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Research report

The effect of stimulus features on working memory of categorical and coordinate spatial relations in patients with unilateral brain damage

Ineke J.M. van der Ham [a,*], *Richard J.A. van Wezel* [b,c,d], *Anna Oleksiak* [b,c], *Martine J.E. van Zandvoort* [a,e], *Catharina J.M. Frijns* [e], *L. Jaap Kappelle* [e] and *Albert Postma* [a,e]

[a] *Helmholtz Institute, Experimental Psychology, Utrecht University, the Netherlands*
[b] *Helmholtz Institute, Utrecht University, the Netherlands*
[c] *Utrecht Institute for Pharmaceutical Sciences, Utrecht University, the Netherlands*
[d] *MIRA, Biomedical Signals and Systems, University of Twente, the Netherlands*
[e] *Department of Neurology and Rudolph Magnus Institute for Neuroscience, University Medical Centre Utrecht, the Netherlands*

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ABSTRACT

Spatial relations are typically divided into categorical and coordinate spatial relations. Categorical relations are abstract and show a left hemisphere (LH) advantage, whereas coordinate relations are metric and related to a right hemisphere (RH) advantage. In the current study a working memory task was used to asses categorical and coordinate performance with two different stimulus sets. In this task, participants had to compare two sequentially presented stimuli, consisting of a dot and a cross. The cross size used in the stimuli was either large or small; a direct manipulation of the amount of information provided to determine a category, or to assess a distance. Patients with damage in the LH or the RH and highly comparable controls were tested. In control participants, categorical processing is faster with the use of a large cross, i.e., more visual information about category boundaries. In contrast, coordinate performance was more accurate with a small cross, i.e., presenting less unnecessary visual information. LH patients showed a specific defect in processing categorical stimuli with a small cross and coordinate stimuli with a large cross. The RH patients were impaired in all conditions except for the categorical small cross condition. We conclude that a larger amount of information present in stimuli increases categorical processing performance and decreases coordinate processing performance, while opposite effects are found for less stimulus information.

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* *Corresponding author*. Heidelberglaan 2, 3584 CS Utrecht, the Netherlands.
E-mail address: c.j.m.vanderham@uu.nl (I.J.M. van der Ham).

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1. Introduction

The spatial relations between or within objects give us vital information on how to interact with the visual world. It helps us to search for items in the right places, navigate from one location to the other, grasp objects and recognize them from unusual viewpoints. Kosslyn (1987) has provided an influential theory on the processing of such spatial relations. He stated that two global classes can be discerned: categorical relations, which are abstract, such as "left of" and "below", and coordinate relations, that are metric in nature, such as "2 cm apart" and "further away". The main feature of Kosslyn's initial proposal was that categorical and coordinate spatial relations are processed by separate subsystems in the brain, characterized by different lateralization patterns: a left hemisphere (LH) specialization for categorical processing and a right hemisphere (RH) specialization for coordinate processing. Over the years, many studies have confirmed this double dissociation pattern empirically (e.g., Hellige and Michimata, 1989; Kosslyn et al., 1989). Yet, some have criticized this theory to a certain extent (e.g., Sergent, 1991; Martin et al., 2008; Oleksiak et al., 2009). Currently the most generally accepted view seems to be that categorical and coordinate relation processing is based on partially separate, but not mutually exclusive subsystems, exemplified by hemispheric advantages (see e.g., Jager and Postma, 2003).

While initially most studies used responses to single stimuli, addressing primarily perceptual mechanisms (e.g., Hellige and Michimata, 1989), a working memory design has been used more frequently in the recent past (e.g., Laeng and Peters, 1995; Van der Lubbe et al., 2006; Van der Ham et al., 2007; Oleksiak et al., 2009). In particular this design circumvents the problem of categorization of coordinate information (see e.g., Baciu et al., 1999).

Van der Ham et al. (2007) introduced the so-called cross dot task and successfully employed it in behavioural (Van der Ham et al., 2007; Van der Ham and Postma, 2010), functional magnetic resonance imaging (fMRI) (Van der Ham et al., 2009) and electroencephalography (EEG) studies (Van der Ham et al., 2010). In this task, participants are shown two sequential images of a dot somewhere around a "+" shaped cross. The categorical instruction is to determine whether the dots in the two images are within the same quadrant, or category, of the cross, disregarding the exact dot positions. In contrast, the coordinate instruction is to compare the distance between the dot and the centre of the cross in the two images, disregarding the quadrant the dots are in. The application of the stimuli in these cross dot studies has been adjusted in two ways: the number of possible dot positions has changed from sixteen to forty, and the size of the cross has been decreased from 2.25° to .35° of visual angle, without altering the dot positions. These changes were made to prevent participants from memorizing the total number of options and to decrease the difference in difficulty between the categorical and coordinate tasks. In a previous study, we have argued that reducing cross size would increase difficulty of the categorical task, as less information concerning the category was available, and decrease difficulty of the coordinate task, as less distracting additional features were present (Van der Ham et al., 2009).

