NEUROPSYCHOLOGIA

Neuropsychologia 45 (2007) 2492–2498

www.elsevier.com/locate/neuropsychologia

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

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Received 5 October 2006; received in revised form 1 March 2007; accepted 23 March 2007
Available online 30 March 2007

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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doi:10.1016/j.neuropsychologia.2007.03.021

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 judgments could thus have been caused by the low level of difficulty in these tasks, while the right hemisphere performs better on the relatively difficult decisions, typical for coordinate tasks. If the categorical tasks can no longer be considered ‘easy’, then a possible left hemispheric advantage can no longer be attributed to a difference in level of difficulty. By creating stimuli with four instead of two categories, we intend to increase this difference in level of difficulty. Because this stimulus type doubles the number of possible categories, the categorical task was expected to show a higher level of difficulty, relative to categorical tasks in previous studies. These four categories were created by adapting the traditional dot-bar stimuli. Instead of a horizontal bar, a cross was chosen consisting of one horizontal bar and one vertical bar. The dot could be in one of the four quadrants (four categorical options), regardless of position within the quadrant and at four different distances (four coordinate options) from the centre of the cross, regardless of which quadrant the dot was in.[2]

2. Methods

2.1. Participants

Twenty-four students participated in exchange for course credit or a small monetary reward. Half of the group of participants consisted of males, the other half of females. The overall mean age was 21.54 (S.D. = 2.04). A Dutch version of the Edinburgh Handedness Inventory was filled out by all participants to ensure right handedness (mean score = +89.42, S.D. = 13.86, on a scale of −100, extremely left-handed, to +100, extremely right-handed) (Oldfield, 1971). All participants had normal or corrected to normal vision and were unaware of the rationale of the experiment.

2.2. Design

The experiment consisted of two match-to-sample tasks, one with a categorical instruction and one with a coordinate instruction. In this match-to-sample paradigm, subjects determined whether the second (S2) of two stimuli matched the first stimulus (S1), in either a categorical or a coordinate fashion, depending on the instruction given. The two different instructions were given for two separate tasks. The categorical instruction was to indicate whether the dot in the second stimulus was presented in the same quadrant as in the first stimulus or not. The coordinate instruction was to pay attention to the distance between the dot and the centre of the cross and state whether the distance in the second stimulus was identical to the distance in the first stimulus or not. The current task design was similar to the S1–S2 paradigm used by Van der Lubbe et al. (2006), but adaptations were made regarding stimulus features and the duration of the retention interval. The task featured a divided visual field approach to examine hemispheric differences. S1 was presented centrally and S2 was presented laterally, either in the left or right visual field. Apart from the difference in instruction the categorical and coordinate tasks were equal in structure and duration. Besides these two tasks, a third task was also administered with the instruction to detect changes of any kind in dot position in S2 compared to S1. The order of the three tasks was counterbalanced. In several of the conditions in the “any change” task performance was not above chance level. Therefore this third task was not included in the results.

For both the categorical and coordinate instruction 96 trials were presented, and for both instructions there were three blocks each with a different retention interval. These intervals correspond to the length of the presentation of the second blank screen and fixation cross in the trial sequence. Thirty-two trials were presented for each retention interval, brief (500 ms), intermediate (2000 ms) and long (5000 ms). The retention intervals were blocked and the order of these three blocks was counterbalanced across subjects. In total, there were 12 separate conditions, two tasks (*instruction*: categorical, coordinate), three blocks (*retention interval*: 500 ms, 2000 ms, 5000 ms) and two lateralized positions of S2 (*visual field*: left, right).

