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A high density ERP comparison of mental rotation and mental size transformation

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Abstract

To compare mental rotation and mental size transformation, 128-channel EEG was recorded while subjects performed both tasks using random two-dimensional shapes as stimuli. Behavioural results showed significant linear effects of both size transformation and mental rotation on reaction times. Rotation ERPs showed experimental effects at two latencies: a bilateral component distributed over posterior parietal electrodes at a latency of approximately 232–300 ms and a second component at approximately 424–492 ms distributed over right anterior parietal electrodes. The latency and spatial distribution of this second effect is consistent with previous research indicating a functional connection between this component and mental rotation. ERPs for the size-transformation task showed an effect at 180–228 ms distributed bilaterally over occipital–temporal electrodes. These results are consistent with previous hemodynamic imaging studies that show involvement of parietal cortex in mental rotation and also the involvement of BA 19 in size-transformation tasks. However, the superior temporal resolution of the present data indicates that BA 19 activation may occur at a latency that is more likely related to apparent motion than to the size-transformation operation per se.

Keywords: Mental rotation; Size transformation; Image transformation; ERPs; EEG; Brain mapping

1. Introduction

Mental rotation and mental size transformation represent two different examples of imagery. Both underlie the ability of the visual system to recognise visual patterns as being the same, despite the fact that any one pattern can create an almost infinite number of retinal images as a result of experimental manipulation. Bundesen and Larsen (1975) investigated the effect of altering the size of objects on reaction time (RT) judgements of same or different. In a simultaneous matching-to-sample task, subjects were presented with two stimuli and were asked to respond as quickly as possible whether the stimulus pair was of the same shape and orientation, regardless of whether they differed in size. It was found that RTs were a linear function of the size ratio of the two stimuli. This was true of both line stimuli and filled two-dimensional stimuli. It was proposed that to perform such tasks one of the stimuli must be transformed in size to that of the other stimulus and then a comparison made. Linear RT functions for size transformation have also been found for successive matching-to-sample tasks (Larsen, McIlhagga, & Bundesen, 1999). In a mental rotation experiment using two-dimensional shapes, Cooper (1975) required her subjects to learn eight different shapes in pre-training. In the experimental conditions stimuli were presented in either their normal or mirror imaged forms at various orientations and subjects had to respond as to whether they were normal or mirror image stimuli. A linear slope for RT as a function of orientation from the upright was found for normal images.

These experiments indicate that rotation and size transformation of visual patterns share several theoretically interesting properties. As well as being examples of visual imagery, they both seem to be performed using an analogue rather than digital process. The linear increases in reaction time with respect to either size ratio

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or orientation suggest that symbolic or propositional processes are not used to perform such tasks (Corballis, 1997). It is theorised that such manipulations require subjects to transform an object in size to match a template (Bundesen & Larsen, 1975), or to rotate a stimulus to a designated orientation (Corballis, 1997). Both processes have been found to occur under a number of stimulus conditions, although Larsen and Bundesen (1978, 1998) have argued that in matching familiar objects such as letters, that size-invariant matching can be achieved without use of size transformation. In contrast, typical mental rotation reaction times functions are found for the rotation of letters (Cooper & Shepard, 1973a).

The recent evolution of brain imaging techniques has generated numerous studies of mental image transformations attempting to localise the cortical areas that perform imagery tasks. A number of functional imaging studies have implicated the role of parietal cortex in mental rotation (e.g., Cohen et al., 1996; Kosslyn, DiGirolamo, Thompson, & Alpert, 1998; Tagaris et al., 1996; Tagaris et al., 1997) although there have been mixed results in the imaging literature as to whether this parietal activation has a hemispheric bias (compare Harris et al., 2000 and Alivisatos & Petrides, 1997). While functional imaging techniques provide detailed evidence about anatomical areas involved in mental transformations, they contain little information about the temporal resolution of these events. Conversely, the ERP technique does not have the spatial resolution of these other imaging techniques, but the recording of the electrical activity of the brain does allow much finer resolution of the temporal course of events during cognitive operations. A number of studies have recorded ERPs as subjects performed mental rotation tasks and the primary finding has been that mental rotation tasks are accompanied by a negative potential located over parietal electrodes with a latency between 400 to 800 ms. The amplitude of this effect has been found in several studies to be a monotonic function of the amount of rotation that must be performed (Desrocher, Smith, & Taylor, 1995; Peronnet & Farah, 1989; Rosler, Heil, Bajric, Pauls, & Henninghausen, 1995; Rosler, Roder, Heil, & Henninghausen, 1993; Stuss, Sarazin, Leech, & Picton, 1983; Wijers, Otten, Feenstra, Mulder, & Mulder, 1989).

While many electrophysiological and imaging studies of mental rotation have been reported, only one ERP study and one PET study have been reported for size transformation. Rosler et al. (1995) recorded ERPs while mental images were rotated or scaled in size, using the procedure of Cooper and Shepard (1973b), which differs dramatically from those employed in other size scaling experiments (e.g., Bundesen & Larsen, 1975) and was designed to separate mental imagery from visual perception. The procedural differences of this task compared with other size transformation experiments make comparisons between the two paradigms difficult. Larsen, Bundesen, Kyllingsbaek, Paulson, and Law (2000) have published the only functional imaging study of size transformation using PET. In this experiment subjects were presented randomly generated line stimuli in a one-back matching-to-sample task. By contrasting conditions in which no size transformation was performed with conditions with conditions where it was, functional areas involved in the transformation task were obtained. Superimposition of these activations onto MRI images revealed several areas involved in the transformation task including bilateral posterior parietal cortex (BA 7), MT/V5 left (BA 19), occipital/temporal/parietal transition zone (left) (BA 19) and bilateral cerebellum. These results appear compatible with those of mental rotation studies, where posterior parietal cortex and dorsal visual stream areas are primarily implicated. Area MT has also been implicated in several studies of mental rotation (Alivisatos & Petrides, 1997; Cohen et al., 1996; Pegna et al., 1997).

The objective of the following experiment was to determine whether the neural generators of size transformation in procedures such as that used by Bundesen and Larsen (1975) are detectable by ERP techniques. A second objective was to directly compare behavioural and electrophysiological measures of mental rotation with corresponding measures of size transformation. A dense electrode array (128 electrodes) was used to increase the spatial resolution of the current generators involved in these tasks. The experiment comprised of two separate tasks: a mental rotation task and a size-transformation task. Both tasks employed near identical experimental procedures and used a successive matching-to-sample procedure. The same sample stimuli were presented in both conditions, but comparison stimuli differed between tasks. In the mental rotation task, the comparison stimuli consisted of different orientations of the sample stimulus, or its mirror image. In the size-transformation task, the relative size of the comparison stimuli was varied with respect to the sample stimulus, and in half the trials a slight shape distortion was introduced to make a mismatch stimulus. It was hoped that the results of the two tasks would allow comparison of the neural mechanisms of size transformation with those of mental rotation.

2. Materials and methods

2.1. Subjects

Twelve right-handed subjects as assessed by the Oldfield Handedness Inventory (Oldfield, 1971), including six males and six females (mean age 23.2 years, range 19–28) participated in this experiment. The Uni-