Ghost hand: My hand is not mine

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Synchronous visuo-tactile stimulation of the type in the rubber hand illusion (RHI)[1-3] and in out of body experience (OBE) [4, 5] can induce the brain to incorporate external objects or images into a part or whole of body image. Whether in the context of RHI or OBE, since the participant passively receives visuo-tactile stimulations, body image appears only with the sense of ownership (SoO), not with the sense of agency (the registration that we are the initiators of our actions; SoA) [6,7]. Insofar as self-consciousness as a body image is a unity acting in its environments, body image has to be investigated in the relationship between SoO and SoA[8,9]. It requires an experimental condition in which SoO and SoA can be independently separated in an active condition. However, no experimental condition that is opposite to RHI and OBE in which a subject can feel SoA but not SoO has been proposed to date[10]. Here, we show that a person loses SoO for his own hand that he can freely move by his own will when he sees himself in a lateral view through a head mounted display. It was previously thought that SoO can be represented by synchronous inter-modal stimulations[10], and that SoO appears to be complemented by SoA[11]. Our findings show that SoO can be lost under a synchronous visuo-proprioceptive condition while SoA can be maintained. SoO and SoA are two aspects of body representation, and similar dissociations have been proposed in various contexts, such as body image and body schema[12,13], and ‘Acting I’ and ‘Mine’[14]. Our result suggests that the two-centric-self consisting of SoA and SoO can enhance dynamically robust self-consciousness.

Under a passive condition revealing RHI and OBE, only SoO is explicitly acquired by a person. By contrast, in an active condition such as the phantom limb experiment[15,16], pantomime task[17], and synchronous virtual hand task[7], SoA is explicitly acquired by the person and SoO seems to accompany SoA. These experiments are conducted so that the person incorporates external objects into body image. Thus, it is difficult to see the loss of SoO. We therefore conducted an experiment in which a person can lose SoO for his own hand.

(Figure 1)

Participants (n= 28) were seated while wearing a head mounted display (HMD) onto which was projected real-time motion images of one side of their own upper body filmed by two video cameras placed side by side. The video cameras were placed 130 cm away from the participant, with a 10-cm distance between the two video cameras. The images from the left video camera were presented via the left eye display and that from the right camera via the right display. The participant could see his or her own lateral view stereoscopically. The participant was shown four kinds of counterbalanced images for 30 seconds: the right or left side of his body and in an invisible or visible condition. In the invisible condition, the participant could not see his upper arm since he was instructed to hide it behind his own body. In the visible condition, he was instructed to keep it on view in front of his body, thereby serving as a control experiment (Figure 1). During each trial, the participant could move his arm behind his body freely under the invisible or visible condition, and he was requested to orally provide an open-ended description of his experiences. All participants reported that they could move their own hands freely as they intended to move them, regardless of the visible and invisible conditions. Such a finding reveals they had SoA.

(Figure 2)

After 30 seconds viewing each motion image, participants were asked to complete a questionnaire in which they had to affirm or deny the occurrence of seven specific perceptual effects using a seven-point visual analog scale. The completed questionnaire indicated that participants experienced strong loss of SoO under the invisible condition (Fig. 2) and the side of subject's body did not influence (maximum $F(1,108)=2.30$ then $P=0.13$). The first three questionnaire items were important to estimate the loss of SoO, and the results for items 1 and 2 showed significant differences between the visible and invisible conditions (item 1: $P<0.001$, $t=4.91$, item 2: $P<0.001$, $t=4.60$). The particularly highly positive score for item 1 indicates that the participant felt as if the hand were not his own despite moving it by his own will. While there was a significant difference between two conditions in the scores for items 2 and 3, the scores were not high. The questionnaire items making the person indicate the owner of the hand (which also included nobody in item 3: $P=0.06$, $t=1.91$) might serve as the justice of ownership[9], different from the feeling of ownership relevant to item 1. Results for items 4 and 5 showed that the hand was not recognized as anything but a hand and to be controllable, thereby confirming SoA. This result held irrespective of the invisible or visible condition (item 4: $P=0.46$, $t=0.74$, item 5: $P=0.27$, $t=1.12$). Items 6 and 7 were also relevant to SoA. Although

participants denied the occurrence of the perceptual effect for these items, there was a significant difference between the visible and invisible conditions (item 6: $P < 0.003$, $t = 3.12$, item 7: $P < 0.02$, $t = 2.45$). A significant difference between the conditions reveals that the feeling that SoA is weakly lost.

