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Biomechanical constraint effects in estimating the congruency between verbal and visual descriptions of hand actions

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This study examined whether the biomechanical constraint effect is observed in comprehending the congruency between visual descriptions (pictures) of hand actions and verbal descriptions (sentences) of those actions. In the first-person pronoun conditions, pictures of intransitive hand actions (e.g., clenching action) and sentences of those actions (e.g., "I clench the hand") were presented on a screen. The hand laterality and the orientation of the pictures were manipulated. The participants estimated the congruency between the sentences and the pictures. In the second-person pronoun conditions, "you" was used instead of "I". The first-person pronoun conditions yielded high congruency scores for manageable hand orientations, suggesting that the participants were estimating the feasibility of imitating the observed hands. In contrast to the first-person pronoun condition, the results of the second-person pronoun conditions showed high congruency scores for the hand orientations of onlooker perspectives without any laterality effect. The results suggest that recognition of linguistic sentences describing actions involves embodiment processing, and action simulation processing triggered by these sentences changes depending on the difference of personal pronouns.

Key words: biomechanical constraint, embodiment, personal pronoun, action simulation

Introduction

Feeling ourselves within our physical body is termed embodiment (Arzy, Thut, Mohr, Michel, & Blanke, 2006). Embodiment is involved in language comprehension (perceptual and motor representations are thought to be used in understanding linguistic stimuli) (see Barsalou, 2008; Beveridge & Pickering, 2013; Jirak, Menz, Buccino, Borghi, & Binkofski, 2010; Pulvermüller, 2013 for review of these theories). For example, previous studies have shown that symbolic meaning is processed in the motor and sensory areas, and brain imaging studies have shown effector-specific activations in the motor cortex while comprehending linguistic action stimuli (Aziz-Zadeh, Wilson, Rizzolatti, & Iacoboni, 2006; Hauk, Johnsrude, & Pulvermüller, 2004; Tettamanti et al., 2005).

Recent experimental psychological studies have shown that a reader's mental perspectives are modulated depending on choice of personal pronoun (e.g., "I" or "you") and context (Brunyé, Ditman, Mahoney, Augustyn, & Taylor, 2009; Pickering, McLean, & Gambi, 2012; Sato & Bergen, 2013). For example, Brunyé et al. (2009) showed that readers took the actor's

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perspective when reading a sentence written with a second-person pronoun (i.e., "you") as the agent of action but took onlooker perspectives for a third-person pronoun (i.e., "he"). They also showed that mental perspectives were variable when the first-person pronoun (i.e., "I") was the agent, depending on the context. Pickering et al. (2012) showed that, even if the same sentences were used as the utterance stimulus, the different roles of speaker and addressee (i.e., one participant read the sentence aloud and the other heard it) influence the perspectives imagined while comprehending the utterance.

The previous studies (Brunyé et al., 2009; Pickering et al., 2012; Sato & Bergen, 2013) used pictures of two-handed transitive actions (e.g., slicing a tomato) as stimuli and manipulated two perspectives: one was the actor's perspective and the other was the onlooker perspective, which was inverted by 180° from the actor's perspective. The present study predicted that if the comprehender embodied the actions described in sentences, a biomechanical constraint effect would be observed in addition to the effect of imagined perspectives. The biomechanical constraint effect has been reported in mental rotation studies, which used human hands as stimuli (e.g., Sekiyama 1982; Sekiyama, Kinoshita, & Soshi, 2014). These studies examined reaction times to pictures of the left and right hand in different orientations and showed that the response times tended to be longer to hands in biomechanically difficult orientations.

The purpose of the present study was to examine whether the biomechanical constraint effect is observed in comprehending verbal descriptions of hand actions. Two types of personal pronoun in the sentence stimulus ("I" or "you") and eight hand orientations in the picture stimulus were manipulated. Intransitive actions (actions without objects) were used in the stimuli to avoid object orientation effects. The view of the hand actions in the pictures was standardized to be from the thumb side to avoid ambiguous interpretations and making experimental tasks too complex (for example, a palm-showing hand such as in "bye-bye" action can be interpreted ambiguously; the hand shape in "bye-bye" can be from either one's own side or the other person's side). The task of the present study was to evaluate the subjective degree of congruency between the pictures and the sentences, both presented on a screen.