This last issue is of particular interest as it raises the question in what way such visuospatial stimulus information interacts with category formation and coordinate verification. In the current study, we have manipulated the cross size in a within subjects approach to find an empirical answer to this particular question. We hypothesized that a large cross size would increase categorical performance, and a small cross size would lead to an increase in coordinate performance. A number of studies have focused on the boundaries of spatial categories within a visuospatial verbal matching case, e.g., when is a certain spatial relation within a visual display considered to be "above" (e.g., Hayward and Tarr, 1995; Crawford et al., 2000). It has been argued that such relations have "fuzzy boundaries" (see Vorwerg and Rickheit, 1998). Arguably, these findings about the linguistic nature of these categories might also apply to the spatial categories used here. In line with this, it can be contended that longer arms of the cross will decrease the uncertainty or "fuzziness" of the boundaries as they clearly mark them, and will therefore facilitate categorical performance. In other words less effort would be required for simply using a category, than for category construction. For coordinate processing, the task is to specifically relate the dot position to the centre of the cross, i.e., the radial distance. Therefore, the small cross seems more suitable for this particular task, as no unnecessary additional information is given. There is a possibility that participants use indirect measures of distance, when such information is provided, even when it is unnecessary for the task. In line with this possibility, Watt (1990) reported that more visual information reduces the need for an internal mechanism to scale distances, as the field itself is used as such a mechanism. This would mean that with a small cross, more emphasis is placed on using such an internal scaling mechanism, which is the aim of a task testing coordinate relation processing. In contrast, the large cross would provide such information externally, or indirectly.

In the current study we therefore manipulated the cross size in a within subjects approach to test whether categorical and coordinate spatial relation processing would be differentially affected. Moreover, in order to gain further insight in the neural basis of spatial relation processing and in particular of category formation, we tested how patients with unilateral brain damage performed on these tasks. Thirty-five patients with left or right hemisphere lesions were recruited. Such a neuropsychological approach is a useful way to complement existing behavioural, EEG, and fMRI data on this task as behavioural measures can be directly linked to the damaged hemisphere in a causal way. Importantly, it allows us to investigate how the amount of relevant information given in the stimuli affects such patients' performance on spatial relation processing.

To summarize, our hypotheses concern two issues. The first issue is the lateralization pattern of categorical and coordinate spatial relation processing. If the double dissociation originally proposed by Kosslyn (1987) is correct, patients with LH damage are impaired in categorical relation processing and patients with RH damage show impairment in coordinate spatial relation processing.

Second, the effects of cross size are examined. If a smaller cross size increases categorical difficulty and reduces coordinate difficulty, then we hypothesize that performance on the categorical task should be better for the large cross, compared to the small cross, whereas performance on the coordinate task should be better for the small cross, compared to the large cross. For the performance of left and right hemisphere damaged patients with regard to cross size our approach is more exploratory. It could well be that performance on the easier conditions (large – categorical, small – coordinate) does not show impairment compared to the more difficult cross sizes. On the other hand, for the categorical condition one could argue that the large cross would create clearer, more typical categories and hence lead to purer categorical processing, and therefore to more impairment in LH patients. This is also comparable to previous categorical tasks where grids were used to define categories (Kosslyn et al., 1995; Van Asselen et al., 2008; Martin et al., 2008). In contrast, for the coordinate condition the use of the internal scaling mechanism for the small cross could be considered a more basic form of coordinate processing, leading to more impairment in RH patients.

2. Methods

2.1. Participants

Thirty-three patients who suffered from cerebral ischaemic stroke or haemorrhage were selected from the Stroke Database of the University Medical Centre Utrecht. Inclusion criteria were: (1) age between 18 and 80; (2) no history of previous neurological or psychiatric disorder; (3) testing occurred six to eighteen months after the onset of the stroke; (4) lesion visible on CT or MRI scan; (5) no hemispatial neglect or severe hemianopia. Informed consent was obtained from each patient. The control group consisted of 28 healthy participants who were highly comparable to the patient groups in age and education.

