Journal of Cognitive Psychology
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/pecp21

The nature of categorical and coordinate spatial relation processing: An interference study

Ineke J. M. van der Ham [a] & Gregoire Borst [b]

[a] Experimental Psychology, Helmholtz Institute, Utrecht University, Utrecht, The Netherlands

[b] Department of Psychology, Harvard University, Cambridge, MA, USA

Available online: 06 Oct 2011

To cite this article: Ineke J. M. van der Ham & Gregoire Borst (2011): The nature of categorical and coordinate spatial relation processing: An interference study, Journal of Cognitive Psychology, DOI:10.1080/20445911.2011.586780

To link to this article: http://dx.doi.org/10.1080/20445911.2011.586780

JOURNAL OF COGNITIVE PSYCHOLOGY, 2011, iFirst, 1–9

Psychology Press
Taylor & Francis Group

The nature of categorical and coordinate spatial relation processing: An interference study

Ineke J. M. van der Ham[1] and Gregoire Borst[2]

[1]Experimental Psychology, Helmholtz Institute, Utrecht University, Utrecht, The Netherlands
[2]Department of Psychology, Harvard University, Cambridge, MA, USA

Spatial relation information can be encoded in two different ways: categorically, which is abstract, and coordinately, which is metric. Although categorical and coordinate spatial relation processing is commonly conceived as relying on spatial representations and spatial cognitive processes, some suggest that representations and cognitive processes involved in categorical spatial relation processing can be verbal as well as spatial. We assessed the extent to which categorical and coordinate spatial relation processing engages verbal and spatial representations and processes using a dual-task paradigm. Participants performed the classical dot-bar paradigm and simultaneously performed either a spatial tapping task, or an articulatory suppression task. When participants were requested to tap blocks in a given pattern (spatial tapping), their performance decreased in both the categorical and coordinate tasks compared to a control condition without interference. In contrast, articulatory suppression did not affect performance in either spatial relation task. A follow-up experiment indicated that this outcome could not be attributed to different levels of difficulty of the two interference tasks. These results provide strong evidence that both coordinate and categorical spatial relation processing relies mainly on spatial mechanisms. These findings have implications for theories on why categorical and coordinate spatial relations processing are lateralised in the brain.

Keywords: Categorical and coordinate spatial relations; Spatial cognition; Verbal and spatial interference.

In many different types of interactions with our surroundings, like grasping, navigating, and memorising objects locations, we make use of spatial relations between objects and between objects and ourselves. Kosslyn (1987) has proposed a distinction between the representations of categorical and coordinate spatial relations. Categorical spatial relations concern relations expressed in abstract, propositional terms, like ‘‘above’’ or ‘‘to the left of’’. In contrast, coordinate relations are more precise in nature and entail the exact distances between and within objects in terms like ‘‘two metres apart’’ or ‘‘three inches away’’. In this theory Kosslyn hypothesised that categorical and coordinate relations are processed by at least partially different cognitive processes localised in different parts of the brain. An increasing amount of evidence supports this hypothesis; studies often report a left hemisphere advantage for categorical processing, and a right hemisphere advantage for coordinate processing (see, e.g., Hellige & Michimata, 1989; Rybash & Hoyer, 1992).

Correspondence should be addressed to Ineke J. M. van der Ham, Heidelberglaan 2, 3584 CS Utrecht, The Netherlands. Email: c.j.m.vanderham@uu.nl

This research was supported by the Netherlands Organisation for Scientific Research (NWO), under Grant Evolution and Behaviour: 051-14-027 and the National Institute of Health (NIH), under Grant R01 MH060734; any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of NIH. The authors would like to thank Stephen M. Kosslyn for helpful discussion and his advice regarding the design of the experiment.