(Figure 3)

We hypothesized that the loss of SoO is caused by the participant's false recognition that the visual configuration of the hand and the body is congruent to the proprioception. The elbow and upper arm can be clearly seen by the participant in the visible condition, making it is easy for him to imagine that the hand is connected by the shoulder. This was tested in a second experiment by measuring the difference between the actual and the participant's estimated angle made by the upper arm and the body (Fig. 3a, also see SI). The difference of the angle in the invisible condition was larger than that in the visible condition (P=0.003, t=3.11) (Fig. 3b), indicating that the participants overestimated the angle and lost the correct positional awareness of body parts under the invisible condition. We also conducted a third experiment to estimate whether participants felt or not as if the hand appearing in front of the body could be the experimenter's arm or a steel arm. Participants were asked to complete the same questionnaire as used in experiment 1. Although the scores of affirmation of the feeling that the hand was owned by another were not high, there was also a significant difference between the visible and invisible conditions (see SI).

The present illusion is fundamentally important because it provides the first experimental condition of SoA without SoO. In the passive condition, RHI and OBE reveal that multi-sensory synchronous interaction (Sense of being acted upon; So-be-A) can produce SoO[1-5]. Conversely, it is reported that SoO can produce the sense of being acted upon[18]. Thus, under the passive condition, SoO is equivalent to So-be-A. Since SoO and SoA are relevant to the distinction between you and me in terms of neuroactivity[7], investigation of the dynamical relation of SoO and SoA is necessary. The feeling of SoO or SoA alone has been noted in deafferented[19] and/or schizophrenia patients[20], and our findings relating to healthy persons' self-consciousness can contribute to expanding the knowledge about these patients.

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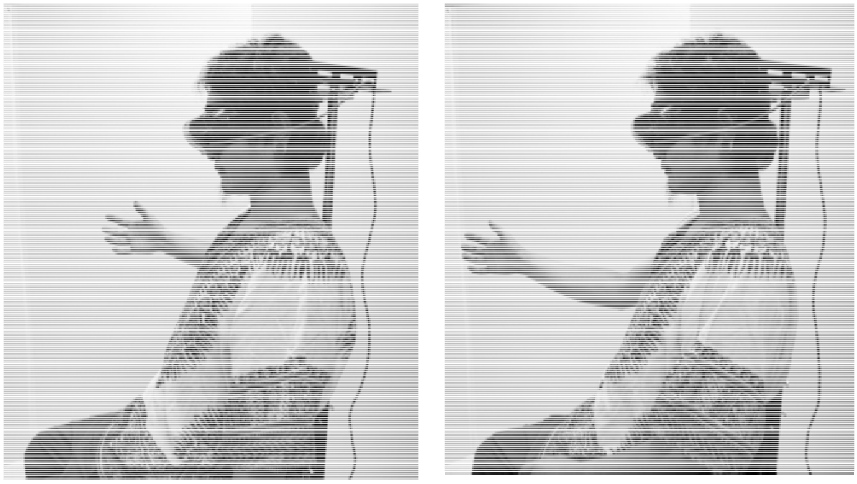


Figure 1. Experimental images viewed by the participant. They viewed these motion images during each trial on a the head mounted display. a: the invisible condition; b: the visible condition.

