Communicating Spatial Information from Verbal Descriptions

Het communiceren van ruimtelijke informatie door middel van verbale beschrijvingen

(met een samenvatting in het Nederlands)

Proefschrift

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Chapter 1 Introduction

Communicating spatial information from verbal descriptions

Communication between people is difficult. To describe to another person what is "on your mind" is not comparable to one computer sending binary information to the serial port of a nearby computer. Instead, it is a far more indirect process in which the apparently rich and multiform mental information that needs to be transferred is reduced to a single serial source: language. In what way people consequently construct their own mental representations from the verbal information and even seem to understand the other person is a fascinating and puzzling phenomenon. However, there are many instances in which the seemingly clear communication fails to elicit an accurate mental representation in the listener. A familiar example comes from communicating spatial information. Asking directions can result in elaborate stories in which the narrator gives detailed and correct information concerning turns that need to be taken and landmarks that will be encountered. Yet, when left alone, the person who needs to find the way is clueless whether to turn left or right at the first crossing. This example (see also Figure 1) nicely illustrates the topic of this thesis: how do people represent spatial information when it is communicated through language?

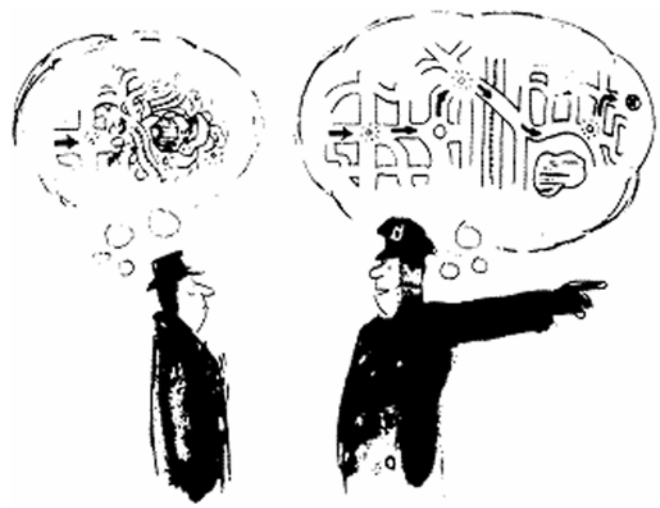

Figure 1.
Cartoon by Stevenson.

The Imagery debate

An important question concerning the mental representation of spatial descriptions is whether these representations resemble those that arise from direct perceptual experience or are in a league of their own. The more general question whether representations formed on the basis of indirect experience resemble, both functionally and neurally, representations from direct perceptual experiences has been the topic of a fierce debate. Depictive theories claim that such indirect experiences can lead to mental imagery, which supposedly shares many characteristics with perception. Supporting facts are, among others, that the occipital lobe contains numerous topographically mapped areas that support depictive representations, and that visual perception and mental imagery share many cortical areas, including the early visual cortex (Kosslyn, 1988, 1994; Kosslyn, Ganis, & Thompson, 2003). However, other theories, and most notably the one from Pylyshyn, state that the imagery phenomena described by "picture theorists" are actually a result of observers inferring what experimenters ask them to do: simulate a perception (Pylyshyn, 1999, 2003a, 2003b). According to this null-hypothesis, indirect experiences result in a single unitary representation, which is similar to an abstract verbal or propositional code.

Simple spatial sentences

Most evidence concerning the representation of simple spatial sentences stems from studies that employed the sentence-picture verification task. (Carpenter & Just, 1975; Chase & Clark, 1972). In this task participants first are asked to read a spatial sentence, after which they are confronted with a picture of which they have to indicate whether the information is the same as in the sentence. The two options for the representational format of a spatial sentence that have been proposed for the sentence-picture verification task echo those from the Imagery debate: a set of propositions or a mental image (MacLeod, Hunt, & Mathews, 1978). In Chapter 2 and 3 of the present thesis we review studies that tried to answer the question which of the two formats people employed in solving the sentence-picture verification task. Furthermore, we searched for ways in which to shed new light on this question by looking at some aspects of the encoding and representation of simple spatial sentences that were previously ignored. In Chapter 2 we examine the effect of a spatial and a verbal dual task on the processing of a spatial sentence (see Figure 2). The rationale behind this study was that the lack of clarity from previous sentence-picture verification tasks (for a review see Roberts, Wood, & Gilmore, 1994) could be avoided by introducing additional tasks that interfere unambiguously with either verbal or visual-spatial processes. Hence, if participants construct a propositional representation, then their performance should be more impaired by a verbal dual task (i.e. articulatory suppression), whereas if participants construct a mental image, then their performance should be more impaired by a spatial dual task (i.e. spatial tapping).

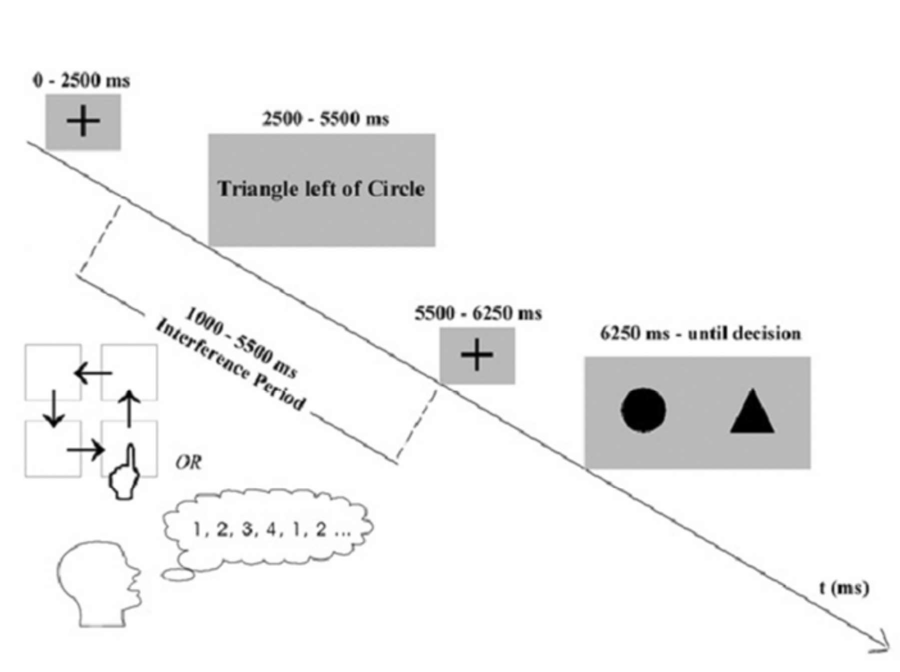

Figure 2.
An example of a sentence-picture verification trial. In addition, participants have to execute a verbal or spatial dual task during the presentation of the spatial sentence (Chapter 2).

In Chapter 3 another innovation for the sentence-picture verification task is introduced: the manipulation of the probability of the second stimulus. Sometimes participants read a spatial sentence and expect a picture in most trials (visual context), while in other conditions they expect to read another sentence in most trials (verbal context). Models that assume that different representational strategies exist predict that the context in which the spatial sentence is read has an effect, while models that assume only one representational format predict that the context has no effect. In Chapter 3 we will also explicitly compare spatial and non-spatial sentences and discuss our findings in the light of a classic model (*dual-code theory*; Paivio, 1983) and a new and currently very influential model (*perceptual symbol systems theory*; Barsalou, 1999) of language and knowledge representation.

If we presume that multiple representations can be derived from spatial sentences, it obviously would be very likely that different brain mechanisms are involved as well. In Chapter 4 and 5 we shift our experimental focus from behavioural measures to the measures from neuro-imaging. In determining the processes in the brain that underlie basic human functions two neuro-imaging techniques play a prominent role: functional Magnetic Resonance Imaging (fMRI) and electroencephalogram (EEG). With both techniques it is possible to examine patterns of brain activity in relation to stimuli or events that are controlled by the researcher. However, the kind of brain activity both techniques represent is quite dissimilar. On the one hand, the fMRI-signal is derived from the relatively slow metabolic changes as measured throughout the brain. On the other hand, the EEG-signal results from the fast electric discharges between nerve cells as measured at the scalp. Because of the different sources of the signals they both have their own specific advantages and disadvantages. It is well beyond the scope of this introduction to discuss all of them, therefore we will focus on the two key features of brain imaging techniques: spatial and temporal resolution. Spatial resolution refers to the extent in which it is possible to determine *where* certain activity in the brain is located, whereas temporal resolution refers to the extent in which it is possible to determine *when* certain activity in the brain takes place. Both with the fMRI and the EEG technique it is possible to show where and when certain activity took place in the brain. Importantly, the fMRI-signal has a high spatial resolution, but a low temporal resolution. In contrast, the EEG-signal has a high temporal resolution, but a low spatial resolution. Therefore the fMRI technique is particularly useful for determining the precise location of brain activity, whereas the EEG technique is more useful for determining the precise timing of brain activity. Because of their different but supplementary merits we have used both techniques to study specific questions concerning the relation between brain activity and the representation of spatial sentences.

The issue whether different representational formats of spatial sentences exist raises the questions *when* and *where* these possible differences arise. Given that the question *"when"* is basically concerned with the timing of certain processes, the EEG technique would be very useful to find an answer, because of its aforementioned excellent temporal resolution. In Chapter 4 we collected EEG measures on the processing of spatial sentences in order to further distinguish between various representational options, and to gain insight in when certain differences in representational format come into being. The question *"where"* is concerned with the location of certain brain activity and therefore it would be most useful to employ the fMRI technique, which has an excellent spatial resolution, to answer this question. Therefore, in Chapter 5 we describe an event-related fMRI experiment in which participants read spatial and non-spatial sentences in a sentence - picture/sentence verification task to find out more about the neural correlates of the processing of spatial sentences.

Complex spatial descriptions

The results from the above mentioned chapters concerning simple spatial sentence form a starting point for experiments with more complex, everyday spatial descriptions. If people can indeed form a spatial representation or a mental image of a spatial description, then we can start investigating what type of spatial information people represent. Spatial information that is transferred by means of a verbal description is usually restricted to simple or categorical spatial relations, such as *the cat lies on the ground under the table*. Although it is possible to say the *cat lies on the ground, 44.77 cm. under the table,* people almost always leave out this detailed, metric spatial information from their verbal descriptions. In contrast, a photograph of your living room, with the aforementioned cat on his favourite spot under the table would contain this detailed information. The differences between on the one hand the lack of detail in spatial descriptions, and on the other hand the precise metric detail in direct perceptual experience might also be reflected in the mental representations people build up from descriptions or perception. Hence, it could be that representations from descriptions are rather crude and only contain categorical spatial information, whereas representations based on direct perception contain metric spatial information (Jager & Postma, 2003). In favour of such a straightforward distinction Kemmerer and Tranel (2000) found a double dissociation in which one person with left-sided lesions was severely impaired on crude linguistic spatial tasks, but scored normal on several purely visual spatial tasks. The other person, with right-sided lesions showed the opposite pattern.

Theories on language comprehension mostly assume that people do in fact build up some type of integrated (spatial) representation when they hear an extensive description (Graesser, Singer, & Trabasso, 1994; Johnson-Laird, 1983; Zwaan & Radvansky, 1998). Therefore, besides the question whether people build up a spatial representation at all, many researchers have looked into the issue what the influence of several characteristics of spatial descriptions is on spatial representations (Rinck & Denis, 2004; Rinck, Hähnel, Bower, & Glowalla, 1997; Shelton & McNamara, 2004; Taylor & Tversky, 1992; Zwaan & Van Oostendorp, 1993). Communicating information involves making choices about *how* to tell something. These choices involve the level of detail in a story, the amount of emotion included, and the perspective from which everything is described. Consequently, the choices people make pertaining to *how* to describe something might have a great impact on *what* the listener or reader thinks the information actually is or means. Especially relevant for spatial descriptions is the perspective with which spatial information is communicated. Speakers mostly seem to choose between two types of spatial perspectives in descriptions, or a mix between the two (Taylor & Tversky, 1996). The first consists of taking listeners or readers on a mental tour, which is termed a route perspective; the second consists of taking a viewpoint that is above the environment, which is termed a survey perspective. Route and survey descriptions have specific characteristics that have their origins in the different reference frames they employ: egocentric (route) vs. allocentric (survey). An issue that is pursued into detail in Chapter 6 and 7 is whether the spatial perspective of a description has an influence on the spatial representation. At this point it is important to remark that experiments, which are described in the present thesis, employed spatial descriptions in Dutch. There is a growing body of evidence emphasizing the cross-cultural differences in spatial communication and spatial representations (Levinson, 1996, 2003; Levinson, Kita, Haun, & Rasch, 2002; Munnich, Landau, & Dosher, 2001). Because the cross-cultural factor was not included in any of our studies, our findings and conclusions are in the first place relevant for the Dutch language, and other languages that share many characteristics with Dutch (such as English). Whether our conclusions generalize to other languages, which differ fundamentally with respect to linguistic spatial aspects, should be the topic of future cross-linguistic research.

In Chapter 6 we examine whether the perspective of complex and real-life spatial descriptions influence the extent to which categorical and metric distance is represented. Although it seems to be the case that the spatial representations based on route and survey descriptions contain similar information regarding categorical spatial information (Taylor & Tversky, 1992), this study is the first to examine the possibility that the spatial perspective of the description does influence the availability of metric spatial information. In addition, the experiment described in Chapter 6 can extend findings from previous studies, which used rather artificial and simple spatial descriptions, and found that people do build up spatial representations based on spatial descriptions that contain metric detail (Denis & Cocude, 1989; Denis, Goncalves, & Memmi, 1995; Denis & Zimmer, 1992).

A very important question in this thesis is whether people can encode spatial descriptions and form spatial models or even mental images, which resemble representations from direct perceptual experience. A natural extension of this theme is to examine how people who have never seen represent spatial descriptions. Spatial mental model construction requires an ongoing integration and transformation of several pieces of information (Zwaan & Radvansky, 1998). It has been suggested that early blind people (people who lost their vision before the age of three) perform normally with respect to the passive storage of visual-spatial information, while they have specific problems with processes that require active integration and transformation (Cornoldi & Vecchi, 2000). Therefore, it could be that the level of abstraction that a spatial representation represents might be unattainable for them. In turn, early blind people could rely more on a representation that requires less integration and is more closely linked to the text (i.e. propositional text base; Mani & Johnson-Laird, 1982). However, other studies have also shown that early blind people perform equally well or only slightly worse than sighted people in a great number of spatial tasks, even tasks that are considered to require active visual imagery processes (for a review see Kaski, 2002). In chapter 7 we describe a study that was designed to evaluate the importance of visual experience, by testing early blind, late blind and sighted participants, for the ability to form spatial representations of complex route and survey descriptions.

An additional interest of the experiment described in chapter 7 was whether blind people prefer the route to the survey description. Research on the coding of space by blind people in haptic and locomotor tasks has shown that these processes might differ from those employed by the sighted with respect to the reference frame that is preferred (Millar, 1994; Zuidhoek, Kappers, Noordzij, Van der Lubbe, & Postma, 2004). Millar (1994) argues that blind people tend to code spatial information (especially of large spaces) in the form of a sequential representation based on routes, whereas sighted people mostly code spatial information in the form of a cognitive map. The preference of blind people for spatial strategies and representations based on an egocentric frame of reference in spatial tasks might extend to the realm of spatial description comprehension. Therefore, in the experiment described in Chapter 7, blind people listen to a route (egocentric) and a survey (allocentric) description, and their performance on different spatial measured is examined.

The issues described in Chapter 7 concerning the ability of blind people to form spatial representations on the basis of verbal descriptions raises the question whether blind people would be capable of imagery and spatial processing at all. In addition, we started this Introduction by explaining the Imagery debate, in which the assumption was put forward that visual imagery and perception share similar mechanisms. The litmus test for this assumption is the examination of the performance of people who have no or little visual experience (i.e. congenitally and early blind people) on tasks that are considered to require visual imagery. In chapter 8 we discuss an experiment in which different types of imagery (visual, spatial, and auditory) on the basis of verbal descriptions are examined with early blind, late blind and sighted participants. In this way we can examine the ability of blind people for different types of imagery and can conclude this thesis with a more general discussion of the similarities between mental imagery and perception.

References

Barsalou, L. W. (1999). Perceptual symbol systems. *Behavioral & Brain Sciences, 22*(4), 577-660.

Carpenter, P. A., & Just, M. A. (1975). Sentence comprehension: A psycholinguistic processing model of verification. *Psychological Review, 82*(1), 45-73.

Chase, W. G., & Clark, H. H. (1972). Mental operations in the comparison of sentences and pictures. In L. W. Gregg (Ed.), *Cognition in learning and memory*. New York: Wiley.

Cornoldi, C., & Vecchi, T. (2000). *Visuo-spatial working memory and individual differences*. Hove and New York: Psychology Press.

Denis, M., & Cocude, M. (1989). Scanning visual images generated from verbal descriptions. *European Journal of Cognitive Psychology, 1*(293-307).

Denis, M., Goncalves, M.-R., & Memmi, D. (1995). Mental scanning of visual images generated from verbal descriptions: Towards a model of image accuracy. *Neuropsychologia, 33*(11), 1511-1530.

Denis, M., & Zimmer, H. D. (1992). Analog properties of cognitive maps constructed from verbal descriptions. *Psychological Research, 54*(4), 286-298.

Graesser, A. C., Singer, M., & Trabasso, T. (1994). Constructing inferences during narrative text comprehension. *Psychological Review, 101*, 371-395.

Jager, G., & Postma, A. (2003). On the hemispheric specialization for categorical and coordinate spatial relations: a review of the current evidence. *Neuropsychologia, 41*, 504-515.

Johnson-Laird, P. N. (1983). *Mental models*. Cambridge, MA: Harvard University Press.

Kaski, D. (2002). Revision: is visual perception a requisite for visual imagery? *Perception, 31*(6), 717-731.

Kemmerer, D., & Tranel, D. (2000). A double dissociation between linguistic and perceptual representations of spatial relationships. *Cognitive Neuropsychology, 17*(5), 393-414.

Kosslyn, S. M. (1988). Aspects of a cognitive neuroscience of mental imagery. *Science, 240*, 1621-1626.

Kosslyn, S. M. (1994). *Image and brain: The resolution of the imagery debate*. Cambridge, Massachusetts: MIT Press.

Kosslyn, S. M., Ganis, G., & Thompson, W. L. (2003). Mental imagery: against the nihilistic hypothesis. *TRENDS in Cognitive Sciences, 7*(3), 109-111.

Levinson, S. C. (1996). Language and space. *Annual Review of Anthropology, 25*, 353-382.

Levinson, S. C. (2003). *Space in language and cognition: Explorations in cognitive diversity*. Cambridge, UK: Cambridge University Press.

Levinson, S. C., Kita, S., Haun, D. B. M., & Rasch, B. H. (2002). Returning the tables: language affects spatial reasoning. *Cognition, 84*, 155-188.

MacLeod, C. M., Hunt, E. B., & Mathews, N. N. (1978). Individual differences in the verification of sentence-picture relationships. *Journal of Verbal Learning & Verbal Behavior, 17*(5), 493-507.

Mani, K., & Johnson-Laird, P. N. (1982). The mental representation of spatial descriptions. *Memory & Cognition, 10*(2), 181-187.

Millar, S. (1994). *Understanding and representing space: Theory and evidence from studies with blind and sighted children*. Oxford: Oxford University Press.

Munnich, E., Landau, B., & Dosher, B. A. (2001). Spatial language and spatial representation: a cross-linguistic comparison. *Cognition, 81*, 171-207.

Paivio, A. (1983). The empirical case for dual coding. In J. C. Yuille (Ed.), *Imagery, Memory and Cognition*. Hillsdale, New Jersey: Lawrence Erlbaum Associates.

Pylyshyn, Z. (1999). Is vision continuous with cognition? The case of impenetrability of visual perception. *Behavioral & Brain Sciences, 22*(3), 341-423.

Pylyshyn, Z. (2003a). Explaining mental imagery: now you see it, now you don't. Reply to Kosslyn et al. *TRENDS in Cognitive Sciences, 7*(3), 111-112.