http://www.psypress.com/ecp http://dx.doi.org/10.1080/20445911.2011.586780

Theories on the origin of these differences in lateralisation have developed over time. Kosslyn (1987) originally proposed an evolutionary explanation in terms of the preexisting qualities of the two hemispheres. According to this view, categorical spatial relations are computed in the left hemisphere because of its role in language processes and linguistic category-formation, whereas coordinate spatial relations are computed in the right hemisphere because of its role in navigation. Ivry and Robertson (1998) and Jacobs and Kosslyn (1994) later suggest that low-level perceptive biases could be at the root of the hemispheric lateralisation of categorical and coordinate spatial relations processing. They propose that each hemisphere preferentially responds to a different set of spatial frequencies or receives output of population of neurons with different receptive field sizes. Hemispheric asymmetries have been documented for spatial frequency processing (e.g., Christman, 1997) and for neuronal receptive field sizes (e.g., Borst & Kosslyn, 2010; Jacobs & Kosslyn, 1994; Kosslyn, Chabris, Marsolek, & Koenig, 1992). However, these hemispheric asymmetries might reflect attentional biases, but not hard-wired anatomical differences (e.g., Laeng, Chabris, & Kosslyn, 2003; Smith, Singh, Williams, & Greenlee, 2001). In fact, the reverse effect has been found as Kosslyn, Anderson, Hillger, and Hamilton (1994) provided evidence that attention can override such hemispheric biases (i.e., spatial frequencies and size of the receptive fields).

Yet, a different recent explanation of the hemispheric lateralisation of spatial relations stresses the role of verbal processing in categorical spatial processing. For example, van der Ham, Van Wezel, Oleksiak, & Postma (2007) showed that participants tend to rely on a verbal strategy to perform a working memory task with a categorical instruction and on a spatial strategy to perform the same working memory task with a coordinate instruction. In addition, brain lesion studies suggest that linguistic and perceptual representations of categorical spatial relations are to some extent dissociable leading some to propose a trichotomy of spatial relations processing into perceptual coordinate processing, perceptual categorical processing, and verbal categorical processing. Kemmerer and Tranel (2000) reported a double dissociation based on two patients, one with left and one with right hemisphere damage, showing isolated impairment in the use of spatial English prepositions and visuospatial processing of categorical relations, respectively. In a follow-up study, Tranel and Kemmerer (2004) reported a similar relationship between left hemisphere damage and a specific impairment in the comprehension of English spatial prepositions, while the ability to process visuospatial relations remained intact. The results of these studies indicate that coordinate and perceptual categorical relations are processed in the right hemisphere, whereas verbal categorical relations are processed in the left hemisphere. As noted by Kemmerer (2006), these results should be interpreted with caution given that none of the tests performed could distinguish specific impairments in coordinate versus categorical spatial relation processing. In contrast, Laeng (1994) found that patients with left hemisphere lesions showed specific impairment in categorical spatial relation processing, but this impairment was not affected by scores on aphasia tests.

Finally, van der Ham and Postma (2010) recently compared verbal and visuospatial categorical relation processing in healthy subjects. They demonstrated that there is no strong divide of verbal and spatial categorical relations, but that the verbal and perceptual properties of the stimuli can affect the strength of lateralisation. The direction of lateralisation only shifted from a left to a right hemisphere advantage when coordinate information was most likely used to solve the categorical task.

In the two experiments reported here, we studied the verbal and spatial characteristics of the processing involved in both categorical and coordinate spatial relation tasks to determine whether participants spontaneously encode them verbally or visuospatially. In order to determine the nature of the representations processed in the spatial relations tasks, we used a dual-task paradigm. Participants performed the classical dot-bar paradigm in its categorical and coordinate version. Concurrently, participants performed either a verbal interference task (articulatory suppression), or a spatial interference task (spatial tapping). These two interference tasks have shown to interfere specifically with verbal processing (e.g., Hitch, Woodin, & Baker, 1989) and spatial processing (e.g., Salway & Logie, 1995), respectively, in working memory. Therefore, the effect of the interference tasks on participants' performance in spatial relations tasks (as compared to their performance in a control condition with no interference), will indicate the type of cognitive processing that is involved in performing the two types of spatial relation tasks.

If spatial relation processing is truly spatial in nature, regardless of type of relation (categorical vs. coordinate), we expect an interference effect of spatial tapping on participants' performance on both spatial relation tasks. On the other hand, if categorical spatial relations are encoded verbally and coordinate spatial relations are encoded spatially, then we expect a double dissociation between the type of spatial relations processing and the type of interference: participants' performance should be affected by articulatory suppression and not spatial tapping in the categorical task, whereas the reverse pattern of interference should be observed in the coordinate task.