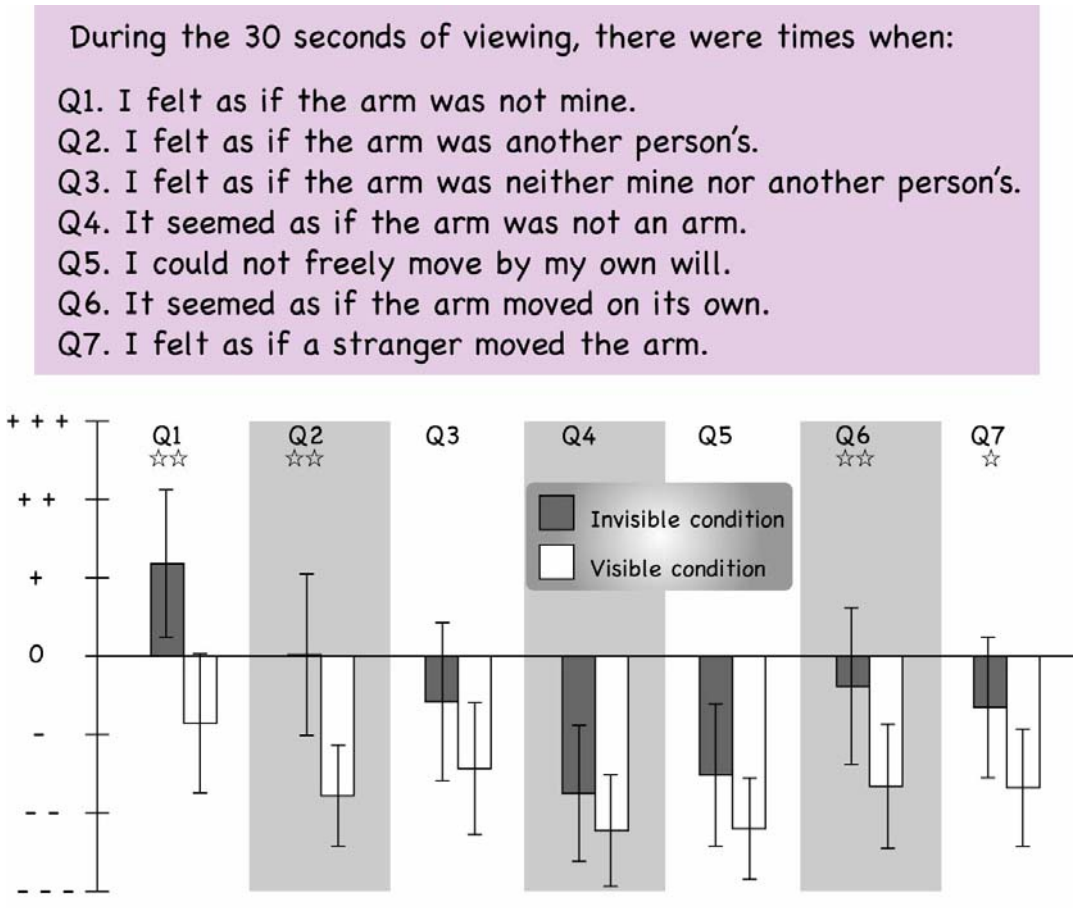


Figure 2. Questionnaire results, presenting means and standard errors of each item for the two experimental (invisible and visible) conditions. The single or double asterisk indicates significant differences (P=0.05 or P=0.01 respectively).