2.3. Procedure

Subjects were seated in front of a 17 in. computer screen (1024 × 768 pixels), at a distance of 50 cm. A chin rest was used to keep the head stabilized in front of the exact centre of the screen. A four button response box was used to register response times (RT) and error rates (ER). The buttons were positioned so that they could be easily operated with the index and middle fingers of both hands. All responses were given bimanually, to eliminate any possible lateralization effects caused by motor activity. The button presses, with simultaneous pressing and fast button release, were demonstrated by the experimenter. By pressing with both index fingers participants gave a ‘match’ response, the middle fingers were used to give a ‘non-match’ response. The RT of the fastest hand was recorded and analysed. Due to technical characteristics of the response box used, the response times given here represent the first button release. A follow up study indicated that pressing and releasing buttons is highly correlated ($R^2 = 0.96$, $p = .000$) and the difference between the two measures of RT is constant over conditions (for 23 subjects; RT difference = 251 ms, S.D. = 62.66, unpublished data). The instructions and the experiment itself were shown on the computer screen, by means of Presentation® 9.90 software (Neurobehavioral Systems). Instructions were given orally and in text on the computer screen. Nine practise trials preceded the actual experiment.

All single trials consisted of the following elements: a blank screen (750 ms), a fixation cross presented centrally (500 ms), S1 presented centrally (150 ms), a blank screen (0 ms, 1500 ms, or 4500 ms), a centrally presented fixation cross (500 ms), S2 presented laterally, either left or right (150 ms) and a blank screen (2000 ms) (see Fig. 1). The fixation cross was “×” shaped (10 × 10 pixels) so it would not provide a cue for the angles of the “+” shaped cross in the stimuli. All text and stimuli displays were presented in black, on a white background, as suggested by Jager and Postma (2003). S2 appeared laterally with a visual angle of 2.5° from the centre of the screen to the centre of the stimulus. The direction of laterality (left or right visual field) was balanced within each retention interval block.

S1 and S2 were dot-cross stimuli, which are an adaptation of the traditional dot-bar stimuli. The size of the cross was 90 × 90 pixels and the dot radius was 6

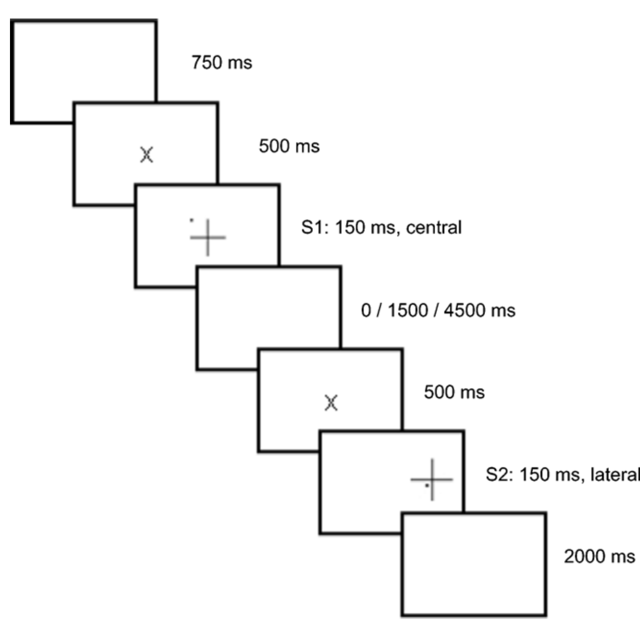

Fig. 1. A diagram of the trial sequence used in both the categorical and coordinate trials.

[2] The term “categorical” used here means abstract and refers to the rough position of the dot relative to the cross. “Coordinate” signifies the metric relationship between the dot and the cross; the absolute distance, regardless of the angle with respect to the fixation origin.

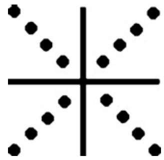

Fig. 2. The 16 possible dot positions, relative to the cross. Note that only one dot was presented in each actual stimulus.

pixels. With the intent to increase the level of difficulty of the categorical task, the dots in the stimuli could appear at 16 different positions with regard to the cross, in each of the four quadrants and with four different distances to the centre of the cross (see Fig. 2). In the categorical task, subjects were instructed to determine whether the dot in S2 appeared in the same quadrant as the dot in S1, regardless of its metric position. In the coordinate task, they were asked to determine whether the dot in S2 appeared at the same distance to the centre of the cross as the dot in S1, ignoring the quadrants they were in (see Fig. 3). Therefore there were four options for each instruction type, four quadrants and four distances, instead of the two options of near/far and above/below in the original dot-bar paradigm. The instructions and examples were carefully composed to keep the subjects naïve to the restriction in number of positions and actual location of the dots in S1 and S2. The subjects were told that the dots could appear at any position in and around the cross. The combinations of the S1 and S2 dot positions and the direction of laterality of S2 were pre-programmed in order to have a balanced number of trials for every condition.

