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Neuropsychologia 44 (2006) 1547–1559

NEUROPSYCHOLOGIA

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Divergence of categorical and coordinate spatial processing assessed with ERPs

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Available online 2 March 2006

Abstract

The spatial relation between two objects may be described either precisely or more coarsely in abstract terms, denoted as coordinate and categorical descriptions, respectively. These descriptions may reflect the outcomes of two spatial coding processes, which are realized in the left- and right-hemisphere. Support for this account comes from visual field effects in categorical and coordinate judgment tasks and from patient studies. In the current study, this hypothesis was tested by using event-related potentials (ERPs) and source localization. ERPs yield information about the processing stage at which the hypothesized categorical and coordinate processing diverge due to different task demands, especially in our S1–S2 version of the Bar Dot task. A centrally presented Bar Dot (S1) was followed after 2.5 s by a second one (S2) in the left or right visual field; participants had to judge whether S2 matched S1 at the categorical, or, in a second task, at the coordinate level. Behavioral measures revealed a left-field advantage in the coordinate task that was absent in the categorical task. S1s elicited stronger early and late bilateral posterior responses in the coordinate than in the categorical task, possibly related to a compensatory strategy at the level of encoding and spatial memory. S2s elicited only stronger early contralateral responses, and stronger late right-hemisphere responses in the categorical task. It is proposed that the left-field advantage in the coordinate task may be due to differences in spatial resolution in perceptual encoding of the left- and right-hemispheres that are largely unaffected by the task at hand.

Keywords: Spatial processing; Categorical; Coordinate; Visual half field; ERPs; Dipole sources

1. Introduction

According to Kosslyn and coworkers, the spatial relation between two objects can be described in two qualitatively different ways; either in broad categorical terms or on the basis of precise coordinates (Kosslyn, 1987; Kosslyn et al., 1989; Kosslyn, Thompson, Gitelman, & Alpert, 1998). The first way refers to an abstract description of the relation between objects (e.g. when using words such as *above* or *below*), which can be related to theories on object identification using structural descriptions to specify spatial relations among parts (Biederman, 1987). These descriptions seem especially useful for viewpoint independent object recognition (e.g. recognizing that an object is a chair on the basis of the relations among its compounding parts), but may also be important for processing and memorizing the location of objects. The second way refers to a description of the precise spatial relation (i.e. the distance) between two objects, which seems essential for motor acts such as the accurate reaching towards objects. For example, to pick up one's cup of coffee, the approximate distance between one's hand and the cup needs to be estimated. In principle, these two types of descriptions could be different outcomes of a single underlying spatial coding process, but they may also reflect the outcomes of two separate types of spatial processing. The latter possibility was first proposed by Kosslyn et al. (1989), which will be denoted as the *separate spatial coding* hypothesis.

A critical aspect of the separate spatial coding hypothesis is the idea that distinct neural circuits are involved in computing these different descriptions. On the basis of computational modeling, Kosslyn, Chabris, Marsolek, and Koenig (1992) argued that when two tasks rely on distinct computations, a split network performs better because of reduced interference between the different computations. Combining this argument for separate

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0028-3932/$ – see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.neuropsychologia.2006.01.019

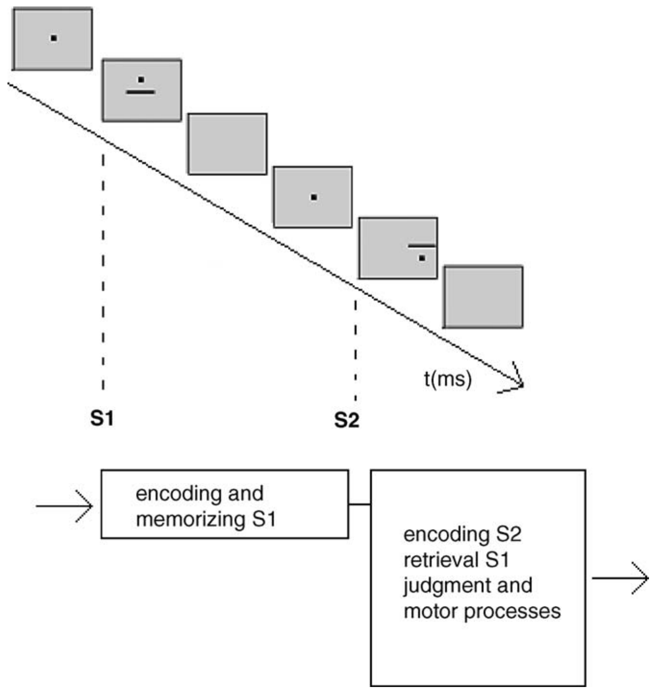

Fig. 1. An example of a trial. S1 was presented for 150 ms in the center of the visual field (CVF). After a blank interval of 2000 ms, the fixation point reappeared, and 500 ms later S2 appeared in the left or right visual field (LVF or RVF). In the categorical task, participants had to indicate whether the position of the dot relative to the bar (above or below) was the same or different for S1 and S2, and in the coordinate task they had to indicate whether the distance between the dot and the bar was the same or different for S1 and S2. In the lower part of the figure, we indicated that encoding and memorizing of S1 is separated in time from judgment and motor processes and from encoding of S2 and retrieval of S1.