Methods

Participants

Sixteen right-handed individuals (7 males and 9 females; age, 20–23 years) participated in this experiment. All participants provided written informed consent to take part. The ethics committee of Tohoku Bunka Gakuen University approved the study.

Stimuli

In total, 32 types of grey-scale pictures of a gloved hand were used as stimuli in which the action was either clenching or pointing. These hand actions were determined by referring to previous mental rotation studies (Sekiyama, 1982; Sekiyama et al., 2014). The laterality

was either the right or the left hand (the left hands were made by reflecting the pictures of the right hand); the orientation was either -135°, -90°, -45°, 0°, 45°, 90°, 135°, or 180° (each orientation was made by rotating the pictures at 0°) (See Fig. 1. The pictures at -180° were the same as those at 180°).

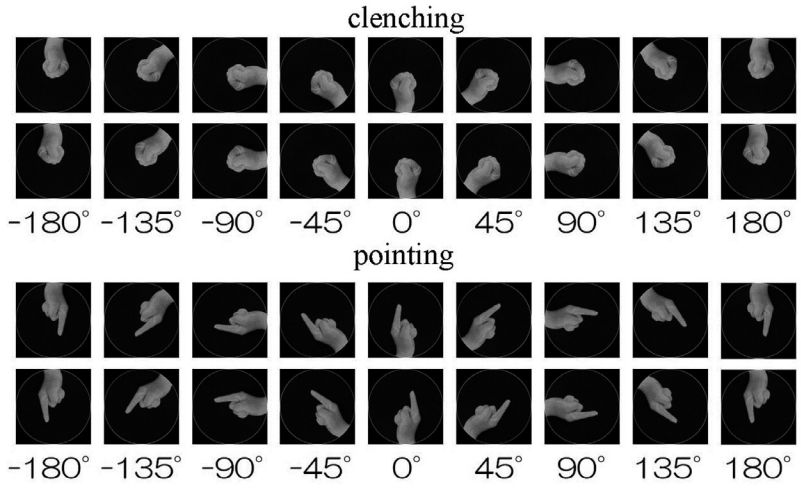

Figure 1. Pictures used in this study. Two types of intransitive hand action (clenching or pointing action) were used. The laterality (left or right hand) and the hand orientation (-180°, -135°, -90°, -45°, 0°, 45°, 90°, 135°, or 180°) were manipulated. The pictures at -180° were the same as those at 180°.

Procedure

During the experiment, participants were seated facing a 21.5-inch liquid crystal display (ST2220L, DELL) placed at a distance of 40 cm with their heads placed on a chin rest. Hand stimuli presented on the screen subtended a visual angle of 11°. The experiment consisted of the first- and second-person pronoun tasks, controlled by the E-Prime 2.0 software (Psychology Software Tools, Inc., Sharpsburg, PA, USA).

At each trial in the first-person pronoun (1pp) condition, one of the clenching pictures and the sentence "I clench the hand (watashi-ga te-wo nigiru)." or one of the pointing pictures and the sentence "I point the finger (watashi-ga yubi-wo sasu).", written in Japanese, were presented on the screen (see Fig. 2). Participants were asked to interpret these sentences as their own words (e.g., as if the participant had said "I clench the hand"). Previous studies have shown that readers' mental perspectives are modulated depending on both the pronouns and the contexts (Brunyé et al., 2009; Pickering et al., 2012; Sato & Bergen, 2013). To avoid ambiguous interpretations, the present experiment made clear the origin of the sentences. A visual analogue scale (VAS) was also presented on the lower part of the screen. Participants were required to estimate the degree of subjective congruency between presented pictures and sentences by moving the pointer on the VAS. They shifted the location of the pointer by moving a mouse with their right hand; locating it to the far left indicated "not congruent"

(0 congruency score) and to the far right indicated "very congruent" (100 congruency score). No time limit was imposed, and after determination of the position of congruency estimation, the next trial began. The mouse and the participants' hands were blocked from view during the experiment by placing a black board above their hands. Before starting the experimental trial, the participants viewed all combinations of pictures and sentences, and underwent 8 practice trials. The experiment consisted of two runs, with each run consisting of 32 trials. Thirty-two types of picture were presented within each run in random order.

In the second-person pronoun (2pp) conditions, "you" was used instead of "I" (see Fig. 2). As in the 1pp conditions, the participants were asked to interpret these sentences as their own words (e.g., as if they had said "you clench the hand"). All other procedures were identical to those in the 1pp conditions. The order of the 1pp and 2pp conditions was counterbalanced across participants.