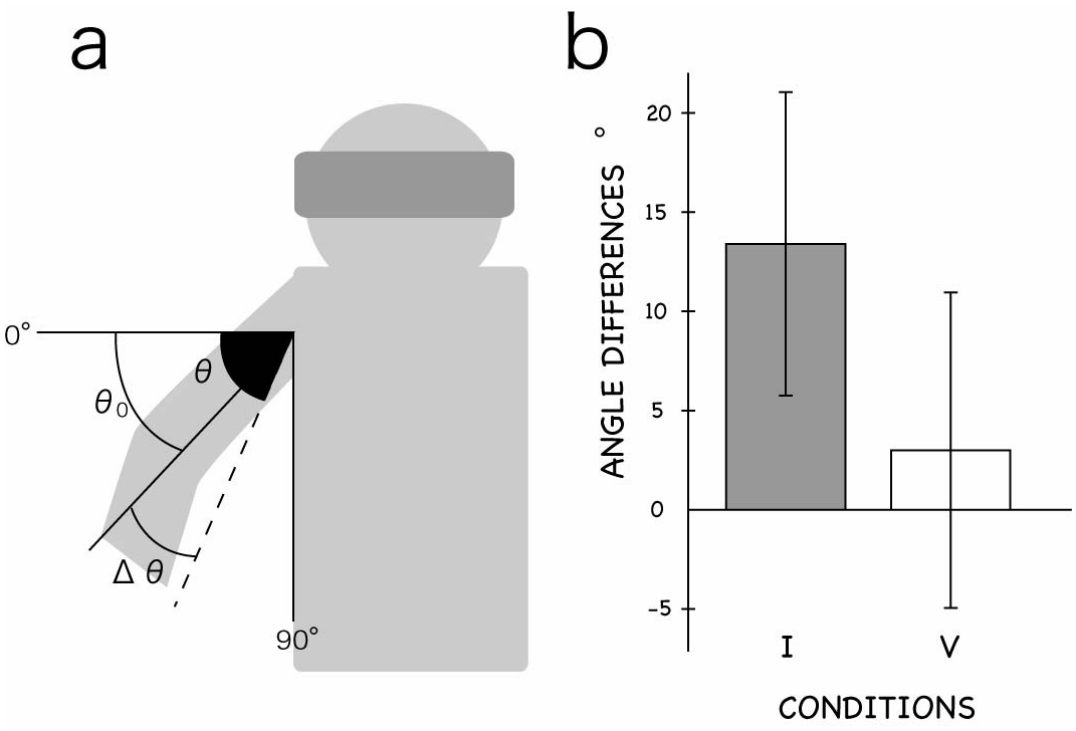
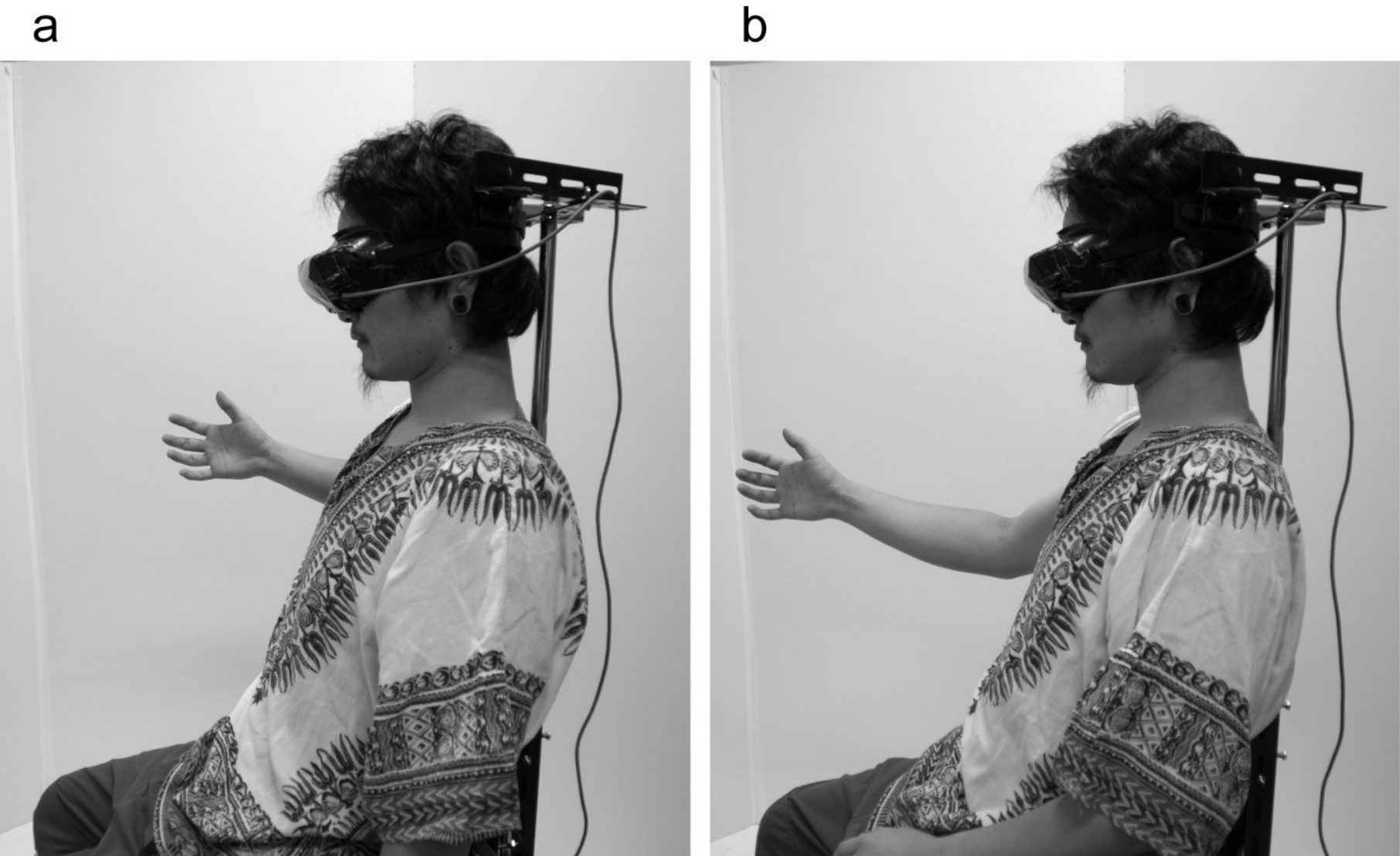


