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The time course of hemispheric differences in categorical and coordinate spatial processing

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Abstract

Spatial relations between objects can be represented either categorically or coordinately. The metric, coordinate representation is associated with predominant right hemisphere activity, while the abstract, qualitative categorical representation is thought to be processed more in the left hemisphere [Kosslyn, S. M. (1987). Seeing and imagining in the cerebral hemispheres: A computational analysis. *Psychological Review, 94*, 148–175]. This hypothesized lateralization effect has been found in a number of studies, along with indications that specific task demands can be crucial for these outcomes. In the current experiment a new visual half field task was used which explores these hemispheric differences and their time course by means of a match-to-sample design. Within retention intervals that were brief (500 ms), intermediate (2000 ms), or long (5000 ms), the processing of categorical and coordinate representations was studied. In the 500 ms interval, the hemispheric effect suggested by Kosslyn (1987) was found, but in the longer intervals it was absent. This pattern of the lateralization effect is proposed to be caused by the differential effect the retention interval has on coordinate and categorical representations. Coordinate spatial relations appear susceptible to changes in retention interval and decay very quickly over time, congruent with previous findings about accurate location memory. The processing of categorical spatial relations showed less decay and only between 2000 ms and 5000 ms. Qualitative self reports suggest that the decay found for categorical relations might be caused by a switch from a visual to a more verbal memorization strategy.

Keywords: Hemispheric specialization; Visual half field; Spatial memory; Retention interval

1. Introduction

The ability to discern the location of objects is crucial in our daily lives. It enables navigation and allows us to interact with our environment. Visuospatial processing of spatial relations within and between different objects and between objects and ourselves, critically contributes to this ability. Spatial relations between, as well as within objects can be subdivided into two distinct types. With *coordinate* spatial relations, these relations are described precisely and in a metric manner, such as ‘the distance from the lamp to the table is 45 cm’. *Categorical* spatial relations are expressed by more abstract, qualitative terms, useful for storing prototypical descriptions, such as ‘the lamp is hanging above the table’ (Kosslyn, 1987; Kosslyn et al., 1989). Kosslyn (1987) first suggested the coordinate–categorical subdivision and linked it to the two cerebral hemispheres. Coordinate representations are thought to be associated more with the right hemisphere, following upon its pre-existing specialization in navigational processes. Categorical representations are assumed to be processed mostly in the left hemisphere, because of its associative memory and linguistic properties.[1]

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[1] There are some indications for relatively higher levels of input from the magnocellular visual pathway and the parvocellular visual pathway to the right and the left hemisphere, respectively. These pathways are also assumed to be related to large and small field sizes, correspondingly (Hellige & Cumberland, 2001; Kosslyn, Chabris, Marsolek, & Koenig, 1992; Roth & Hellige, 1998). The right hemisphere is suggested to be biased toward encoding outputs from neurons with relatively large and overlapping field sizes, suitable for encoding of coordinate representations. The receptive field size attended to by the left hemisphere seems relatively small and more appropriate for encoding categorical representations (Chabris & Kosslyn, 1998; Jacobs & Kosslyn, 1994; Kosslyn et al., 1992).

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The hypothesized hemispheric differentiation in the two types of spatial relations has received empirical support by experiments applying divided visual field tasks, neuroimaging and neuropsychological studies (e.g. Baciu et al., 1999; Banich & Federmeier, 1999; Jager & Postma, 2003; Laeng, 1994). Yet, a number of research reports has presented opposite results (e.g. Niebauer, 2001; Sergent, 1991a, 1991b). Part of this incongruence appears attributable to experimental design and specific task demands (Bruyer, Scailquin, & Coibion, 1997; Wilkinson & Donnelly, 1999).

A widely used and much adapted task design in this field is the dot-bar paradigm, first reported by Hellige and Michimata (1989) and Kosslyn et al. (1989). In this task a dot is presented either above or below a horizontal line, at several predetermined positions. Some of those positions are 'near' the line, and the others are 'far' from the line. Subjects are instructed to respond either categorically or coordinately to the presented dot-bar combinations. The categorical response is an indication of whether the dot is above or below the line, the coordinate response is the assessment whether the dot is positioned near or far from the bar. One problem commonly found in this task design is that the hemispheric pattern related to coordinate responses disappears after a number of trials. Because of the repetition of the same stimulus type, subjects likely develop new binary categories in the coordinate condition, as the exact dot positions become familiar to them (Rybash & Hoyer, 1992).