Pylyshyn, Z. (2003b). Return of the mental image: are there really pictures in the brain? *TRENDS in Cognitive Sciences, 7*(3), 113-118.

Rinck, M., & Denis, M. (2004). The metrics of spatial distance traversed during mental imagery. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 30*(6), 1211-1218.

Rinck, M., Hähnel, A., Bower, G. H., & Glowalla, U. (1997). The metrics of spatial situation models. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 23*(3), 622-637.

Roberts, M., Wood, D., & Gilmore, D. (1994). The sentence-picture verification task: Methodological and theoretical difficulties. *British Journal of Psychology, 85*, 413-432.

Shelton, A. L., & McNamara, T. P. (2004). Orientation and perspective dependence in route and survey learning. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 30*(1), 158-170.

Taylor, H. A., & Tversky, B. (1992). Spatial mental models derived from survey and route descriptions. *Journal of Memory & Language, 31*(2), 261-292.

Taylor, H. A., & Tversky, B. (1996). Perspective in spatial descriptions. *Journal of Memory & Language, 35*(3), 371-391.

Zuidhoek, S., Kappers, A. M. L., Noordzij, M. L., Van der Lubbe, R. H., & Postma, A. (2004). Frames of reference in a haptic parallelity task: Temporal dynamics and the possible role of vision. In S. Ballesteros & M. A. Heller (Eds.), *Touch, blindness and neuroscience* (pp. 155-164). Madrid, Spain: UNED Press.

Zwaan, R. A., & Radvansky, G. A. (1998). Situation models in language comprehension and memory. *Psychological Bulletin, 123*(2), 162-185.

Zwaan, R. A., & Van Oostendorp, H. (1993). Do readers construct spatial representations in naturalistic story comprehension? *Discourse Processes, 16*, 125-14

Chapter 2 Spatial tapping interferes with the processing of linguistic spatial relations

Abstract

Simple spatial relations may be represented either in a propositional format that is dependent on verbal rehearsal or in a picture-like format that is maintained by visual-spatial rehearsal. In sentence-picture and picture-picture verification tasks we examined the effect of an articulatory suppression and a spatial tapping dual task on the encoding of simple spatial relations (e.g. triangle left of circle). Articulatory suppression did not interfere, while spatial tapping lowered performance in both tasks. Apparently, both linguistic and perceptual inputs of simple spatial relations engaged the visual-spatial working memory. In the sentence-picture verification experiments spatial tapping only hampered performance of participants who were classified on basis of their RT patterns as having used a visual-spatial strategy, while it had no effect for those who were classified as having applied a verbal strategy. Therefore, this study provides converging evidence, using a dual-task methodology, that both separate verbal and visual-spatial strategies exist for the processing of simple spatial sentences.

Noordzij, M. L., Van der Lubbe, R., Neggers, S. F. W., & Postma, A. (2004). *Canadian Journal of Experimental Psychology, 58(4),* 259-271.

Introduction

A picture of a spatial configuration of two objects can be easily described in a sentence. This description will usually mention the objects and the categorical spatial relation between them: "the knife is to the right of the plate". Conversely, it is also easy to construct a generic or specific image of the aforementioned spatial description. An interesting question is to what extent representations generated by verbal or pictorial information are similar. In a well known spatial description task (Clark & Chase, 1972; Just & Carpenter, 1975), which enables an answer to this question participants read a sentence describing the categorical spatial relation between two objects (e.g. star is above plus), followed by a picture that does (e.g. a star above a plus) or does not (e.g. a plus above a star) exemplify the description. The participant has to decide whether the picture is a true or false depiction of the spatial description. Several authors (e.g. MacLeod, Hunt, & Mathews, 1978; Reichle, Carpenter, & Just, 2000) suggested that this sentence-picture verification task can be achieved in two distinct ways: using a verbal or a visual-spatial strategy. The verbal strategy involves the formation of a propositional representation dependent on verbal working memory, whereas the visual-spatial strategy involves the formation of a pictorial representation dependent on visual-spatial working memory. The current study used a dual task methodology to improve our understanding of the type of representation that is employed in the verification of sentences and pictures that specify *left* and *right* relations between two objects.

In a sentence-picture verification task participants compare linguistic information in a sentence with visual-spatial information in a picture. Some transformations seem necessary to enable a comparison between the two types of information. One possibility is that the representation of a spatial sentence has a proposition-based format that is maintained through active verbal rehearsal. Subsequently, the picture is encoded into the same propositional format as the sentence, after which a comparison is possible. Evidence for the employment of verbal strategies comes from studies in which the linguistic complexity of the spatial sentence was varied. The underlying assumption is that the representations (of the sentence and of the picture) are compared component by component, until all components have been resolved. Adding more linguistic components, such as a negation, would lengthen the verification time. Hence, the sentence "star is above plus" should be compared faster to a subsequent picture than the sentence "star is not above plus". In line with this prediction, Clark and Chase (1972) found that participants became slower when the sentence became more complex (e.g. the star is not above the plus).

Another possibility is that the initial sentence is transformed immediately into a representation with a pictorial format, which can be maintained by active visual-spatial rehearsal until the picture appears. Subsequently, the pictorial representation of the sentence can be directly compared to the picture. For a visual-spatial strategy the linguistic complexity of the sentence should not play a role in the comparison process because the sentence is converted to a pictorial format that does not retain the additional complexities (e.g. negation). Therefore, the sentence "star is above plus" should be compared equally fast to a subsequent picture as the sentence "star is NOT above plus". Evidence for the employment of a visual-spatial strategy comes from studies in which linguistic complexity had little or no effect on picture verification time (e.g. Seymour, 1974).

Apparently, evidence is found for the presence of verbal strategies as well as visual-spatial strategies in sentence-picture verification tasks. Interestingly it has been suggested that both strategies might apply, i.e. there may be inter-subject differences in which strategy is preferred. Glushko and Cooper (1978) showed that the effects of linguistic complexity could be diminished by explicitly instructing participants to use imagery to solve the task. MacLeod et al. (1978) argued that they could divide their participant group on the basis of RTs into one group that employed the verbal strategy and a group that was supposed to employ the visual-spatial strategy. Furthermore, participants who scored high on psychometric measures of spatial ability were more likely to have chosen a visual-spatial strategy.

Eley (1981) compared RT-patterns of participants, who were classified as having followed a visual-spatial or verbal strategy, in sentence-picture and picture-picture verification tasks. For one group this classification was based upon self-reports after the experiment, whereas another group was instructed to follow a specific strategy. Participants who were classified as having used a visual-spatial strategy were equally fast on a sentence-picture verification task as on a picture-picture verification task, while participants who were classified as having used a verbal strategy were slower on a sentence-picture verification task than on a picture-picture verification task. Eley argued that participants who follow a visual-spatial strategy transform the sentence representation into a pictorial representation before the picture appears. Consequently, the comparison between the pictorial representations of the sentence and the picture should be very similar to the comparison process in a picture-picture verification task. In contrast, participants who follow a verbal strategy have to transform the picture into a propositional representation in the sentence-picture verification task. This additional transformation, which is absent in picture-picture verification, may be responsible for longer RTs in the sentence-picture task than in the picture-picture task. Further support for the division of participants into a verbal and visual-spatial group comes from neuroimaging research. In a recent fMRI study (Reichle et al., 2000), the sentence-picture verification paradigm was used to investigate the cortical systems that are involved with verbal and visual-spatial processing. Participants that were instructed to follow a verbal strategy produced more activation in traditional language areas such as Broca's area, whereas participants that were instructed to follow a visual-spatial strategy showed more activation in traditional visual-spatial areas such as the parietal cortex.

The sentence-picture verification task has proven to be a paradigm that is useful for contrasting different types of processes, namely verbal and visual-spatial, the application of which can differ between participant groups as a whole as well as between individual participants. Nevertheless, there could be some problems with classifying a type of processing by looking at RT-patterns (or possibly error scores) in a sentence-picture verification task. As noted by Marquer and Pereira (1990) two identical individual verification RT-patterns can originate from two different strategies. Hence, Marquer and Perreira suggested that a more valid approach would be to use self-reports to classify participants into strategy groups and then compare this classification against RT-patterns. However, a commonplace finding in cognitive psychology is that introspective reports provide inaccurate information about the processes that participant actually employ in a task (e.g. Evans, 1989). In a review of the sentence-picture verification task Roberts, Wood and Gilmore (1994) argued that all the main strategy classification systems based upon verification RT-patterns, and also sources of converging evidence based on psychometric test scores and introspective reports, seem to be problematic. The lack of clarity that seems to be associated with the methods that have been used for strategy classification in sentence-picture verification tasks could be avoided by introducing additional tasks that interfere unambiguously with either verbal or visual-spatial processes. It was exactly the goal of the present study to employ dual-tasks, which selectively interfere with the verbal or spatial components of working memory, in order to shed light on which type of representation, i.e. propositional or pictorial, is employed in the verification of spatial relationships.

In the domain of working memory there are many studies that support the view that verbal and visual-spatial information are processed by dissociable sub-components. Therefore the examination of the sub-components of working memory that are engaged during a sentence-picture verification task might provide an insight into which of the two strategies are employed. In Baddeley´s (1986) model of working memory, the storage and processing of task-relevant information is achieved by three modules. Verbal information is encoded and maintained by the so-called phonological loop, whereas visual-spatial information is processed by another specialised system- the so-called visual-spatial sketchpad. Both systems are coordinated and controlled by a central executive of limited capacity. The verbal strategy in a sentence-picture verification task can be expected to depend on the phonological loop; the propositional representation of the first sentence needs to be constructed and maintained in verbal working memory. In contrast, the visual-spatial strategy can be expected to depend on the visual-spatial working memory; the transformation of the first sentence into a representation with a pictorial format and the subsequent rehearsal of this visual-spatial representation would require the use of visual-spatial working memory.

Dual task procedures have been used extensively in studies aiming to disrupt the phonological loop or the visual-spatial working memory. A secondary task that is thought to disrupt the phonological loop is articulatory suppression (e.g. Baddeley & Andrade, 2000; Chincotta & Underwood, 1997; Milner, Jeeves, Ratcliff, & Cunnison, 1982), which requires participants to repeat aloud a single word as "the" or a predictable sequence such as the digits 1, 2, 3 and 4. The working memory model accounts for the effects of articulatory suppression by suggesting that it places a load on the articulatory rehearsal process, thereby undermining an important facility for retention. A secondary task that is thought to disrupt the visual-spatial working memory is spatial tapping (e.g. Beech, 1984; Logie, 1995; Sussman, 1982), which requires participants to tap a predetermined spatial array, like the four corner points of a square following a counter clockwise direction. The working memory model accounts for these effects by suggesting that it places a load on an active (spatial) rehearsal process, thereby impairing retention possibilities.

In the present study we employed sentence-picture and picture-picture verification tasks, in combination with the aforementioned verbal and spatial dual tasks. Our main interest was to further examine what type of representation is employed when participants encode categorical spatial relations. If participants follow a verbal strategy and construct a propositional representation then their performance should be more impaired by articulatory suppression than by spatial tapping. If participants follow a visual-spatial strategy and construct a pictorial representation then their performance should be more impaired by spatial tapping than by articulatory suppression. In addition the possibility that different participants employed different strategies in the sentence-picture verification tasks was examined. Following Eley (1981), participants who showed similar RTs in a sentence-picture and a picture-picture task were classified as having used a visual-spatial strategy, whereas participants who showed slower RTs in a sentence-picture task than in a picture-picture task were classified as having used a verbal strategy. To verify the validity of the classification on basis of RTs we examined whether 'verbal' participants were indeed most interfered by articulatory suppression, and 'visual-spatial' participants were more hampered by spatial tapping.

Experiment 1

Method

Participants

Eighteen right-handed participants (9 men, 9 women, all undergraduate students), with normal or corrected-to-normal vision, gave informed consent.

They were naive with respect to the hypotheses and were paid € 7 per hour for participating.

Materials

Stimuli were presented on a 19" Dell monitor with E-Prime software running on a Pentium III computer. Visual stimuli were composed of three shapes (circle, triangle and square). The stimuli were the same color (black), the same size and at the same distance from one another (although this distance was different for the first and second picture (twice as far)). Pictorial objects subtended 4.8° x 4.8° of visual angle. The text that participants read (e.g. Triangle left of Circle) was of 18 points, Times New Roman type, and was written in Dutch. Individual letters subtended 1.0° x .6° of visual angle. In a sentence-picture verification task participants read a sentence and in the picture-picture verification task they saw a picture; both were placed in the centre of the screen and provided information concerning a simple categorical relation (only "to the left of" and "to the right of") between two objects (circle, square and triangle). Subsequently a picture was presented and participants had to decide as fast and accurately as possible whether this second picture exemplified the sentence or first picture correctly. The second picture was placed randomly in one of four positions (top-left, top-right, bottom-left, bottom-right). The second picture depicted the two objects that were presented in the first sentence in a horizontal (left-right) relation.

A serial response box was used to collect key-press responses from the participants. A Quartz metronome was used to train the participants to tap and count at a speed of 184 beats per minute. The spatial tapping task consisted of four wooden plates, each 70 mm square, arranged in a square on a horizontal board with 25 mm between each plate. The 3D-position of the tapping finger was sampled at a rate of 100 Hz by means of a miniBIRD 800 motion tracking system from Ascension Technology Corporation.

Design and Procedure

Before the start of the experiment participants were trained on the interference tasks. For the articulatory suppression task, participants were asked to count aloud repeatedly from one to four throughout presentation of the first stimulus. For the spatial tapping task, participants were asked to tap repeatedly with their left (non dominant) hand throughout presentation of the first stimulus. The tapping pattern consisted of touching with the index finger in a counter clockwise direction each of the plates (which were arranged in a square) in turn. The wooden plates were placed in a closed box with a half open front for the tapping hand to make sure that participants did not look at their hands while executing the spatial tapping task. The experiment started when participants were able to perform the interference tasks without mistakes and at the correct speed. The presentation of stimuli and interference tasks was blocked and counterbalanced over participants. Each condition consisted of 4 practice trials and 36 experimental trials.

At the beginning of each trial a fixation cross was presented in the centre of the screen and after 1000 ms a beep of 1000 Hz sounded (500 ms), indicating that participants had to start the interference task (counting or tapping). After 1500 ms a sentence or a picture appeared for 3000 ms. When the stimulus disappeared another 1000Hz beep sounded to signal participants to stop counting or tapping. After a delay of 750 ms with a fixation cross, a picture was presented and participants had to press the correct button with their right hand for the same/ different decision. Participants responded by pressing the left or right button of the response box. A left button press equalled "same" for one half of the participants and a right button press equalled "same" for the other half of the participants. The beeps were also presented in the conditions without an interference task (baseline conditions), but participants were told to ignore them.

Data analysis

The data of the practice trials were discarded, as were trials on which the RT was either 2.5 standard deviation above or below the mean of the condition. As a result of this criterion .5% of the trials were considered to be an outlier. The between-subjects variable Group was constructed by using a K-means clustering algorithm that maximised a t-test for two groups based on the differences between RTs in the sentence-picture and picture-picture baseline task (see Mathews, Hunt, & MacLeod, 1980). This resulted in a visual-spatial group (n= 11) who showed a difference in RTs (mean=118 ms, minimum= -72 ms, maximum= 244 ms, standard deviation= 92.5) between the sentence-picture and picture-picture baseline tasks that was significantly smaller than the difference in RTs (mean= 409 ms, minimum= 290 ms, maximum= 542 ms, standard deviation= 106.9) for the verbal group (n=7), $t(16)= 5.9$, $p< .001$. Mean RTs, computed over correct trials, and mean percentage error scores were analysed using separate 2 x 3 x 2 ANOVAs with Format (Sentence or Picture) and Interference (Baseline, Articulatory Suppression or Spatial Tapping) as within-subjects variables and Group (Verbal or Visual-Spatial) as between-subjects variable. In addition planned comparisons were carried out to test specifically whether the verbal and visual-spatial groups were differently impaired by the two dual tasks.

Previous studies showed that sentences with "to the right of" were compared faster to a subsequent picture than sentences with "to the left of" (e.g. Just & Carpenter, 1975). However, Just and Carpenter (1975) also found that if a picture stored in long-term memory had to be compared to a sentence than the asymmetry reversed (i.e. "left of" faster than "right of"). Therefore, an analysis of the different sentences was carried out to establish whether there was a difference between sentences containing "to the left of" and sentences containing "to the right of". Mean RTs, computed over correct trials, and mean percentage error scores were analysed using separate 3 x 2 x 2 ANOVAs Interference (Baseline, Articulatory Suppression or Spatial Tapping) and Locative Preposition (Left or Right) as within-subjects variables and Group (Verbal or Visual-Spatial) as between-subjects variable. Greenhouse-Geisser correction was applied in all tests involving variables with more than two levels to correct for possible violations of sphericity assumptions (e.g. Maxwell & Delaney, 1990). An alpha level of .05 was used for all statistical tests.

Results

Reaction times

The main effect of Format was significant, $F(1, 16) = 51.8$, $p < .001$, $MSE = 47339.1$, showing that RTs were faster when the format of the first stimulus was a picture (mean= 754 ms) than when it was a sentence (mean= 1063; see Figure 1). The main effect of Interference was significant, $F(2, 32) = 5.3$, $p = .02$, $\varepsilon = .72$, $MSE = 54251.7$. Analysis of this effect indicated that RTs were slower in the Spatial Tapping condition (mean= 996 ms) than in the Baseline (mean= 884 ms) and the Articulatory Suppression condition (mean= 845 ms), $t(17) = 3.1$, $p = .006$ and $t(17) = 2.6$, $p = .02$, whereas RTs in the Articulatory Suppression condition did not differ from the RTs in the Baseline condition, $t(17) < 1$.

The main effect of Group was not significant, $F(1, 16) < 1$. The interaction between Format and Group was significant, $F(1, 16) = 5.2$, $p = .04$, $MSE = 47339.1$, showing that the participants classified as the visual-spatial group (mean= 959 ms) had faster RTs than the participants classified as the verbal group (mean= 1167 ms) when the first stimulus was a sentence, $t(16) = 2.6$, $p = .02$. In contrast, both groups had similar RTs when the first stimulus was a picture, $t(16) < 1$.No other interactions among Format, Interference and Group were significant, all $Fs < 1.3$. Planned comparisons for the sentence-picture verification trials showed that the verbal group was neither impaired by Articulatory Suppression or by Spatial Tapping, both $ts < 1$, whereas the visual-spatial group was impaired by Spatial Tapping, but not by Articulatory Suppression, $t(10) = 2.6$, $p = .03$ and $t < 1$. The analyses with the variable Locative Preposition (Left or Right) showed no significant effects, all $Fs < 1.6$ (see Table 1).

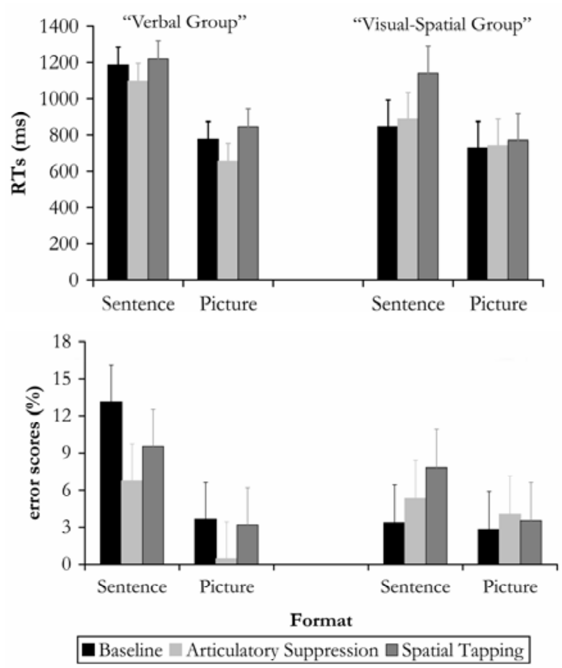

Figure 1.
Mean RTs (ms) and error scores (%) for sentence-picture and picture-picture verification tasks in baseline and interference conditions (Experiment 1), computation of within-subjects standard errors based on (Loftus & Masson, 1994).