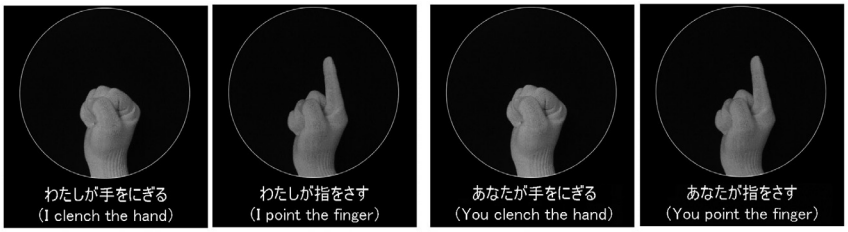

Figure 2. Examples of the combination of sentences and pictures. The example pictures all show the right-hand and 0°-orientation condition.

Results

Fig. 3a and 3b shows the mean congruency scores in each condition, indicating the same pattern of change between the clenching and pointing actions. Therefore, the mean scores across the two actions were calculated (Fig. 3c) and ANOVAs were performed for the mean data[1]. The degrees of freedom were modified by applying the Greenhouse-Geisser correction for sphericity departures.

The three-way ANOVA of the personal pronoun (1pp, 2pp), laterality (left, right), and orientation (-135°, -90°, -45°, 0°, 45°, 90°, 135°, or 180°) factors showed a significant main effect of personal pronoun [$F(1, 15) = 4.656$, $p < .05$, $\eta^2 = .022$], significant first-order interactions between personal pronoun and orientation [$F(1.60, 24.02) = 21.448$, $p < .001$, $\eta^2 = .314$] and between laterality and orientation [$F(2.63, 39.39) = 16.122$, $p < .001$, $\eta^2 = .037$], and a significant second-order interaction between personal pronoun, laterality, and orientation [$F(1.64, 24.60) = 7.504$, $p < .005$, $\eta^2 = .027$].

The two-way ANOVAs of the laterality and orientation factors were conducted by splitting the dataset according to personal-pronoun condition. In the 1pp condition, the ANOVA showed a significant main effect of orientation [$F(1.69, 25.41) = 35.400$, $p < .001$, $\eta^2 = .432$] and a significant interaction between laterality and orientation [$F(1.79, 26.79) =$