A way to circumvent this problem is to apply a match-to-sample S1–S2 design (Laeng & Peters, 1995; Van der Lubbe, Schölvinck, Kenemans, & Postma, 2006). In this type of design the required response depends on the categorical or coordinate similarity between the first (S1) and second stimulus (S2), which prohibits the emergence of general practise effects. Van der Lubbe et al. (2006) applied this design in an event related potential (ERP) study in which they studied the time course of brain activity during encoding and memorizing S1, and encoding S2 and retrieval of S1, separately. Behaviourally, they found a right hemispheric advantage for coordinate trials, but the proposed left hemispheric advantage for the categorical tasks was not found. ERP analysis showed a quantitative, but not qualitative, divergence between categorical and coordinate processing during encoding and memorization.

At a behavioural level time course effects can be further examined by varying the length of the retention interval between the first and second stimuli. In a different, spatial memory paradigm, in which a dot had to be relocated within a circle, according to an example, Postma, Huntjens, Meuwissen, and Laeng (2006) employed retention interval variation to examine the time course of categorical biases and found deviations in both the angular and radial position features. The longer the interval was, the larger the deviation of the dot placements towards the outer circumference of the circle. The authors suggested that categorical coding might be a default way in which spatial information is remembered over time, since the categorical biases grew stronger with larger retention intervals.

In the current task design the match-to-sample and retention interval variation were combined to further examine the potential hemispheric lateralization of the categorical and coordinate spatial representations over time. A new and important aspect of the current study is that it compared the effects of three separate retention intervals on hemispheric lateralization of categorical as well as coordinate responses in equivalent experimental circumstances. This allowed us to take a closer look at the effect of retention interval on both categorical and coordinate representations, as has been found for categorical bias in the study of Postma et al. (2006).

We may consider three effects of different retention intervals. One possibility could be that the hypothesized double dissociation in hemispheric differences is present only in the brief, 500 ms interval and diminishes in the intermediate (2000 ms) and long (5000 ms) retention intervals. This pattern could occur if categorical representations persist over time (Postma et al., 2006), while the coordinate representations do not. Accurate location memory, required for coordinate representations, is prone to fast decay (Huttenlocher, Hedges, & Duncan, 1991; Werner & Diedrichsen, 2002). The decay is expected to be expressed in a lower level of performance and a decrease of the hypothesized right hemispheric advantage in the coordinate trials. This temporal pattern is in line with the functional properties of both representations, as proposed by Kosslyn (1987). Coordinate representations serve actions such as grasping an object or avoiding it while navigating through space, these actions are immediate and the representations involved are not necessarily required to be retained in memory for a long time. Categorical representations however, serve to select the constancies in a continuously changing world. There is a clear need to keep this information available for longer durations.

A second option follows upon a number of reports stressing the effect of interval length on the extent of hemispheric lateralization, which grows larger with longer intervals in several paradigms. Several reports (Dee & Fontenot, 1973; Hannay & Malone, 1976) have pointed out an increase of the left hemispheric advantage in verbal tasks as the interval between two stimuli is longer. Coney and MacDonald (1988) suggested that lateral asymmetries appear and grow stronger when processing reaches a more complex level of representation. Assuming that longer retention intervals put a higher strain on memory and induce a higher level of complexity, the proposed hemispheric advantages in this task should increase from the brief, 500 ms interval to the long, 5000 ms retention interval.

Another alternative outcome might be that performance in both categorical and coordinate trials is equally affected by the manipulation of retention interval, while a longer retention interval might yield a higher task difficulty and therefore more errors and longer RTs, the lateralization pattern should not be altered. Admittedly, this outcome would be close to the null hypothesis, at least for the interaction between instruction, hemisphere, and retention interval.

It should be mentioned here that the current S1–S2 paradigm, besides avoiding possible undesired practice effects, was also intended to raise the level of difficulty, thus making the task more sensitive. In particular, this could be relevant for the categorical condition, because in most dot-bar experiments, categorical responses are much faster and more accurate than the coordinate responses. The left hemispheric advantage in categorical