Table 1[1].
Mean RTs (ms) and error scores (%) for sentence-picture tasks in Experiment 1.

	RTs (ms)			
Group	Verbal		Visual-Spatial	
Locative Preposition	"Left of"	"Right of"	"Left of"	"Right of"
Type of Interference				
Baseline	1151	1234	857	835
Articulatory Suppression	1127	1059	904	870
Spatial Tapping	1220	1229	1196	1109
	error scores (%)			
Baseline	9.5	16.7	4.0	2.5
Articulatory Suppression	4.8	8.7	5.6	5.1
Spatial Tapping	7.1	11.9	8.1	7.6

[1] *Computation of within-subjects standard errors amounted to 100.1 ms and 3.0 % for the Verbal, and 146.7 ms and 3.1 % for the Visual-Spatial group (based on (Loftus & Masson, 1994)).*

Error scores

The main effect of Format was significant, $F(1, 16)= 28.7$, $p< .001$, $MSE= 19.9$, showing that participants made more errors when the first stimulus was a sentence (mean = 7.6 %) than a picture (mean= 2.9 %). The main effects of Interference and Group were not significant, $F(2, 32)= 2.0$, $p= .16$, and $F(1, 16)= 1.7$, $p= .22$. The interaction between Format and Group was significant, $F(1, 16)= 9.3$, $p= .007$, $MSE= 19.9$. Analysis of this interaction showed that participants who were classified as the verbal group made more errors when the first stimulus was a sentence (mean= 9.8 %) than a picture (mean= 2.4 %), $t(6)= 6.8$, $p< .001$. Participants who were classified as the visual-spatial group made the same amount of errors with sentences and pictures, $t(10)< 1.7$, $p= .13$. The interaction between Type of Interference and Group was significant, $F(2, 32)= 5.3$, $p= .01$, $\varepsilon= .98$, $MSE= 18.1$, showing that the verbal group (mean= 8.3 %) made more errors than the visual-spatial group (mean= 3.0 %) in the baseline condition, $t(16)= 4.8$, $p< .001$, whereas both groups made the same amount of errors in the Articulatory Suppression and Spatial Tapping conditions, both $ts< 1$. No other interaction between Format, Interference and Group was significant, all $Fs< 2.0$. Planned comparisons for the sentence-picture verification trials showed that the verbal group was not impaired by Spatial Tapping and, surprisingly, facilitated by Articulatory Suppression, $t< 1.1$ and $t(6)= 2.8$, $p= .03$, whereas the visual-spatial group was marginally impaired by Spatial Tapping and not by Articulatory Suppression, $t(10)= 2.1$, p= .06 and $t< 1$.The analyses with the variable Locative Preposition (Left or Right) showed no significant effects, all $Fs< 2.1$.

Discussion

The main focus of this first experiment was to examine which representational format (pictorial or verbal) is involved in the processing of linguistic and perceptual categorical spatial relations. Participants were slower verifying the second picture when they performed the spatial tapping task than when they performed the articulatory suppression task or when they performed no secondary task. This pattern of interference suggests that in the present task conditions participants primarily relied on a visual-spatial strategy rather than on a verbal strategy in processing simple spatial relations. Participants were faster and made fewer errors when the first stimulus was a picture than when it was a sentence. Apparently the pictorial representation based on a picture was more effectively compared to a second picture than the visual-spatial representation based on a sentence. The pictorial representation of the sentence could have been less effective for a subsequent comparison to a picture because participants made more errors reading and interpreting the sentence than viewing the picture. Although previous research showed that there might be differences in processes related to reading and understanding sentences with opposite locative prepositions such as “ left of” and “ right of”, we found no differences in this experiment.

The division of the participants into two groups on the basis of the difference between their sentence-picture and picture-picture verification RTs, resulted in a visual-spatial group of eleven participants and a verbal group of seven participants. The visual-spatial group was faster and better than the verbal group, but only when the first stimulus was a sentence. Of course, this is consistent with the above-mentioned criterion that was used to divide the participants in groups. We found that spatial tapping significantly impaired the visual-spatial, and not the verbal group. Articulatory Suppression did not impair the visual-spatial and verbal group, and surprisingly, the verbal group made fewer errors in the articulatory suppression condition than in the baseline condition. Thus, we did find that the visual-spatial group was more impaired by spatial tapping, but we did not find that the verbal group was more impaired by articulatory suppression. Possibly, the present verbal dual task interferes mostly with the phonological surface structure of the spatial sentence and not with the underlying propositional content. Therefore, a different verbal dual task might be needed to yield verbal interference effects for participants who employ a verbal strategy in sentence-picture verification paradigms. Previous research has consistently shown that articulatory suppression and spatial tapping are approximately equally demanding in their own domain (i.e. verbal or visual-spatial), and that both tasks put a negligible load on the central executive (e.g. Brooks, 1967; Quinn & McConnel, 1996; Smyth & Pelky, 1992). Hence, we want to point out here that it is not simply the case of making the verbal dual task more demanding, as we found that an equally demanding visual-spatial dual task did yield clear interference effects (indicative of a visual-spatial strategy). In addition, simply increasing the complexity of the verbal dual task would unavoidably turn it into a central executive interference task as well, with all sorts of undesired, non-modality specific, side effects. The notion that it was not simply differences in dual task difficulty that accounted for selective interference effects was further supported by the fact that most articulatory suppression condition scores were not even in between baseline and spatial tapping scores, but either completely the same or even slightly better than the baseline scores.

An alternative explanation for the interference of spatial tapping, which is hard to refute, is that it originates from similarity between this task and the response mode (pressing the left or right button of a response box). Spatial tapping could hamper a participant because the motor activity related to the interference task slows down the subsequent motor preparation and carrying out of the key-press. This is not the case for articulatory suppression because activity from this task stems from a completely different modality. To avoid the possible confound between spatial tapping and the response mode we conducted a second experiment in which we changed the response mode from the spatial-motor domain (same for spatial tapping) to the verbal-vocal domain (different for spatial tapping). For Experiment 2 we used a voice-key as response mode and we only examined the effect of spatial tapping relative to baseline in a sentence-picture and picture-picture verification task.

Experiment 2

Method

Participants

Twenty-four right-handed participants (6 men, 18 women, all undergraduate students) cooperated, with normal or corrected-to-normal vision. They all gave informed consent and were naive with respect to the hypotheses, and were paid € 7 per hour for participating.

Design and Procedure

The interference task used was a visual-spatial (spatial tapping) task; the articulatory suppression task was not included in Experiment 2. All other aspects of the design and procedure of Experiment 2 were identical to those used in Experiment 1, except for the response mode (voice key); when S2 was presented participants had to say "goed" or "fout" ("true" and "false" in Dutch) as fast as possible without making any mistakes.

Data analysis

The data of the practice trials were discarded, as were trials on which the RT was either 2.5 standard deviation above or below the mean of the condition. As a result of this criterion .8% of the trials were considered to be an outlier. The cluster analysis resulted in a visual-spatial group (n= 16) who showed a difference in RTs (mean=17 ms, minimum= -94 ms, maximum= 83 ms, standard deviation= 48.2) between the sentence-picture and picture-picture baseline tasks that was significantly smaller than the difference in RTs (mean=174 ms, minimum= 110 ms, maximum= 377 ms, standard deviation= 85.7) for the verbal group (n=8), $t(22)= 5.8$, $p< .001$. Mean RTs, computed over correct trials, and mean percentage error scores were analysed using separate 2 x 2 x 2 ANOVAs with Format (Sentence or Picture) and Interference (Baseline or Spatial Tapping) as within-subjects variables and Group (Verbal or Visual-Spatial) as between-subjects variable.

In addition, an analysis of the different sentences was carried out to establish whether there was a difference between sentences containing "to the left of" and sentences containing "to the right of". Mean RTs, computed over correct trials, and mean percentage error scores were analysed using separate 2 x 2 x 2 ANOVAs Interference (Baseline or Spatial Tapping) and Locative

Preposition (Left or Right) as within-subjects variables and Group (Verbal or Visual-Spatial) as between-subjects variable.

Results

Reaction times

The main effect of Format was significant, $F(1, 22) = 52.5$, $p < .001$, $MSE = 5899.2$, showing that RTs were faster when the first stimulus was a picture (mean= 699 ms) than a sentence (mean= 820 ms; see Figure 2). The main effect of Interference was not significant, $F(1, 22) < 1$. The main effect of Group was not significant, $F(1, 22) < 1$.

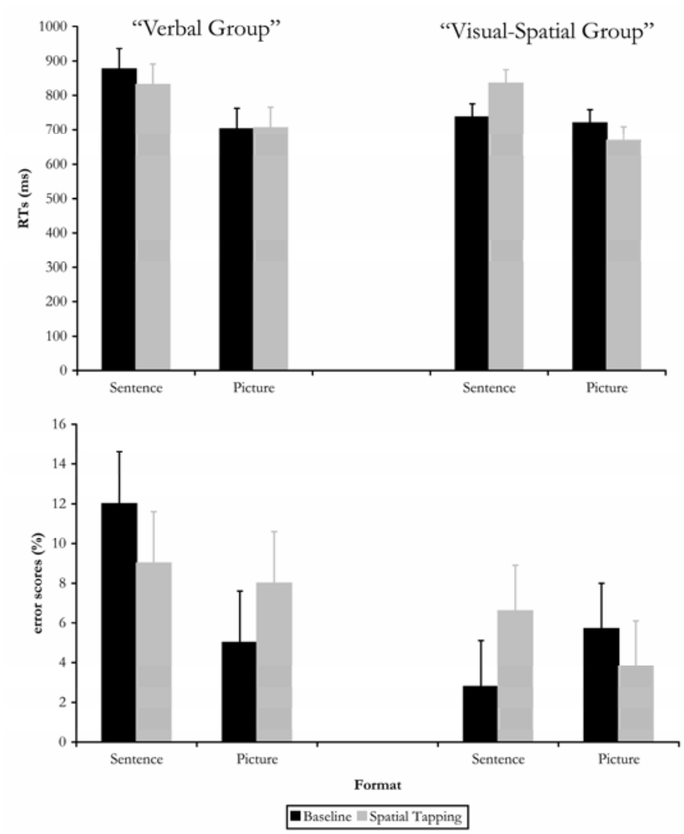

Figure 2.
Mean RTs (ms) and error scores (%) for sentence-picture and picture-picture verification tasks in baseline and spatial tapping conditions (Experiment 2), computation of within-subjects standard errors based on (Loftus & Masson, 1994).

The interaction between Format and Group was not significant, $F(1, 22) = 3.0$, $p = .1$, $MSE = 5899.2$. The interaction between Format, Interference and Group was significant, $F(1, 22) = 7.1$, $p = .01$, $MSE = 7332.1$. Analysis of this interaction revealed that the visual-spatial group showed a significant interaction between Format and Interference, $F(1, 16) = 13.0$, $p = .003$, $MSE = 6807.8$, while the verbal group did not, $F(1, 6) < 1$. Further analysis indicated that the visual-spatial group was impaired by spatial tapping when the first stimulus was a sentence, $t(15) = 2.8$, $p = .013$, while the verbal group was not impaired by spatial tapping when the first stimulus was a sentence, $t(7) < 1.1$. No other interactions among Format, Interference and Group were significant, all $Fs < 2.2$. The analyses with the variable Locative Preposition (Left or Right) showed no significant effects, all $Fs < 1$ (see Table 2).

Table 2[2]
Mean RTs (ms) and error scores (%) for sentence-picture tasks in Experiment 2.

	RTs (ms)			
Group	Verbal		Visual-Spatial	
Locative Preposition	"Left of"	"Right of"	"Left of"	"Right of"
Type of Interference				
Baseline	877	874	738	735
Spatial Tapping	819	843	838	832
	error scores (%)			
Baseline	11.1	13.2	3.8	6.6
Spatial Tapping	10.4	7.6	9.7	6.3

Error scores

The main effect of Format was significant, $F(1, 22) = 15.6$, $p = .001$, $MSE = 20.4$, indicating that fewer errors were made when the first stimulus was a picture (mean= 4.7 %) than a sentence (mean= 8.6 %). The main effect of Interference was not significant, $F(1, 22) < 1$. The main effect of Group was not significant, $F(1, 22) = 1.4$, $p = .24$, $MSE = 56.5$.

The interaction between Format and Group was significant, $F(1, 22) = 4.3$, $p = .049$, $MSE = 20.4$. Analysis of this interaction showed that the verbal group (mean= 10.6 %) made more errors than the visual-spatial group (mean= 6.6 %) when the first stimulus was a sentence, but not when it was a picture, $t(22) = 2.2$, $p = .04$ and $t(22) < 1$. The interaction between Format, Type of Interference and Group was significant, $F(1, 22) = 12.7$, $p = .002$, $MSE = 14.2$.

[2] *Computation of within-subjects standard errors amounted to 60.3 ms and 2.6 % for the Verbal, and 38.5 ms and 2.3 % for the Visual-Spatial group (based on (Loftus & Masson, 1994)).*

Analysis of the component interactions revealed that both the visual-spatial group and the verbal group showed a significant interaction between Format and Interference, $F(1, 15)= 5.7$, $p= .03$, $MSE= 15.4$, and $F(1, 7)= 8.3$, $p= .02$, $MSE= 11.6$. Further analysis indicated that the visual-spatial group was impaired by spatial tapping when the first stimulus was a sentence and facilitated by spatial tapping when it was a picture, $t(15)= 2.4$, $p= .03$. In contrast, the verbal group was facilitated by spatial tapping when the first stimulus was a sentence and impaired by spatial tapping when it was a picture, $t(7)= 2.9$, $p= .02$. No other interactions between Format, Interference and Group were significant, all $Fs< 1$.

The analyses with the variable Locative Preposition (Left or Right) showed a significant interaction between Type of Interference and Locative Preposition, $F(1, 22)= 6.1$, $p= .02$, $MSE= 26.9$. Further analysis showed that Spatial Tapping (mean= 10.0 %; Baseline mean= 6.3 %) lowered performance for sentences containing "left of", $t(23)= 2.2$, $p= .04$, whereas there was no difference between Baseline (mean= 8.8 %) and Spatial Tapping (mean= 6.7%) conditions if the sentence contained "right of", $t(23)< 1.1$. No other effects concerning Locative Preposition were significant, all $Fs< 1$.

Discussion

The main focus of Experiment 2 was to determine whether the effect of spatial tapping found in Experiment 1 originated from the specific response mode used in that experiment. In Experiment 2 we also observed diminished performances (i.e. slower RTs and more errors) in comparison with the baseline condition. Hence, the spatial tapping interference obtained in Experiment 1 did not originate from the similarity between the response mode (a left or right key-press) and the dual task (tapping a simple spatial pattern), because the interfering effect of spatial tapping was also present in this second experiment that used a voice-key as response-mode. Similar to Experiment 1, participants were faster and made fewer errors when the first stimulus was a picture than when it was a sentence. Therefore, the pictorial representation based on a picture seemed to be compared more effectively to a second picture than the pictorial representation based on a sentence.

The division of the participants into two groups in Experiment 2 resulted in a visual-spatial group of sixteen participants and a verbal group of eight participants. Only the visual-spatial group showed a diminished performance in the spatial tapping condition in comparison to the baseline condition. For the visual-spatial group, as became apparent from the second order interaction between Format, Type of Interference and Group, the interference caused by spatial tapping was limited to the condition in which the first stimulus was a sentence. In contrast, spatial tapping facilitated the performance of the verbal group when the first stimulus was a sentence, but impaired the performance when the first stimulus was a picture. Interestingly, in this experiment the detrimental effect of spatial tapping on the accuracy of participants in the visual-spatial group was confined to trials in which the spatial sentence contained the preposition "left of". We will further elaborate on the issues of the classification criterion, the resulting groups, and the difference between "left of" and "right of" in the general discussion.

General Discussion

This study started from the premise that a linguistic spatial relation may be represented with either a propositional format that is dependent on rehearsal in the phonological loop or a pictorial format that is dependent on rehearsal in the visual-spatial working memory. A spatial and a verbal dual task were employed, which were assumed to load on the visual-spatial working memory and the phonological loop, respectively. We found that the spatial dual task interfered in sentence-picture verification tasks, whereas the verbal dual task showed no effect. Apparently, most participants followed a visual-spatial strategy and not a verbal strategy in the sentence-picture verification task. Experiment 2 ruled out a possible confounding between the spatial dual task and the response mode. The fact that spatial tapping interfered with a sentence-picture verification task suggests that most participants formed a pictorial representation of the first sentence. In both experiments participants performed better when they had to verify a picture after viewing an initial picture than after reading a sentence. This could indicate that the pictorial representation based on the picture was more effectively compared to a following picture than the pictorial representation based on a sentence. The difference in effectiveness might arise because participants made more errors reading and interpreting the sentence than viewing the picture. Taken together, the two experiments provide evidence for the pictorial nature of the representation of linguistic categorical spatial relations in a sentence-picture verification task.

If participants formed a pictorial representation of the spatial sentence then this representation had to be generated and subsequently maintained in working memory. Whether the spatial tapping interfered mostly with the generation or the maintenance process cannot be inferred from the present findings. However, in either case, the relevant processes were clearly spatial. This finding does not fit a model for processing of simple spatial sentences that assumes that the representational format of a spatial sentence is always propositional (e.g. Logan & Sadler, 1996).

Previous research has used RT patterns to demonstrate that individual participants might choose different strategies within a sentence-picture verification experiment (e.g. Kroll & Corrigan, 1981; MacLeod et al., 1978; Russell & Taggart, 1995). To examine the possibility of the employment of different strategies in our experiments we used a classification criterion based upon the difference between sentence-picture and picture-picture verification RTs. Participants that were about equally fast in both tasks were thought to be using a visual-spatial strategy and participants that were much faster in the picture-picture task than in the sentence-picture task were classified as using a verbal strategy. Participants were divided into two groups with the above-mentioned criteria (using a cluster analysis), and we did indeed find that that spatial tapping impaired participants that were classified as using a visual-spatial strategy, while the participants that were classified as using a verbal strategy were not impaired by spatial tapping. The fact that the verbal group was not hampered by articulatory suppression might indicate that this task mostly interfered with the phonological surface structure of the spatial sentence and not with the underlying propositional content. Importantly, spatial tapping did not hamper (and in some cases facilitated) the performance of the verbal group. Therefore, the present study, using a dual-task methodology, provides converging evidence that both separate verbal and visual-spatial strategies exist for the processing of simple spatial sentences (e.g. Glushko & Cooper, 1978; MacLeod et al., 1978; Reichle et al., 2000).

In Experiment 2 there was a significant difference in the effect of spatial tapping on the picture-picture verification task: spatial tapping impaired the verbal group, but not the visual-spatial group. It may be that the picture-picture task was a passive "image maintenance" task, and that the sentence-picture task was an active "image generation" task. Spatial tapping impaired the verbal group on the image maintenance task, while this dual task impaired the visual-spatial group only on the more demanding image generation task. This could indicate that the verbal and visual-spatial group were not only employing different strategies, but also were composed of participants with different spatial abilities; i.e. low (verbal group) and high spatial abilities (visual-spatial group).

Previous studies (e.g. Just & Carpenter, 1975) found that there are differences in the way sentences with different locative prepositions (e.g. "above" vs. "below" and "left of" vs. "right of") are encoded. Usually, sentences with "above" and "right of" were found to be easier to compare to subsequent pictures than sentences with "below" and "left of". In the present study we found no differences between sentences with "left of" and "right of", except for the result that in Experiment 2 the detrimental effect of spatial tapping on accuracy was only found for sentences containing "left of" and not for sentences containing "right of". First, the fact that we found no systematic differences between sentences with different locative prepositions is probably because of the specific types of locative prepositions in our experiment. Just and Carpenter (1975) already noted that the above-below asymmetry seems to be more general than the right-left asymmetry. Second, it could be that the spatial tapping task only yielded its deteriorating effects because participants always code "left of" and "right of" in terms of their hands. Hence, the tapping task, which was always executed with the left hand, might have interfered more with the understanding of "to the left of" than with "to the right of" (as we found in Experiment 2). Yet, we did not find this in Experiment 1, where participants also always tapped with their left hand. Importantly, throughout all the analyses no clear effect of "left of" vs. "right of" was observed for the present study, and therefore it seems unlikely that tapping works by hampering body-centred prepositional coding.