Education level was scored using seven categories, one being the lowest and seven the highest level (Verhage, 1964). Handedness was assessed with the Dutch version of the Annett Handedness Inventory, with scores ranging between −24 (extremely left-handed) and +24 (extremely right-handed) (Annett, 1970). Lesions were classified on the basis of the description of the CT or MRI data by an experienced neurologist. Sixteen patients had damage in the LH, and seventeen in the RH. In Appendix A, a detailed description is given for all patients individually, including lesion localisation.

2.2. Neuropsychological screening tests

Standard neuropsychological tests were administered to obtain measures of overall cognitive impairment and general memory function. The Dutch version of the National Adult Reading Task (Schmand et al., 1991) was used as a measure of verbal intelligence. The 12 item short form of the Raven Advanced Progressive Matrices (Raven APM, set I) served as a measure of non-verbal intelligence (Raven et al., 1998). The subtest Letter Number Sequencing of the Wechsler Adult Intelligence Scale (WAIS) (Wechsler, 1987) was used as an estimate of verbal working memory. The Corsi block tapping test, both forwards and backwards, was used as a measure of spatial working memory (Corsi, 1972). The trail making test (TMT) was used to test visual attention and divided attention (Reitan, 1955). The Rey Auditory Verbal Learning Test (RAVLT) was included to assess verbal working memory including learning, consolidation, and retrieval (Rey, 1964; Taylor, 1959). To test comprehension of the spatial prepositions above, below, left, and right, a spatial preposition test was composed. Participants were presented with sixteen different pictures depicting two objects, along with a sentence, e.g., “the telephone is above the ball”. They were asked to indicate whether the sentence matched the picture or not. If the sentence did not match the picture, it would contain the correct object names, but an incorrect preposition. One point was awarded for each correct answer, leading to a maximum score of sixteen.

2.3. Cross dot task

The task we used to assess spatial relation processing was the cross dot task (Van der Ham et al., 2007, 2009; Van der Ham and Postma, 2010): a match-to-sample, visual half field task that assessed working memory for both categorical and coordinate spatial relations. In total four subtasks were used; categorical instruction with a large cross, categorical instruction with a small cross, coordinate instruction with a large cross, and coordinate instruction with a small cross. Therefore, two sets of stimuli were used with either a large or a small cross. Both sets were designed in a similar fashion; a black dot (.15° visual angle) was positioned at one of forty possible locations around the black, “+” shaped cross (large: 2.25°, small: .35°). The forty dot positions were placed at four equally different distances from the centre of the cross, with ten positions within each quadrant of the cross. In Fig. 1 all dot positions are given in one configuration for both the small and large cross stimuli. The categorical instruction was to match the two sequentially presented cross dot stimuli, based on the quadrant of the cross the dots appeared in, which were same or different. The coordinate instruction was to compare the distance between the dot and the centre of the cross in both stimuli, these were the same or longer/shorter.

A single trial sequence consisted of the following elements: a blue square indicating the start of a new trial (500 msec), a blank screen (250 msec), an “x” shaped fixation cross (500 msec), the first cross dot stimulus (150 msec), a blank screen (1500 msec), an “x” shaped fixation cross (500 msec), the second cross dot stimulus (150 msec), a blank screen during which a response should be given (maximum 4000 msec). Responses were given by pressing the arrow keys of a regular keyboard. In comparison to previous version of

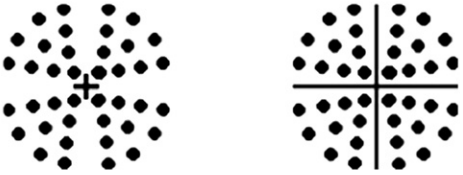

Fig. 1 – Examples of both the large and small cross with all forty possible positions. Note that in the actual stimuli a dot was visible in only one of these positions.

this task two small adaptations were made. The current task did not entail visual half field measures, but the presentation of both stimuli at the exact same position was likely to facilitate strategies like using the fixation cross as an anchor point. Therefore, the first stimulus was presented centrally and the second stimulus slightly off centre, at one of four possible positions (combinations of 1.25° up or down and 1.25° left or right, with regard to the centre of the screen). The second adaptation was the selection of a retention interval of 2000 msec. In previous versions we have included durations of 500 msec and 5000 msec as well, but the 2000 msec interval has shown to be most successful in demonstrating lateralization effects and is most suitable for testing patients for practical reasons as for them it is the most comfortable interval duration. In total, twenty trials were presented for each of the four subtasks; ten match trials and ten non-match trials, amounting to eighty trials in total.