EXPERIMENT 1

Method

Participants. Sixteen Harvard students and Cambridge community members volunteered to take part in the study for pay or course credit. The sample consisted of five males and 11 females with a mean age of 24.1 years ($SD = 4.1$). All participants were right-handed according to the Edinburgh Handedness Inventory (Oldfield, 1971) with a mean score of 68.0 ($SD = 22.8$, range 38–100). All participants had normal or corrected-to-normal vision and provided written consent. Participants were tested in accordance with national and international norms governing the use of human research participants. The research was approved by the Harvard University Institutional Review Board.

Materials and procedure. Stimuli were presented on a 17-inch IBM monitor (1280×1024 pixels resolution and refresh rate of 75 Hz). The spatial relation processing tasks were adapted from the dot-bar task designed by Hellige and Michimata (1989). A horizontal bar was presented along with a single dot on the vertical axis of the bar, at one of 20 possible positions above and below the bar. The bar was 110×10 pixels in size. The dot's diameter was 10 pixels and could appear at one of 10 distances away from the bar. The distances ranged from 10 to 105 pixels, with 10 pixel intervals, and an additional five pixels difference between the fifth and sixth distance away from the bar, as this was the 0.5 inch cutoff point for the coordinate decision. The categorical and coordinate tasks were presented separately, each with their own set of instructions. In the categorical task, participants were asked to decide whether the dot appeared above or below the bar. In the coordinate task, participants indicated whether the dot appeared within 0.5 inch away from the bar. Participants responded by pressing one of two keys on a regular keyboard with the index and middle finger of their dominant right hand.

In each task, participants performed 192 trials per task divided up into four blocks of 48 trials. Before each task, participants performed 24 practice trials. The order of the two tasks was counterbalanced across participants. In each block of trials, participants performed two-thirds of the trials with a concurrent interference task (one-third with spatial tapping [ST] and one-third with articulatory suppression [AS]) and one-third with no concurrent task (control condition). The sequence of a single trial consisted of the presentation of a word indicating the type of concurrent task to perform (1000 ms, "nothing", "speak", or "tap"), a central fixation cross (1000 ms), the presentation of one of the dot-bar stimuli in the centre of the screen (150 ms), and a blank screen during which participants provided their response (maximum 2000 ms). In the AS task participants repeated the syllables "bi-be-ba-bo-bu" aloud throughout the trial. In the ST task, participants tapped an eight shaped figure with their nondominant hand on six small wooden blocks arranged in a 2×3 configuration. Highly similar types of articulatory suppression and spatial tapping have been successfully applied to affect verbal and spatial processing, respectively (e.g., Garden, Cornoldi, & Logie, 2002; Noordzij, van der Lubbe, Neggers, & Postma, 2004; Rusted, Eaton-Williams, & Warburton, 1991). Participants were instructed to start the interference task when the condition cue ("speak" or "tap") appeared on the screen and repeat the sequence until they had provided a response to the dot-bar stimulus. Participants were asked to repeat two syllables or to tap two blocks per second. The experimenter trained the participants on the interference tasks by having them practice until they were performing correctly at the right speed (checked with a stopwatch). During the task itself, the experimenter monitored interference speed and indicated when participants should increase or decrease their speed, if necessary.

Results

First, we analysed error rates (ERs) and response times from correct answers (RTs) in the 2 types of task (categorical vs. coordinate) $\times$ 3 interference conditions (control, ST, and AS) with within-subjects analyses of variance (ANOVAs). Then, using paired-sample *t*-tests (Bonferroni corrected $\alpha = .0125$), we compared ERs and RTs in AS and ST to the control condition, for both the categorical and coordinate tasks separately. Figure 1A and B present the mean ERs and RTs, respectively, for each of the three interference conditions in both spatial relation tasks.