How does the present conclusion that most participants followed a visual-spatial strategy bear upon previous studies that examined the presence of different strategies in the sentence-picture verification task? These studies (e.g. MacLeod et al., 1978) typically seemed to find that the majority of the participants followed a verbal strategy, while a small subset of participants was classified as having followed a visual-spatial strategy. How can we account for this discrepancy? It could be that the current classification method based on RT differences on sentence-picture and picture-picture tasks might not be reliable, while the method of previous studies, i.e. measuring the effect of linguistic complexity could be a better way to assign participants to a strategy group. Therefore, it could be that this latter, more reliable, classification method (although it has also been criticised, cf. Roberts et al., 1994) would have resulted in assigning more participants in the verbal strategy group. However, it would still not change the fact that the visual-spatial strategy (as indicated by the effect of spatial tapping) and not the verbal strategy was dominant in the present set-up.

Finally, in order to explain our evidence concerning the dominance of a visual-spatial strategy, we turn to the specific characteristic of our sentence-picture verification task. There are several arguments supporting the view that the current procedure might be ideal for participants to choose a visual-spatial strategy. First, Tversky (1975) found that the effect of a negation in a spatial sentence on picture verification times was dependent on the moment the picture was presented in relation to the sentence: if a sentence and picture were presented simultaneously, a negation lengthened the verification RTs, while if a picture was presented after the sentence disappeared, a negation had no effect. Apparently, participants maintained a verbal strategy for simultaneous comparison, but in case of a delay they changed to a visual-spatial strategy. Given these findings, it is not surprising that we found participants to predominantly choose a visual-strategy in the present study, because pictures followed the spatial sentences after a delay. Second, in a recent study (Noordzij, Van der Lubbe, & Postma, in press), we found support that participants choose a visual-spatial strategy when a picture was most likely to follow (80% of the trials a picture, 20% of the trials a sentence) a spatial sentence, while participants did not form a pictorial representation when a sentence was most likely to occur. Therefore, the expected stimulus-modality (context) seems to plays a major role in the availability of a visual-spatial strategy. In the current study a picture always followed a spatial sentence, which would constitute a situation in which participants seem very likely to adopt a visual-spatial strategy. Hence, our findings have relevance for a setting in which linguistic spatial information is compared to visual information. An interesting next step would be to examine the influence of verbal and spatial dual tasks on the processing of a sentence such as "X is to the left of Y" when the ensuing task is not visual but verbal: verifying this spatial relation in a subsequent sentence. If the context in which a spatial sentence is read is indeed a crucial factor with respect to processing strategies, then a spatial dual task should not interfere with the encoding of the sentence in a verbal context, indicating that people predominantly choose a verbal strategy.

In conclusion, the present study demonstrated that most participants consistently formed a pictorial representation of a spatial sentence in a sentence-picture verification task. Furthermore, we provided converging evidence, using a dual-task methodology, that both separate verbal and visual-spatial strategies exist for the processing of simple spatial sentences. Finally, our findings have relevance for a common situation in which people know that they have to use the information in a spatial sentence to verify information in a visual scene. However, further research is required to establish whether different types of processing occur when a spatial sentence is read in a purely verbal context.

References

Baddeley, A. (1986). *Working memory*. Oxford, England UK: Clarendon Press/Oxford University Press.

Baddeley, A. D., & Andrade, J. (2000). Working memory and the vividness of imagery. *Journal of Experimental Psychology: General, 129(1)*, 126-145.

Beech, J. R. (1984). The effects of visual and spatial interference on spatial working memory. *Journal of General Psychology, 110(2*), 141-149.

Brooks, L. R. (1967). The suppression of visualisation by reading. *Quarterly Journal of Experimental Psychology, 19*, 289-299.

Chincotta, D., & Underwood, G. (1997). Digit span and articulatory suppression: A cross-linguistic comparison. *European Journal of Cognitive Psychology, 9(1)*, 89-96.

Clark, H. H., & Chase, W. G. (1972). On the process of comparing sentences against pictures. *Cognitive Psychology, 3(3)*, 472-517.

Eley, M. G. (1981). Distinguishing imagery from propositional recoding processes in sentence-picture verification tasks. *Canadian Journal of Psychology, 35(3)*, 254-269.

Evans, J. (1989). *Bias in human reasoning: Causes and consequences*. Hove & London: Lawrence Erlbaum Associates Ltd.

Glushko, R. J., & Cooper, L. A. (1978). Spatial comprehension and comparison processes in verification tasks. *Cognitive Psychology, 10(4)*, 391-421.

Just, M. A., & Carpenter, P. A. (1975). The semantics of locative information in pictures and mental images. *British Journal of Psychology, 66(4)*, 427-441.

Kroll, J. F., & Corrigan, A. (1981). Strategies in sentence-picture verification: The effect of an unexpected picture. *Journal of Verbal Learning & Verbal Behavior, 20(5)*, 515-531.

Loftus, G. R., & Masson, M. E. J. (1994). Using confidence intervals in within-subject designs. *Psychonomic Bulletin & Review, 1(4)*, 476-490.

Logan, G. D., & Sadler, D. D. (1996). A computational analysis of the apprehension of spatial relations. In P. Bloom & M. A. Peterson & L. Nadel & M. F. Garret (Eds.), *Language and Space* (pp. 493-529). Cambridge, MA: MIT Press.

Logie, R. H. (1995). *Visuo-spatial working memory*. Hove, England UK: Lawrence Erlbaum Associates, Inc.

MacLeod, C. M., Hunt, E. B., & Mathews, N. N. (1978). Individual differences in the verification of sentence-picture relationships. *Journal of Verbal Learning & Verbal Behavior, 17(5)*, 493-507.

Marquer, J., & Pereira, M. (1990). Reaction times in the study of strategies in sentence^picture verification: A reconsideration. *Quarterly Journal of Experimental Psychology. A, Human Experimental Psychology, 42(1-A)*, 147-168.

Mathews, N. N., Hunt, E. B., & MacLeod, C. M. (1980). Strategy choice and strategy training in sentence-picture verification. *Journal of Verbal Learning & Verbal Behavior, 19(5)*, 531-548.

Maxwell, S. E., & Delaney, H. D. (1990). *Designing experiments and analyzing data: A model comparison perspective*. Pacific Grove, California: Brooks/ Cole Publishing Company.

Milner, A. D., Jeeves, M. A., Ratcliff, P. J., & Cunnison, J. (1982). Interference effects of verbal and spatial tasks on simple visual reaction time. *Neuropsychologia, 20(5)*, 591-595.

Noordzij, M. L., Van der Lubbe, R. H., & Postma, A. (in press). Strategic and automatic components in the processing of linguistic spatial relations. *Acta Psychologica*.

Quinn, J. G., & McConnel, J. (1996). Irrellevant pictures in visual working memory. *Quarterly Journal of Experimental Psychology, 49A*, 200-215.

Reichle, E. D., Carpenter, P. A., & Just, M. A. (2000). The neural bases of strategy and skill in sentence-picture verification. *Cognitive Psychology, 40(4)*, 261-295.

Roberts, M., Wood, D., & Gilmore, D. (1994). The sentence-picture verification task: Methodological and theoretical difficulties. *British Journal of Psychology, 85*, 413-432.

Russell, J., & Taggart, A. (1995). One model or two? Sentence verification in children and adults. *Educational Psychology, 15(4)*, 379-404.

Seymour, P. H. (1974). Generation of a pictorial code. Memory & Cognition, 2(2), 224-232.

Smyth, M. M., & Pelky, P. L. (1992). Short-term retention of spatial information. *British Journal of Psychology, 83(3)*, 359-374.

Sussman, H. M. (1982). Contrastive patterns of intrahemispheric interference to verbal and spatial concurrent tasks in right-handed, left-handed and stuttering populations. *Neuropsychologia, 20(6)*, 675-684.

Tversky, B. (1975). Pictorial encoding of sentences in sentence-picture comparison. *Quarterly Journal of Experimental Psychology, 27*, 405-410.

Chapter 3 | Strategic and automatic components in the processing of linguistic spatial relations

Abstract

The objective of the present study was to determine the extent to which strategies influence the representational format of a linguistic spatial relation. The propositional model assumes that a sentence describing a spatial relation is always represented as a set of propositions, whereas the strategic model claims that a spatial sentence can be represented either as a set of propositions or as a mental image, depending on the strategy (verbal or visual-spatial) an individual follows. Participants read a sentence (spatial or not spatial) followed by a picture or sentence, which did or did not exemplify the information of the first sentence. In order to examine the involvement of strategic and automatic components the probability (20% or 80%) of the nature (sentence or picture) of the second stimulus was varied. Participants had slower verification RTs for unexpected stimuli than for expected stimuli, but this cost was significantly larger for an unexpected picture than an unexpected sentence. Furthermore, this asymmetric cost for the unexpected visual-spatial stimulus only occurred with spatial sentences and not with non-spatial sentences. Surprisingly, these data do not support a strictly propositional or a strategic model. Instead, we propose a third option: a dual representational model, in which people automatically represent the spatial sentence propositionally. In addition, depending on the context, a pictorial strategy is employed, which results in a supplementary visual-spatial representation.

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Introduction

People can fairly easily describe a visual scene in which several objects occupy different positions. Usually such a description will mention the objects and the categorical spatial relations between them, e.g. *the table is to the right of the chair, and on the table are the car-keys*. Conversely, in many situations people need to rely on spatial descriptions in order to verify certain spatial relations in a visual scene, for example when you need to find the aforementioned car-keys. Therefore, an interesting question concerns the way in which people map language onto space. Several researchers (e.g. Carpenter & Just, 1975; Clark & Chase, 1972) have proposed that a comparison between linguistic and perceptual spatial information can only take place when both types of information are represented as a set of propositions. Others have suggested that the comparison is also possible when a mental image is generated from the spatial sentence, after which this mental image can be directly compared to the picture (e.g. Seymour, 1974; Tversky, 1975). MacLeod, Hunt, and Mathews (1978) argued that the representational format of a spatial sentence may either be propositional or pictorial, and depends on factors such as task instructions and an individual's strategic choice. The objective of the present study was to determine to what extent strategies influence the representational format of a linguistic spatial relation.

Clark and Chase (1972) proposed a theory of the processes and representations that might be involved when a sentence is compared against a picture. In their experiments participants read a sentence describing the categorical spatial relation between two objects (e.g. "plus is above star"), followed by a picture that did or did not exemplify the description. Participants had to decide whether the picture was a true or false depiction of the spatial description. Their theory postulated that sentences and pictures are represented as a set of propositions, whereby the comparison process between these two representations is a series of mental operations, each of which additively contributes to response latency. Clark and Chase predicted that the more complex a sentence was (in terms of its propositional components) the more time the comparison process would take. Hence, a sentence such as "star is above plus" was predicted to be verified faster against a subsequent picture than a linguistically more complex sentence such as "star is not above plus". Clark and Chase did indeed find that the time required to verify the information in the picture was a regular function of the linguistic complexity of the first sentence.

Logan (1994) employed sentence-picture verification tasks that used multi-element pictures. Therefore, participants had to actively search through this pictorial display to be able to verify the spatial relation. Using this paradigm Logan (1994) actually found similar results regarding the verification of a spatial relation when the first stimulus was a spatial sentence or a picture. Logan argued that the spatial sentence and the first picture were both represented as a set of propositions and that this representation was compared against the multi-element pictorial display. Similar to Clark and Chase (1972), Logan and Sadler (1996) assumed that the processing of a simple spatial sentence such as "star is above plus" entails representing this sentence as a set of propositions (e.g. *[above [star, plus]]*).

In contrast to the foregoing, MacLeod et al. (1978) found that a subset of the participants in a sentence-picture paradigm showed verification times that were not affected by the linguistic complexity of the sentence. MacLeod et al. (1978) argued that the differences between participants emerged because they were using two separate strategies. Some participants presumably employed a verbal strategy, which was accurately described by the Clark and Chase (1972) theory. The other participants were thought to have adopted a visual-spatial strategy, which consisted of an immediate transformation of the spatial sentence into a mental image, which was subsequently compared to a perceptual representation of the picture. In addition, Glushko and Cooper (1978) showed that the effects of linguistic complexity could be diminished by explicitly instructing participants to use imagery to solve the task.

Reichle, Carpenter, and Just (2000) employed the sentence-picture verification task to investigate the neural correlates of the linguistic and visual-spatial aspects of human cognition. Following MacLeod et al. (1978), participants were either instructed to adopt a verbal strategy or a visual-spatial strategy. Interestingly, the fMRI results showed that the verbal strategy was associated with more activation in classical language areas (Broca, Wernicke), while the spatial strategy was associated with more activation in a classical spatial area (parietal cortex).

In sum, there seem to be two models associated with the processing of simple spatial sentences: (1) a purely *propositional model*, which assumes that the sentence is always (automatically) represented as a set of propositions (*propositional representation*), whereby propositions are defined as abstract amodal codes, (2) a *strategic model*, which assumes that the spatial sentence can be represented as a set of propositions or as a visual-spatial code (*pictorial representation*), dependent on the strategy (verbal or visual-spatial) an individual follows. This visual-spatial code is defined as a mental image that can be seen before the mind's eye. The aim of the present experiment was to examine to what extent strategic and automatic components play a role in the processing of simple spatial sentences.

In the current experiment participants read a sentence (S1) describing the relation between two objects and then another sentence or a picture (S2), which did or did not match the information from the first sentence. We used the relations "to the left of", "to the right of", and "and". In order to examine the involvement of strategic components, the probability of the nature of S2 was varied. This resulted in conditions where in 80% of the trials S2 was a sentence and in 20% of the trials S2 was a picture, while in other conditions S2 was in 80% of the trials a picture and in 20% of the trials a sentence. Participants were instructed before a condition on which type of stimulus (sentence or picture) would follow the first sentence in most of the trials.

The *propositional model* predicts that the performance on expected and unexpected sentences and pictures is the same, because the representational format of a spatial sentence is propositional irrespective of whether the sentence needs to be compared against another sentence or a picture. Therefore, both when S2 is a sentence and a picture, a propositional representation has to be formed of S2 in order to allow a comparison between S1 and S2.

We assumed that if the representational format of the spatial sentence is dependent on the participants' strategy, then participants take advantage of the advance information concerning which type of modality, verbal or pictorial, is most likely to occur. Consequently, if a sentence is probable then participants will adopt a verbal strategy, whereas if a picture is probable then participants will adopt a visual-spatial strategy. In this situation, when participant read the spatial sentence they will form a proposition or a mental image dependent on what they expect. Furthermore, we assumed that if the modality of the representational format of the sentence was the same as the stimulus modality of S2 then the verification process would always be faster than when the modalities were different. Therefore, the *strategic model* predicts that the performance on expected stimuli (sentences or pictures) will be faster than on unexpected stimuli, because the modality of the representational format of the spatial sentence will always differ from the modality of an unexpected second stimulus. In order to allow a comparison between S1 and S2 the representational format of S2 will be propositional when participants expected a sentence and formed a propositional representation of S1, or the representational format of S2 will be pictorial when participants expected a picture and formed a pictorial representation of S1.

The assumptions mentioned above are supported by research with single objects, which has shown that participants' encoding strategies for a single word or a single pictorial object depends on the expectation the participant has of what has to be done with the stimulus. (Tversky, 1969, 1974) employed schematic faces or geometrical figures (pictorial stimulus) and names of these objects (verbal stimuli) in S1-S2 paradigms. In these studies the second stimulus was predominantly (79%) pictorial or verbal, or alternatively, advance information was given on which modality the second stimulus would be. Participants were faster when the modality of S2 was congruent than when it was incongruent with what they expected. Tversky concluded that participants encoded the first stimulus in the expected modality of the second. The goal of the present study was to extend these effects of expectancies for single objects to a situation of two objects, in particular thereby focusing upon the role of the spatial relation between the objects. In their seminal paper, Landau and Jackendoff (1993) already showed that the representations and language labels associated with spatial relations differ markedly from those engaged in single object processing. Furthermore, Kosslyn already pointed out the close connection between (visual) perception of categorical spatial relations and verbal categorization (such as in spatial prepositions) (cf. Jager & Postma, 2003; Kosslyn, 1987). Elsewhere, however, it has been claimed that there is still an essential distinction between perceptual and linguistic categorical spatial relations (Kemmerer & Tranel, 2000).

Of course, the aforementioned predictions of the two models do not take into account the fact that it is very likely that general switch costs play a role, whereby participants will be slower in processing an unexpected than an expected stimulus-modality. It is possible that having to read a sentence, while expecting to view a picture is associated with greater processing demands (and longer RTs) than reading a sentence, while expecting to read a sentence. These general costs might be related to differences in perceptual readiness; if participants expect a sentence, they may (covertly) focus their attention to the left of the screen, whereas if they expect a picture they may focus broadly toward the centre of the screen. Therefore an unexpected stimulus might require a shift in attention prior to processing. In order to get a measure for possible general switch costs, we used spatial sentences such as "triangle left of circle" and non-spatial sentences such as "triangle and circle". We reasoned that the representational format of the non-spatial sentences would be propositional, because it is not possible to construct a mental image that can be unambiguously matched with a description such as "triangle and circle"[3]. Therefore, the difference in performance, after participants have read a non-spatial sentence, between expected and unexpected sentences and pictures can be attributed to general switch costs, which are not related to effects associated with the representational format (set of propositions or a mental image) of the first sentence. The above-mentioned predictions of the propositional and strategic model concern differences that remain after those associated with general switch costs, as found with non-spatial sentences, have been taken into account.

The predictions derived from the models for the processing of linguistic spatial relation can be translated into distinctly different predictions regarding the interactions between the independent variables in the present

[3] It is logically but not psychologically impossible to have one unambiguous mental image of "triangle and circle". However, within the current study our non-spatial sentences always described two configurations correctly (i.e. "triangle and circle"/ "circle and triangle"). Therefore, within the context of our experiment it was impossible to construct a unique mental image that would always coincide with the correct answer. Admittedly, it would be possible for participants to form two more abstract mental models. We will return to this possibility in the discussion.

experiment. The propositional model predicts that the differences in performance on expected and unexpected stimuli will be the result of general switch costs. These general costs should be identical for spatial and non-spatial sentences. Therefore, the propositional model predicts no interaction between the type of sentence (spatial or non-spatial) and the probability (80% or 20%) of the second stimulus. The strategic model predicts that the differences in performance on expected and unexpected stimuli will be the result of general switch costs, and of costs related to an incompatibility of the representational format (set of propositions or mental image) for both sentences and pictures. The difference between expected and unexpected stimuli should thus be greater for spatial than for non-spatial sentences, and this effect should occur for both sentences and pictures. Hence, the strategic model predicts an interaction between the type of sentence participants have read and the probability of the second stimulus.

It is important to note that the computational model of Logan and Sadler (1996), which we have placed under the propositional model, also makes very clear predictions concerning differences in a sentence-picture verification task between spatial sentences (containing a spatial preposition) and non-spatial sentences (containing a conjunction). In the computational model there are three steps that are supposed necessary for apprehending a spatial relation: spatially indexing and identifying the objects, assigning directions to the spatial terms and finally computing the spatial relation and comparing this information to the information in the spatial sentence (for a summary of the characteristics of the model see Carlson, 2003). Recently, evidence for the existence and independence of these steps and their neural correlates have been found in an ERP study (Carlson, West, Taylor, & Herndon, 2002). Relevant for the current study is that "and" relations only require people to spatially index and identify the objects, while "left/right" relation additionally require the assigning of directions and the computation of relations. Therefore, if these steps are psychologically real then participants are expected to be slower in a sentence-picture verification task with "left/ right" relations than with "and" relations because they have to engage in more processing steps in the spatial task. Logan and Compton (Experiment 2; 1996) did indeed find that "and" relations were verified faster than "above/below" relations in sentence-picture verification tasks. Nevertheless, the predicted difference between spatial and non-spatial sentences only pertain to a general performance difference. The steps of the computational model would not be expected to differ for an expected or unexpected stimulus. Thus, the abovementioned predictions concerning expected and unexpected stimuli for the propositional model also hold for this particular computational model.

