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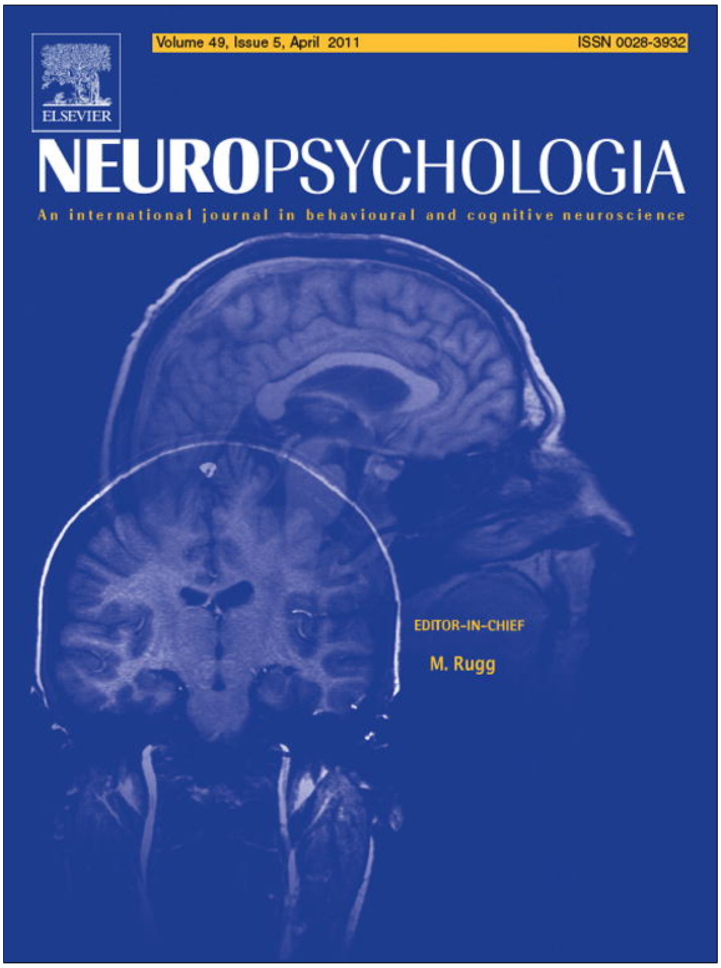

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Hemispheric differences in spatial relation processing in a scene perception task: A neuropsychological study

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ABSTRACT

Understanding a complex visual scene depends strongly on our ability to process the spatial relations between objects in that scene. Two classes of spatial relations can be distinguished. Categorical information concerns more abstract relations, like "left of", while coordinate information is metric and more precise, such as "2 cm apart". For categorical processing a left hemisphere advantage is typically found, and coordinate processing is linked to a right hemisphere advantage. However, this has scarcely been investigated in more naturalistic settings. The aim of the present study was to explore spatial relation coding in natural scenes as well as to gain more insight in hemispheric differences in processing categorical and coordinate position changes, by testing patients with unilateral stroke. By means of a comparative visual search task using images of rooms, a healthy control group ($N=28$), patients with left hemisphere stroke (LH) ($N=16$), and patients with right hemisphere stroke (RH) ($N=17$) were tested on their ability to detect position changes that were either only coordinately different (coo), or both coordinately and categorically different (coo + cat). The response pattern of the control subjects confirmed previous findings that both coordinate and categorical information contributed to position change detection. Compared to the control group, the RH patient group showed an impairment on both coo and coo + cat position changes. In contrast, the LH patient group was not impaired on the coo condition and showed only a trend of impairment on the coo + cat condition. These response patterns suggest that lateralisation patterns found in previous, more simple and controlled experiments are also present to some degree in a more complex and lifelike setting.

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1. Introduction

During scene perception only very little visual information about the scene is coded (see Henderson & Hollingworth, 1999) as is illustrated by the change blindness phenomenon, in which large differences between scenes can remain undetected (Rensink, O'Regan, & Clark, 2000). However, the mechanisms that have been proposed to underlie this finding appear to lack a clear description of the type of information that is extracted to detect changes in scenes. As an exception, Rosielle, Crabb, and Cooper (2002) investigated the process of location encoding during scene perception. Based on their results, they proposed that position coding can occur in a categorical as well as in a metric, or coordinate, fashion. These two types of encoding relate directly to Kosslyn's (1987) theory on spatial relation processing between and within objects. This theory distinguishes categorical, abstract relations like "left of", from coordinate, metric relations like "2 cm apart". It is proposed that these form two separate classes of relations which engage separate underlying mechanisms (for a review see Jager & Postma, 2003).