Error rates. ANOVA on the ERs revealed a significant main effect of the type of spatial relation task, $F(1, 15) = 8.41$, $p < .05$, $\eta^2_p = .36$, and of the interference condition, $F(2, 14) = 7.47$, $p < .01$, $\eta^2_p = .33$, as well as a significant interaction between the two factors, $F(2, 14) = 5.52$, $p < .05$, $\eta^2_p = .27$. In addition, the paired sample *t*-tests for ERs revealed that in the categorical task, participants were equally accurate in the two interference conditions (AS and ST) as compared to the control condition, $t(15) = 1.94$, $p = .07$, and $t(15) = 1.09$, $p = .29$, respectively. In the coordinate task, participants made more errors in ST than in the control condition, $t(15) = 4.95$, $p < .001$, $d = .75$. In addition, we found no difference on the ERs between the control and the AS condition, $t < 1$.

Reaction times. ANOVAs on RTs revealed a significant main effect of the type of task, $F(1, 15) = 9.20$, $p < .01$, $\eta^2_p = .38$, and a main effect of the interference conditions, $F(2, 14) = 35.96$, $p < .001$, $\eta^2_p = .71$. Additionally, the interaction between the type of task and the interference conditions was significant, $F(2, 14) = 8.96$, $p < .01$, $\eta^2_p = .37$. The paired sample *t*-tests in the categorical task indicated significantly longer RTs in the ST condition compared to the control condition, $t(15) = 5.33$, $p < .001$, $d = .91$, and no difference between AS and the control condition, $t < 1$. In the coordinate task, participants were slower in the ST condition compared to the control condition, $t(15) = 4.70$, $p < .001$, $d = .75$, whereas they were faster for AS, compared to the control condition, $t(15) = 3.10$, $p < .01$, $d = .39$.

Finally, RTs and ERs within each interference condition of each task did not correlate, all *r*s $< .32$,

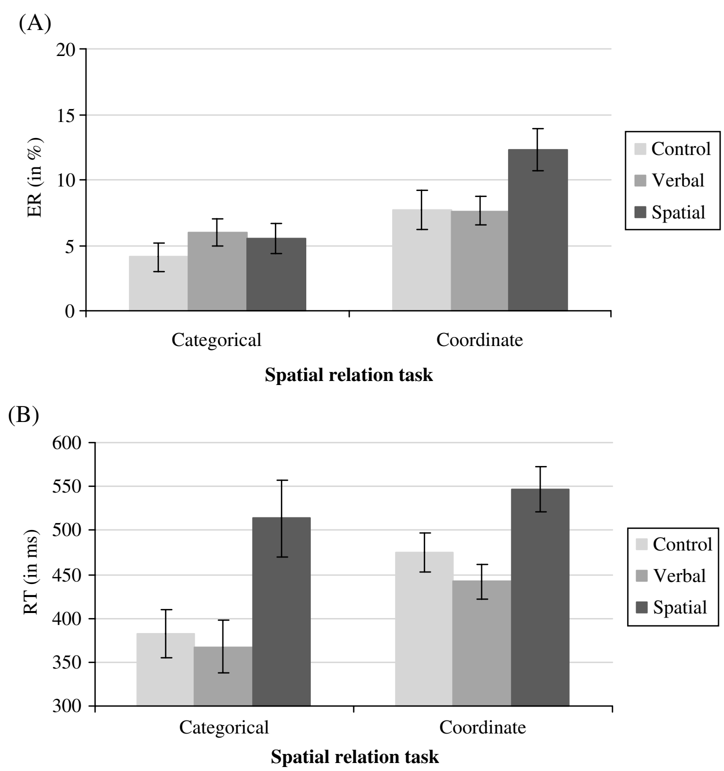

Figure 1. The mean (A) error rates and (B) response times in the control, verbal interference, and spatial interference conditions for both the categorical and coordinate tasks. Error bars denote standard error of the mean (SEM).

*p*s > .22. Thus, the effects found here cannot be attributed to a speed–accuracy tradeoff.

Discussion

The outcome of Experiment 1 showed that spatial tapping interferes with both coordinate and categorical processing, indicating a spatial nature to both types of spatial relation processing. However, the design of the interference tasks could have affected performance on the primary tasks because of other properties, such as the difficulty of ST relative to AS. To reduce the possibility that such a difference in difficulty affected our results, we conducted an additional experiment.