Finally, we turn to the possibility that individual differences might play a role in the current experiment. Mathews, Hunt, and MacLeod (1980) found evidence that participants, who scored high on psychometric measures of spatial ability, were more likely to adopt a spatial strategy than participants who scored low on psychometric measures of spatial ability. Hence, if a spatial strategy for the processing of simple spatial sentences exists, then it could be expected that individual differences are present in the application of this strategy. In order to be able to examine possible individual differences related to the use of visual-spatial (imagery) processing we employed an additional task in this study: the mental clock test (Paivio, 1978). In the present study we will investigate the correlations between the performance on the mental clock test and the "sentence-expected picture" (associated with a visual-spatial strategy) and "sentence-unexpected picture" trials (associated with a verbal strategy).

Method

Participants

The participants were 11 undergraduate students of the Utrecht University (5 male, 6 female). All participants were native Dutch speakers and reported normal or corrected-to-normal vision. They all gave informed consent and were naïve with respect to the hypotheses. Participants were paid € 7 per hour for participating.

Stimulus materials

Trials consisted of two sequentially presented stimuli: a sentence followed by either another sentence or a picture. Moreover, sentences could either be spatial or non-spatial. In total four different conditions were included: spatial sentences followed by a second stimulus, which was another spatial sentence on 80% of the trials and a picture on 20% of the trials (*spatial 80/20*), spatial sentences followed by a second stimulus, which was another spatial sentence on 20% of the trials and a picture on 80% of the trials (*spatial 20/80*), non-spatial sentences followed by a second stimulus, which was another non-spatial sentence on 80% of the trials and a picture on 20% of the trials (*non-spatial 80/20*), non-spatial sentences followed by a second stimulus, which was another non-spatial sentence on 20% of the cases and a picture on 80% of the trials (*non-spatial 20/80*).

Spatial conditions

For the *spatial 80/20* and the *spatial 20/80* conditions the trial-lists were made up of 32 practice trials and 192 experimental trials, giving a total of 64 practise trials and 384 experimental trials. To ensure that participants could not prepare for a fixed configuration, i.e. always a triangle left of a circle or a circle left of a triangle, we used a small number of "new-object" trials that contained only one of the objects from the sentence (e.g. if S1 was "Triangle left of Square" S2 might be "Triangle left of Circle" or "Circle left of Square"). The practice trials consisted of 24 (80%) and 6 (20%) sentences or pictures as S2, and two "new-object" trials, which were either sentence-sentence (in the spatial 80/20 condition) or sentence-picture (in the spatial 20/80 condition). The experimental trials consisted of 144 (80%) and 36 (20%) sentences or pictures as S2. In addition, 12 "new-object" trials were added, of which 9 were sentence-sentence and 3 were sentence-picture in the spatial 80/20 condition, whereas 9 were sentence-picture and 3 were sentence-sentence in the spatial 20/80 condition. In the spatial conditions S1 was a sentence that described the left/right relation between two objects (circle, square or triangle were the options). The words were displayed vertically for S1, while for S2 both the sentences and pictures were placed in a horizontal organization. The first sentence was displayed vertically to ensure that the position of the two object-words would not be congruent or incongruent with the position of the two objects in S2.

Four options existed for S2, given a sentence-sentence trial with for instance "Triangle left of Circle" as S1: first, spatial expression and position of words were identical i.e. "Triangle left of Circle", second, spatial expression and position of words changed i.e. "Circle right of Triangle", third, spatial expression changed and position of words was identical i.e. "Triangle right of Circle", fourth, spatial expression was identical and position of words changed i.e. "Circle left of Triangle". All options for S2 occurred equally often in the trial-list. In a "new-object" sentence-sentence trial the first two possibilities for S2 of the "normal" trials were available, with one difference: one object was mentioned in S2, which was not mentioned in S1. In a "normal" sentence-picture trial there were two options for S2, which occurred equally often in the trial-list: either the picture depicted the correct spatial relation between the two objects mentioned in S1 or it depicted the opposite spatial relation. In a "new-object" sentence-picture trial there were again two options: an object that was not mentioned in S1 replaced either the left or the right object in the picture. Approximately half of the trials had a S2 that was a correct exemplification of S1. Because of the "new-object" trials there were slightly more trials that had an S2 that was an incorrect exemplification of S1.

Non-spatial conditions

For the *non-spatial 80/20* and the *non-spatial 20/80* conditions the trial-lists had 30 practice trials and 180 experimental trials, giving a total of 60 practise trials and 360 experimental trials. The practice trials consisted of 24 (80%) and 6 (20%) sentences or pictures as S2. The experimental trials consisted of 180 trials, 144 (80%) and 36 (20%) sentences or pictures as S2. S1 was a sentence that described two objects (circle, square or triangle were the options). The words were displayed vertically. In contrast, for S2 both the sentences and pictures were placed in a horizontal organization.

There were six options for S2 in a sentence-sentence trial with for instance "Triangle and Circle" as S1: first, position of words was identical i.e. "Triangle and Circle", second, position of words changed i.e. "Circle and Triangle", third, left object was different i.e. "Square and Circle", fourth, right object was different i.e. "Triangle and Square", fifth and sixth, position of words changed and one object was different i.e. "Circle and Square" or "Square and Triangle". The options that existed for S2 in a sentence-picture trial were identical to those in the sentence-sentence trials. Half of the trials for both sentence-sentence and sentence-picture trials included a S2 that was made up of the same two objects as those mentioned in S1, the other half of the trials had an S2 with one object that wasn't mentioned in S1. The position of the objects was irrelevant for the verification decision, and therefore if S1 was "Triangle and Circle", then both "Circle and Triangle" and "Triangle and Circle" were correct options for S2. The order of the presentation of trials within a trial-list was random for both the non-spatial and the spatial conditions.

All words (written in Dutch) were of 36 points, Courier New type. Viewing distance was not constrained, but the computer was situated so that it was approximately 60 cm. Individual letters subtended 1.0° × .6° of visual angle and pictorial objects subtended 4.8° × 4.8° of visual angle. All stimuli were white on a black background and presented on a 19" Dell monitor with E-Prime software running on a Pentium III computer. A response box was connected to the serial port to collect key-press responses from the subjects.

Design and procedure

Individual participants were tested for about two and a half hours divided over two separate days. On one particular day they either were presented with conditions in which S2 was a sentence on 80% of the trials or with conditions in which S2 was a picture on 80% of the trials. Order of presentation of the spatial and non-spatial conditions was counterbalanced over participants.

Before the start of a condition participants were instructed to respond as quickly as possible while maintaining high accuracy. At the beginning of each condition, participants were informed whether a sentence or a picture would occur most likely after the first sentence. Furthermore, for both spatial and non-spatial conditions, participants were explicitly instructed to verify whether the two objects mentioned in S1 were present in S2 and whether they were in the correct spatial arrangement (spatial condition only). No strategy instructions were given to the participants.

A trial consisted of the following sequence: fixation point (1000 ms), S1 (2000 ms), fixation point (2500 ms), S2 (a maximum of 5000 ms or until response) and finally participants decided whether S2 exemplified S1 correctly. Participants responded by pressing the left or right button of the response box. A left button press equalled "same" for one half of the participants and a right button press equalled "same" for the other half of the participants. Feedback was only given on practice trials and consisted of the word "Correct" or "Incorrect" and the RT. Participants received a 1-minute break after every 60 trials (non-spatial condition) or 64 trials (spatial condition).

Data analysis

The data of the practice trials were discarded, as were trials on which the RT was either 2.5 standard deviations above or below the mean of the condition. Furthermore, the mean percentage error scores for the "new-object" trials were computed to verify whether participants were not relying on a fixed configuration, which would result in very low levels of accuracy on these trials. The independent variables were all varied within participants and included S1 (Spatial or Non-Spatial), S2 (Sentence or Picture), Probability (80% or 20%), and Answer (True or False). Mean RTs, computed over correct trials, and mean percentage error scores were analysed using separate 2 x 2 x 2 x 2 ANOVAs with repeated measures. Additional 4 x 2 ANOVAs were carried with Sentence Option ("Identical to S1", "Spatial expression and position of words changed", "Spatial expression changed" and "Position of words changed") and Probability (80% or 20%) as within-subjects variables.

Individual differences

After the sentence-picture and sentence-sentence tasks had been completed participants were presented with a final task: the mental clock test (Paivio, 1978). In this task participants heard two clock times (e.g. 3:30 and 5:00) and they had to indicate, as fast as possible, for which time the hour hand and minute hand formed the larger angle. Paivio (1978) found that fast average responses, which showed an inverted relationship with the orientation difference between the two sharp angles, correlated with good performance on other spatial imagery tasks ((Space relations, Minnesota Paper Form board (MPFB) (Ernest & Paivio, 1969) and Block Visualization (Guilford, 1967)). Participants who did not show such a "symbolic distance effect", in which the decision becomes faster when the difference in angle becomes greater, were likely to have used strategies other than imagery. Participants in the present study, showing an inverse relationship between the size of the orientation difference and their response time, were labelled "imagers"; participants, who did not show this inverse relationship, were labelled "non-imagers". The lower the average RT of "imagers", the higher the ranking, in which "1" was the lowest and "11" the highest rank. All "non-imagers" were ranked lower than all "imagers", and the "non-imagers" all received the same rank. Participants with error rates higher than 25% were considered to have been using inappropriate strategies or to have been guessing often, and were always ranked lower than subjects with error rates lower than 25%. Correlations (Spearman; two-tailed) were computed between the rank score on the clock task and the RTs on the spatial sentence-picture task.

Results

Reaction times

The main effect of S1 was significant, $F(1, 10) = 117.5$, $p < .001$, showing that participants were faster in the Non-Spatial than in the Spatial condition (see Table 1). The main effect of S2 was significant, $F(1, 10) = 6.1$, $p = .03$, indicating that RTs were faster when S2 was a picture than when S2 was a sentence. The main effect of Probability was significant, $F(1, 10) = 72.2$, $p < .001$, showing that RTs were faster for trials with an 80% probability than for trials with a 20% probability. The main effect of Answer just missed significance, $F(1, 10) = 4.3$, $p = .07$, indicating a trend for faster RTs when the answer was True than when the answer was False.

Table 1.
Mean RTs (ms), standard errors in parentheses.

Answer	True		False	
S2	Sentence	Picture	Sentence	Picture
	"Spatial"			
Probability				
20%	1744	1611	1848	1746
	(130.8)	(139.7)	(145.9)	(119.5)
80%	1580	1007	1641	1194
	(62.0)	(126.9)	(74.2)	(155.1)
	"Non-spatial"			
20%	986	969	1007	926
	(71.0)	(62.1)	(75.9)	(55.0)
80%	832	774	855	780
	(25.8)	(65.8)	(21.7)	(66.1)

Importantly, the interaction between S1 and Probability was significant, $F(1, 10) = 72.9$, $p < .001$. Analysis of this interaction showed that RTs were faster for trials with an 80% probability than with a 20% probability, but this difference was greater for the spatial sentences (mean= 1355 ms vs. 1738 ms) than for the non-spatial sentences (mean= 810 ms vs. 972 ms), $t(10) = 8.5$, $p < .001$. The interaction between S1 and S2 was significant, $F(1, 10) = 7.1$, $p = .03$. Further analysis showed that if participants had read a spatial sentence they were faster when S2 was a picture (mean= 1390 ms) than when S2 was a sentence (mean= 1703 ms), $t(10) = 2.6$, $p = .03$, whereas if they had read a non-spatial sentence they showed similar RTs when S2 was a picture (mean = 920 ms) or a sentence (mean= 862 ms), $t(10)= 1.7$, $p= .11$. The interaction between S1 and Answer was significant, $F(1, 10)= 8.7$, $p= .01$, indicating faster RTs for True than False responses, but this effect was only significant when participants had read a spatial sentence (mean= 1485 ms vs. 1608 ms), $t(10)= 2.8$, $p= .02$, and not when they had read a non-spatial sentence (mean= 890 ms vs. 892 ms), $t(10)< 1$. There were no other significant first-order interactions, all $F(1, 10)< 1.6$.

Highly relevant for the discussion was that the second-order interaction between S1, S2 and Probability was significant, $F(1, 10)= 7.7$, $p= .02$. Further analysis indicated that the interaction between S1 and Probability was significant, but only when S2 was a picture, $F(1, 10)= 30.6$, $p< .001$, and not when S2 was a sentence, $F(1, 10)< 1$. Therefore, participants were slower on unexpected than on expected stimuli, but this effect was only significantly stronger for spatial sentences than for non-spatial sentences, $t(10)= 5.5$, $p< .001$, when S2 was a picture (mean = 1101 ms vs. 1679 ms; See Figure 1).

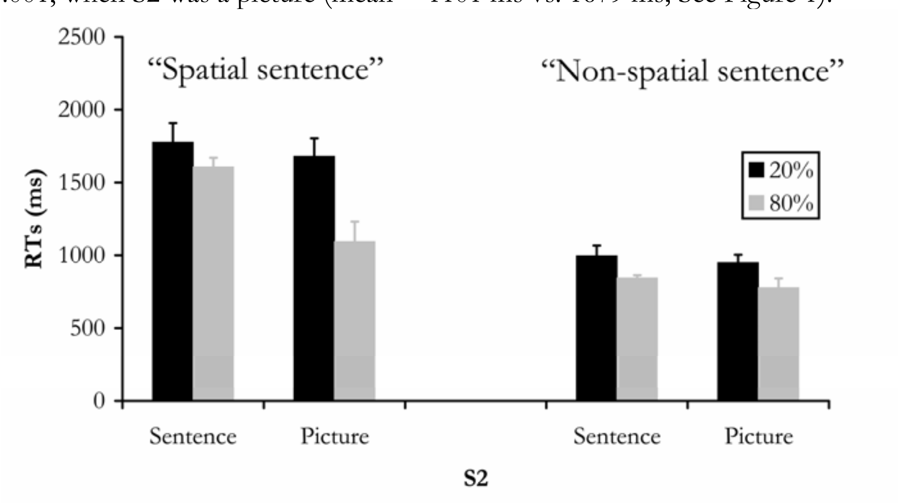

Figure 1.
Mean RTs (ms) for both the spatial and non-spatial sentences.

The second-order interaction between S1, S2 and Answer was significant, $F(1, 10)= 7.4$, $p= .02$. Analysis of the component interactions showed that the interaction between S1 and Answer was only significant when S2 was a picture, $F(1, 10)= 18.8$, $p= .001$, and not when S2 was a sentence, $F(1, 10)= 1.5$, $p= .25$. This interaction between S1 and Answer indicated that RTs were faster for True than for False responses, but only if participants had read a spatial sentence (mean= 1309 ms vs. 1470 ms), $t(10)= 3.1$, $p= .01$, and not when they had read a non-spatial sentence (mean= 872 ms vs. 853 ms), $t(10)< 1$. In general, the RTs for True responses tended to be faster than False responses. The interaction between S1, S2, and Answer did not compromise the interpretation of the main results concerning S1, S2, and Probability. All other interactions were not significant, all $F(1, 10) < 1$.

Sentence options

The main effect of Sentence option was significant, $F(3, 30) = 20.3$, $p < .001$. Further analysis indicated that RTs were faster for identical sentences than for sentences with a changed spatial expression, $t(10) = 3.9$, $p = .003$, sentences with a changed position of words, $t(10) = 5.5$, $p < .001$, and sentences with a changed spatial expression and a changed position of words, $t(10) = 6.0$, $p < .001$. RTs were also faster for sentences with a changed spatial expression than for sentences with a changed spatial expression and a changed position of words, $t(10) = 3.5$, $p = .005$, and sentences with a changed position of words, $t(10) = 3.5$, $p = .006$. RTs were similar for sentences with a changed position of words and sentences with a changed spatial expression and a changed position of words, $t(10) = 1.4$, $p = .20$ (see Table 2). The main effect of Probability was not significant, $F(1, 10) = 2.9$, $p = .12$. The interaction between Sentence Option and Probability was not significant, $F(1, 10) = 1.3$, $p = .29$.

Table 2.
Mean RTs (ms) for the four spatial sentence options for S2 in relation to S1, standard errors in parentheses.

Sentence Option (e.g. S1 is 'Triangle left of Circle')	
Spatial expression and position of words identical	1405
S2 is 'Triangle left of Circle'	(70.5)
Spatial expression and position of words changed	1985
S2 is 'Circle right of Triangle'	(98.5)
Spatial expression changed and position of words identical	1608
S2 is 'Triangle right of Circle'	(106.9)
Spatial expression identical and position of words changed	1899
S2 is 'Circle left of Triangle'	(108.1)

Error scores

The mean percentage error scores for "new-object" trials was 19% for sentence-sentence trials and 17% for sentence-picture trials. The main effect of S1 just missed significance, $F(1, 10) = 4.2$, $p = .07$, indicating a trend towards participants making less errors when they read a non-spatial sentence than when they read a spatial sentence (see Table 3). The main effect of Probability was significant, $F(1, 10) = 8.2$, $p = .02$, showing that participants made more errors in the 20% conditions than in the 80% conditions. All other effects were not significant, All $F(1, 10) < 3.0$, $p > .11$.

Table 3.
Mean error scores (%), standard errors in parentheses.

Answer	True		False	
S2	Sentence	Picture	Sentence	Picture
	"Spatial"			
Probability				
20%	15 (2.6)	16 (3.3)	14 (4.8)	16 (3.9)
80%	10 (1.5)	9 (1.7)	8 (1.2)	13 (2.4)
	"Non-spatial"			
20%	9 (2.3)	6 (1.9)	11 (3.5)	11 (2.1)
80%	6 (.7)	10 (2.6)	6 (1.1)	10 (2.1)

Sentence Options

No significant effects were found in relation to the four different spatial sentence options, all $F < 2.4$, $p > .16$.

Individual differences

Based on the mental clock test the participants were ranked for their spatial imagery ability. Of the participants, five were labelled as an "imager", and six were labelled as a "non-imager". There was one participant who made an error on more than 25% of the trials, and was therefore assigned the lowest rank. The Spearman correlation between the rank number based on the clock test and the RTs on the "sentence-expected picture" trials was -.61, $p = .02$, indicating that the higher the ranking on the mental clock test was, the faster the verification RTs for expected pictures were. The Spearman correlation between the rank number and the RTs on the "sentence- unexpected picture" trial was -.32, $p = .17$.

Discussion

In the present study we investigated the extent to which strategic and automatic processes influence the representational format of linguistic spatial relations. In order to examine the possible effect of strategies we used sentence-sentence and sentence-picture verification trials in mixed blocks, whereby the probability of a specific second stimulus was fixed within a block. The performance of participants was always worse for unexpected than for expected stimuli. Therefore, there was a general cost associated with expecting to verify information in one modality, verbal or pictorial, while this had to be done in the other modality. In addition, the difference between expected and unexpected stimuli was significantly greater for spatial sentences ("Triangle left of Circle") than for non-spatial sentences ("Triangle and Circle"). Hence, there was an additional cost associated with verifying spatial information in an unexpected stimulus. If a spatial sentence is always represented propositionally then there should not be a difference in performance on unexpected and expected stimuli for spatial and non-spatial sentences. However, the presence of additional costs for spatial sentences suggests that participants followed different strategies depending on the context (i.e. likelihood of a certain modality) in which the spatial sentence was read.

Although we found that the advantage of expected over unexpected stimuli was greater after participants had read a spatial than a non-spatial sentence, we only found this difference between spatial and non-spatial sentences for sentence-picture trials and not for sentence-sentence trials. MacLeod et al. (1978) argued that a spatial sentence is represented either propositionally or pictorially dependent on the strategy an individual follows. If participants in our experiment had formed a propositional representation or a pictorial representation, then one would expect an additional cost for both sentence-picture and sentence-sentence trials, in which the second stimulus was unexpected. Yet, we only found these costs for the sentence-picture trials. Therefore, a model that assumes that the representational format of the spatial sentence is either a set of propositions or a mental picture does not fit these data very well. Instead, we want to suggest a *dual-representational* or *dual-code* model that assumes that participants automatically represented the spatial sentence propositionally. This was indicated by the fact that there were no additional costs for unexpected sentences. In addition, participants formed a pictorial representation strategically dependent on the context (i.e. expecting a sentence or a picture) in which the sentence was read. This was supported by the fact that there were additional costs for unexpected pictures.