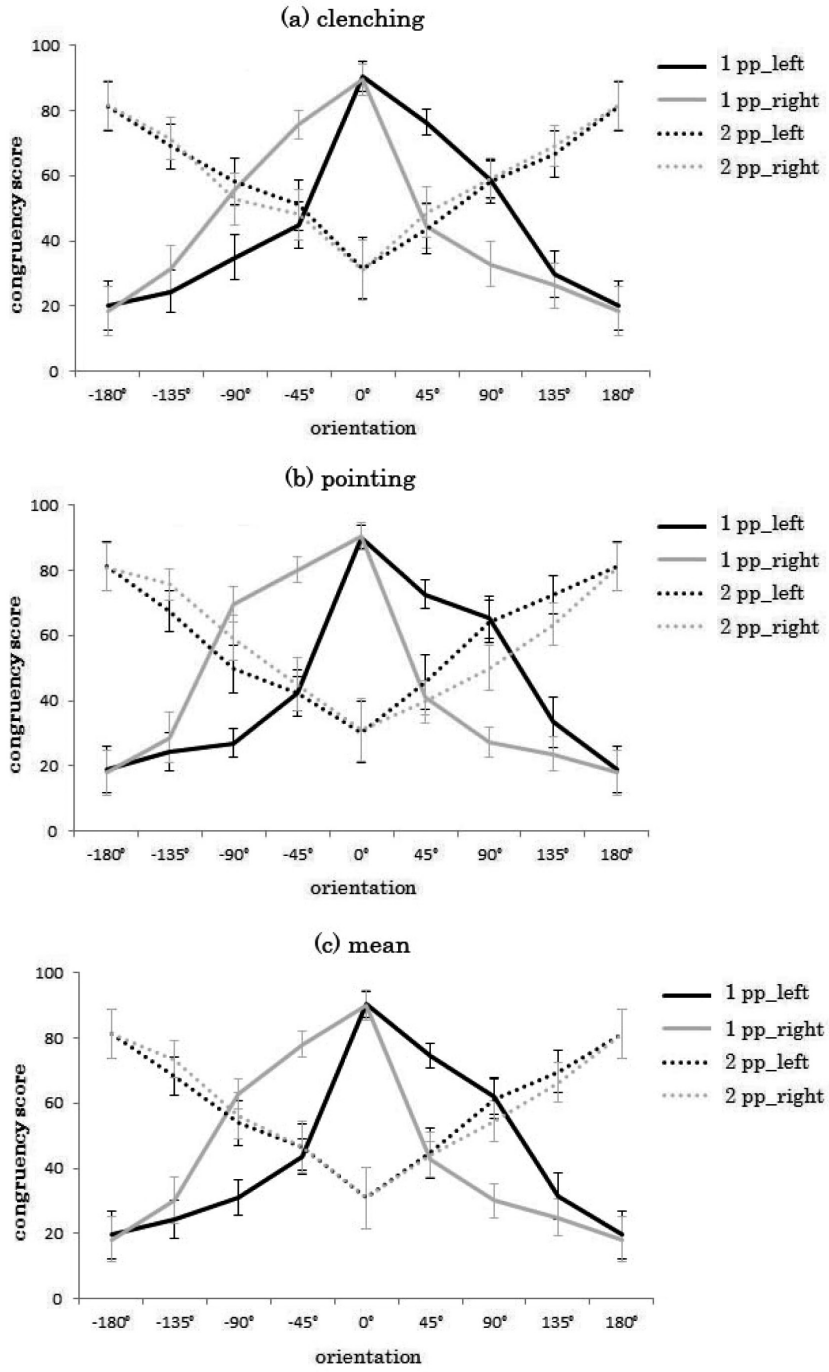

Figure 3. Congruency scores in each condition. Error bars represent standard error. (a) Congruency scores in clenching. (b) Congruency scores in pointing. (c) Mean congruency scores across the two actions. 1pp = first-person pronoun; 2pp = second-person pronoun; left = left hand; right = right hand.

26.320, $p < .001$, $\eta^2 = .126$]. Simple main effects of laterality were significant at -90°, -45°, 45°, and 90° [$F(1, 15) = 32.585$, $p < .001$, $\eta^2 = .399$; $F(1, 15) = 40.636$, $p < .001$, $\eta^2 = .466$; $F(1, 15) = 24.098$, $p < .001$, $\eta^2 = .417$; $F(1, 15) = 21.810$, $p < .001$, $\eta^2 = .356$; respectively], indicating that the congruency scores of the left hand were higher than those of the right hand at 45° and 90°, and the congruency scores of the right hand were higher than those of the left hand at -45° and -90°. In the 2pp condition, the two-way ANOVA showed a significant main effect of orientation [$F(1.60, 23.95) = 8.161$, $p < .005$, $\eta^2 = .228$], but there was no significant main effect of laterality or significant interaction.

The two-way ANOVAs of personal pronoun and laterality were conducted by splitting the dataset according to orientation condition. At 0°, the main effect of personal pronoun was significant [$F(1, 15) = 23.939$, $p < .001$, $\eta^2 = .524$], indicating higher scores at 1pp than at 2pp. There was no significant main effect of laterality or significant interaction. At 45°, the main effect of laterality and the interaction of personal pronoun and laterality were significant [$F(1, 15) = 22.947$, $p < .001$, $\eta^2 = .086$; $F(1, 15) = 12.700$, $p < .005$, $\eta^2 = .081$; respectively]. Subsequent analysis showed the significant simple-main effect of personal pronoun at the left hand [$F(1, 15) = 8.270$, $p < .05$, $\eta^2 = .276$]. The results indicated a higher score of the left hand at 1pp than at 2pp. At 90°, there was a significant main effect of laterality [$F(1, 15) = 30.762$, $p < .001$, $\eta^2 = .137$]. Although the interaction effect between personal pronoun and laterality did not reach statistical significance [$F(1, 15) = 4.017$, $p = .063$, $\eta^2 = .058$], subsequent analysis showed the significant simple-main effect of personal pronoun at the right hand [$F(1, 15) = 7.994$, $p < .05$, $\eta^2 = .228$]. A tendency of the score of the right hand at 2pp to be higher than that at 1pp was observed. At 135°, 180°, and -135°, the main effects of person were significant [$F(1, 15) = 23.603$, $p < .001$, $\eta^2 = .392$; $F(1, 15) = 31.549$, $p < .001$, $\eta^2 = .550$; $F(1, 15) = 29.494$, $p < .001$, $\eta^2 = .457$; respectively], indicating higher scores at 2pp than at 1pp. There was no significant main effect of laterality or significant interaction. At -90°, the main effect of laterality and the interaction of personal pronoun and laterality were significant [$F(1, 15) = 17.074$, $p < .001$, $\eta^2 = .102$; $F(1, 15) = 8.610$, $p < .05$, $\eta^2 = .078$; respectively]. Subsequent analysis showed the significant simple-main effect of personal pronoun at the left hand [$F(1, 15) = 6.322$, $p < .05$, $\eta^2 = .187$]. The results indicated a higher score of the left hand at 2pp than at 1pp. In the -45° condition, the main effect of laterality and the interaction of personal pronoun and laterality were significant [$F(1, 15) = 35.589$, $p < .001$, $\eta^2 = .092$; $F(1, 15) = 13.852$, $p < .005$, $\eta^2 = .094$; respectively]. Subsequent analysis showed the significant simple-main effect of personal pronoun at the right hand [$F(1, 15) = 8.970$, $p < .01$, $\eta^2 = .297$]. The results indicated a higher score of the right hand at 1pp than at 2pp.