After each task was completed subjects were asked about the strategy they had applied to solve the task and the subjective level of difficulty. They were specifically asked about what they did during both tasks, and the perceived effect of the different retention intervals on these strategies. As one of the anonymous reviewers suggested, it should be noted here that these qualitative self reports do not exclude the possibility of other processes taking place, of which the subjects are unaware. Yet, the use of typical verbal and visuo-spatial strategies in comparing sentences and pictures can be strongly influenced by the explicit instruction to apply one of those strategies (Mathews, Hunt, & MacLeod, 1980). In other words subjects can evaluate and adapt their strategy, which implies a conscious perception of the strategy used.

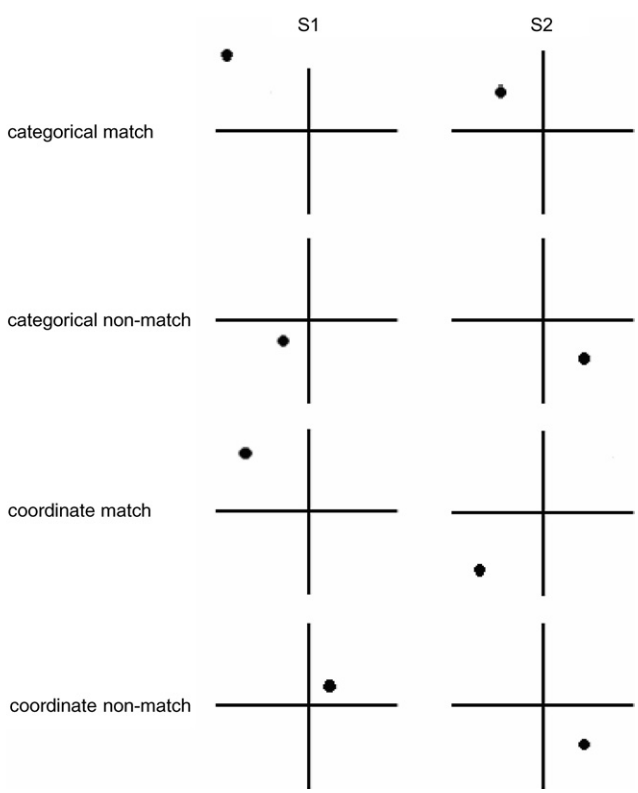

Fig. 3. Examples of S1–S2 combinations for the categorical and coordinate instructions. All four options are given: categorical and coordinate, matching and not matching.

2.4. Data analysis

The RT and ER measured in the categorical and coordinate tasks were analysed to examine the performance levels in all 12 conditions. All scores, RT and ER, were first subjected to a repeated measures general linear model (GLM) with instruction (categorical and coordinate) visual field (left and right, corresponding to the contra lateral cerebral hemispheres; LVF/RH and RVF/LH) and retention interval (500 ms, 2000 ms, and 5000 ms) as within subject factors. Bonferroni corrected post hoc analyses were used to further examine possible significant interaction effects. In addition, the qualitative self reports the subjects provided are discussed.