Moreover, the dual-representational model also predicts that if employment of a spatial strategy is stimulated, it is likely that the application or the efficiency of this strategy is dependent on individual differences in spatial (imagery) ability. Indeed we observed that when participants expected a picture after a spatial sentence, the verification RTs were (significantly) negatively correlated with the rank number of spatial imagery ability based on the mental clock task (Paivio, 1978). This correlation indicated that participants who were classified as good spatial imagers had faster verification RTs than participants who were classified as poor spatial imagers. Moreover, when participants did not expect a picture after a spatial sentence the verification RTs and the rank numbers of spatial imagery ability were not significantly correlated. We hypothesize that at least a part of the faster verification RTs for expected than unexpected pictures can be explained by the availability of a mental image (thanks to a pictorial strategy) when a picture is expected, contrasted with a situation in which a picture is not expected. An interesting question is at what point participants choose to employ a pictorial strategy. The present experiment introduced a strong bias (80% vs. 20%) for either sentences or pictures. What would happen if there had been no bias (50% vs. 50%) for either modality? We speculate that the individual spatial and verbal abilities will play an even more prominent role. If individual ability is indeed the main factor in a no bias situation, then only the "high-spatial imagers" would construct the optional pictorial representation.

Several sentence-picture verification studies (e.g. Hunt & MacLeod, 1978; MacLeod et al., 1978), supporting the existence of a spatial strategy, shared a common trait: the picture that followed the spatial sentence only depicted either the correct spatial relation between the objects mentioned in the sentence or the opposite spatial relation. Therefore, participants could be preparing for these two specific pictures and the spatial strategy might be dependent on this highly predictable stimulus. Kroll and Corrigan (1981) replicated the results of MacLeod et al. (1978) with respect to the two distinct response patterns suggestive of two different strategies, but also found that only one response pattern (i.e. indicative of a verbal strategy) was left after unexpected pictures were introduced in the experiment. It could be that the spatial strategy in a sentence-picture task with just two possible configurations is actually a "one-object" strategy, in which participants only need to remember one object to be able to correctly respond to the picture. As noted by Logan and Compton (1996), correctly apprehending a spatial sentence such as "star is above plus" requires that each of the arguments is identified separately and that the spatial relation between them is computed. In our experiment we made sure that participants had to identify both objects by the inclusion of "new-object" trials. Participants scored well above chance on these trials, which indicated that they were not relying on a single object to make a verification decision. Consequently, the evidence we found for a spatial strategy cannot be explained by the fact that it was actually a "one-object strategy".

As a secondary result, we looked at the four different possibilities for the second spatial sentence in a sentence-sentence trial. These possibilities were: the second sentence was identical to the first sentence, the spatial expression and the position of the words were changed, the spatial expression was changed, or the position of the words was changed. We found that the more the second sentence differed from the first sentence the slower the participants were at making a verification decision concerning the second sentence. This effect is in line with the notion that both the first and the second sentence were represented as a set of propositions, whereby the differences in propositional components needed to be resolved in a serial fashion. Interestingly, this effect was the same for expected and unexpected sentences. This finding is in accordance with a dual-representational model that assumes that even when participants follow a pictorial strategy the sentence is also represented (automatically) as a set of propositions.

The dual-representational model predicts that people will form a pictorial representation in a visual-spatial context. If the construction of a pictorial representation is under strategic control then it is worth considering what other variables might influence the utilization of the visual-spatial strategy. We already mentioned the influence of individual imagery differences on the likelihood that a pictorial strategy was chosen. Further evidence for the role of individual differences in the representation of spatial sentences comes from a recent study of ours (Noordzij, Van der Lubbe, Neggers, & Postma, 2004). In this study we found that performance on a sentence-picture verification task was hampered by a spatial dual task (i.e. spatial tapping during the presentation of the spatial sentence), but only for participants who were classified on basis of their RT patterns as having used a visual-spatial strategy, and not for those who were classified as having used a verbal strategy. Another variable that might influence the utilization of a visual-spatial strategy is the time that people have between reading the spatial sentence and consequently comparing it to a visual-spatial stimulus. Tversky (1975) found that the delay between presenting a spatial sentence and a subsequent picture influenced the modality of the representation. When the sentence and the picture were presented simultaneously sentences containing "not" were processed slower than positive sentences, whereas when the picture was presented five seconds after the sentence had disappeared negative and positive sentences resulted in similar verification RTs. Tversky (1975) concluded that the sentences were encoded verbally for simultaneous comparison, whereas they were encoded pictorially when compared to a picture that appeared after the sentence had disappeared. In line with this we found evidence for a visual-spatial strategy in our study in which a picture followed a spatial sentence after a delay of two and a halve seconds.

Several recent neuroimaging studies support a dual-representational view that assumes that the representation of a linguistic spatial sentence can depend on both propositional and visual-spatial processes. Damasio et al. (2001) found in a PET study that naming static spatial relationships was associated with activation in the left inferior prefrontal cortex as well as activation in the left supramarginal gyrus, an area in the inferior parietal cortex. Furthermore, Carpenter, Just, Keller, Eddy, and Thulborn (1999) observed that, within a sentence-picture verification paradigm, reading the simple spatial sentence not only always involved activation in classical language areas (Broca and Wernicke), but also always involved activation in classical spatial areas in the parietal cortex. While these results were interpreted to indicate that spatial prepositions such as "to the left of" are processed in the left parietal cortex, it might also be that left parietal activation follows from the fact that participants always applied a pictorial strategy. This can be argued because these aforementioned neuroimaging studies presented the spatial sentence only in relation to visual-spatial stimuli.

The current dual representational model has some resemblance with other models that have been proposed for text comprehension. The mental or situation model theory (Johnson-Laird, 1983; Zwaan & Radvansky, 1998) assumes that people do not only form a propositional representation of a text, but also a representation, called a mental or situation model, that has a structure similar to the structure of what (for instance a spatial relation) the text describes. However, mental models, or situation models should not be confused with mental images, because the former are more general and abstract than the latter. Mental models can represent concepts such as negation, which cannot be visualised. One of our assumptions was that non-spatial sentences such as "triangle and circle" are represented propositionally. Within the mental model theory such an indeterminate (i.e. with respect to spatial position) sentence could be represented as a set of mental models and not as a proposition. For the present study this means that both spatial and non-spatial sentences could be represented in a non-propositional format: A sentence such as "triangle left of circle" corresponds with one unique mental model, whereas a sentence such as "triangle and circle" requires at least two mental models. Therefore, according to the mental model theory, if both sentences were represented in a non-propositional format, then spatial sentences (i.e. one model) should be easier to verify against a picture than non-spatial sentences (i.e. at least two models). We found that verification RTs were much faster for non-spatial sentences than for spatial sentences, and therefore, also given the mental model theory, it is not likely that non-spatial sentences were represented in a non-propositional format.

The dual representational model is in a way an extension of the dual-coding hypothesis of Paivio (1971). The dual coding hypothesis assumes that words can be represented both in a verbal code and an imaginal code in memory. This hypothesis is mainly supported by findings that concrete words are generally remembered better than abstract words (for an overview of findings supporting the dual-coding hypothesis, see Paivio (1983)). The idea is that the concrete words elicit imagery more easily than abstract words, and the imaginal representation serves as supplementary memory in item retrieval. Furthermore, the dual-coding hypothesis does not assume that the imaginal representation is represented automatically, which is an assumption that is shared with the dual-representational model. Importantly, the dual-coding hypothesis concerns the representation of meaning of single words in memory, while the dual-representational model is specifically designed for the representation of linguistic spatial relations. As noted in the Introduction the representation of single words and concepts are different from those associated with spatial relations between objects (Landau & Jackendoff, 1993). Therefore, the dual representational model actually extends the dual-coding hypothesis to encoding of spatial relation terms, and the role of situational context.

The most recent model concerning text comprehension, which is currently receiving a great deal of attention is the "perceptual symbols systems" theory (Barsalou, 1999; Barsalou, Simmons, Barbey, & Wilson, 2003).

According to this theory perceptual representations rather than amodal propositions would be the basis of all cognitive processes. For instance, in a recent study participants read sentences in which the shape of an object was implied (Zwaan, Stanfield, & Yaxley, 2002). Next, participants saw a picture in which the object was depicted, and they were faster to respond to this picture when the shape of the object in the picture matched the shape implied by the sentence, than when the shape mismatched the information in the sentence. The researchers concluded that perceptual symbols are routinely activated in language comprehension. The perceptual symbols systems theory has been confirmed in experiments that focused on single object processing. Interestingly, our present findings concerning linguistic spatial relations seem to contradict the notion that activation of perceptual representations is obligatory. We argue that it is more likely that a perceptual representation of a sentence such as "triangle left of circle" is formed strategically and not automatically.

Further research on the dual representational model should be focused on the comparison processes that are involved in verifying linguistic spatial information in a picture. The dual representational model assumes that a spatial sentence is represented propositionally and pictorially in a visual-spatial context, and only propositionally in a verbal context. An interesting question is how a dual representation (propositional/ pictorial), instead of a single representation (propositional) can be used to verify information in a picture. We would like to suggest two possibilities. The additional pictorial representation in a dual representation enables a fast, pre-attentive mechanism that allows a template match (pop-out) of the picture against the pictorial representation. Alternatively, the processes belonging to a single or dual representation are similar and accurately described by a constituent comparison model (such as those of Clark & Chase (1972) and Logan & Sadler (1996)) in which objects have to be identified and spatial relations have to be computed in a serial fashion. The difference between single and dual representations would then arise because the comparison process between the representation of the spatial sentence and the picture are overall faster when the modality of the representation of the sentence matches the modality of the picture.

To distinguish between these two options (template matching and constituent steps) it might be interesting to determine the effect of additional distractors in expected and unexpected pictures. According to the theory of Logan and Sadler (1996), which assumes constituent steps in the comparison, all objects in the picture are spatially indexed (i.e. establish a correspondence between the linguistic and perceptual representation of an object). However, only the reference and located object are used for establishing a reference frame and computing a spatial relation. Carlson and Logan (2001) provided evidence for the constituent model by showing that in a sentence-picture verification task the specific position of a distractor did not have an effect on performance, and this was found after comparing distractor positions that were competing or non-competing with the position of the located object. Therefore, if these kind of constituent steps play a role for both single and dual representations then you expect the addition of distractors to result in slower RTs (due to additional spatial indexing for every distractor), and you also expect the position of distractors to be irrelevant (because no spatial information is computed for the distractors) for both expected and unexpected pictures. In contrast, if template matching plays a role for the dual representation, then you expect that the number of objects would have no effect on RTs of expected pictures, because pop-out is by definition insensitive to the number of items in the display (e.g. Heathcote & Mewhort, 1993). However, the position of distractors would be crucial for the processing advantage of expected over unexpected pictures. If a distractor is placed in a position in between a reference and located object then template matching is disturbed, whereas if a distractor is placed in a position outside the configuration formed by the reference and located object then template matching is possible.

Another possibility for further research might be to design an experiment identical to the present one in which S1 is a picture. According to the dual representational model this picture is automatically represented propositionally and strategically represented pictorially. Therefore, the results of the experiment with S1 as a picture should be similar to those found in the present experiment. In our above-mentioned recent study (Noordzij et al., 2004) we did include both sentence-picture and picture-picture trial in combination with a spatial dual task during the presentation of S1. Participants made more accurate decisions and they were faster when S1 was a picture than when S1 was a sentence. This could indicate that the pictorial representation based on the picture was more effectively compared to another picture than a pictorial representation based on a sentence. This difference might arise because fast template matching was available for the pictorial representation based on a picture but not for the pictorial representation based on the sentence. Furthermore, we found that spatial tapping mostly interfered with the performance on the sentence-picture task and less with the performance on the picture-picture task. In this study, template matching in the picture-picture condition was likely because the pictorial S1 and S2 were very similar (i.e. S2 only appeared on a different location than S1 and the distance between the objects was different). Therefore, it seems likely that only in the sentence-picture task participants were actively constructing a pictorial representation, while they could rely on passively storing the visual characteristics of the picture in the picture-picture trials. In addition, this might indicate that fast template matching is not available for a dual-representation based on a spatial sentence.

In summary, the present study provides evidence for a dual-representational model, in which people automatically represent a spatial sentence propositionally. In addition, dependent on the context in which this spatial sentence is read, people can follow a pictorial strategy, which results in a supplementary visual-spatial representation. This finding has implications for research into the neural bases of the apprehension of linguistic spatial relations and more specifically spatial prepositions. The recent findings concerning involvement of parietal areas in the processing of spatial sentences could either reflect a necessary involvement of these areas for understanding spatial terms or it could reflect the application of a pictorial strategy in a visual-spatial context. Future neuroimaging research should investigate the involvement of parietal areas with the processing of spatial sentences in both verbal and visual-spatial contexts.

References

Barsalou, L. W. (1999). Perceptual symbol systems. *Behavioral & Brain Sciences, 22*(4), 577-660.
Barsalou, L. W., Simmons, W. K., Barbey, A. K., & Wilson, C. D. (2003). Grounding conceptual knowledge in modality-specific systems. *TRENDS in Cognitive Sciences, 7*(2), 84-91.
Carlson, L. A. (2003). Using spatial language. *Psychology of Learning and Motivation, 43*, 127-161.
Carlson, L. A., & Logan, G. D. (2001). Using Spatial Terms to Select an Object. *Memory & Cognition, 29*(6), 883-892.
Carlson, L. A., West, R., Taylor, H. A., & Herndon, R. W. (2002). Neural correlates of spatial term use. *Journal of Experimental Psychology: Human Perception & Performance, 28*, 1391-1408.
Carpenter, P. A., & Just, M. A. (1975). Sentence comprehension: A psycholinguistic processing model of verification. *Psychological Review, 82*(1), 45-73.
Carpenter, P. A., Just, M. A., Keller, T. A., Eddy, W. F., & Thulborn, K. R. (1999). Time course of fMRI-activation in language and spatial networks during sentence comprehension. *Neuroimage, 10*(2), 216-224.
Clark, H. H., & Chase, W. G. (1972). On the process of comparing sentences against pictures. *Cognitive Psychology, 3*(3), 472-517.
Damasio, H., Grabowski, T. J., Tranel, D., Ponto, L. L. B., Hichwa, R. D., & Damasio, A. R. (2001). Neural Correlates of Naming Actions and of Naming Spatial Relations. *Neuroimage, 13*, 1053-1064.
Ernest, C. H., & Paivio, A. (1969). Imagery ability in paired-associate and incidental learning. *Psychonomic Science, 15*, 181-182.
Glushko, R. J., & Cooper, L. A. (1978). Spatial comprehension and comparison processes in verification tasks. *Cognitive Psychology, 10*(4), 391-421.
Guilford, J. P. (1967). *The nature of human intelligence*. New York: McGraw-Hill.
Heathcote, A., & Mewhort, D. J. K. (1993). Representation and selection of relative position. *Journal of Experimental Psychology: Human Perception & Performance, 19*(3), 488-516.
Hunt, E., & MacLeod, C. M. (1978). The sentence-verification paradigm: A case study of two conflicting approaches to individual differences. *Intelligence, 2*(2), 129-144.
Jager, G., & Postma, A. (2003). On the hemispheric specialization for categorical and coordinate spatial relations: a review of the current evidence. *Neuropsychologia, 41*, 504-515.
Johnson-Laird, P. N. (1983). *Mental models*. Cambridge, MA: Harvard University Press.
Kemmerer, D., & Tranel, D. (2000). A double dissociation between linguistic and perceptual representations of spatial relationships. *Cognitive Neuropsychology, 17*(5), 393-414.
Kosslyn, S. M. (1987). Seeing and imagining in the cerebral hemispheres: A computational approach. *Psychological Review, 94*(2), 148-175.
Kroll, J. F., & Corrigan, A. (1981). Strategies in sentence-picture verification: The effect of an unexpected picture. *Journal of Verbal Learning & Verbal Behavior, 20*(5), 515-531.
Landau, B., & Jackendoff, R. (1993). "What" and "where" in spatial language and spatial cognition. *Behavioral & Brain Sciences, 16*(2), 217-265.
Logan, G. D. (1994). Spatial attention and the apprehension of spatial relations. *Journal of Experimental Psychology: Human Perception & Performance, 20*(5), 1015-1036.
Logan, G. D., & Compton, B. J. (1996). Distance and distraction effects in the apprehension of spatial relations. *Journal of Experimental Psychology: Human Perception & Performance, 22*(1), 159-172.

Logan, G. D., & Sadler, D. D. (1996). A computational analysis of the apprehension of spatial relations. In P. Bloom & M. A. Peterson & L. Nadel & M. F. Garret (Eds.), *Language and Space* (pp. 493-529). Cambridge, MA: MIT Press.

MacLeod, C. M., Hunt, E. B., & Mathews, N. N. (1978). Individual differences in the verification of sentence-picture relationships. *Journal of Verbal Learning & Verbal Behavior, 17*(5), 493-507.

Mathews, N. N., Hunt, E. B., & MacLeod, C. M. (1980). Strategy choice and strategy training in sentence-picture verification. *Journal of Verbal Learning & Verbal Behavior, 19*(5), 531-548.

Noordzij, M. L., Van der Lubbe, R. H., Neggers, S. F. W., & Postma, A. (2004). Spatial tapping interferes with the processing of linguistic spatial relations. *Canadian Journal of Experimental Psychology, 58*(4), 259-271.

Paivio, A. (1971). *Imagery and verbal processes*. New York: Holt, Rinehart, and Winston.

Paivio, A. (1978). Comparisons of mental clocks. *Journal of Experimental Psychology: Human Perception & Performance, 4*(1), 61-71.

Paivio, A. (1983). The empirical case for dual coding. In J. C. Yuille (Ed.), *Imagery, Memory and Cognition*. Hillsdale, New Jersey: Lawrence Erlbaum Associates.

Reichle, E. D., Carpenter, P. A., & Just, M. A. (2000). The neural bases of strategy and skill in sentence-picture verification. *Cognitive Psychology, 40*(4), 261-295.

Seymour, P. H. (1974). Generation of a pictorial code. *Memory & Cognition, 2*(2), 224-232.

Tversky, B. (1969). Pictorial and verbal encoding in a short-term memory task. *Perception and Psychophysics, 6*(4), 225-233.

Tversky, B. (1974). Retrieval of pictorial and verbal stimulus codes. *Bulletin of the Psychonomic Society, 4*(6), 580-582.

Tversky, B. (1975). Pictorial encoding of sentences in sentence-picture comparison. *Quarterly Journal of Experimental Psychology, 27*, 405-410.

Zwaan, R. A., & Radvansky, G. A. (1998). Situation models in language comprehension and memory. *Psychological Bulletin, 123*(2), 162-185.

Zwaan, R. A., Stanfield, R. A., & Yaxley, R. H. (2002). Language Comprehenders Mentally Represent the Shapes of Objects. *Psychological Science, 13*(2), 168-171.

Chapter 4 | Electrophysiological support for the existence of different strategies in the processing of spatial sentences

Abstract

Various models for the representation of spatial sentences have been proposed. The aims of the present EEG-study were to further distinguish between the various representation options, and to gain insight in *when* certain differences in representational format arise. In order to examine the possible existence of different strategies we used sentence-sentence and sentence-picture verification trials in mixed blocks, whereby the probability of a specific second stimulus was fixed within a block. We again found behavioural evidence for different processing strategies for the encoding of spatial sentences that result in different representational formats. Early brain activation linked to parsing spatial sentences (and not non-spatial sentences) occurred in areas generally associated with mental image processing, and only so when participants were explicitly expecting to compare verbal information to a picture. Therefore, this is the first study to provide neuroimaging evidence that different representational formats of spatial sentences arise almost directly when people are reading a spatial sentence. These findings were in line with the *dual-representational model*, which assumes that people automatically represent the spatial sentence as a set of propositions, and strategically form a mental image.