EXPERIMENT 2

One could argue that differences observed in the effects of the two interferences tasks (AS and ST) in Experiment 1 do not reflect the nature of the cognitive processes involved in the primary task (i.e., spatial relations tasks) but a difference in difficulty of the two interference tasks. If so, then the effect of ST on the spatial relation processing tasks does not demonstrate spatial processing but it shows that ST results in a greater attentional load than AS. In order to address this alternative explanation, we modified the AS and the ST tasks by matching them in number of items to pronounce or tap, respectively. This is a commonly used approach to create comparable conditions (e.g., Noordzij et al., 2004). Furthermore, we used a nonsequential order for both types of interference to increase similarity. Participants were instructed to repeat a randomly selected series of four digits in the AS condition or to tap sequences of four, instead of six, blocks in the ST condition, which matched the number of digits to repeat in the AS condition. In addition, in the AS condition, we asked participants to tap a single block (i.e., nonspatial tapping [NT]) at the same rate as they tapped the four blocks in the ST condition. This allowed us to equate the amount of motor interference in the ST and the AS conditions. This could be of particular importance in the current experiment as tapping, a manipulospatial task, has been argued to be mainly controlled by the right hemisphere (LeDoux, Wilson, & Gazzaniga, 1977).

Finally, to determine whether AS or ST produced any interference on top of motor interference, participants performed the two spatial relation processing tasks in an NT condition. The NT condition served as our baseline and the interference effect of the AS and the ST were directly compared to the interference effect in the NT condition. In addition, the NT condition could assess whether the ST effect on coordinate processing could be explained by the motor activity involved. To limit possible carryover effects we tested three groups of participants in a between-subjects design.

Method

Participants. Twelve right-handed participants (five males, mean age = 25.3, *SD* = 3.2), 12 right-handed participants (four males, mean age = 25.3, *SD* = 4.2), and 14 right-handed participants (seven males, mean age = 22.3, *SD* = 2.8) performed the two spatial relations tasks in the AS, ST, and NT conditions, respectively. Participants in the AS and the ST conditions were students or employees at Utrecht University, The Netherlands; participants in the NT condition were Harvard students and Cambridge community members. All participants had normal or corrected-to-normal vision and were tested in accordance with national and international norms governing the use of human research participants. The research was approved by the Utrecht University and the Harvard University Institutional Review Board.

Materials and procedure. The task design for this experiment was highly similar to the one in Experiment 1. Each participant performed the categorical and the coordinate tasks in two conditions: control and interference. In each condition, four blocks of 32 trials were presented, preceded by 18 practice trials. The trial sequence was identical to the sequence in Experiment 1. In the AS condition, participants were asked to repeat out loud the sequence of digits: “2-5-9-3”. This sequence was selected randomly and kept identical for all participants. Participants were instructed to tap on a single block with the index finger of their nondominant hand each time they said a digit. In the ST condition, participants were asked to tap four wooden blocks in an hourglass figure. In the NT condition, participants were instructed to tap a single block, with no spatial configuration. In each condition, the order of the categorical and coordinate tasks was counterbalanced between participants.

Results

Given that the three groups of participants were selected from different populations error rates and response times were analysed within separate 2 (categorical vs. coordinate spatial relations tasks) × 2 (control vs. interference conditions) ANOVAs—one for each interference condition (AS, NT, and ST). In Table 1 all mean error rates and response times are given for all three interference conditions.

Error rates. In the AS condition, the two-way repeated ANOVA revealed a significant main effect of task, $F(1, 11) = 14.63$, $p < .01$, $\eta_p^2 = .57$, a marginal effect of interference, $F(1, 11) = 4.37$, $p = .06$, and no interaction between the two factors, $F(1, 11) = 1.39$, $p = .26$. Fewer errors were made for the categorical task, compared to the coordinate task. In the NT condition, a significant main effect of task was found as well, $F(1, 13) = 15.53$, $p < .01$, $\eta_p^2 = .54$, but the effect of interference was marginal, $F(1, 13) = 4.16$, $p = .06$, and the interaction was not significant, $F(1, 13) = 2.98$, $p = .11$. Again, fewer errors were made for the categorical condition and the control condition. Finally, in the ST condition, participants also made fewer errors in the categorical task than in the coordinate task, $F(1, 11) = 15.42$, $p < .01$, $\eta_p^2 = .58$, but error rates were similar in the two interference conditions, $F(1, 11) = 1.48$, $p = .25$, and the two way interaction was not significant, $F < 1$.