Figure 3 a. Difference of the angle ($\Delta\theta$) between the actual angle made by the upper arm and the body (θ_0) and the estimated angle (θ). Participants were exposed to the condition of our first experiment for a prolonged period, and were asked to estimate the angle between the body and the upper arm at the hidden side in the anterior view (also see SI). b. The angle difference under the invisible (I) and visible (V) conditions.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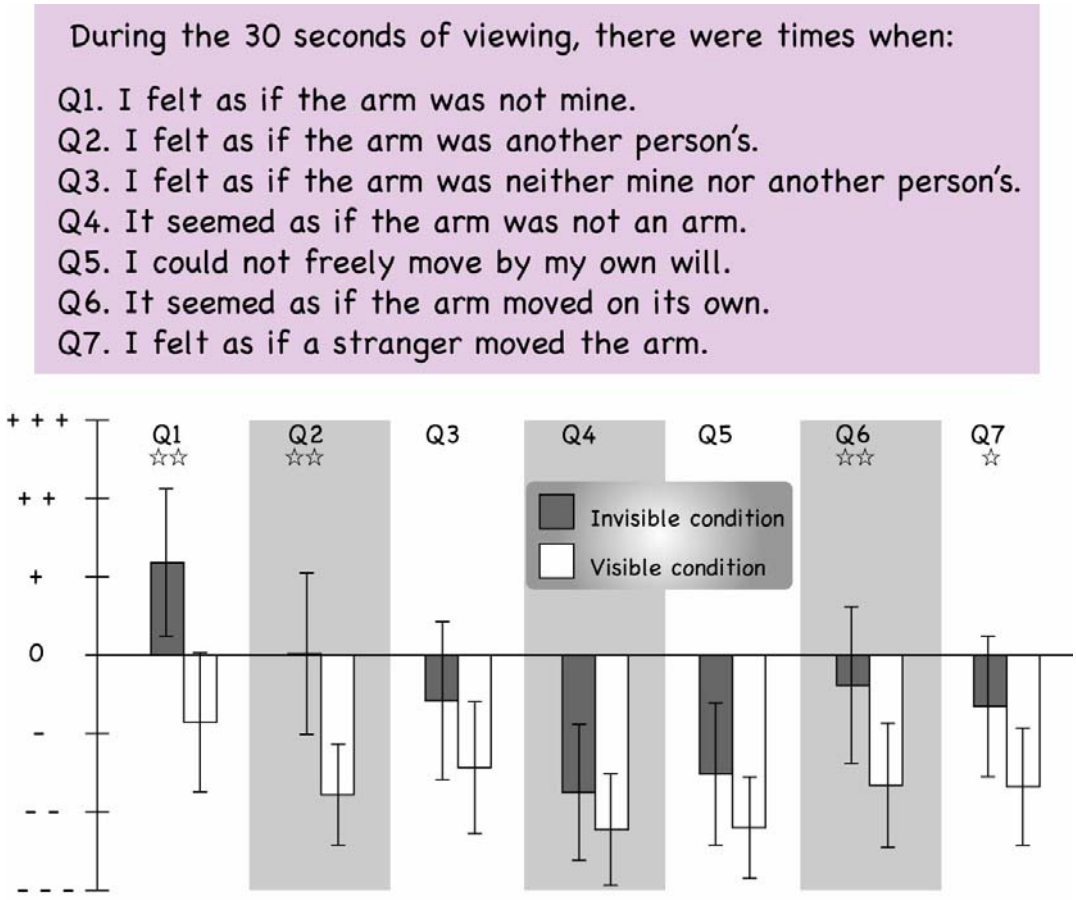