Rosielle et al. (2002) found that both categorical and coordinate position information is encoded during scene perception. In their change detection experiment participants viewed scenes in which the spatial position of an object was changed. This change could be categorically the same or different with regard to its nearest surroundings. In any position change the coordinate relation would change, as any change in spatial position is coordinate by definition. Therefore, a categorical change can be regarded as the addition of a categorical change of the objects' position with regard to its surroundings, to a coordinate change. Rosielle et al.'s results indicated that a coordinate change was sufficient to detect the change, and that a categorical change enhanced detection performance. This categorical advantage has also been confirmed by Dent (2009), who replicated this effect with stimuli consisting of simple configurations of four small squares.

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Within the field of spatial relation processing, the main focus is directed at the neural underpinnings of the suggested separate processing mechanisms. Along with the first description of this distinction, Kosslyn (1987) linked spatial relation processing to differences in hemispheric lateralisation. Categorical processing was thought to show a left hemisphere advantage, whereas the right hemisphere would predominate in processing coordinate information. In many behavioural (e.g. Hellige & Michimata, 1989; Laeng & Peters, 1995; van der Ham, van Wezel, Oleksiak, & Postma, 2007) and neurofunctional studies (e.g. Baciu et al., 1999; Trojano, Conson, Maffei, & Grossi, 2006; van der Ham, Raemaekers, van Wezel, Oleksiak, & Postma, 2009; van der Ham, van Strien, Oleksiak, van Wezel, & Postma, 2010), this lateralisation pattern has been found for tasks testing categorical and coordinate relation processing. Neuropsychological studies thus far have been sparse but have also found supportive evidence (e.g. Laeng, 1994; Palermo, Bureca, Matano, & Guariglia, 2008; van Asselen, Kessels, Kappelle, & Postma, 2008). Yet, to the best of our knowledge, direct evidence that these lateralisation patterns are also present in the processing of spatial relations in natural scenes is lacking. Therefore, in this study we compared patients with unilateral brain damage with respect to their abilities to detect spatial relation changes of objects situated in a daily life setting. Importantly, the outcomes could have clinical relevance by increasing the understanding of the problems these patients may experience in their personal environment.

Rosielle et al. (2002) employed the "flicker" paradigm, which entails a very fast and intermittent presentation of two scenes; one without and one with a position change. Here we have used the slightly different "comparative visual search" task (Pomplun et al., 2001). In this type of task the subject compares two scenes that are simultaneously presented. This design has several advantages over the flicker paradigm. The limited exposure duration of the flicker paradigm influences the scanning rate of the subject's eye movements and potentially also limits the functional field for information acquisition. Furthermore, the flicker paradigm may violate some of the observer's assumptions about the visual world (Galpin & Underwood, 2005; Simons, 2000). In contrast, the comparative visual search allows for the adoption of a clustering strategy (Pomplun et al., 2001), which decreases memory usage and does not hinder the subject's preferred eye movement patterns (Galpin & Underwood, 2005). We implemented the same two conditions as reported by Rosielle et al. (2002): one in which position changes were only coordinately different ("lamp left of chair" would remain "lamp left of chair", but with a different distance), and one in which position changes were different coordinately and categorically ("lamp left of chair" would change to "lamp right of chair").

Here, the lateralisation pattern was not determined based on differences between visual half fields, but between patients with lesions in the left hemisphere (LH) and patients with lesions in the right hemisphere (RH). The more traditional visual half field approach requires very brief presentation durations and consequently limited stimulus complexity. In the comparative visual search task, we could use relatively long and simultaneous presentation of realistic stimuli, which fits well within the neuropsychological setting. We hypothesized that patients with LH or with RH damage are impaired on categorical or coordinate processing, respectively. In terms of our experimental design LH patients should be able to process coordinate information correctly, but would show impairment in categorical processing, in turn leading to impaired performance on categorical change trials, but not on coordinate change trials. In contrast, RH patients were expected to be impaired in determining both types of location changes as they both include coordinate changes, but they might benefit from additional categorical information and show a categorical advantage.