2.4. *Procedure*

Participants started with all screening tests, in fixed order. The cross dot task was introduced by first showing the participants pictures of possible stimuli in the following subtask. An elaborate instruction was given on what was defined as a category, and to what (coordinate) distance participants should pay attention. It was clearly stated that the dots could appear at any position around the cross, to avoid any possible categorization of the coordinate judgements, as they were in fact limited to four possible distances. The experiment started with five practice trials that were repeated if necessary. The four subtasks were presented in pseudo-randomised order.

2.5. *Statistical analysis*

The scores of the neuropsychological screening tests were analyzed by means of analyses of variance (ANOVAs) with group (controls, LH patients, RH patients) as between subject factors. Significant effects of group were followed up by Bonferroni corrected pairwise comparisons. Instead of using norm scores we decided to compare the patient groups directly to the available control score, which were matched in age and education, as reported in Table 1.

For the primary experimental tasks, error rates (ERs) and response times (RTs) were recorded for all eighty trials of the cross dot task. For both measures, a general linear model (GLM) was used with instruction (categorical, coordinate) and cross size (small, large) as within subject factors for all control subjects to establish a baseline effect of cross size on both categorical and coordinate judgements.

In addition to this approach, a performance score was calculated for each participant by adding z scores of both ER and RT (see e.g., Allen et al., 1996). After visual inspection of the ERs and RTs of both patient groups this score appeared to be representative and sensitive to the performance as a whole, as the two separate measures complemented each other. To be fully informative, all three measures, ER, RT and z scores, were analyzed by means of a repeated measures general linear model (GLM), including instruction (categorical, coordinate) and cross size (small, large) as within subject factors and group (control subjects, LH and RH patients) as a between subject factor. Any significant interaction effects were followed up by Bonferroni corrected post hoc tests. To observe any absolute impairments for each condition, the performance score analysis was complemented by a t-test comparison to 0 for both patient groups and all four conditions.

Table 1 – The mean scores on the neuropsychological tests for all three groups. Standard deviation in parentheses.

	Controls ($N = 28$)	LH patients ($N = 16$)	RH patients ($N = 17$)
Delay event – test (months)		14.0 (3.8)	14.6 (5.2)
Age	58.3 (6.5)	62.4 (11.2)	56.1 (14.7)
Gender	12 M/16 F	12 M/4 F	10 M/7 F
Education	5.4 (1.0)	5.6 (1.2)	5.1 (1.1)
Handedness (Annett)	11.6 (17.7)	16.6 (11.0)	15.8 (12.9)
NART verbal IQ	106.6 (15.8)	108.6 (16.6)	102.1 (18.1)
Raven APM	58.8 (28.1)	62.3 (28.4)	34.0 (33.2)*
Letter Number Sequencing	48.0 (29.5)	44.3 (30.1)	32.3 (30.5)
Corsi forward	7.7 (1.4)	7.4 (1.1)	7.5 (1.7)
Corsi backward	7.8 (1.7)	7.7 (1.7)	6.4 (2.0)*
TMT B/A	2.1 (.8)	2.9 (1.6)*	2.1 (.4)
RAVLT immediate recall	44.0 (10.7)	30.4 (12.8)**	38.5 (11.6)
RAVLT delayed recall	8.9 (3.5)	5.9 (4.4)*	8.3 (3.0)
Spatial preposition task	15.9 (.3)	15.8 (.5)	15.8 (.6)

$^{*}p < .05$, $^{**}p < .01$ (compared to control scores).

3. Results

3.1. *Neuropsychological screening tests*

In Table 1, the gender, age, education level and neuropsychological screening results are given for all three groups. No significant difference was found between the patient groups and controls for age, $F(1,42) = 2.35$, $p > .10$ for the LH patients and $F(1,43) < 1$ for the RH patients, or education, $F(1,42) < 1$, for the LH patients, and $F(1,43) < 1$ for the RH patients. As indicated in the table, significant main effects of group were found for the Raven test, $F(2,55) = 4.37$, $p < .05$, the backwards Corsi block test, $F(2,58) = 3.61$, $p < .05$, the TMT, $F(2,56) = 3.60$, $p < .05$, and the immediate recall and delayed recall in the RAVLT, $F(2,57) = 7.11$, $p < .01$, and $F(2,57) = 3.44$, $p < .05$, respectively. Follow up tests showed that the LH patient group was significantly impaired on the TMT ($p < .05$), and both immediate ($p < .01$) and delayed recall ($p < .05$) on the RAVLT, compared to the controls, whereas the RH patient group scored significantly lower on the Raven test ($p < .05$) and the backward Corsi block test ($p < .05$) than the controls. Consequently, the LH group was impaired on verbal working memory, learning and consolidation and divided attention, whereas the RH group was impaired on non-verbal intelligence and spatial working memory. As spatial working memory was a vital prerequisite for the cross dot task, individual Corsi block test scores were evaluated. Based on norm scores (Kessels et al., 2008) two patients in the RH group (MS and JV) performed below normal range on the backwards Corsi block test. These two patients were excluded from the analyses of the cross dot task.

