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Does thumb posture influence the mental rotation of hands?

Bettina Bläsing[a,b,*], Peter Brugger[c], Matthias Weigelt[d], Thomas Schack[a,b]

[a] Neurocognition and Action Research Group, Department of Sport Science, Faculty of Psychology and Sport Science, Bielefeld University, Universitätsstrasse 25, 33615 Bielefeld, Germany
[b] Center of Excellence Cognitive Interaction Technology, Bielefeld University, Universitätsstrasse 25, 33615 Bielefeld, Germany
[c] Neuropsychology Unit, Department of Neurology, University Hospital Zurich, 8091 Zurich, Switzerland
[d] Sport Psychology Unit, Department of Sports and Health, Faculty of Science, Paderborn University, Warburger Str. 100, 33098 Paderborn, Germany

HIGHLIGHTS

- ► We tested the effect of thumb posture in a hand laterality judgement task.
- ► Thumb posture was modified in the stimulus pictures and for participants' hands.
- ► Effect of stimulus thumb posture occurred only when participants' thumbs were fixed.
- ► In palmar view, RTs for 90° orientations were influenced by biomechanical constraints.

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ABSTRACT

The function of thumb posture in mental rotation has not yet been studied intensely, despite its special role in manual action. To investigate if thumb posture modifies relative visual and proprioceptive contributions, we conducted two experiments comprising hand laterality judgement tasks with identical stimuli (left and right hands in palmar and dorsal views presented at four orientations). In half of the stimuli, all digits were extended, whereas in the other half the thumb was flexed into the palm of the hand. In the second experiment, participants' thumbs were taped in the same flexed posture that was displayed in half of the stimuli one hour previous to and throughout the experiment. Results of both experiments revealed effects of orientation, side and view on reaction time, but an effect of stimulus thumb posture occurred only in the second experiment in which participants' thumbs were fixed. In palmar view, stimuli rotated by 90° with fingers pointing towards the participant's midline had shorter reaction times than stimuli rotated (evidentially less comfortably) in the opposite direction. This finding suggests that participants applied motor imagery strategies for palmar but not for dorsal views of the hand, indicating a difference in visual and sensorimotor familiarity.

1. Introduction

Mental rotation of human body parts, especially hands, has been found to differ essentially from mental rotation of abstract objects [10,14]. Using a handedness paradigm in which participants had to decide if a displayed hand was a right or left one, Parsons [10,14] showed that RTs were not only influenced by the rotation angle of the hand stimulus but also by the implicit awkwardness of the displayed hand position. He concluded that movements performed mentally would induce motor imagery and would therefore be constrained by anatomical joint characteristics in a similar way as real movements [11]. The use of motor imagery strategies in the mental rotation of hands has been corroborated by many authors [6,11,20]. Evidence for motor imagery being involved in mental rotation of body parts comes from clinical cases [3,9,13] and from neuroimaging studies (see [19] for review). Further studies have proposed that mental rotation tasks can be solved with different strategies, involving visual imagery or motor imagery [2,8], and that the choice of strategy might depend on the type of stimuli [18] or the instructions [17].

One argument that has been brought forward in favour of a motor imagery strategy is the posture effect. Accordingly, the posture the participant's hand adopts during the experimental task also influences the processing of handedness decisions [11]. Sirigu and Duhamel [15] showed an inhibiting influence of hand position on body part imagery in an egocentric first person perspective. Mental rotation of hands, but not feet, was found to be slower when

* Corresponding author at: Neurocognition and Action Research Group, Faculty of Psychology and Sport Science and Center of Excellence Cognitive Interaction Technology, Bielefeld University, Universitätsstrasse 25, 33615 Bielefeld, Germany. Tel.: +49 521 106 5137; fax: +49 521 106 6432.
E-mail address: bettina.blaesing@uni-bielefeld.de (B. Bläsing).

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the participants were keeping their hands behind their backs with interweaved fingers than when their hands were placed on their knees [6]. The authors argued that current hand posture should influence limb-specific laterality decisions via the body schema in a bottom-up manner.

Previous mental rotation studies have only paid little attention to the role of the thumb. This is surprising, given the special role of the thumb in human hand anatomy and hand function [5,12]. Several authors pointed towards the significance of the thumb as asymmetry marker in handedness tasks if visual strategies are applied [16,17]. For motor strategies, the role of the thumb has not been studied so far. In the present study, we investigated the influence of thumb posture on performance in a handedness judgement task. Thumb posture was modified in the stimulus images (visual influence) as well as for participants' hands (sensorimotor influence). Two experiments were conducted with the same stimulus pictures of hands in which thumb posture was varied in such a way that the thumb was either extended like the other digits in an open hand posture (pointing outward), or flexed into the palm of the hand (pointing inward). In Experiment 1, the participants' hands were unrestricted, whereas in Experiment 2, the participants' thumbs were fixed to the palm of the hand in a position corresponding to that displayed in one half of the stimulus pictures. We expected that under normal (i.e., unrestricted) conditions the stimulus pictures with extended thumbs pointing outward would be easier to process than the ones with flexed thumbs, due to their clearer and more typical shape, resulting in shorter RTs and lower error rates. Second, we expected that this effect would be reduced by a facilitating posture effect in Experiment 2 in which the participants' thumbs were fixed in the flexed posture. All participants were healthy volunteers who gave written informed consent before participation. Both experiments, to which we now turn in detail, were conducted in accordance with the 1964 Declaration of Helsinki. The local Ethical Committee of Bielefeld University did not object to the procedures as described below, especially concerning the thumb fixation procedure of Experiment 2.