2. Methods

2.1. Participants

Thirty-three patients who suffered from ischemic or haemorrhagic stroke were selected from the Stroke Database of the University Medical Center Utrecht. Inclusion criteria were: (1) age between 18 and 80 years; (2) no history of previous neurological or psychiatric disorder; (3) testing occurred 6–18 months after the onset of the stroke; (4) lesion visible on CT or MRI scan; and (5) no hemispatial neglect or hemianopia. Neurological and neuropsychological reports in hospital records were consulted to exclude patients with neglect or hemianopia. In addition, patients with aphasia were excluded. Informed consent was obtained from each patient. The control group consisted of 28 healthy subjects who were highly comparable to the two patient groups with respect to age (M = 58.3, SD = 6.5) and level of education (M = 5.4, SD = 1.0). All controls had normal or corrected to normal vision and had no history of neurological or psychiatric illness.

Level of education 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 lesions in the left hemisphere, and 17 in the right hemisphere. In Appendix A, a detailed description is given for all patients individually, including detailed lesion information. In Table 1 characteristics concerning age, gender, education, and handedness are provided for all three groups.

Table 1
The mean scores on the neuropsychological tests for all three groups. Standard deviation in parentheses. 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 short form = 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. RAVLT = Rey Auditory Verbal Learning Test, immediate = total number of words recalled, delayed = age controlled decile. Spatial preposition task = number of correctly identified pictures, range 1–16.

	Controls (N = 28)	LH patients (N = 16)	RH patients (N = 17)
Delay event – test (months)		14.0 (3.8)	13.8 (5.5)
Age	58.3 (6.5)	62.4 (11.2)	55.4 (14.3)
Gender	12 M/16 F	12 M/4 F	10 M/7 F
Education	5.4 (1.0)	5.6 (1.2)	5.2 (1.0)
Handedness (Annett)	11.6 (17.7)	16.6 (11.0)	15.9 (13.0)
NART verbal IQ	106.6 (15.8)	108.6 (16.6)	101.8 (18.2)
Raven short form	58.8 (28.1)	62.3 (28.4)	35.0 (32.7)
Letter number sequencing	48.0 (29.5)	44.3 (30.1)	38.1 (32.7)
Corsi Block-Tapping Task forward	7.7 (1.4)	7.4 (1.1)	7.8 (1.7)
Corsi Block-Tapping Task backward	7.8 (1.7)	7.7 (1.7)	6.5 (1.9)
TMT B/A	2.1 (0.8)	2.9 (1.6)*	2.1 (0.3)
RAVLT immediate recall	44.0 (10.7)	30.4 (12.8)**	39.7 (11.4)
RAVLT delayed recall	8.9 (3.5)	5.9 (4.4)*	8.4 (3.0)
Spatial preposition task	15.9 (0.3)	15.8 (0.5)	15.8 (0.6)

* $p < .05$ (compared to control scores).
** $p < .01$ (compared to control scores).

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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, Bakker, Saan, & Louman, 1991) was used as a measure of verbal intelligence. By means of the 12 item short form of the Raven Advanced Progressive Matrices (Raven, Raven, & Court, 1993) non-verbal intelligence was assessed. Visual attention and divided attention were measured with the Trail Making Test (TMT) (Reitan, 1955). The subtest Letter Number Sequencing taken from the Wechsler Adult Intelligence Scale (WAIS) (Wechsler, 1987) was used to provide an estimate of verbal working memory. The Rey Auditory Verbal Learning Test was included as a measure of verbal learning and episodic memory (Rey, 1964; Taylor, 1959). The Corsi Block-Tapping Task, both forward and backward, was used as a measure of spatial working memory (Kessels, van Zandvoort, Postma, Kappelle, & De Haan, 2000). Additionally, to test comprehension of the basic spatial prepositions above, below, left, and right, a spatial preposition test was composed. Participants were shown 16 different pictures depicting two objects against a white background, along with a sentence describing the situation, e.g. "the telephone is above the ball". Participants indicated 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, yielding a maximum score of 16 points.

2.3. Scene perception task

We composed the scene perception task to assess the participants' ability to detect changes in object positions in a virtual scene. Two identical rooms were shown simultaneously, one above the other, with only one differing feature: one object (the target object) was moved to a different position. Participants were asked to identify the moved object as soon as possible.