Response times. In the AS condition, we found a main effect of task, $F(1, 11) = 5.87$, $p < .05$, $\eta_p^2 = .35$, but no effect of interference, $F(1, 11) = 1.39$, $p = .26$, and no interaction, $F(1, 11) = 3.25$, $p = .10$, with faster RTs for the categorical condition. The ANOVA for NT revealed a significant main effect of task, $F(1, 13) = 9.86$, $p < .01$, $\eta_p^2 = .43$, a marginal effect of interference, $F(1, 13) = 4.05$, $p = .07$, and no interaction, $F(1, 13) = 1.51$, $p = .24$. Last, in the ST condition, the same main effect of task was found, $F(1, 11) = 8.17$, $p < .05$, $\eta_p^2 = .43$. In addition the main effect of interference was significant, $F(1, 11) = 15.90$, $p < .01$, $\eta_p^2 = .59$, but not the interaction between the two factors, $F < 1$.

Finally, we computed Bravais-Pearson correlations between RTs and ERs within each interference condition of each task to determine whether the interference effects reported on RTs could reflect a speed–accuracy tradeoff. We found no hint of significant correlations (all rs $< -.33$, ps $> .10$).

Discussion

Experiment 2 allowed us to reduce the possibility that differences in difficulty between AS and ST were present obscuring the observation of verbal and spatial interference. In the improved versions of AS and ST, both categorical and coordinate spatial processing were shown to be mostly spatial in nature, as in Experiment 1. Only ST showed an overall interference effect, regardless of the task at hand, whereas no significant interference was found for AS or NT. None of the interference tasks interacted significantly with task, suggesting that categorical and coordinate processing are not dissociable based on the nature of processing (verbal vs. spatial) involved. Furthermore, because ST affected performance, whereas NT did

TABLE 1
All mean error rates (ER) and response times (RT) for all three parts of Experiment 2

	ER				*RT*			
	cat		*coo*		*cat*		*coo*	
	C	*I*	*C*	*I*	*C*	*I*	*C*	*I*
AS	4.3 (3.1)	5.6 (4.6)	10.5 (6.0)	13.8 (7.8)	314 (146)	358 (150)	439 (114)	432 (120)
ST	2.7 (2.8)	4.8 (2.7)	9.1 (6.0)	9.8 (5.5)	343 (118)	415 (137)	465 (120)	517 (118)
NT	3.2 (3.2)	4.1 (6.2)	10.4 (10.5)	13.4 (12.2)	321 (117)	384 (180)	412 (111)	440 (150)

Standard deviation in parentheses. C = control condition, I = interference condition, specified by: AS = articulatory suppression, ST = spatial tapping, NT = nonspatial tapping.

not, the effect of ST cannot be solely addressed to its motor component. The spatial component of ST seems to be the crucial factor affecting performance on both the categorical and coordinate task.

GENERAL DISCUSSION

In this study we followed up on the debate in the literature on the nature of spatial relation processing. Most studies agree on the explicit spatial nature of categorical and coordinate relation processing, whereas some have stressed the distinction of verbal and spatial characteristics, with regard to categorical relations in particular (see Kemmerer, 2006), and more generally in strategy use (e.g., van der Ham et al., 2007). To identify the nature of the underlying cognitive processes involved in the two types of spatial relation processing (i.e., categorical and coordinate), we studied the effects of a concurrent spatial or verbal interference task on participants' performance in a categorical and a coordinate spatial task.

In Experiment 1, participants were slower and less accurate in the coordinate task when they performed a concurrent spatial tapping task compared to their performance in a control condition (with no concurrent task). In the categorical task, response times were affected by concurrent spatial tapping. This is further confirmed by the increase in response times for both categorical and coordinate spatial relation processing tasks when a simpler pattern of spatial tapping was performed (Experiment 2). It should be noted that spatial tapping primarily affected the time taken to make a judgement in the spatial relation task. Previous studies have demonstrated that although interference effects can occur in either ERs or RTs, they reflect similar impairments of underlying cognitive processes (e.g., Garden et al., 2002; Noordzij et al., 2004). In addition, it is reasonable to study the nature of spatial relation processing using RTs, given that hemispheric lateralisation of spatial relation processing tasks has more frequently been reported for RTs than for ERs. Also, categorical judgements commonly show ceiling effects in ERs, due to low task difficulty. Finally, the effects of spatial tapping or the lack of effect of the two other interference tasks cannot be attributed to a speed–accuracy tradeoff.

