1 (2005) 9–16. <https://doi.org/10.2478/v10053-008-0039-7>.
- [3] F.R. Sarlegna, R.L. Sainburg, The effect of target modality on visual and proprioceptive contributions to the control of movement distance, *Exp. Brain Res.* 176 (2007) 267–280. <https://doi.org/10.1007/s00221-006-0613-5>.
- [4] L. Mikula, S. Sahnoun, L. Pisella, G. Blohm, A.Z. Khan, Vibrotactile information improves proprioceptive reaching target localization, *Plos One*. 13 (2018) e0199627. <https://doi.org/10.1371/journal.pone.0199627>.
- [5] G.A. Manson, L. Tremblay, N. Lebar, J. de Grosbois, L. Mouchnino, J. Blouin, Auditory cues for somatosensory targets invoke visuomotor transformations: Behavioral and electrophysiological evidence, *Plos One*. 14 (2019) e0215518. <https://doi.org/10.1371/journal.pone.0215518>.
- [6] A. Goettker, K. Fiehler, D. Voudouris, Somatosensory target information is used for reaching but not for saccadic eye movements, *J. Neurophysiol.* 124 (2020) 1092–1102. <https://doi.org/10.1152/jn.00258.2020>.
- [7] S. Mueller, K. Fiehler, Effector movement triggers gaze-dependent spatial coding of tactile and proprioceptive-tactile reach targets, *Neuropsychologia*. 62 (2014) 184–193. <https://doi.org/10.1016/j.neuropsychologia.2014.07.025>.
- [8] F. de Vignemont, Body schema and body image—Pros and cons, *Neuropsychologia*. 48 (2010) 669–680. <https://doi.org/10.1016/j.neuropsychologia.2009.09.022>.
- [9] V. Harrar, L.R. Harris, Eye position affects the perceived location of touch, *Exp. Brain Res.* 198 (2009) 403–410. <https://doi.org/10.1007/s00221-009-1884-4>.
- [10] C.T. Fuentes, M.R. Longo, P. Haggard, Body image distortions in healthy adults, *Acta Psychol.* 144 (2013) 344–351. <https://doi.org/10.1016/j.actpsy.2013.06.012>.
- [11] S. Gallagher, *How the Body Shapes the Mind*, Oxford University Press, 2005. <https://doi.org/10.1093/0199271941.001.0001>.
- [12] V. Pitron, F. de Vignemont, Beyond differences between the body schema and the body image: insights from body hallucinations, *Conscious. Cogn.* 53 (2017) 115–121. <https://doi.org/10.1016/j.concog.2017.06.006>.

- [13] H. Gray, *Anatomy, descriptive and surgical*, Lea Brothers & Co, Philadelphia, 1887.
<https://doi.org/10.5962/bhl.title.26041>.
- [14] A. Mehrabyan, S. Guest, G. Essick, F. McGlone, Tactile and thermal detection thresholds of the scalp skin, *Somatosens. Mot. Res.* 28 (2011) 31–47.
<https://doi.org/10.3109/08990220.2011.602764>.
- [15] R.J. van Beers, D.M. Wolpert, P. Haggard, When feeling is more important than seeing in sensorimotor adaptation, *Curr. Biol.* 12 (2002) 834–837.
[https://doi.org/10.1016/S0960-9822\(02\)00836-9](https://doi.org/10.1016/S0960-9822(02)00836-9).
- [16] F. Mancini, M.R. Longo, G.D. Iannetti, P. Haggard, A supramodal representation of the body surface, *Neuropsychologia.* 49 (2011) 1194–1201.
<https://doi.org/10.1016/j.neuropsychologia.2010.12.040>.
- [17] H.H. Ehrsson, C. Spence, R.E. Passingham, That’s my hand! Activity in premotor cortex reflects feeling of ownership of a limb, *Science.* 305 (2004) 875–877.
<https://doi.org/10.1126/science.1097011>.