Thirty lifelike rooms, one for each of the 30 trials, were designed with a home interior design software package (3D huis & tuin, Transposia, Belgium). The rooms were filled with furniture and common household objects, all in full colour. Each room represented a conventional area in a home, such as a bathroom or a living room. Objects were evenly spread out over the room, controlling for potential attentional biases to a particular part of the scene (left, right, upper or lower half). For each room one object was selected as the target object; the object that occupied a different location in one of the two images. The different target objects varied both in location within the scene and in size (mean width and height = $1.1^\circ \times 0.8^\circ$ visual angle, smallest target = $0.3^\circ \times 0.3^\circ$, largest target = $2.7^\circ \times 2.0^\circ$), whereas the individual scenes were identical in size for all trials ($11.9^\circ \times 15.8^\circ$). The occlusion of target objects (e.g. by other objects blocking them) was minimised.

There were two conditions: one in which the category of the target object changed (coo + cat), and one in which the category of the object remained the same (coo). In Fig. 1 an example is given of two stimuli, one for each condition used in the experiment; in Fig. 1A the coordinate + categorical (coo + cat) stimulus is shown, in Fig. 1B a coordinate (coo) stimulus. In each stimulus the top depiction of the room was neutral (and therefore identical in the coo and coo + cat versions of that room) and the bottom depiction of the room contained the position change. A category change was defined as a change in the categorical relation between the target object and the nearest object in its surroundings, such as from "right of", into "above". When the category did not change, the relation between the target object and the nearest object would still be within the same category. Two counterbalanced versions of the task were designed; for each room both a coo + cat and a coo trial were created, to control for any potential biases. Both trial types were evenly and randomly spread over the two versions. The two versions of the task were evenly and randomly assigned to participants of all three groups. Additionally, the comparison was controlled for distance; the distance between the original and changed location was the same in the coo and coo + cat version of a stimulus. This way performance on coo trials could be easily compared to the performance on coo + cat trials. Any difference between the two was therefore attributable to the effect of the categorical difference.

Participants viewed the two versions of the room simultaneously for a maximum of 30 s. The instruction was to name the target object as soon as they had identified it. For practical reasons, in particular for some of the patients who had trouble responding by using the keyboard correctly, the experimenter would press a button as soon as an object was named and write down the response. This button press directly terminated the stimulus presentation. Afterwards, responses were labelled correct, incorrect, or absent if the participant did not complete a response within 30 s. Participants were instructed to use alternative strategies like naming features of the target object, like colour or shape, or pointing to it on the screen, if they were unable to come up with the appropriate name of the object. Only one LH patient was unable to provide a sufficiently descriptive verbal response to some trials; she supported verbal labels like "that thing here" with finger pointing to the screen.

2.4. Procedure

Participants started with all screening tests, in a fixed order. For the scene perception task, participants were tested with a laptop computer with a 15″ monitor (resolution 1024 × 768 pixels) and sat at a distance of approximately 50 cm from the screen. Two practice trials were presented, in the same manner as the experimental trials. If the instructions were clear to the participants, the 30 experimental trials were presented, in random order.

2.5. Statistical analysis

The scores of the neuropsychological screening tests were analysed by means of ANOVAs with group (controls, LH patients, RH patients) as between subject factors. Significant effects of group were followed up by Bonferroni corrected pairwise comparisons.

For the scene perception task error rates (ER) and response times (RT) were recorded for all 30 responses. The average ERs and RTs on the coo and coo + cat trials were determined for each participant. ERs seem most relevant in the current setting, but the RTs can provide valuable additional information, therefore both measures of performance are considered. First a general ANOVA was performed with task (coo, coo + cat) as a within subject factor and group (control, LH patients, RH patients) as a between subject factor. Given our straightforward hypotheses this was complemented by a direct comparison between the coo and coo + cat condition for each group of subjects, by means of a paired sample *t*-test for both ERs and RTs. In addition, a oneway ANOVA was used to directly compare the two patient groups (LH and RH patients) to the control group on both experimental conditions (coo and coo + cat), for both ERs and RTs. In addition a direct comparison between the LH and RH patient groups was implemented by means of an ANOVA.

Even though age did not significantly differ between the patient groups and the control group, age could have had a differential effect on performance. To control for this possibility, age was added as a covariate to the analyses described above. Another effect brain lesions could have, is a general processing bias towards the ipsilateral hemifield. To assess the possibility that RH patients would have a preference for stimuli presented in the right left visual field, and vice versa for LH patients, the location of the target object in the right or left visual field was also addressed. It was added, along with task and group, as a within subjects factor to an additional ANOVAs on both ERs and RTs. If there would be a general spatial bias towards one visual hemifield for either patient group, the interaction of group and target location, or the main effect of target location would have to be significant.