Crucially, articulatory suppression performed concurrently with both the categorical and coordinate task did not produce interference in Experiment 1. Strikingly, in the coordinate task, participants were even faster to make their judgement with concurrent articulatory suppression than with no concurrent task. A possible explanation for this facilitation effect might be that by preventing phonological coding through articulatory suppression, the likelihood of visuospatial coding of the dot-bar stimuli was increased (Hitch et al., 1989), which fits best with the type of judgement participants have to make in the coordinate task.

When articulatory suppression was made more difficult and combined with nonspatial tapping (Experiment 2), performance was not affected. This suggests that neither categorical nor coordinate spatial relation processing relies substantially on verbal coding. Thus, as opposed to Kemmerer's hypothesis (2006), the left hemisphere advantage for categorical spatial relation processing does not seem to arise because these processes are verbal.

As there is no effect of AS in any of the tasks, it could be argued that this might be because the task does not provide a sufficiently large attentional load. However, in our attempt to make our two interference conditions AS and ST more comparable in Experiment 2, we have consulted previous studies and matched the two conditions based on number of items and the use of an identical, random sequence throughout all trials. Therefore, the AS as we used it is commonly applied and the fact that it did not affect either categorical or coordinate processing is in line with a clear spatial nature of processing as argued in Kosslyn's original proposal (1987).

It should be noted that we have used a dual-task approach that is generally used in working memory literature but less commonly in spatial vision studies. However, the short presentation of the stimuli (150 ms) in our tasks forced participants to maintain the representation in short-term memory in order to process spatial relations. Thus, we wish to argue that spatial tapping interfered with categorical and coordinate spatial relation processing because in both tasks, spatial relations were processed within spatial short-term memory. Conversely, the lack of effect of articulatory suppression on both coordinate and categorical spatial relation tasks revealed that spatial relations were not processed within the phonological loop. The lack of an effect of articulatory suppression should not be taken as simply reflecting a null result given that ability to perform two concurrent tasks is very limited even in simple perceptual situations (see Pashler, 1994). However, we note that interference in such ''immediate spatial memory'' tasks has been linked to the amount of active spatial attention involved (Smyth & Scholey, 1994). Thus, spatial interference effects could reflect an increase in active use of spatial attention.

Taken together our data support the notion that spatial relation processing relies predominantly on spatial processing, or the use of spatial attention. Participants clearly rely on spatial processing even in the categorical task in which participants could easily encode the position of the dots verbally. Therefore, the left hemisphere advantage for categorical spatial relation processing when basic visual stimuli are used (like the ones in the dot-bar task) cannot be attributed solely to a linguistic coding of categorical spatial relations. This contradicts some of the findings based on brain lesion studies (see Kemmerer, 2006). Instead, it seems more likely that the two hemispheres are biased to process coordinate or categorical spatial relations because the two hemispheres operate most efficiently on outputs from units with large or small receptive fields, respectively (see Borst & Kosslyn, 2010). Importantly, our findings do not imply that spatial relations cannot be encoded and processed verbally. Our data support the view that although a verbal approach can be used to process categorical information, spatial processes are more dominant. As shown by van der Ham and Postma (2010) and van der Ham et al. (2007), verbal processes can be used, but are not required for successful performance.

Original manuscript received February 2010
Revised manuscript received February 2011
First published online October 2011

REFERENCES

Borst, G., & Kosslyn, S. M. (2010). Varying the scope of attention alters the encoding of categorical and coordinate spatial relation. *Neuropsychologia*, *48*, 2769–2772.

Christman, S. (Ed.). (1997). *Cerebral asymmetries in sensory and perceptual processing*. Amsterdam, The Netherlands: Elsevier Science.

Garden, S., Cornoldi, C., & Logie, R. H. (2002). Visuospatial working memory in navigation. *Applied Cognitive Psychology*, *16*, 35–50.