3.2. Cross dot task

In Table 2, the mean ERs and RTs are given for all groups in each condition. The GLM of ERs of the control group showed a significant main effect of instruction, $F(1,27) = 7.94$, $p < .01$, and cross size, $F(1,27) = 143.16$, $p < .001$. ERs were higher for the coordinate instruction, compared to categorical instruction and for large crosses compared to small crosses. A significant interaction effect was found for instruction and cross size, $F(1,27) = 14.29$, $p < .01$. Paired sample *t*-tests showed that for the coordinate instruction responses were more accurate for small crosses than for large crosses, $t(27) = 4.21$, $p < .001$. No statistically significant difference between the cross sizes was found for the categorical instruction.

The GLM on RT revealed no significant main effects, but a significant interaction of instruction and cross size, $F(1,27) = 19.93$, $p < .001$. Both instructions showed an effect of cross size; for the categorical instruction RTs were significantly higher for the small cross compared to the large cross, $t(27) = 4.26$, $p < .001$, whereas at trend level responses were faster for the small cross than for the large cross for the coordinate instruction, $t(27) = 1.86$, $p = .074$.

The repeated measures GLM on ERs, including instruction (categorical, coordinate), cross size (small, large) and group (controls, LH patients, RH patients) showed significant main effects of instruction, $F(1,56) = 252.08$, $p < .001$, cross size, $F(1,56) = 6.80$, $p < .05$, and group, $F(2,55) = 5.15$, $p < .01$. Fewer errors were made for the categorical instruction and the small cross size. Furthermore, the RH patient group performed significantly worse than the controls ($p < .01$). Furthermore, the interaction of instruction, cross size, and group was at trend level, $F(2,55) = 2.77$, $p = .071$.

For RTs, this analysis also showed significant main effects of instruction, $F(1,56) = 15.28$, $p < .001$, and group, $F(2,55) = 5.67$, $p < .01$. RTs were faster for the categorical instruction and the RH patients were significantly slower compared to controls ($p < .01$). The interaction of instruction and cross size was also significant, $F(1,57) = 11.85$, $p = .001$. Follow up tests showed that there was a significant difference between small and large cross size for the categorical instruction ($p < .001$); RTs were shorter for the large cross size. The coordinate instruction did not show a significant effect of cross size.

After visual inspection of the ERs and RTs of both patient groups, a general performance measure was created to equally represent both measures. Based on the means and standard deviations of the control group, z scores were computed for all individuals for both ER and RT. The performance score was calculated by adding those z scores of ERs and RTs for each individual in each condition. This combined z score indicated lower scores for better performance, and by definition the scores for the control group were zero in all conditions. In Fig. 2 the mean performance scores are given for both patient groups in all four conditions. For this measure of general performance a main effect of group was found, $F(2,55) = 7.17$, $p < .01$, and a significant interaction effect of instruction, cross size, and group, $F(2,55) = 5.66$, $p < .01$. RH patients performed worse compared to the control group ($p < .01$). LH patients performed worse than controls at a very slight trend level ($p = .097$). Follow up tests showed that the impairments of the patients with regard to the controls were limited to some combinations of strategy and cross size. The LH patient group was impaired for coordinate – large cross ($p < .05$) and slightly impaired for the categorical – small cross condition ($p = .056$). The RH patients were impaired for categorical – large cross ($p < .01$), coordinate – large cross ($p < .001$), and the coordinate – small cross condition ($p = .001$).

4. Discussion

The current study focused on two main issues; lateralization of spatial relation processing and more importantly the effect of the amount of stimulus information on both categorical and coordinate spatial relation processing. The cross dot task used in several previous studies (e.g., Van der Ham et al., 2007) was now applied in a group of healthy controls as well as a group with LH damage and a group with RH damage.