3. Results

3.1. Neuropsychological screening tests

In Table 1 the gender, age, level of education, and neuropsychological screening results are given for all three groups. As indicated in the table, significant main effects of group were found for the Trail Making Test, $F\,(2,55) = 3.65$, $p < .05$, and the immediate recall and delayed recall in the Rey Auditory Verbal Learning Test, $F\,(2,57) = 7.21$, $p < .01$, and $F\,(2,57) = 3.54$, $p < .05$, respectively. Follow up tests showed that in comparison with the controls the LH patient group was significantly impaired on the Trail Making Test ($p = .05$), and both immediate recall ($p < .01$) and delayed recall ($p < .05$) on the Rey Auditory Verbal Learning Test.

3.2. Scene perception task

In Fig. 2A and B the mean accuracy and response times are given for each group of participants. In Appendices A (patients) and B (controls), the individual accuracy levels and response times are provided for each subject and for both conditions. The general ANOVA including task and group, showed that there was a significant effect of task for ER, $F\,(1,58) = 7.92$, $p < .01$, indicating a better performance for coo + cat trials, compared to coo trials. Furthermore, a significant effect of groups was found for both ER, $F\,(1,58) = 6.92$, $p < .01$, and RT, $F\,(2,58) = 5.29$, $p < .01$. For both measures the RH group performed significantly worse than the controls ($p < .01$). No such difference was found for the LH group. The interaction of task and group did not reach significance for either ER, $F < 1$, or RT, $F < 1$.

The planned comparison approach first entailed a paired sample *t*-tests on the control data, which indicated that there was a significant difference between coo and coo + cat trials for ER, $t(27) = 2.67$, $p < .05$, but not for RT. The control subjects were more accurate for trials including a categorical change, compared to the coo trials, which did not include a categorical change. The LH patients did not

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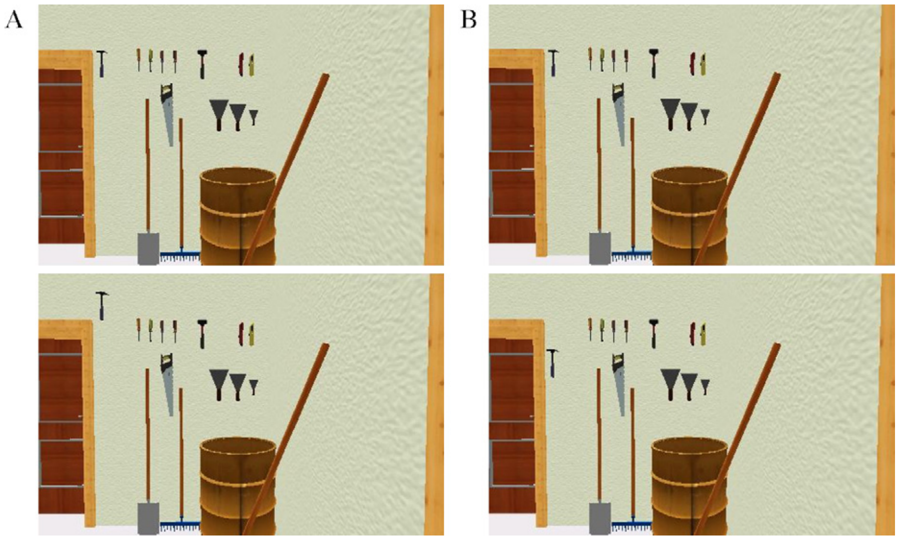

Fig. 1. One of the stimulus combinations used in the scene perception task. The hammer in the upper left corner is either moved up or down. (A) Moved up = coordinate + categorical change stimulus, (B) moved down = coordinate change stimulus.

show a difference between the two conditions for either ER or RT. For the RH patients the differences between coo and coo + cat were not statistically significant.

Furthermore, the oneway ANOVA comparing the ERs of the three groups of participants indicated a significant effect of group for both the coo, $F(2,58) = 4.09$, $p < .05$, and the coo + cat conditions, $F(2,58) = 7.16$, $p < .01$. The RH patients were impaired as compared to the control group on coo, $p < .05$, and coo + cat trials, <.01. The LH patients showed impairment at trend level on the ERs in the coo + cat condition, $p = .072$, but not in the coo condition ($p > .10$).

The oneway ANOVA on the RTs showed a significant effect of group for both the coo, $F(2,58) = 4.46$, $p < .05$, and the coo + cat conditions, $F(2,58) = 4.26$, $p < .05$. Again, the RH patients were impaired on both the coo ($p < .05$) and the coo + cat condition ($p < .05$). The RTs of the LH patients were not significantly different from the control subjects.

