Human Movement Science 31 (2012) 1151–1160

Contents lists available at SciVerse ScienceDirect

Human Movement Science

journal homepage: www.elsevier.com/locate/humov

Mental rotation of letters, body parts and complex scenes: Separate or common mechanisms?

Marc Dalecki *, Uwe Hoffmann, Otmar Bock

Institute of Physiology and Anatomy, German Sport University Cologne, Germany

ARTICLE INFO

Article history:
Available online 14 January 2012

PsycINFO calssification:
2300
2340

Keywords:
Reaction time
Error rate
Self-rotation
Perspective taking
Allocentric
Egocentric

ABSTRACT

This study compares mental rotation with three stimuli: letters, body parts and complex scenes. Twenty-four subjects saw letters and judged whether they were mirror-reversed or not (task LETTER), saw pictures of a hand and indicated whether it was a right or a left one (task HAND), and saw drawings of a person at a table on which a weapon and a rose laid and decided whether the weapon was to the person's right or left (task SCENE). Stimuli were presented in canonical orientation or rotated by up to 180°. Our analyses focused on intra-subject correlations between reaction times of the different tasks. We found that reaction times for stimuli in canonical orientation co-varied in HAND and LETTER, the increase of reaction times with increasing object rotation co-varied in HAND and SCENE, and reaction times for 180° rotations co-varied between all tasks. We suggest that basic processes like visual perception and decision-making are distinct for scenes versus letters and body parts, that the mechanism for mental rotation of letters is distinct from that for mental self- and body part rotation, and suggest an extra mechanism for 180° rotations that shared among all tasks. These findings confirm and expand hypotheses about mental rotation that were based on comparisons of between-subject means.

1. Introduction

In mental-rotation tasks, subjects are asked to judge stimuli that are presented in different orientations. Reaction times increase consistently with the angle between the actual and a canonical

* Corresponding author. Address: Institute of Physiology and Anatomy, German Sport University Cologne, Am Sportpark Müngersdorf 6, 50933 Cologne, Germany. Tel.: +49 4982 6780; fax: +49 4982 6790.

E-mail addresses: Dalecki@dshs-koeln.de (M. Dalecki), u.hoffmann@dshs-koeln.de (U. Hoffmann), Bock@dshs-koeln.de (O. Bock).

0167-9457/$ - see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.humov.2011.12.001

orientation, which has been taken as evidence that the stimuli are first mentally rotated into the canonical orientation before the judgment is made (Ionta, Fourkas, Fiorio, & Aglioti, 2007; Kessler & Thomson, 2010; Shepard & Metzler, 1971). Stimuli used in mental-rotation tasks can be broadly categorized as external objects (letters, abstract 3D forms), human shapes (hands, whole bodies) and complex scenery (landscapes, table scenes). Subjects' reaction time and error rate was found to be consistently related to stimulus orientation in all three categories, but this relationship has been interpreted differently: it has been argued that external objects are judged after mentally rotating them in an allocentric reference frame, while scenery and human shapes are judged in an egocentric reference frame after mental self-rotation – often called "spatial perspective taking" (Hegarthy & Waller, 2004; Kessler & Thomson, 2010; Kozhevnikov & Hegarty, 2001; Kozhevnikov, Motes, Rasch, & Blajenkova, 2006; Piaget & Inhelder, 1967; Zacks & Michelon, 2005). Experimental evidence suggests that mental self-rotation is indeed a feasible concept: mental rotation of displayed hands depends on the subjects' actual hand orientation (Parsons, 1987; Sirigu & Duhamel, 2001), deteriorates when the displayed hand positions are biomechanically difficult to achieve (Ionta et al., 2007), when the primary motor cortex is stimulated by TMS (Ganis, Keenan, Kosslyn, & Leone, 2000; Tomasino, Borroni, Isaja, & Rumiati, 2005) and when the motor system is affected disease (Fiorio et al., 2007).

The existence of distinct mechanisms for different mental-rotation tasks seems to be supported by neuroimaging studies which found that object, hand and whole-body rotation activates different brain areas. However, the activation pattern differed not only between stimulus categories, but also between studies using the same category: Thus, mental rotation of external objects was associated with activation of the left parietal cortex and the right caudate head in one study (Alivisatos & Petrides, 1996), of the left *and* right parietal cortex and area 19 in another study (Kosslyn, Digiloramo, Thompson, & Alpert, 1998), and of *only* the right parietal cortex in yet other studies (Harris et al., 2000; Nunez-Pena & Aznar-Casanova, 2009; Zacks, Vettel, & Michelon, 2003). Mental rotation of hands activated the *left* primary motor and insular cortex as well as the area 6, 7 and 9 in two studies (Kosslyn et al., 1998; Parsons et al., 1995), but *both* parietal, extrastriate and premotor cortices in another study (Vingerhoets, de Lange, Vandemaele, Deblaere, & Achten, 2002). Finally, mental rotation of scenes was found to activate the left posterior parietal, secondary visual, premotor and frontal areas in one (Creem et al., 2001), but the left temporal areas in another study (Zacks et al., 2003). This inconsistency could well be related to the fact that several factors which are known to modulate neural activation in mental-rotation tasks, varied between studies. Those factors include female versus male subjects (Jordan, Wüstenberg, Heinzem, Peters, & Jäncke, 2002), self-paced versus externally paced stimuli (D'Esposito et al., 1997) and single versus paired stimuli (Vingerhoets et al., 2001). It is highly desirable to control for these confounding factors in future imaging and behavioral studies.

Behavioral data comparing different stimulus categories reported that scene rotation is faster and more accurate than object rotation (Amorim & Stucci, 1997; Keehner, Guerin, Miller, Turk, & Hegarty, 2006; Kozhevnikov et al., 2006; Wraga, Creem, & Proffitt, 1999; Zacks & Michelon, 2005), that it depends less on the rotation plane (Zacks & Michelon, 2005), and that unlike object rotation, it exhibits a distinct non-linearity at about 75° (Keehner et al., 2006; Kozhevnikov & Hegarty, 2001; Michelon & Zacks, 2006). The latter phenomenon has been taken as evidence for a visual-matching process at lower angles, which is replaced by a mental-rotation process at higher angles. Not only scene rotation but also hand rotation was found to be faster and more accurate than object rotation (Kosslyn et al., 1998). From this it has been concluded that scene and hand rotation is based on a neural mechanism operating in egocentric coordinates, while object rotation is based on a mechanism operating in allocentric coordinates (Zacks, Mires, Tversky, & Hazeltine, 2000). In accordance with this hypothesis, several studies documented that processing in an egocentric reference frame is faster and more effective than in an allocentric frame (Iachini & Ruggiero, 2006; Nori, Iachini, & Giusberti, 2004).

However, it remains conceivable that scene, hand and object rotation is based on a common mechanism which operates with different efficiency. For example, body part rotation is common in everyday life (e.g., when telling a person she has a smudge on her *right* cheek), and our brain may therefore be optimized for this task rather than for object rotation. The present study introduces a fresh approach to deal with this issue. We test scene, hand and object rotation in the *same* subjects using the *same* experimental procedure, and analyze not only across-subject means but also individual differences: if those subjects who performed well with one stimulus category also excel with another