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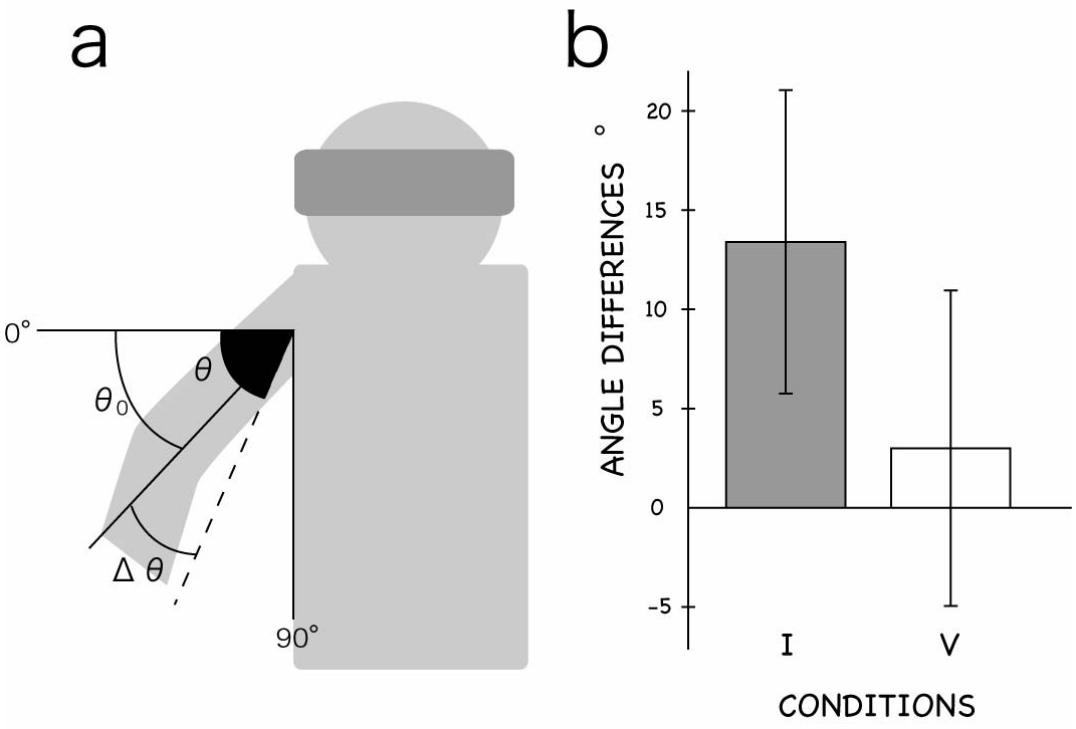

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