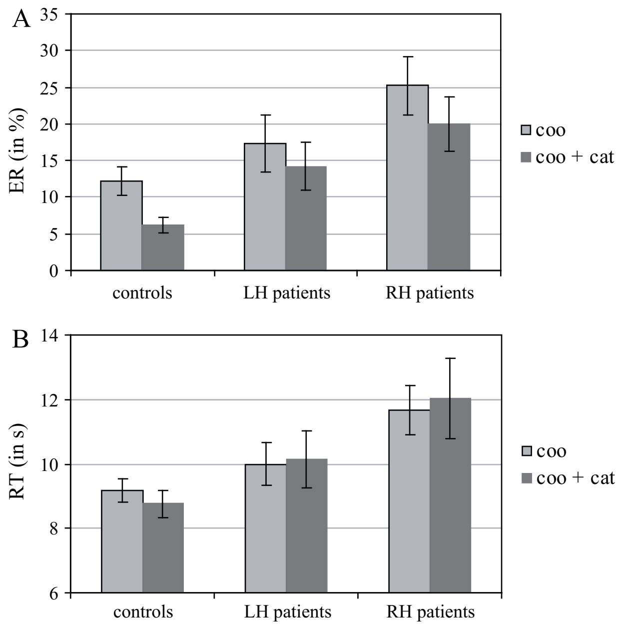

Fig. 2. Mean error rates (A) and response times (B) for controls, the LH patients, and the RH patients, for both the coordinate (coo) and coordinate + categorical (coo + cat) conditions. Error bars represent standard error of the mean (SEM).

The direct comparison of the two patient groups showed that the RH group made slightly more errors than the LH group, regardless of task, as indicated by a minor trend level effect, $F(1,31) = 3.09$, $p = .09$. There were no other significant differences when the two patient groups were directly compared.

The additional ANCOVAs with age as a covariate indicated that age did not affect the differences in performance of the groups ($p > .10$ for both ER and RT). Therefore, we can exclude age as a possible explanation for our results. Furthermore, there were no differential effects of target location (left or right) of the target objects in the two patient groups, as the interactions of target location and group were not significant for ER, $F < 1$, and RT, $F < 1$. Also, there was no main effect of target location in ER, $F < 1$, or RT < 1. Neither the LH nor the RH patient groups showed an advantage for one of the visual half fields.

4. Discussion

The main aim of the present study was to assess the lateralisation pattern of both categorical and coordinate spatial relation processing, within a realistic experimental setting. To test for such lateralisation effects, patients with left (LH group) and right hemisphere (RH group) brain damage were tested. A previous study (Rosielle et al., 2002) has shown that both coordinate and categorical spatial relation information is used in spatial location encoding. The performance of the healthy control subjects in the present study confirms these findings. By adding categorical information to the position change, fewer errors were made in detecting the location changes. This means that it is easier to detect an object's position change when the categorical location between the displaced object and its nearest surrounding object is changed. The control data revealed that both coordinate and categorical position information is used to determine location changes. Coordinate information by itself sufficed to solve the task at an above-chance level, and categorical information improved performance. Importantly, compared to the previously used flicker paradigm, we were able to find these results in a setting that allowed for unrestricted and more natural eye movement patterns (Galpin & Underwood, 2005).

As the RH patient group was impaired on both the coo and coo + cat conditions, the pattern of performance of the two patient groups provides an indication that the right hemisphere is particularly involved in location change detection. This is in agreement with the widely documented finding that the right hemisphere has

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a key role in processing coordinate spatial relation information. However, in RH patients the difference between the two conditions was not significant, indicating that the categorical advantage is not present as it is in the control subjects. Possibly, coordinate information should be processed to a sufficient degree first, in order to incorporate categorical spatial information as well. This would suggest a form of unilateral dependency between both types of processing.

Interestingly, compared to the controls, the LH patient group did not show any impairment in the coo condition, suggesting that coordinate changes can be adequately detected when the right hemisphere is intact and damage is restricted to the left hemisphere. The LH group did show a decline at trend level when categorical information was added to the position change. Furthermore, the addition of categorical information did not increase their performance. Together this suggests that the left hemisphere in particular might be involved in processing the additional categorical information given in the coo + cat condition. Combined with the performance of the RH patient group, a pattern emerges which corroborates and extends what is known from previous reports on spatial relation processing, i.e. a right hemisphere bias for coordinate processing, and a particular left hemisphere role in processing categorical relations. The strength of the lateralisation effects suggests that the coordinate right hemisphere advantage is strong and convincing, whereas the categorical advantage seems weaker (see also Jager & Postma, 2003).