The main hypothesis concerning stimulus information was that clear boundaries, as in the large cross conditions, would selectively benefit categorical processing, whereas less visual information, as in the small cross conditions, would favour coordinate processing. In general, Kosslyn's original

Table 2 – Means for both ERs and RTs in all conditions for each group. M = mean, SD = standard deviation. Education = category of education level, range 1–7 (low–high). Handedness = raw score of Annett Handedness Questionnaire. NART = National Adult Reading Task (Dutch version). Raven APM = advanced progressive matrices, 12 items, age controlled percentile. Letter Number Sequencing = age controlled percentile as indicated by WAIS. Corsi block test forward and backward = number of correct trials. TMT B/A = trail making test, time version B/time version A. Immediate = total number of words recalled, Delayed = age controlled decile. Spatial preposition task = number of correctly identified pictures, range 1–16.

		ER (in %)			RT (in msec)		
		Controls	LH	RH	Controls	LH	RH
Large cross	Cat	6.8 (9.2)	10.5 (9.5)	15.1 (13.3)	1174 (173)	1257 (398)	1527 (493)
	Coo	32.0 (9.4)	39.2 (13.6)	39.0 (10.6)	1323 (230)	1597 (475)	1733 (360)
Small cross	Cat	7.5 (10.1)	17.5 (17.7)	17.7 (16.5)	1323 (214)	1651 (824)	1560 (466)
	Coo	22.2 (9.7)	24.9 (12.6)	32.6 (11.6)	1250 (238)	1528 (615)	1705 (520)

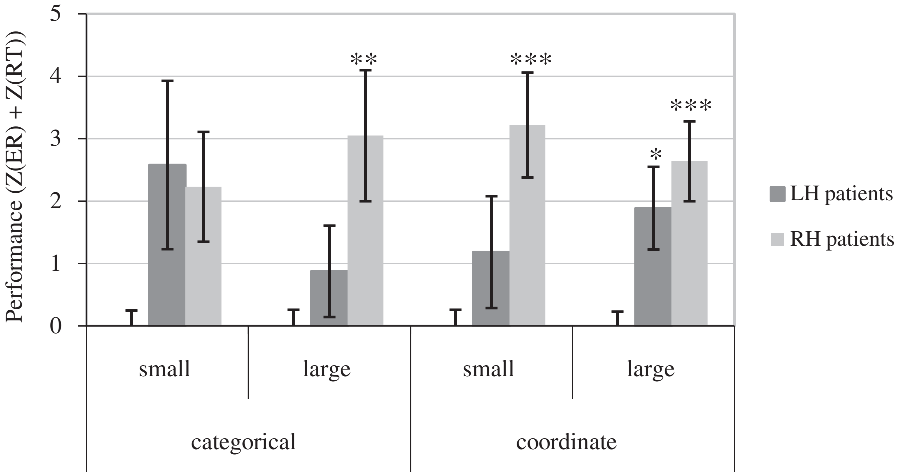

Fig. 2 – The mean performance scores for both patient groups, in all conditions. Performance reflects the combined z score of [$z^{(ER)} + z^{(RT)}$]. Higher scores indicate a lower level of performance, compared to controls. Error bars represent standard error of the mean (SEM). The error bars on the left of each condition represent the performance of healthy controls, due to the nature of the performance score, their mean performance was 0 in all conditions. $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$, compared to the control performance.

model of a LH categorical advantage and a RH coordinate advantage has been accepted, although some alternative explanations have been suggested over the years. Therefore we hypothesized a general association between LH damage and impairment in categorical relation processing and RH damage and coordinate relation processing, regardless of the amount of stimulus information.

The performance of healthy controls confirmed the hypothesis that coordinate processing is more accurate when less, unnecessary visual information is provided about category boundaries. Participants overall were more accurate, and slightly faster for the small cross condition, compared to the large cross condition. This shows that less information benefits distance estimations, as long as the vital information for the task is still present. As the task was to determine the distance between the dot and the centre of the cross, the only required visual information for the task was the dot and the centre of that cross. This finding is in agreement with literature stating that boundaries have a strong effect on the quality of distance estimations; locations on the same side of a boundary appear closer than locations on different sides of a boundary (Kosslyn et al., 1974).

For the categorical instruction, responses of the healthy controls were faster when the large cross was used, compared to the small cross. This suggests that even for a relatively simple and straightforward categorical instruction, there is some uncertainty when only part of the categorical boundaries is directly available. This confirms previous statements on spatial categorization, concerning the fuzziness of such boundaries (e.g., Hayward and Tarr, 1995; Vorwerg and Rickheit, 1998; Crawford et al., 2000). In other words, the more explicitly a category is defined, the better categorical performance will be.