3. Results

3.1. Overall response times and error scores

The means of RT and ER for all conditions were analysed (Fig. 4A and B). For RT the GLM revealed a significant main effect of instruction, $F(1, 23) = 16.35$, $p = .001$, and retention interval, $F(2, 22) = 8.96$, $p = .001$. Post hoc tests showed that RT was significantly higher in the coordinate instruction, than in the categorical instruction. Moreover, post hoc tests revealed that RT was significantly higher for the 5000 ms interval, than for the 500 ms and 2000 ms intervals, $p = .004$, and $p = .002$, respectively. Significant interaction effects were found for visual

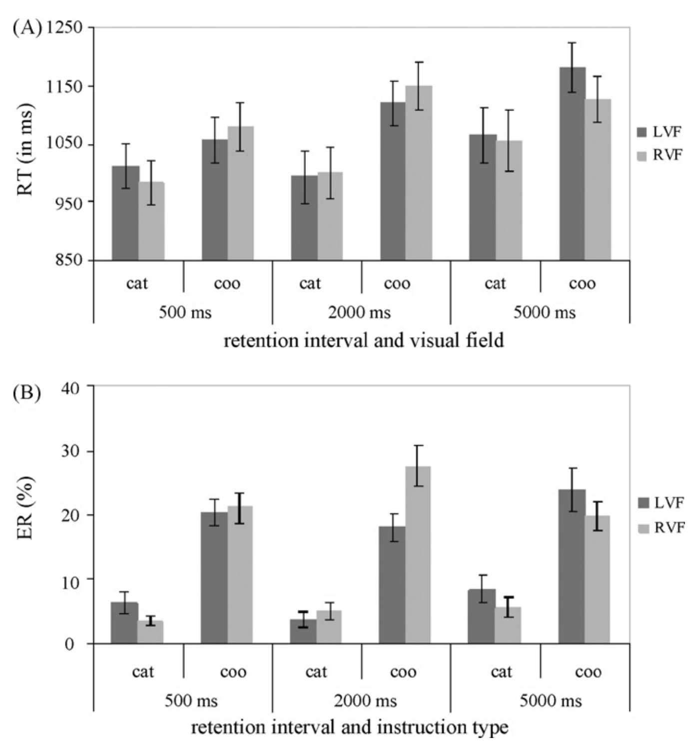

Fig. 4. (A) Average response times (RT) and (B) error scores (ER) for the categorical and coordinate instruction tasks in both the left (LVF) and the right (RVF) visual field and all three retention intervals. The error bars represent the standard error of the mean (S.E.M.).

field × retention interval, $F(2, 22) = 4.67$, $p = .020$, and instruction × visual field × retention interval, $F(2, 22) = 4.33$, $p = .026$. Post hoc repeated measures GLMs were performed on the latter interaction effect within each retention interval to investigate it more thoroughly.

At 500 ms, a significant main effect for instruction, $F(1, 23) = 4.97$, $p = .036$, and a significant interaction effect of instruction × visual field, $F(1, 23) = 5.19$, $p = .032$, were found. Again the average RT was higher for the coordinate instruction than for the categorical instruction. In the categorical instruction the RVF/LH outperforms the LVF/RH and the reverse is true for the coordinate instruction. A paired samples *t*-test revealed that the difference between both visual fields at the 500 ms interval, was significant within the categorical instruction, $t(23) = 2.31$, $p = .030$, but not within the coordinate instruction, $t(23) = -1.57$, $p = .130$. At 2000 ms a similar main effect for instruction was found, $F(1, 23) = 16.94$, $p = .000$. The same main effect was found at 5000 ms, $F(1, 23) = 12.71$, $p = .002$, as well as a main effect for visual field, $F(1, 23) = 5.94$, $p = .023$, indicating that the average RT was higher in the LVF/RH, than in the RVF/LH.

Furthermore, the interaction effect of instruction × visual field × retention interval was analysed within both instruction types. For the categorical task, there was a main effect of retention interval, $F(2, 22) = 7.80$, $p = .003$, indicating that for the longer retention intervals, there was a higher mean RT. Post hoc pair wise comparisons showed a significantly higher RT in the 5000 ms interval, compared to the 2000 ms interval, $p = .002$. A similar main effect was found for the coordinate task, $F(2, 22) = 6.22$, $p = .007$, but in this case the increase of RT was significant between the 500 ms and 2000 ms interval, $p = .019$ after which it remains similar at the 5000 ms interval, $p = 1.000$. A closer look at the retention interval × visual field interaction shows that only within the 5000 ms interval there is a significant main effect of visual field, $F(1, 23) = 5.94$, $p = .023$, as mentioned earlier, indicating a higher mean of RT in the LVF/RH, compared to the RVF/LH.