Importantly, these findings indicate that it is possible to find this pattern of lateralisation not only with very simple stimuli, but also with stimuli and a task design that are more lifelike. It raises the opportunity to make inferences about spatial relation processing in a more natural setting, which is similar to the environment people perceive and interact with in daily life. It could well be that the design and lay-out of certain products, like interfaces, could be ergonomically improved based on these findings.

It should be noted that the patient groups in the current sample were heterogeneous. However, there is no statistical evidence for potential effects of age and visual field bias. Moreover, by reviewing medical records and comparing performance for the left and right visual field we cannot fully exclude the possibility of a more fine grained covert spatial bias in patients. However, if such a bias would have existed within our sample, it would have been at a relatively minor level and cannot explain the main findings reported here. Furthermore, exploratory attempts have been made to analyse data from meaningful subgroups, e.g. focusing on parietal lesions. However, we did not find any significant differences between subgroups based on lesion location, most likely due to reduction of statistical power in comparing these relatively small subgroups.

In short, the control group results have shown that both categorical and coordinate location information is encoded and used in scene perception, in particular in location change detection. The results of the two patient groups point towards a differential involvement of the right and left hemisphere in the processing of these two types of information. The right hemisphere has a general influence on change detection in the current setting, which always concerned coordinate changes. In contrast there appears to be a marginal link between the left hemisphere and the detection of categorical changes. This lateralisation pattern confirms similar findings for more simple stimuli reported in the literature.

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Appendix A. Lesion locations based on Duvernoy (1999).

Descriptives of all patients, including age, gender, level of education, Annett's handedness score (−24 to +24), side of lesion, specification of lesion location(s), and individual mean performance. Education level range 1–7, low to high, based on Verhage (1964). M = male, F = female, LH = left hemisphere, RH = right hemisphere, g = gyrus.