The analyses of the whole dataset, including controls and patient data, showed that there was no main lateralization effect as expressed by the interaction of instruction and group. This contradicts the general view that the distinction between categorical and coordinate processing lies with a left and right hemisphere advantage, respectively. It should be mentioned here that such a clear double dissociation of instruction and hemisphere is most often found within the parietal cortex (e.g., Trojano et al., 2002; Van der Ham et al., 2009). However, the heterogeneity in lesion location in our current sample did not allow for more detailed analyses concerning lesion location (see Appendix).

Nonetheless, we did find a significant interaction of instruction, group, and cross size in the analyses of the performance score, and at trend level in the ER. Instead of a clear two-way interaction, the effects in the current sample are more subtle. Follow up tests of this three-way interaction showed that LH damage was linked to categorical performance, but only when a small cross was used, and to coordinate performance, but only when a large cross was used. RH damage was linked to performance in all conditions, except for categorical processing when a small cross was used. This indicates that although there is no clear overall effect, there is a double dissociation of categorical and coordinate processing and LH and RH performance, respectively, but only when the stimuli with a small cross were presented. This is a confirmation of Kosslyn's original proposal, and also in line with previous findings for the cross dot task with a small cross (Van der Ham et al., 2009; Van der Ham et al., 2010). Also the relative weaker impairment of the LH group for the categorical task is in line with previous findings stating that the LH involvement in categorical processing is often weaker or not present, whereas the coordinate RH involvement is clearly present (see e.g., Van der Ham and Postma, 2010).

Yet, the pattern found for the large cross stimuli was unexpected: the RH patients were impaired on both the categorical and coordinate task, whereas the LH patients were impaired on the coordinate task, but not the categorical task. Previous studies have shown that the LH has an essential role in categorical processing, but in the current case this was only noticeable when categories had to be actively reconstructed. On one hand, it could be argued that this task requires more active categorical processing, related to LH involvement, or that just a more difficult version of categorical processing will lead to the surfacing of such impairment, as suggested in Introduction. On the other hand, the large cross clearly reflects more stereotypical categories. An alternative explanation could be that the LH patients lack some form of perceptual imagery required to perform this task, that was not necessary in any of the other three tasks.

The RH group displayed an overall impaired performance, with the categorical small cross condition as the only exception. As spatial attention and spatial working memory were crucial to our experimental task, we controlled for this factor. The outcome of the backwards Corsi block tapping task was used to exclude any patients significantly impaired on this task; leading to the exclusion of two RH patients. It is uncommon to find strong RH involvement in an explicitly categorical task such as the categorical large cross task we used here. However, explanations concerning general impairments affecting spatial relation processing, e.g., purely representational neglect, cannot be used here, as there was no impairment for the categorical small cross condition. If any of the conditions would require mental representation of the figure, it would have been this condition, due to the mental elongation of the arms to fully construct the categories. A feasible alternative explanation is lacking at this point.

The impairment of LH patients in coordinate processing, in which a large cross was used was also surprising. This effect cannot be explained by a general perceptual imagery deficit. Instead, it might be that the large cross usually triggers some categorical processing that could be beneficial, but only when processed properly. In the first report on the cross dot task a LH advantage was also found for coordinate processing, with the use of a large cross (Van der Ham et al., 2007). This LH advantage only occurred when the retention interval between the two cross dot stimuli was 5 sec long, compared to 2 sec in the current task design. A verbalization strategy was originally opted to explain for this effect, but subsequent studies showed that for both categorical and coordinate a spatial strategy was clearly present (e.g., Van der Ham and Postma, 2010). The alternative of an explicitly spatial categorical approach to this coordinate task seems more viable in light of these findings taken together.

It appears that category construction, as used in the categorical – small cross condition in particular, requires specific LH processing in the absence of RH involvement. It could well be that some adjustment to Kosslyn's model (1987) is in order. Over the years, almost all studies on spatial relation processing have confirmed the RH involvement in coordinate processing, whereas the categorical LH advantage is not always found. It may be that the LH only becomes explicitly involved with stimulus properties that require active category construction.

Taken together, in our working memory cross dot task categorical judgements benefit from clear category boundaries in terms of RTs. In contrast, coordinate distance judgements are more accurate when only the necessary position information is provided to allow for the use of an internal scaling mechanism. Furthermore, the patient data suggest that the previously proposed LH bias for categorical processing and a RH bias for coordinate processing are only present for the stimuli with the least visual information. It seems a special LH involvement is only evident when a category has to be constructed, and less when it is already clearly marked in the stimuli. In contrast, some RH involvement may exist to some extent in all clear spatial categories. Future studies are needed to further investigate this dissociation between category recognition and category construction with regard to hemispheric differences.