A GLM on ER showed a significant main effect of instruction, $F(1, 23) = 84.44$, $p = .000$, and a significant interaction effect of visual field × retention interval, $F(2, 22) = 9.13$, $p = .001$. Post hoc tests showed that ER was higher for the coordinate instruction, than for the categorical instruction, congruent with the RT outcome. A closer examination of the visual field × retention interval effect revealed a significant main effect of visual field at the intermediate interval of 2000 ms, $F(1, 23) = 11.14$, $p = .003$, indicating a lower ER for the LVF/RH.

3.2. Qualitative self reports

When asked about the difficulty of the tasks, most subjects reported that they experienced the categorical task to be easier than the coordinate task. The differences in retention interval affected the comfort with which the tasks were performed. In the 2000 ms interval this comfort was highest because it provided an agreeable rhythm in which the answers could be given. The 500 ms interval was mainly experienced as demanding concentration, while the 5000 ms interval put noticeably more weight on memory.

The reported strategies used can be roughly divided into the use of words, visual imagery and a combination of both. Nearly all subjects used only words to solve the categorical task; they coded S1 with verbal labels as “top left” or “bottom right”. This effect appeared to be moderated by the retention interval, some subjects report that the use of words became easier with longer retention intervals, for both the categorical as the coordinate tasks. The coordinate task was mainly solved by applying visual imagery, many subjects developed techniques to make this imagery easier. Some subjects imaged circles around the centre of the cross, others imaged additional lines in the figure and paid attention to the angle those lines created. A few subjects reported the use of words in the coordinate task as well, but because the number of possible positions of the dots were unknown the verbal codes were restricted to terms like “nearby”, “somewhere in the middle”, and “further away”, which could not uniquely describe the actual distance, because there were four possible distances. Only one of the 24 subjects had deducted that there were four predefined distances at which the dots could appear.

4. Discussion

Spatial relations between objects can be represented either categorically or coordinately. The abstract, categorical representation is thought to be processed predominantly in the left hemisphere, while the metric, coordinate representation is associated more with right hemisphere activity (Kosslyn, 1987). Although spatial relations have been studied extensively, the time course of these two representations has not been examined much. In the current experiment three different time intervals were employed in a divided visual field, match-to-sample task, to investigate the effect of delay on both representations and the related hemispheric lateralization patterns.

For the brief retention interval of 500 ms, the hemispheric differences proposed by Kosslyn (1987) were found in the RT analysis; presentation in the LVF/RH showed better performance for coordinate trials, while RVF/LH presentation had the same effect on categorical trials. Notably, this effect was not present in the intermediate and long intervals. Therefore the interaction of instruction and visual field appears to have been affected by the length of the retention interval. While the coordinate trials showed an increase in RT between the brief and intermediate retention interval, which remains the same for the long retention interval, an increase in RT only appeared between the intermediate and the long interval for the categorical responses. The coordinate trials therefore seem to have been affected at an early stage by the duration of the retention interval, while RT for the categorical trials was only affected by the long duration of the retention interval. The results for the coordinate condition are congruent with the notion that exact location memory decays very quickly (Huttenlocher et al., 1991; Werner & Diedrichsen, 2002). Because of the decay, the intermediate and long intervals were very likely to be too long to examine responses based purely on exact, coordinate representations, because they were simply not present anymore.