Hellige, J. B., & Michimata, C. (1989). Categorization versus distance: Hemispheric differences for processing spatial information. *Memory and Cognition*, *17*, 770–776.

Hitch, G. J., Woodin, M., & Baker, S. (1989). Visual and phonological components of working memory in children. *Memory and Cognition*, *17*, 175–185.

Ivry, R. B., & Robertson, L. C. (1998). *The two sides of perception*. Cambridge, MA: MIT Press.

Jacobs, R. A., & Kosslyn, S. M. (1994). Encoding shape and spatial relations: The role of receptive field size in coordinating complementary representations. *Cognitive Science*, *18*, 361–386.

Kemmerer, D. (2006). The semantics of space: Integrating linguistic typology and cognitive neuroscience. *Neuropsychologia*, *44*, 1607–1621.

Kemmerer, D., & Tranel, D. (2000). A double dissociation between linguistic and perceptual representations of spatial relationships. *Cognitive Neuropsychology*, *17*, 393–414.

Kosslyn, S. M. (1987). Seeing and imagining in the cerebral hemispheres: A computational approach. *Psychological Review*, *94*, 148–175.

Kosslyn, S. M., Anderson, A. K., Hillger, L. A., & Hamilton, S. E. (1994). Hemispheric differences in sizes of receptive fields or attentional biases? *Neuropsychology*, *8*, 139–147.

Kosslyn, S. M., Chabris, C. E., Marsolek, C. J., & Koenig, O. (1992). Categorical versus coordinate spatial relations: Computational analyses and computer simulation. *Journal of Experimental Psychology: Human Perception and Performance*, *18*, 562–575.

Laeng, B. (1994). Lateralization of categorical and coordinate spatial functions: A study of unilateral stroke patients. *Journal of Cognitive Neuroscience*, *6*, 189–203.

Laeng, B., Chabris, C. F., & Kosslyn, S. M. (2003). Asymmetries in encoding spatial relations. In K. Hugdahl & R. J. Davidson (Eds.), *The asymmetrical brain* (pp. 303–339). Cambridge, MA: The MIT Press.

LeDoux, J. E., Wilson, D. H., & Gazzaniga, M. S. (1977). Manipulo-spatial aspects of cerebral lateralization: Clues to the origin of lateralizsation. *Neuropsychologia*, *15*, 743–750.

Noordzij, M. L., van der Lubbe, R. H. J., Neggers, S. F. W., & Postma, A. (2004). Spatial tapping interferes with the processing of linguistic spatial relations. *Canadian Journal of Experimental Psychology*, *58*, 259–271.

Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychologia*, *9*, 97–113.

Pashler, H. (1994). Dual-task interference in simple tasks: Data and theory. *Psychological Bulletin*, *116*, 220–244.

Rusted, J. M., Eaton-Williams, P., & Warburton, D. M. (1991). A comparison of the effects of scopolamine and diazepam on working memory. *Psychopharmacology*, *105*, 442–445.

Rybash, J. M., & Hoyer, W. J. (1992). Hemispheric specialization for categorical and coordinate spatial representations: A reappraisal. *Memory and Cognition*, *20*, 271–276.

Salway, A. F. S., & Logie, R. H. (1995). Visuo-spatial working memory, movement control, and executive demands. *British Journal of Psychology*, *86*, 253–269.

Smith, A. T., Singh, K. D., Williams, A. L., & Greenlee, M. W. (2001). Estimating receptive field size from fMRI data in human striate and extrastriate visual cortex. *Cerebral Cortex*, *11*, 1182–1190.

Smyth, M. M., & Scholey, K. A. (1994). Interference in immediate spatial memory. *Memory and Cognition*, *22*, 1–13.

Tranel, D., & Kemmerer, D. (2004). Neuroanatomical correlates of locative prepositions. *Cognitive Neuropsychology*, *21*, 719–749.

Van der Ham, I. J. M., & Postma, A. (2010). Lateralization of spatial categories: A comparison of verbal and visuospatial categorical relations. *Memory and Cognition*, *38*, 582–590.

Van der Ham, I. J. M., van Wezel, R. J. A., Oleksiak, A., & Postma, A. (2007). The time course of hemispheric differences in categorical and coordinate spatial processing. *Neuropsychologia*, *45*, 2492–2498.