Patient	Age	Gender	Education	Annett	Side	Lesion	Performance scene perception			
							Accuracy (in %)		Response time (in s)	
							coo	coo + cat	coo	coo + cat
1	65	M	4	6	LH	Insula, putamen, caudate nucleus	93	93	16.8	17.1
2	78	M	5	22	LH	Temporal g.	47	60	14.0	17.2
3	67	F	6	18	LH	Occipital g., cuneus, thalamus	53	79	11.8	14.1
4	43	M	7	23	LH	Precentral g.	100	100	6.7	5.6
5	79	F	3	15	LH	Insula, putamen, precentral g., postcentral g., inferior parietal g., superior temporal g. supramarginal g.	73	87	10.2	11.2
6	51	F	6	15	LH	Fusiform g., inferior lingual g., parahippocampal g.	93	100	7.2	7.1
7	60	M	5	12	LH	Caudate nucleus, internal capsule	73	80	11.7	8.5
8	67	F	7	20	LH	Insula, precentral g., postcentral g., supramarginal g.	93	80	9.9	7.9
9	71	M	4	20	LH	Occipital medial g.	73	53	11.1	13.1
10	63	M	5	20	LH	Medial frontal g., pars triangularis, pars opercularis, pars orbitalis, precentral g., insula, superior temporal g.	67	93	8.1	9.3
11	46	M	7	23	LH	Caudate nucleus, putamen, precentral g.		100	8.0	5.9
12	73	M	6	24	LH	Insula, claustrum, external capsule, precentral g., pars opercularis, pars orbitalis, lateral orbitofrontal g., postcentral g., superior temporal g.	87	80	10.7	12.8
13	63	M	5	−20	LH	Parietal cortex	87	93	8.4	9.1
14	50	M	7	24	LH	Caudate nucleus, internal capsule, putamen, corona radiata	93	80	7.5	10.2
15	71	M	6	18	LH	Putamen, internal and external capsule, claustrum, corona radiata	100	87	10.3	7.9
16	51	M	6	19	LH	Parahippocampal g., lingual g., cingulate g., cuneus, precuneus	93	100	6.7	6.3
17	60	F	5	−1	RH	Precentral g., medial frontal g., anterolateral thalamus, internal capsule, pars retrolentiformis, caudate nucleus caudatus, hippocampus, basal nuclei amygdala, g. descendens, inferior occipital g., inferior lingual g., cuneus, optic radiation	80	60	16.4	27.4
18	49	M	5	24	RH	Superior temporal g., insula, precentral g., postcentral g., caudate nucleus, putamen	73	93	13.9	16.7
19	25	F	5	22	RH	Orbitoposterior g., orbital g., inferior frontal g., insula, claustrum, caudate nucleus, putamen, medial frontal g.	93	80	12.7	10.5
20	61	M	5	24	RH	Medial temporal g., medial occipital g.	67	60	12.6	17.1
21	36	F	6	−2	RH	Medial occipital g., angular g., postcentral g.	100	100	9.7	8.1
22	47	F	4	22	RH	Superior temporal g., insula, putamen, caudate nucleus, medial temporal g., inferior frontal g.	80	80	6.7	10.6
23	66	F	4	19	RH	Precentral g., postcentral g., supramarginal g, angular g., superior temporal g., medial frontal g., optic radiation, medial and superior occipital g., cuneus	47	60	12.4	9.1
24	78	F	4		RH	Optic radiation, superior occipital g., superior parietal g., precentral g., inferior and medial frontal g., angular g.	73	93	11.5	16.7
25	55	M	6	−22	RH	Posterior and lateral orbital g., insula, external capsule, claustrum, inferior frontal g., pars orbitalis, pars opercularis, pars triangularis, precentral and postcentral g., superior temporal g.	80	87	8.8	6.8
26	46	M	6	24	RH	Insula, putamen, precentral g., postcentral g.	93	100	8.0	7.8
27	49	M	5	24	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., pars orbitalis, pars opercularis, pars triangularis, precentral and postcentral g., angular g., supramarginal g.	53	47	15.9	12.6
28	58	F	4	24	RH	Superior temporal g., internal capsule, transverse temporal g., posterior angular g.	73	80	11.7	10.1
29	77	M	5	24	RH	Superior temporal g., internal capsule, inferior frontal pars opercularis, precentral g., inferior and medial frontal g., cingulate g., superior temporal g.	33	73	14.2	17.0
30	67	M	5	20	RH	Medial and inferior temporal g., precuneus, paracentral lobule, superior parietal g., cingulate g.	93	100	6.1	7.9
31	73	M	7	24	RH	Coronaradiata, thalamus, internal capsule	80	87	12.3	10.7
32	49	M	5	6	RH	Insula, caudate nucleus, internal and external capsule, putamen, corona radiata, thalamus, precentral g., inferior frontal pars opercularis	73	80	15.8	12.3
33	46	M	7	22	RH	Corona radiata	87	93	7.4	4.8
							80	60	16.4	27.4

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Descriptives of all control subjects, including age, gender, level of education, Annett's handedness score (−24 to +24), and individual mean performance. Education level range 1–7, low to high, based on Verhage (1964). M = male, F = female.

Age	Gender	Education	Annett	Accuracy (in %)		Response time (in s)	
				coo	coo + cat	coo	coo + cat
47	F	3	−17	73	87	8.8	14.0
60	F	5	21	80	93	11.1	11.9
47	M	4	−13	87	87	6.8	7.9
49	F	6	24	100	100	8.9	8.1
62	M	6	24	73	100	10.6	9.9
56	M	6	−24	100	93	8.3	7.6
62	F	5	−20	93	87	13.2	7.8
58	F	6	24	93	100	9.6	9.1
58	M	6	20	93	87	7.1	5.7
67	M	5	23	93	93	9.9	7.9
65	F	4	20	87	93	9.9	12.3
64	M	6	24	100	93	8.0	9.4
61	M	4	24	73	80	8.2	10.0
49	F	7	24	100	93	5.8	5.6
63	F	6	14	73	93	6.5	11.7
57	F	6	24	100	93	12.1	7.4
61	F	5	24	80	100	9.0	7.7
48	F	5	22	87	100	8.8	8.6
57	M	5	24	73	100	11.7	10.9
68	M	5	−20	67	93	8.9	11.5
49	F	7	13	93	100	8.6	6.7
64	F	5	24	87	100	8.6	6.4
63	M	5	−20	87	93	12.3	7.0
61	M	6	24	93	93	5.8	5.0
65	F	7	−10	100	87	10.0	9.4
60	M	5	20	93	93	7.5	9.9
49	F	5	20	100	93	9.7	8.5
62	F	5	12	80	100	11.0	7.2

Appendix B. Control subjects.

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