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Introduction

After hearing a spatial description, such as *the car-keys are on the table,* people need to encode this verbal information in such a way that it enables them to find the keys in a visual scene. Previous research has indicated that a simple spatial sentence might elicit two types of mental representations. On the one hand, a specific pictorial code (i.e. mental image) could be constructed of the described spatial configuration. Consequently, when the car-keys have to be found in a visual scene, the mental image can be directly compared to the available perceptual information. On the other hand, it might also be that people form an abstract verbal code (set of propositions) that is compared to the visual scene by also recoding this visual scene into a propositional representation. Various models for the representation of spatial sentences have been proposed based on the two options mentioned above: people always represent a spatial sentence as a set of propositions (*constituent comparison model*; Clark & Chase, 1972; Logan & Sadler, 1996), people always represent a spatial sentence as a type of mental image (perceptual simulation) (*perceptual symbol systems*; (Barsalou, 1999), people can deliberately switch between a set of propositions and a mental image (*strategic model*; MacLeod, Hunt, & Mathews, 1978), or people always represent a spatial sentence as a set of propositions and can strategically form a mental image on top of that (*dual-representational model*; Noordzij, Van der Lubbe, & Postma, in press; Paivio, 1983). The first two models assume that people can only maintain one type of representation and cannot vary between the two, whereas the last two models assume that people can follow different strategies to form distinctly different representations of a spatial sentence. The aims of the present EEG-study were to further distinguish between the various representation options, and to gain insight in *when* certain differences in representational format arise.

Previous studies investigating the representational format of spatial sentences have often employed a so called sentence-picture verification task. In this task participants first read a sentence such as "the star is above the plus" and consequently see a picture of two objects and have to decide whether this picture contains the two objects in the correct spatial arrangement. Researchers examined the influence of linguistic complexity (Clark & Chase, 1972; MacLeod et al., 1978), task instructions (Eley, 1981; Glushko & Cooper, 1978), individual differences (Hunt & MacLeod, 1978), context (Noordzij et al., in press), and dual tasks (Noordzij, Van der Lubbe, Neggers, & Postma, 2004) on performance in this task. The majority of these studies provided evidence that people used verbal and visual-spatial strategies in executing the sentence-picture verification task (for a review see Noordzij et al., in press; Roberts, Wood, & Gilmore, 1994). Assuming that sentence-picture verification tasks can be executed in different ways, a logical next question is then *when* these differences arise. During a sentence-picture verification trial participants have to encode the sentence, encode the picture, compare the sentence and the picture, make a decision, and they have to express this decision by means of a button press or a verbal response. If the difference emerges after the picture is shown, then it could be that presumed differences in representations actually entailed some sort of difference in the comparison processes or even a response bias. Only when evidence for differences in processing emerge before the picture is shown can the conclusion be drawn that people indeed form different representations of the spatial sentence. Hence, in order to delineate the different processes and isolate differences that might result from different processing strategies of the spatial sentence it would be necessary to include amore online type of measure of all the involved processes. A good candidate is the recording of neural activity with electroencephalogram (EEG) or functional Magnetic Resonance Imaging (fMRI).

Reichle, Carpenter, and Just (2000) used fMRI to investigate the existence of different strategies in a (spatial) sentence-picture verification task. Participants were taught to use both a visual-spatial strategy (i.e. form a mental image) and a verbal strategy (i.e. suppress a mental image and remember only the actual wording). In the scanner participants performed a sentence-picture verification task in different, short blocks with alternating strategies between blocks. The verbal strategy induced more activation in verbal areas (e.g. Broca's area), whereas the visual-spatial strategy activated areas associated with spatial processing (e.g. parietal cortex), which provides strong evidence that different strategies and representations can be employed in the sentence-picture verification task. Unfortunately, a block design was employed, which excludes the possibility to discern whether the differences were related to encoding the spatial sentence or the picture, or to the comparison between the sentence and the picture. In order to avoid this problem in the current study we used a behavioural (spatial) sentence-picture and sentence-sentence verification experiment (Noordzij et al., in press), while measuring EEG. Using this S1-S2 verification task in combination with ERPs has several advantages. First, it enables the exclusion of processes that are related to the encoding of the second stimulus, and the subsequent response, because they will be carried out after S2. Second, ERPs yield precise information about the timing of specific effects, and source localization analyses (Scherg, 1990) gives an indication of the likeley cortical areas that are involved in the effects of interest.

Most of the studies examining ERPs and verbal stimuli focused on early, short-lived components (N1, P2, N400) in the ERP, related to the processing of a single word (e.g. Hagoort, 2003; West & Holcomb, 2000). However, we were not interested in initial processing differences between spatial and non-spatial sentences. Instead, we were interested in differences with respect to higher levels of encoding and short-term storage of the stimuli and possibly in preparatory processes with respect to a forthcoming stimulus. Therefore, we examined two slow wave components of the ERP: a slow wave

(SW) between 550 and 1100 ms after the onset of the first stimulus (S1: spatial or non-spatial sentence) and a slow wave (late contingent variation (CNV)) 1000 to 0 ms before the onset of the second stimulus (S2: sentence or picture). The SW is considered to reflect processes that are closely related to the encoding and storage of information (Cohen et al., 2001; Ruchkin, Johnson , Grafman, Canoune, & Ritter, 1997; Ruchkin, Johnson, Mahaffey, & Sutton, 1988), and the late CNV is considered to reflect processes that are associated with preparatory processes before a response to a forthcoming stimulus (Cohen et al., 2001; Rösler, Heil, & Röder, 1997; Walter, Cooper, Aldridge, McCallum, & Winter, 1964). In the present EEG study we examined at what point in time event related potentials (ERP) differ between trials in which participants supposedly follow a visual-spatial strategy when encoding a spatial sentence, and for trials in which participants do not follow a visual-spatial strategy (i.e. when the second stimulus was a sentence).

In the present experiment participants read a sentence (spatial or non-spatial, S1) followed by a picture (S2) or a sentence (S2). The tasks were thus sentence-picture verification or sentence-sentence verification. The probability of the second stimulus was varied: either 80% of the stimuli were pictures and 20% were sentences, or 80% of the stimuli were sentences and 20% were pictures. In our previous study (Noordzij et al., in press) we found that people were slower on unexpected than expected stimuli, especially for the spatial sentences. However, this difference between spatial and non-spatial sentences was only present when the second stimulus was a picture and not when the second stimulus was a sentence. We suggested a dual-representational model in which participants automatically represented the spatial sentence propositionally, and participants formed a mental image when they expected a picture, but not when they expected a sentence.

If participants formed different representations of spatial sentences dependent on the nature of S2 (sentence or picture) then the SW and/ or the CNV was expected to differ for spatial sentences followed by sentences or pictures. More specifically, the dual representational model predicts that people will employ imagery when they read a spatial sentence and expect a picture, but not when they expect a sentence. Previous ERP studies have shown that imagery processes are associated with negative slow wave activity (mostly between ± 600-1200 ms after S1 onset) at parieto-occipital regions (e.g. Rösler, Heil, Bajric, Pauls, & Hennighausen, 1995). Therefore, we expected to find a larger slow wave at parieto-occipital regions when participants read a spatial sentence and expected a picture than when participants read a spatial sentence and expected a sentence. Of course, general differences in the SW or CNV might be expected because participants are preparing to view a picture or read a sentence, and therefore the abovementioned prediction holds after correcting for effects that have been found in the control conditions with non-spatial sentences.

In sum, in the present study we can investigate whether the representational differences in a sentence-picture verification task arise either during the slow wave or during the CNV, indicative of a direct formation of a mental image during the reading of the spatial sentence or a later formation as a result of the anticipation of S2, respectively. In contrast , if participants only formed one type of representation of spatial sentences then the SW and/ or the CNV was expected to be the same for spatial sentences independent of the likely forthcoming stimulus (after correcting for general differences based on the control conditions with non-spatial sentences).

Method

Participants

Twelve participants (6 male, 6 female, aged 19- 37 years) were included in this study. All participants were native Dutch speakers and reported normal or corrected-to-normal vision. They were all right handed as assessed with Annet's handedness questionnaire (Annet, 1970). They all gave informed consent, and the study was approved by the ethics committee of the faculty of social sciences. Participants were paid € 7 per hour for participating.

Stimulus materials

Trials consisted of an S1-S2 paradigm: a sentence followed by either another sentence or a picture. Moreover, sentences could either be spatial or non-spatial. In total four different conditions were included: spatial sentences followed by a second stimulus, which was another spatial sentence on 80% of the trials and a picture on 20% of the trials (*spatial 80/20*), spatial sentences followed by a second stimulus, which was another spatial sentence on 20% of the trials and a picture on 80% of the trials (*spatial 20/80*), non-spatial sentences followed by a second stimulus, which was another non-spatial sentence on 80% of the trials and a picture on 20% of the trials (*non-spatial 80/20*), non-spatial sentences followed by a second stimulus, which was another non-spatial sentence on 20% of the cases and a picture on 80% of the trials (*non-spatial 20/80*).

Spatial conditions

For the *spatial 80/20* and the *spatial 20/80* conditions the trial-lists were made up of 32 practice trials and 240 experimental trials. To ensure that participants could not prepare for a fixed configuration, i.e. always a triangle left of a circle or a circle left of a triangle, we used a small number of "new-object" trials that contained only one of the objects from the sentence. The practice trials consisted of 24 (80%) and 6 (20%) sentences or pictures as S2, and two "new-object" trials, which were either sentence-sentence (in the spatial 80/20 condition) or sentence-picture (in the spatial 20/80 condition). The experimental trials consisted of 192 (80%) and 48 (20%) sentences or pictures as S2. In addition, 16 "new-object" trials were added. In the spatial conditions S1 described the left/right relation between two objects (circle, square or triangle were the options).

Four options existed for S2: first, spatial expression and position of words were identical, second, spatial expression and position of words changed, third, spatial expression changed and position of words was identical, fourth, spatial expression was identical and position of words changed. All options for S2 occurred equally often in the trial-list. In a "new-object" sentence-sentence trial the first two possibilities for S2 of the "normal" trials were available, with one difference: one object was mentioned in S2, which was not mentioned in S1. In a "normal" sentence-picture trial there were two options for S2, which occurred equally often in the trial-list: either the picture depicted the correct spatial relation between the two objects mentioned in S1 or it depicted the opposite spatial relation. In a "new-object" sentence-picture trial there were again two options: an object that was not mentioned in S1 replaced either the left or the right object in the picture. Approximately half of the trials had a S2 that was a correct exemplification of S1. Because of the "new-object" trials there were slightly more trials that had an S2 that was an incorrect exemplification of S1.

Non-spatial conditions

For the *non-spatial 80/20* and the *non-spatial 20/80* conditions the trial-lists had 30 practice trials and 224 experimental trials. The practice trials consisted of 24 (80%) and 6 (20%) sentences or pictures as S2. The experimental trials consisted of 224 trials, 180 (80%) and 44 (20%) sentences or pictures as S2. S1 was a sentence that described two objects (circle, square or triangle were the options).

There were six options for S2 in a sentence-sentence trial: first, position of words was identical, second, position of words changed, third, left object was different, fourth, right object was different, fifth and sixth, position of words changed and one object was different. The options that existed for S2 in a sentence-picture trial were identical to those in the sentence-sentence trials. Half of the trials for both sentence-sentence and sentence-picture trials included a S2 that was made up of the same two objects as those mentioned in S1, the other half of the trials had an S2 with one object that wasn't mentioned in S1. The position of the objects was irrelevant for the verification decision, and therefore if S1 was "Triangle and Circle", then both "Circle and Triangle" and "Triangle and Circle" were correct options for S2. The order of the presentation of trials within a trial-list was random for both the non-spatial and the spatial conditions.

The words were displayed vertically for S1, while for S2 both the sentences and pictures were placed in a horizontal organization. The first sentence was displayed vertically to ensure that the position of the two object-words would not be congruent or incongruent with the position of the two objects in S2. All words (written in Dutch) were of 36 points, Courier New type. Viewing distance was not constrained, but the computer screen was situated so that it was approximately 60 cm. Individual letters subtended 1.0° × .6° of visual angle and pictorial objects subtended 4.8° × 4.8° of visual angle. All stimuli were white on a black background. Participants answered by means of a response box with four buttons, which was placed on their lap, and these responses were measured by Vision recorder from BrainProducts GmbH.

Design and procedure

Individual participants were tested for about three hours. Order of presentation of the conditions was counterbalanced over participants. Before the start of a condition participants were instructed to respond as quickly as possible while maintaining high accuracy. At the beginning of each condition, participants were informed whether a sentence or a picture would occur most likely after the first sentence. Furthermore, for both spatial and non-spatial conditions, participants were explicitly instructed to verify whether the two objects mentioned in S1 were present in S2 and whether they were in the correct spatial arrangement (spatial condition only). No strategy instructions were given to the participants.

A trial consisted of the following sequence: fixation point (750 ms), S1 (1500 ms), fixation point (1500 ms), S2 (a maximum of 4000 ms or until response) and finally participants decided whether S2 exemplified S1 correctly. Participants responded by pressing the left or right button of the response box. A left button press equalled "same" for one half of the participants and a right button press equalled "same" for the other half of the participants. Feedback was only given on practice trials and consisted of the word "Correct" or "Incorrect" and the RT. Participants received a 1-minute break after every 75 trials (non-spatial condition) or 80 trials (spatial condition).

Data recording and analysis

EEG was recorded continuously from 61 channels, using Ag/AgCl ring electrodes attached to an electrocap. The electrodes were online referenced to Cz, but were off-line referenced to the average across all EEG electrodes. The vertical and horizontal electro-oculogram (vEOG and hEOG) were measured from electrodes above and below the left eye and from the outer canthi of both eyes, respectively. Electrode resistance was kept below 5 kΩ. Signals were passed through a BrainAmp amplifier (Brain Products GmbH) and recorded on-line at a sample rate of 200 Hz. Measured activity was digitally filtered on line (TC= 4 s, low pass 100 Hz) by Vision Recorder installed on a Pentium III computer. Presentation (Neurobehavioral systems, version .76), installed on a Pentium II computer, controlled stimulus presentation on a 17-inch monitor and sent digital codes to Vision Recorder to indicate the moment and the type of stimulus.

Behavioural data

The data of the practice trials were discarded. Furthermore, the mean percentage error scores for the "new-object" trials were computed to verify whether participants relied on a fixed configuration, which would result in very low levels of accuracy on these trials. The independent variables were all varied within participants and included S1 (Spatial or Non-Spatial), S2 (Sentence or Picture), Probability (80% or 20%), and Answer (True or False). Mean RTs, computed over correct trials, and mean percentage error scores were analysed using separate 2 x 2 x 2 x 2 ANOVAs with repeated measures. Additional 4 x 2 ANOVAs were carried with Sentence Option ("Identical to S1", "Spatial expression and position of words changed", "Spatial expression changed" and "Position of words changed") and Probability (80% or 20%) as within-subjects variables.

EEG data

The results were analysed using Vision Analyzer (Brain Products GmbH). The mean amplitude from –100 to 0 ms before S1 served as a baseline. ERPs were computed for all electrodes by averaging EEGs for all trials that were without artefacts. We examined EOGs for every participant to establish a correct EOG threshold for every participant individually. Lowest allowed activity was 0.10 μV for 50 ms, minimum/ maximum allowed amplitude was ± 200, 150, and 100 μV, for frontal, central and parietal electrodes, respectively. Different criteria were employed to avoid the exclusion of EEG data due to EOG artefacts, which induces larger amplitudes at frontal than at parietal sites. In addition, EEG was corrected for ocular artefacts by employing the method of Gratton, Coles, and Donchin (1983). Local DC trend correction was applied before correction for ocular artifacts. In addition, before computing grand averages data were filtered with a low pass filter of 20 Hz. Two analyses were performed (for comparable analyses see Bosch, Mecklinger, & Friederici, 2001; Cohen et al., 2001; Mecklinger, 1998), and electrode sites were pooled to nine (averaged) topographical regions: left frontal (F7, F5, F3, AF7), medial frontal (Fp1, Fpz, Fp2, AFz), right frontal (F8, F6, F4, AF8), left central (FT7, FC5, T7, C5, TP7, CP5), medial central (C2, C1, Cz, CPz, FCz), right central (FT8, FC6, T8, C6, TP8, CP6), left parieto-occipital (P7, P5, P3, PO7), medial parieto-occipital (O2, O1, Oz, POz), and right parieto-occipital (P8, P6, P4, PO8). First, we examined the slow wave activity, determined as the average activity from 550-1100 ms after onset of S1. Second, we examined the slow wave activity preceding the onset of S2, determined as the average activity from 550-0 ms preceding S2 (i.e. the CNV). Analyses were performed on average activity in the above-mentioned time windows by subjecting them to an ANOVA with factors S1 (Spatial/ Non-spatial), S2 (Sentence/ Picture), Anterior-Posterior (frontal, central, parieto-occipital), and Laterality (left, medial, right). Only main effects or interactions relevant for our hypotheses (i.e. including the S1 or S2 factor) will be reported. Huynh-Feldt correction was applied in all tests involving the factors Anterior-Posterior and Laterality (i.e. only factors with more than two levels) to correct for possible violations of sphericity assumptions (e.g. Maxwell & Delaney, 1990). We also analysed average activity of the vertical and horizontal EOG in the SW and CNV time windows with ANOVAs including the factors S1 and S2 to examine whether possible effects of interest in the EEG could be explained by differences in the EOG.

In order to specify possible differences in recruited brain areas between the four conditions (i.e. spatial sentence/ picture expected, spatial sentence/ sentence expected, non-spatial sentence/ picture expected, non-spatial sentence/ sentence expected) we additionally performed source localization analyses by employing the brain electricity source analysis (BESA) algorithm (version 2.2). These source localizations were done on ERPs at the moment where possible effects of interests showed the largest difference within the relevant time interval. BESA estimates the location and orientation of multiple dipolar sources by calculating the scalp distribution that would be obtained for a given dipole model and comparing it to the original distribution (Scherg, 1990). Iterative changes in localization and orientation parameters of the sources lead to minimization of the residual variance between the model and the data. The energy criterion was set at 20% to reduce the interaction between dipoles, and separation was set at 10%. The number of dipole pairs (with mirrored location and orientation parameters) was set to two.

Results

Behavioural measures: Reaction times

The main effect of S1 was significant, $F(1, 11)= 118.2$, $p< .001$, showing that participants were faster in the Non-Spatial than in the Spatial condition (see Table 1). The main effect of S2 was significant, $F(1, 11)= 32.0$, $p< .001$, indicating that RTs were faster when S2 was a picture than when S2 was a sentence. The main effect of Probability was significant, $F(1, 11)= 167.1$, $p< .001$. RTs were faster for trials with an 80% probability than for trials with a 20% probability. The main effect of Answer was significant, $F(1, 11)= 7.5$, $p=$

.02, indicating faster RTs when the answer was True than when the answer was False.

Table 1.
Mean RTs (ms), standard errors in parentheses.