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Appendix

Descriptives of all patients, including age, gender, level of education, Annett's handedness score, side of lesion, and specification of lesion location(s).

Patient	Age	Gender	Education	Annett	S/H	Side	Lesion
PM	65	M	4	6	S	LH	Insula, putamen, caudate nucleus, precentral g., postcentral g.
JB	78	M	5	22	S	LH	Superior, middle, and inferior temporal g.
HB	67	F	6	18	S	LH	Superior occipital g., g. descendens, cuneus, thalamus
NS	43	M	7	23	S	LH	Precentral g.
JQ	79	F	3	15	H	LH	Insula, putamen, precentral g., postcentral g., inferior parietal g., superior temporal g., supramarginal g.
MS	51	F	6	15	H	LH	Fusiform g., inferior lingual g., parahippocampal g.
JK	60	M	5	12	H	LH	Caudate nucleus, internal capsule
CW	67	F	7	20	S	LH	Insula, precentral g., postcentral g., supramarginal g.
ES	71	M	4	20	S	LH	Medial occipital medial g.
B	63	M	5	20	S	LH	Medial and inferior frontal g., precentral g., insula, superior temporal g.
HZ	46	M	7	23	S	LH	Caudate nucleus, putamen, precentral g.
S	73	M	6	24	S	LH	Insula, claustrum, external capsule, precentral g., inferior frontal g., lateral orbital g., postcentral g., superior temporal g.
MP	63	M	5	−20	S	LH	Parietal cortex
DG	50	M	7	24	H	LH	Caudate nucleus, internal capsule, putamen, corona radiata
AM	71	M	6	18	H	LH	Putamen, internal and external capsule, claustrum, corona radiata

(*continued on next page*)

(continued)

Patient	Age	Gender	Education	Annett	S/H	Side	Lesion
RV	51	M	6	19	H	LH	Parahippocampal g., lingual g., cingulate g., cuneus, precuneus
AM	60	F	5	−1	S	RH	Precentral g., medial frontal g., anterolateral thalamus, internal capsule, caudate nucleus, hippocampus, basal nucleus of amygdala, g. descendens, inferior occipital g., inferior lingual g., cuneus, optic radiation
LB	49	M	5	24	S	RH	Superior temporal g., insula, precentral g., postcentral g., caudate nucleus, putamen
MS	25	F	5	22	S	RH	Posterior and lateral orbital g., inferior and medial frontal g., insula, claustrum, caudate nucleus, putamen, thalamus
CT	61	M	5	24	S	RH	Medial temporal g., medial occipital g.
AC	36	F	6	−2	S	RH	Medial occipital g., angular g., postcentral g.
MP	47	F	4	22	S	RH	Superior and medial temporal g., insula, putamen, caudate nucleus, inferior frontal g.
MT	66	F	4	19	S	RH	Precentral g., postcentral g., supramarginal g., angular g., superior temporal g., medial frontal g., optic radiation, medial and superior occipital g., cuneus
WH	70	F	3	23	S	RH	Precentral g., postcentral g., medial and inferior frontal g., caudate nucleus, lateral orbital g.
JB	78	F	4		S	RH	Optic radiation, superior occipital g., superior parietal g., precentral g., inferior and medial frontal g., angular g.
LS	55	M	6	−22	S	RH	Posterior and lateral orbital g., insula, external capsule, claustrum, inferior frontal g., precentral g., postcentral g., superior temporal g.
RS	46	M	6	24	H	RH	Insula, putamen, precentral g., postcentral g.
JV	49	M	5	24	S	RH	Superior, medial and inferior temporal g., posterior and lateral orbital g., insula, external capsule, claustrum, putamen, caudate nucleus, internal capsule, lateral thalamus, inferior frontal g., precentral g., postcentral g., angular g., supramarginal g.
GD	77	M	5	24	S	RH	Superior temporal g., internal capsule, precentral g., inferior and medial frontal g., cingulate g., superior temporal g., angular g.
LG	67	M	5	20	H	RH	Medial and inferior temporal g., precuneus, paracentral lobule, superior parietal g., cingulate g.
HW	73	M	7	24	H	RH	Corona radiata, thalamus, internal capsule
SS	49	M	5	6	H	RH	Insula, caudate nucleus, internal and external capsule, putamen, corona radiata, thalamus, precentral g., inferior frontal pars opercularis
EL	46	M	7	22	S	RH	Corona radiata

Education level range 1–7, low to high, based on Verhage (1964). M = male, F = female, g = gyrus, S = stroke, H = haemorrhage.

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