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Brain and Cognition 51 (2003) 95–101
Brain and Cognition
www.elsevier.com/locate/b&c

Representation of anatomical constraints in motor imagery: Mental rotation of a body segment

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Accepted 9 August 2002

Abstract

Classically, the mental rotation paradigm has shown that when subjects are asked to judge whether objects that differ in orientation are spatially congruent, reaction times increase with angular discrepancy, although some reports have shown that this is not always the case. Would similar results be obtained with realistic figures of body segments? In this work, the mental rotation of a hand attached to its forearm and arm in anatomically possible and impossible starting positions is compared with the mental rotation of a hammer. The main results show that reaction times increase monotonically with the angle of discrepancy for both stimuli and that the speed of rotation is higher for anatomically possible orientations in the case of the hand. Thus, mental rotation of body segments follows the same empirical rules as objects of another nature, and biomechanical constraints imposed to the motility of these segments can be considered as attributes of the mental representation.

Keywords: Mental rotation; Mental imagery; Body segment; Biomechanical constraints

1. Introduction

Since the 1960's, the development of Piagetian and cognitive psychology has provided research on mental imagery with a new impulse.

In 1966, Piaget and Inhelder established a classification of images based on the fact that a child, from around the age of 8, has the ability to imagine not only static objects but also movements and known transformations. At this age it also becomes able to anticipate novel transformations. Later on, Shepard and Metzler (1971) first described the mental rotation paradigm which consists in presenting subjects with pairs of drawings of non-significant objects, one of them rotated with respect to the other. The subjects' task is then to determine as quickly as possible whether the two drawings are identical or mirror reflected. It is classically hypothesised that, in order

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0278-2626/03/$ - see front matter
doi:10.1016/S0278-2626(02)00526-2

to succeed in such a task, the subject has to master an internal rotation which consists in reorienting the rotated object with respect to the other. Numerous reports have shown that reaction times increase monotonically with the angle of discrepancy between the two members of the pair of objects presented (for instance, Shepard & Cooper, 1982).

This applies to non-significant objects, alpha-numeric characters and line drawings of significant objects. The question arises whether the same occurs with body segments. Since movements of body segments are naturally constrained by biomechanical laws, one may ask whether these will be taken into account during mental imagery, i.e., if mental space is free of all constraint, or if those related to the actual use of objects interfere with the mental imagery? The type of object chosen for the mental rotation paradigm would thus be of great importance.

As far as the visual level of processing is concerned, an object is a non significant form, defined by contours, angles, textures, and shadows (Boucart, 1995). The comparison of this form with the representation of objects in the semantic memory is the necessary operation through which a perceived object can be actually identified and, if requested, named. The literature on agnosia is compatible with this view, reporting for example dissociations in the identification of natural versus artificial, manufactured objects (Charnallet & Carbonnel, 1995, for a review). Of particular interest here is Warrington's hypothesis (Warrington & McCarthy, 1987) according to which objects are stored in semantic memory on the basis of the sensory modality(ies) through which they are perceived. Thus, certain objects are only visually accessible (mainly natural objects), whereas others are visually and haptically accessible (mainly artificial objects manufactured to sustain a function). In this context, the question arises which kind of objects constitute the segments of the human body? On the one hand, they are obviously natural objects, but, on the other hand, they can fulfil several functions and are massively accessible on the proprioceptive level.

Elements of response were brought by Shiffrar and Freyd (1990) who used the apparent motion phenomenon with human body parts as stimuli. This phenomenon is produced by presenting subjects with two successive stimuli. Under appropriate conditions of frequency of presentation, a single moving stimulus is perceived. If the movement can follow two different paths, subjects always perceive the shortest one. However, when stimuli are parts of the human body, for example a forearm, the two paths are not equivalent due to the body's anatomical contingencies. In this particular case, Shiffrar and Freyd showed that subjects do not choose the shortest path anymore but the one that respects the biomechanical constraints of the body.

Wexler, Kosslyn, and Berthoz (1998) argue that mechanisms used in visual perception play a key role in visual mental imagery. For these authors, when the Shepard and Metzler stimuli are shown to an adult, his or her typical reaction will be to physically, usually manually, rotate one of them until it visually matches the other. If the stimuli themselves cannot be rotated, people will often try to turn their heads in order to align the retinal image of one stimulus with a memory trace of the other. When neither the stimuli nor the subject's head can be moved, the Shepard and Metzler task is performed. In this situation, people typically carry out a mental rotation of the object.

According to Wexler, Kosslyn and Berthoz, mental rotation is a covert simulation of motor rotation. Instead of overtly performing a rotation, with the hand or the head, and observing its results, in mental rotation we plan the action but do not execute it overtly; instead of seeing the outcome, we simulate the perceptual result of our planned action. Visuo-motor anticipation is thus the engine that drives mental rotation.