Discussion

The purpose of the present study was to examine the biomechanical constraint effect in addition to the hand orientation effect on peoples' comprehension of sentences describing actions. The results showed a high congruency score for 1pp at 0° and for 2pp at 180°,

indicating that the former was congruent with the hand orientation in the actor's perspective and the latter was congruent with the hand orientation in the onlooker's perspective. Interaction effects were found at 45°, 90°, -45°, and -90° (although the interaction effect at 90° did not reach significance), suggesting that these orientation ranges were the boundary of congruence between personal pronoun and observed hands.

The congruency score patterns found in 1pp were consistent with the results of previous mental rotation studies which showed that the reaction times were shorter to the manageable hand orientations (e.g., Sekiyama, 1982; Sekiyama et al., 2014). That is, the results of 1pp showed not only the hand orientation effect, but also the hand laterality effect at 45°, 90°, -45°, and -90°; higher scores of the left hand at 45° and 90°, and higher scores of the right hand at -45° and -90°. The results suggest that participants were estimating the feasibility of imitating the observed hands (to be precise, they would estimate the degree of effort needed to simulate the observed hands while locating themselves within their physical body) and judged that manageable hand directions were congruent with the 1pp sentences.

Previous psychological experiments based on the affordance theory (e.g., Carello, Grosofsky, Reichel, Solomon, & Turvey, 1989; Warren, 1984) have investigated the perception of the boundaries of available actions (e.g., the boundary between climbable and unclimbable). The results of the present experiment suggest that humans can recognize biomechanical constraints of their own body and that the manageable action range is related to the recognition of 1pp. Gallagher (2000) classified the conceptions of the "self" into the sense of agent, the sense of ownership, and so on. For future research, an investigation of the relationship between the biomechanical constraint (manageable range of own body) and the concept of the self would be meaningful.

The results with 2pp showed the hand orientation effect but no laterality effect. The high score at 180° suggests that the face-to-face position was assumed for the agent of the second-person pronoun sentences. The absence of laterality effect suggests that the participants did not take the biomechanical constraint of observed hand actions into account during the estimation of congruency. These results might reflect the following processing: the participants observed the presented hand actions from an onlooker perspective (to be precise, when they observed the hands, they located themselves within their physical body without mentally simulating the actions) and judged that hand directions that would be seen from the face-to-face position were congruent with the 2pp sentences. These results suggest that action simulation processing during the recognition of sentences changes depending on the person of the pronouns used.

One limitation of this study is that the experiment examined the congruency between sentences and pictures under very specific conditions. For example, this study used only the thumb-side view for the picture stimuli and the first-person origin for the sentence stimuli (i.e., the person who said the sentences), to simplify interpretation of the picture and sentence stimuli. However, interpretation of verbal and visual descriptions of actions would often encounter ambiguity in the real world. It may be advisable to investigate the congruency between verbal and visual descriptions in more varied contexts.

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Footnotes

[1] The ANOVA in each action condition (clench or point) showed the same pattern of results: a hand orientation effect was found both in 1pp and 2pp (1pp and 2pp were congruent with actor and onlooker perspectives, respectively), but a hand laterality effect was found only in 1pp.

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