2. Experiment 1

Experiment 1 tested the effect of two different thumb postures (extended, pointing outward vs. flexed into the palm of the hand, pointing inward) displayed in the stimulus pictures on the mental rotation of human hands.

2.1. Material and methods

2.1.1. Participants

Eighteen healthy right-handed participants (age 23.56 ± 2.62 years, sports science students of Bielefeld University, 15 females) participated in the experiment.

2.1.2. Stimuli

The set of 32 stimuli used in this experiment consisted of colour photographs of a left or right human hand in palmar or dorsal view, with the thumb either extended like the other fingers or flexed into the palm of the hand (and hence only visible in palmar view; see Fig. 1). The hand images were displayed in four orientations: 0° (fingers pointing upward), 90°M (fingers pointing in medial direction and the thumb pointing upward), 90°L (fingers pointing in lateral direction and the thumb pointing downward), and 180° (fingers pointing downward). Stimuli were presented in nine randomised blocks, in which each stimulus was displayed once for an exposure time of 2000 ms, resulting in 32 trials per block, and a total of 288 stimuli for the whole experiment.

2.1.3. Task and procedure

Participants were seated in front of a computer screen. Presentation software (Neurobehavioral Systems Inc., CA), was used to control stimulus presentation and to collect responses. Participants were instructed to respond to the presentation of each stimulus by pressing one of two defined keys on the computer keyboard with their left or right index finger in order to indicate if the stimulus was a left or right hand.

2.1.4. Data analysis

We measured error rates and response times (RT). Error rates were defined as the number of incorrect responses, regardless of RT, and analysed using Friedman tests and Wilcoxon signed-rank tests. RT was measured as the time between stimulus onset and key press. Previous studies using similar hand laterality tasks reported RTs ranging between 500 ms and 3500 ms (e.g., [7]). Therefore, for the analysis of RTs, only correct trials with RTs between 500 ms and 3500 ms were regarded. RTs were analysed using repeated measures analysis of variance (ANOVA) with the main factors THUMB posture (inward, outward), VIEW (dorsal, palmar), SIDE (left, right), and orientation ANGLE (0°, 90°M, 90°L, 180°). In total, 5760 trials were recorded. For the analysis of RT, 654 trials were disregarded due to incorrect answers and 64 trials due to aberrant RTs (33 < 500 ms, 31 > 3500 ms). Finally, 87.5% of the total number of trials were included in the analysis of RT.

The finding that hands pointing medially with their fingers reliably produces shorter RTs than hands pointing laterally [14] has been described as the medial-over-lateral advantage (MOLA, [4]). We calculated the MOLA by testing the differences between corresponding medial and lateral stimuli (90°L–90°M) against zero using one-sample Student's *t*-tests.

3. Results

3.1. Error rates

Error rates for corresponding stimuli (left/right hand, thumbs inward/outward, dorsal/palmar view) were compared using Wilcoxon signed-rank tests. No differences occurred between corresponding left and right stimuli and stimuli with thumbs pointing inward vs. outward. Significant differences were found for corresponding stimuli of different views presented at 0° and 90°L orientations (all $p < 0.05$, palmar > dorsal view; exception: 0° left outward) (see Fig. 2C). Error rates for the different orientation angles were compared within each thumb position, side, and view, using Friedman tests. Differences between orientation angles were found for all stimuli in dorsal view (right inward: $\chi^2(3) = 22.795$, $p < 0.001$; left inward: $\chi^2(3) = 11.686$, $p < 0.01$; right outward: $\chi^2(3) = 17.452$, $p < 0.01$; left outward: $\chi^2(3) = 12.157$, $p < 0.01$). Post hoc Wilcoxon signed–rank tests revealed that, in dorsal view, 180° stimuli elicited higher error rates than 0°, 90°M and 90°L stimuli for both sides and thumb postures (all $p < 0.05$; see Fig. 2C).

3.2. Reaction times

The results of the ANOVA with main factors THUMB posture (inward, outward), VIEW (dorsal, palmar), SIDE (left, right), and orientation ANGLE (0°, 90°M, 90°L, 180°) revealed effects of SIDE ($F[1,19] = 12.160$; $p < 0.01$; partial $\eta^2 = 0.390$; Mean right: 1228, left: 1276; see Fig. 2B), ANGLE ($F[2.135, 40.559] = 40.824$; $p < 0.001$; part. $\eta^2 = 0.682$; Mean 0°: 1138, 90°M: 1131, 90°L: 1331, 180°: 1432), VIEW ($F[1,19] = 51.670$; $p < 0.001$; part. $\eta^2 = 0.7131$; Mean dorsal: 1108, palmar: 1409), and an interaction between VIEW and ANGLE ($F[2.245, 42.663] = 19.394$; $p < 0.001$; part. $\eta^2 = 0.505$; see Fig. 2A), but no effect of THUMB (Mean inward: 1262, outward: 1242; see Fig. 2B). Mauchly's test showed that the assumption