Some subjects reported a verbal encoding strategy for the coordinate trials, but this was mainly restricted to the long, 5000 ms interval. It is very well possible that in the long interval, the coordinate strategy failed completely, because the exact, metric information had decayed in memory. A verbal approach could replace the coordinate strategy, which would result in a lower level of performance, because the coordinate trials were not perfectly solvable without knowing the total number of possible positions. A verbal, more categorical strategy, using words like near, in the middle, and far, could well have caused the left hemispheric advantage found, because of the use of categories and verbal memorization. A drawback of a verbal approach in the long intervals might be the effects of interfering intrusive thoughts. Some of the subjects mentioned they found it harder to concentrate during the long intervals because they suffered from involuntary intrusions, unrelated to the task.

Detection of categorical changes was also affected by an increase of the length of retention intervals. The RTs for categorical trials showed decay over time, but at a later point in time than the responses to coordinate trials. A possible explanation for this effect could be a shift in the format in which S1 is retained over time. Qualitative self reports indicated the use of words in solving the categorical trials, but this strategy differed between the intervals for a number of subjects. More subjects reported a verbal strategy in the long, 5000 ms interval than in the brief 500 ms interval. Thus, for the brief interval these reports suggest the possibility to encode the category in a visual manner, without actively naming it. The modality switch between the intervals could have caused the increase in RT. A switch between visual and verbal strategies has been found in the past, yet in a different setting and in the opposite direction. Tversky (1975) found that sentences are encoded verbally in sentence–picture comparisons, but only with simultaneous presentations. This strategy changed when the picture was presented 5 s after the sentence. In this case the sentences were encoded pictorially. Perhaps the reverse is true when pictures are encoded in picture–picture comparisons as present in the current study. Kemmerer and Tranel (2000) have proposed a subdivision in the modality of categorical representations: it can be either perceptual or verbal. It is very well possible that the manipulation of interval length has separated perceptual categorical representations from verbal ones. It should be acknowledged that the time course of categorical responses seems to differ from what is reported by Postma et al. (2006). However, the task and experimental design were clearly different in their experiment, where the main focus was on error biases instead of absolute performance levels.

Surprisingly, in light of the foregoing considerations, the categorical LH advantage seems to disappear after the 500 ms interval, both RT and ER were no longer significant. However, when looking at the patterns together, there still seems to be a LH advantage in the categorical task for the long retention interval (5000 ms). Therefore, it might not be the case that the categorical LH advantage simply disappears with longer intervals. It may be affected by the strategy switch which might be present at the intermediate interval (2000 ms) and absent in most cases at the long interval (5000 ms). Additional experimental designs are needed to further investigate this issue.

The overall level of difficulty of the 'dot-cross task' is higher than the level usually found for the dot-bar task. The average overall RT and the ER for the coordinate trials found in the current task are higher than found by Van der Lubbe et al. (2006), in similar match-to-sample task with the dot-bar stimuli. The coordinate trials appear to be systematically more difficult than the categorical trials, as indicated by the RT and ER scores. The difference in difficulty in the current experiment does not seem to depend on the number of categories and coordinates, because the same pattern of difficulty is found in categorical and coordinate trials in most dot-bar reports (e.g. Wilkinson & Donnelly, 1999). We can disqualify the argument that hemispheric differences between categorical and coordinate trials are simply due to a difference in difficulty, and a right hemispheric advantage in more difficult tasks. Strikingly, the trials in the long, 5000 ms interval have the longest RT, but exhibit a left hemispheric advantage, contrary to the argument that perceptually more difficult tasks are performed better by the right hemisphere.

In conclusion, the current results show that hemispheric differences exist for categorical and coordinate judgments, in line with the findings of Kosslyn (1987). The categorical responses were performed better by the left hemisphere, while the right hemisphere yielded better coordinate responses. Importantly, this effect is restricted to the brief, 500 ms retention interval. The coordinate responses were directly affected by the increase of retention interval duration while the categorical responses were only affected when the retention interval changed from intermediate to long. On the long run, at least at 5000 ms, it is possible that subjects switch from visual to verbal memorization of S1, in accordance with the pattern of self reports.

Acknowledgements

This study was supported by a grant of the Netherlands Organisation for Scientific Research (NWO) (Evolution and Behaviour: 051-14-027) and an EU NEST Fp6 grant (No. 12959—Wayfinding).

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