neural circuits with the traditional distinction between the left-hemisphere, associated with language, which implies the facility to form abstract categorical descriptions, and the right cerebral hemisphere, associated with spatial attention and search (e.g. see Mangun et al., 1994), it may indeed be hypothesized that categorical and coordinate spatial processing are realized in the left- and right-hemisphere, respectively. Empirical results from visual half field studies with healthy subjects (Kosslyn et al., 1989), and studies with patients suffering unilateral brain damage (Laeng, 1994) seem to support this hypothesis.

In visual half field studies, to be judged stimuli are presented briefly in the left or the right visual field (LVF or RVF), which should yield initial and more extensive processing in the contralateral hemisphere. The idea behind this manipulation, introduced by Kosslyn et al. (1989), is that for LVF stimuli the contralateral right-hemisphere is the one that is specialized for coordinate processing, whereas for RVF stimuli the contralateral left-hemisphere is specialized for categorical processing. Therefore, coordinate judgment should be faster and more accurate for LVF than for RVF stimuli, while the reverse holds for categorical judgments. Most visual half field studies employed versions of the Bar Dot task originally designed by Hellige and Michimata (1989), in which a dot appears at various distances either above or below a bar (see Fig. 1). An above/below judgment of the dot relative to the bar is supposed to require categorical processing, while coordinate processing is thought to be involved when judging the distance, near or far (relative to an earlier reference stimulus), between the dot and the bar. Several studies (Banich & Federmeier, 1999; Cowin, Roth, & Hellige, 1994; Kosslyn et al., 1989, 1998; Laeng & Peters, 1995; Parrot, Doyon, & Cardebat, 1998; Parrot, Doyon, Demonet, & Cardebat, 1999; Wilkinson & Donnelly, 1999) found support for the dependency of the visual field effect on the required type of judgment, but there were some exceptions (Bruyer, Scailquin, & Coiboin, 1997; Sergent, 1991a, 1991b; see also Jager & Postma, 2003). In addition, a number of studies (Cowin et al., 1994; Kosslyn et al., 1989; Michimata, 1997; Rybash & Hoyer, 1992) revealed that practice effects may introduce a confounding as the LVF advantage in case of coordinate judgments disappeared over time, which may be explained in terms of the development of new categorical spatial representations (Baciu et al., 1999; Jager & Postma, 2003). Finally, although several studies demonstrated a LVF advantage for coordinate judgments, the reversal (a RVF advantage) for categorical judgments was either absent (Cowin et al., 1994; Hellige & Michimata, 1989; Hellige & Cumberland, 2001; Michimata, 1997; Rybash & Hoyer, 1992; Wilkinson & Donnelly, 1999) or only present in a subset of the reported experiments (Kosslyn et al., 1989; Laeng & Peters, 1995).

Interestingly, the distinction between categorical and coordinate spatial relations has not only been applied to visual perception but also to spatial memory (Laeng & Peters, 1995; Postma, Izendoorn, & De Haan, 1998), mental imagery (Trojano et al., 2002), object recognition and identification (Laeng, Shah, & Kosslyn, 1999), and spatial communication (Kemmerer & Tranel, 2000). In all these domains the same separate spatial processes may be differentially engaged, which emphasizes the importance of the question at what particular stage of information processing differences in computing categorical and coordinate spatial relations actually originate. Are these differences already present at the level of perceptual encoding, as originally proposed by Kosslyn, or do they specifically emerge during later stages of information processing involved with maintenance in and retrieval from memory, or even with response decision making? In all the aforementioned domains these possibilities are more or less applicable. Thus, the principal goal of the current study was to assess the level at which categorical and coordinate spatial processing start to diverge due to different task instructions.

As mentioned above, empirical results from visual half field studies with the Bar Dot task do not unambiguously support the separate spatial coding hypothesis. One problem with this technique is that half field stimuli are eventually also processed in the ipsilateral hemisphere, which may conceal differences in the involvement of the two hemispheres. Another reason may be that hemispheric specialization for categorical and coordinate processing is relative rather than absolute (Sergent, 1991a, 1991b) and that the degree of laterality differs between individuals. Specifically, both hemispheres may be involved in categorical and coordinate computations, but the left- hemisphere is more specialized in the former, whereas the right-hemisphere is more specialized in the latter type of computations. Indeed, this possibility has repeatedly been raised by Kosslyn et al. (1992).