Answer	True		False	
S2	Sentence	Picture	Sentence	Picture
	"Spatial"			
Probability				
20%	1509 (51.3)	1338 (69.3)	1581 (72.0)	1450 (93.4)
80%	1411 (56.0)	894 (54.1)	1525 (78.9)	1051 (83.9)
	"Non-spatial"			
20%	994 (52.9)	1014 (59.4)	1049 (60.8)	1033 (58.2)
80%	916.5 (43.9)	788 (55.3)	984 (58.6)	882 (65.3)

Importantly, the interaction between S1 and Probability was significant, $F(1, 11)= 10.4$, $p= .008$. Analysis of this interaction showed that RTs were faster for trials with an 80% probability than with a 20% probability, but this difference was greater for the spatial sentences than for the non-spatial sentences, $t(11)= 3.2$, $p= .008$. The interaction between S1 and S2 was significant, $F(1, 11)= 35.0$, $p< .001$. Further analysis showed that if participants had read a spatial sentence they were faster when S2 was a picture than when S2 was a sentence, $t(11)= 6.7$, $p< .001$whereas if they had read a non-spatial sentence they showed similar RTs when S2 was a picture or a sentence, $t(11)= 1.9$, $p= .09$. The interaction between S2 and Probability was significant, $F(1, 11)= 12.8$, $p= .004$. Analysis of this interaction showed that RTs were faster for trials with an 80% probability than with a 20% probability, but this difference was greater when S2 was a picture than when S2 was a sentence, $t(11)= 3.6$, $p= .004$. The interaction between Probability and Answer was significant, $F(1, 11)= 14.3$, $p= .003$. Further analysis showed that participants responded faster for True than False trials, but this was only significant for trials with an 80% probability, $t(11)= 3.2$, $p= .008$, and not for trials with a 20 % probability, $t(11)= 2.1$, $p= .06$. There were no other significant first-order interactions, all $F(1, 11)< 1.4$.

Highly relevant for the discussion was that the second-order interaction between S1, S2 and Probability was significant, $F(1, 10)= 6.5$, $p= .03$. Further analysis indicated that the interaction between S1 and Probability was significant, but only when S2 was a picture, $F(1, 10)= 10.7$, $p= .007$, and not when S2 was a sentence, $F(1, 11)< 1$. Therefore, participants were slower on unexpected than on expected stimuli, but this effect was only significantly stronger for spatial sentences than for non-spatial sentences, $t(11) = 3.3$, $p = .007$, when S2 was a picture (See Figure 1). No other interaction was significant, all $Fs < 1.4$.

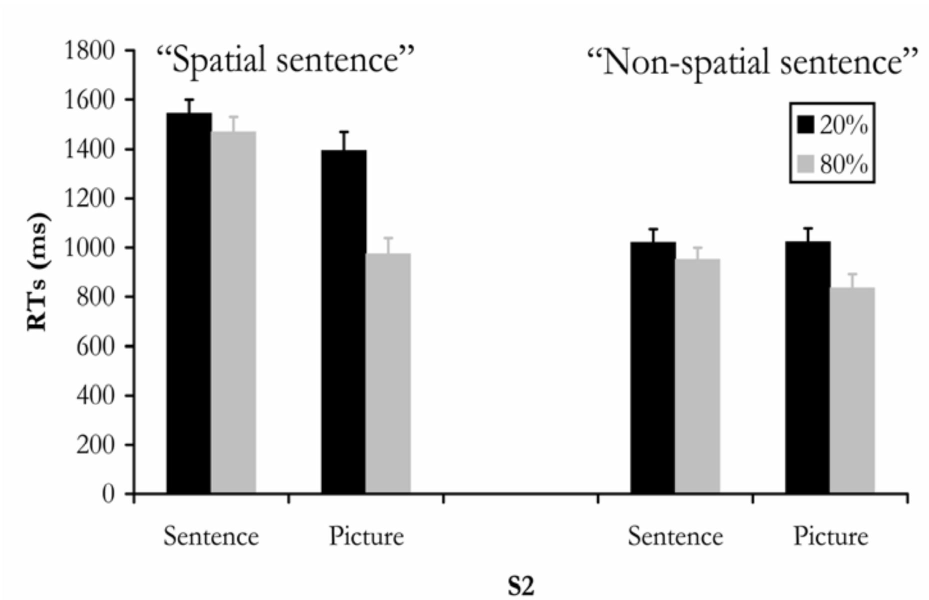

Figure 1
Mean RTs (ms) for both the spatial and non-spatial sentences.

Sentence options

The main effect of Sentence option was significant, $F(3, 33) = 21.6$, $p < .001$. Further analysis indicated that RTs were faster for identical sentences than for sentences with a changed spatial expression, $t(11) = 4.0$, $p = .002$, sentences with a changed position of words, $t(11) = 6.6$, $p < .001$, and sentences with a changed spatial expression and a changed position of words, $t(11) = 5.5$, $p < .001$. RTs were also faster for sentences with a changed spatial expression than for sentences with a changed spatial expression and a changed position of words, $t(11) = 3.3$, $p = .007$, and sentences with a changed position of words, $t(11) = 4.9$, $p < .001$. RTs were similar for sentences with a changed position of words and sentences with a changed spatial expression and a changed position of words, $t(11) = 2.0$, $p = .07$ (see Table 2). The main effect of Probability was marginally significant, $F(1, 11) = 4.6$, $p = .06$, indicating a trend for faster RTs for sentences with an 80% probability than for sentences with a 20% probability. The interaction between Sentence Option and Probability was not significant, $F(1, 11) = 1.7$, $p = .20$.

Table 2.
Mean RTs (ms) for the four spatial sentence options for S2 in relation to S1, standard errors in parentheses.

Sentence Option (e.g. S1 is 'Triangle left of Circle')	**Probability**	
	80%	*20%*
Spatial expression and position of words identical *S2 is 'Triangle left of Circle'*	1166 (55.0)	1270 (59.3)
Spatial expression and position of words changed *S2 is 'Circle right of Triangle'*	1718 (97.1)	1839 (95.0)
Spatial expression changed and position of words identical *S2 is 'Triangle right of Circle'*	1414 (74.9)	1513 (82.7)
Spatial expression identical and position of words changed *S2 is 'Circle left of Triangle'*	1639 (87.2)	1658 (69.6)

Behavioural measures: Error scores

The mean percentage error scores for "new-object" trials was 8%. The main effect of S1 was significant, $F(1, 11)= 20.9$, $p< .001$, indicating that participants made less errors when they read a non-spatial sentence than when they read a spatial sentence (see Table 3). The main effect of Probability was significant, $F(1, 11)= 13.2$, $p= .004$, showing that participants made more errors in the 20% conditions than in the 80% conditions. The interaction between S1 and Probability was significant, $F(1, 11)= 22.6$, $p= .001$. Further analysis showed that participants made less errors on trials with an 80% probability than with a 20% probability, but this was only found when S1 was a spatial sentence, $t(11)= 4.4$, $p= .001$,and not when S1 was a non-spatial sentence, $t(11)= 1.2$, $p= .26$. The interaction between S2 and Answer was significant, $F(1, 11)= 4.9$, $p= .049$. Analysis of this interaction showed that participants made more errors when S2 was a sentence, than when S2 was a picture, but this was only found when the answer was True, $t(11)= 2.2$, $p= .05$, and not when the answer was False, $t(11)< 1$. The interaction between S1 and S2 was marginally significant, $F(1, 11)= 4.2$, $p= .07$. The interaction indicated a trend for more errors when S2 was a sentence than when S2 was a picture, but only when the first sentence was spatial, $t(11)= 1.9$, $p= .09$, and not when the first sentence was non-spatial, $t(11)< 1$. All other effects were not significant, All $F(1, 11)< 3.1$, $p> .10$.

Table 3.
Mean error scores (%), standard errors in parentheses.

Answer	True		False	
S2	Sentence	Picture	Sentence	Picture
Probability	*"Spatial"*			
20%	14 (3.3)	7 (1.7)	7 (1.7)	9 (2.3)
80%	10 (2.0)	4 (1.0)	4 (1.0)	5 (2.4)
	"Non-spatial"			
20%	3 (1.0)	4 (1.1)	4 (1.7)	4 (1.5)
80%	3 (.5)	3 (.5)	3 (.5)	4 (1.0)

Sentence Options

The main effect of Probability was not significant, $F(1, 11)= 4.2$, $p= .07$. The main effect of Sentence Option was significant, $F(3, 33)= 7.5$, $p= .001$. Further analysis indicated that participants made less errors with identical sentences than with sentences with a changed position of words, $t(11)= 2.2$, $p= .050$, and sentences with a changed spatial expression and a changed position of words, $t(11)= 3.1$, $p= .01$ (see Table 4). In addition, participants made less errors with sentences with a changed spatial expression than with sentences with a changed position of words, $t(11)= 2.7$, $p= .02$. The percentage errors was greater for sentences with both a changed spatial expression and a changed position of words than for sentences with a changed spatial expression, $t(11)= 2.9$, $p= .01$, and for sentences with a changed position of words, $t(11)= 2.2$, $p= .048$. All other comparisons were not significant, all *ts*< 1. The interaction between Sentence Option and Probability was not significant, $F(3, 33)= 1.5$, $p= .24$.

Table 4.
Mean error scores (%) for the four spatial sentence options for S2 in relation to S1, standard errors in parentheses.

Sentence Option (e.g. S1 is 'Triangle left of Circle')	**Probability**	
	80%	*20%*
Spatial expression and position of words identical S2 is 'Triangle left of Circle'	4 (1.2)	6 (2.0)
Spatial expression and position of words changed *S2 is 'Circle right of Triangle'*	16 (3.8)	21 (5.6)
Spatial expression changed and position of words identical *S2 is 'Triangle right of Circle'*	4.8 (1.5)	5.3 (2.1)
Spatial expression identical and position of words changed *S2 is 'Circle left of Triangle'*	5.6 (1.9)	12.9 (3.4)

EEG data

No differences were found in the EOG with respect to the below mentioned effects regarding the interaction between S1 and S2, $F < 1$. Figure 2 depicts grand average ERP- waveforms from the nine pooled topographical regions as evoked by the four different types of S1: [1] spatial sentence followed by a picture in 80% of the trials, [2] spatial sentence followed by a sentence in 80% of the trials, [3] non-spatial sentence followed by a picture in 80% of the trials, [4] non-spatial sentence followed by a sentence in 80% of the trials.

Slow wave

The interactions between S1 and Laterality, S1 and Anterior/Posterior, and S1, Laterality, and Anterior/ Posterior were significant, $F(2, 22) = 17.7$, $p < .001$, $F(2, 22) = 4.9$, $p = .03$, and $F(4, 44) = 5.9$, $p = .008$. Analysis of the component interactions revealed that the interaction between S1 and Laterality was significant at parieto-occipital regions, $F(4, 44) = 28.0$, $p < .001$, but not at central and frontal regions, $Fs < 2.1$, $p > .16$. This interaction between S1 and Laterality indicated that the negative slow wave activity was larger for spatial sentences than non-spatial sentences at medial and left parieto-occipital regions, $t(11) = 5.0$, $p < .001$ and $t(11) = 2.2$, $p = .05$, but not at right parieto-occipital regions, $t < 1$.

The interactions between S1 and S2, and between S1, S2, Anterior/ Posterior and Laterality were significant, $F(2, 22) = 4.9$, $p = .03$ and $F(4, 44) = 3.1$, $p = .03$. Analysis of the component interactions indicated that the interaction between S1, S2 and Laterality was only significant for the parieto-occipital regions, $F(2, 22) = 3.8$, $p = .04$, and not for all the other regions, all $Fs < 1$. In addition, the interaction between S2 and Laterality was only significant for spatial and not for non-spatial sentences, $F(2, 22) = 4.8$, $p = .02$ and $F < 1$. Importantly, the larger negative slow wave activity at central parieto-occipital regions when participants expected a picture than when they expected a sentence, was significantly stronger at medial regions than at left and right regions, $t(11) = 2.7$, $p = .02$ an $t(11) = 2.9$, $p = .02$. There was no difference between left and right regions, $t < 1$.

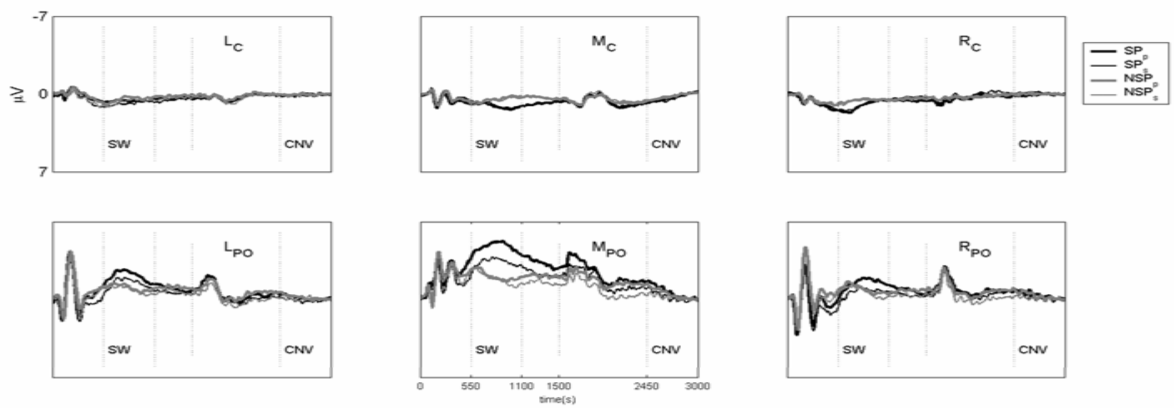

Figure 2.
Grand averages of ERPs as evoked by the combination of S1 and expected S2: spatial sentence, picture expected (SP_p, thick black line), spatial sentence, sentence expected (SP_s, thin black line), non-spatial sentence, picture expected (NSP_p, thick gray lines), and non-spatial sentence, sentence expected (NSP_s, thin gray line). The nine ERPs reflect the regions of interest for the analyses (Left (L), Medial (M), Right (R), Frontal (F), Centre (C), and Parieto-Occipital (PO)). The time segments of the analysed ERP components SW (550-1100 ms) and CNV (2450-3000 ms) are marked in every ERP with vertical dotted lines. The moment that S1 disappeared (1500 ms) is also marked with a vertical dotted line. Negativity is up.

The above mentioned third order interaction between S1, S2, Anterior/ Posterior and Laterality suggested that negative slow wave activity over parieto-occipital electrodes was larger when participants read a spatial sentence and expected a picture than when participants read a spatial sentence and expected a sentence or a non-spatial sentence and expected a picture or a sentence. Figure 3A shows the spline maps at 900 ms after the onset of S1 for the four conditions and these show a greater negativity at parieto-occipital electrodes for the "spatial sentence/ picture expected" condition, than for the other conditions. Moreover, source modelling with two symmetrical dipole pairs (from 875-925 ms) revealed a strong medial occipital source for the "spatial sentence/ picture expected" condition, whereas the other conditions all showed a strong left central/ frontal source (all residual variances< 4.3 %, see Figure 3B).

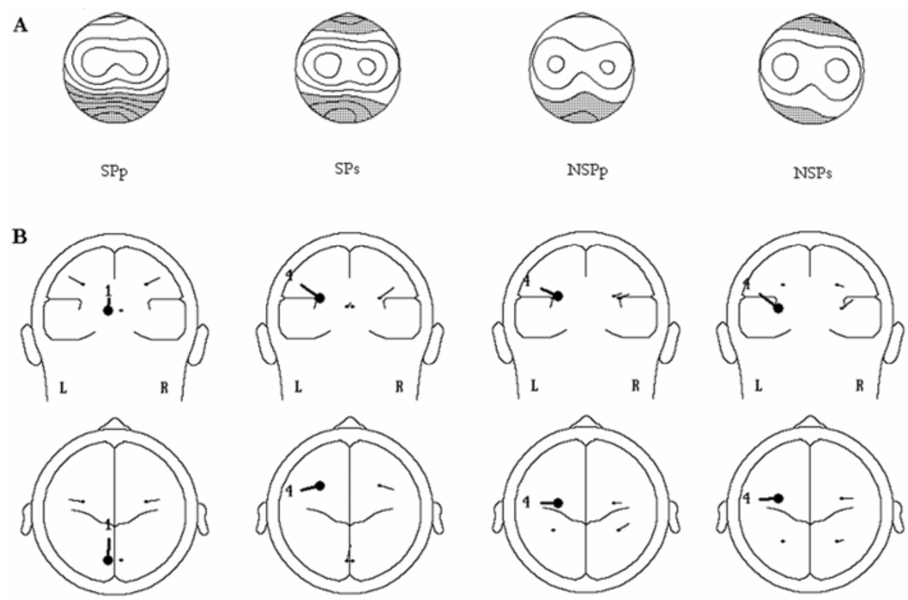

Figure 3.
A *Spline maps for activity at 900 ms after S1 onset as evoked by the combination of S1 and expected S2: spatial sentence, picture expected (SPp), spatial sentence, sentence expected (SPs), non-spatial sentence, picture expected (NSPp), and non-spatial sentence, sentence expected (NSPs). Spacing for the spline maps amounted 1 µV, and negativity is indicated by hatching.*
B *Results of the source analyses with two symmetrical dipole pairs at 900 ms after S1 onset as evoked by the combination of S1 and expected S2. The resulting dipole solutions left 2.0 %, 3.6%, 3.4 %, and 4.2 % residual variance in the SPp, SPs, NSPp, and NSPs conditions, respectively.*

CNV

The main effect of S1 was significant, $F(1, 11)= 5.1$, $p= .05$, indicating a more negative CNV for spatial than non-spatial sentences. Furthermore, the interaction between S2 and Anterior/ Posterior was significant, $F(2, 22)= 7.0$, $p= .01$. Analysis of this interaction indicated that the CNV was larger at parieto-occipital regions when participants expected a picture than when they expected a sentence, $t(11)= 4.0$, $p= .002$ (see Figure 4). There were no differences at central and frontal regions, $t(11)= 1.3$, $p= .22$ and $t(11)= 1.9$, $p= .09$. No other effects concerning the CNV were significant, all $Fs< 2.5$, $p> .1$.

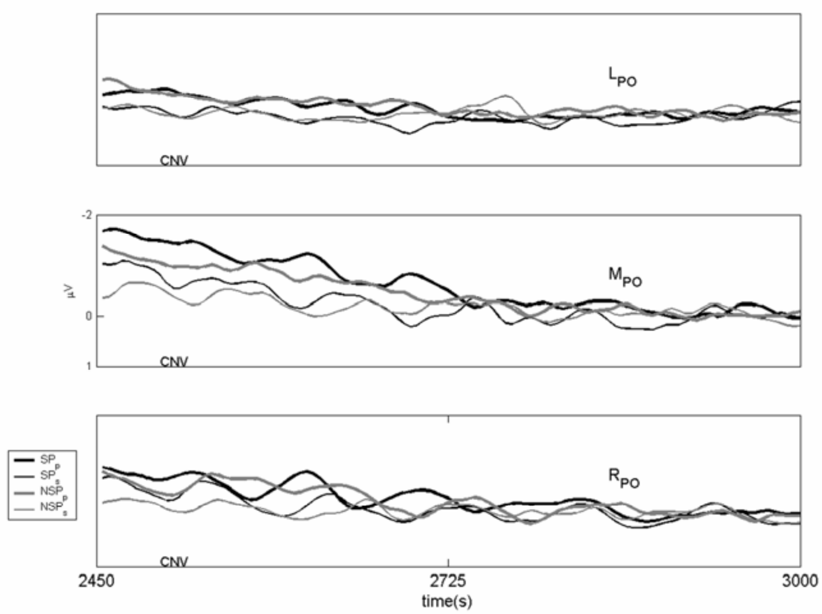

Figure 4.
Grand averages of ERPs as evoked by the combination of S1 and expected S2: SP_p *(thick black line),* SP_s *(thin black line),* NSP_p *(thick gray lines), and* NSP_s *(thin gray line). The three ERPs reflect the pooled averages of the three parietal- occipital regions (Left (L), Medial (M), Right (R), Frontal (F)). The time segment of the analysed ERP is the CNV (2450-3000 ms). Negativity is up.*

Discussion

Previous studies employing the sentence-picture verification task claimed to have found evidence for the existence of different processing strategies for encoding a spatial sentence that resulted in different representational formats (MacLeod et al., 1978; Mathews, Hunt, & MacLeod, 1980; Noordzij et al., 2004; Noordzij et al., in press; Reichle et al., 2000). The behavioural results of the present study further corroborate this claim. We examined the existence of different strategies by using sentence-sentence and sentence-picture verification trials in mixed blocks, whereby the probability of a specific second stimulus was fixed within a block. RTs and error scores showed that the performance of participants was always worse for unexpected than for expected stimuli. In addition, the difference between expected and unexpected stimuli was significantly greater for spatial sentences ("Triangle left of Circle") than for non-spatial sentences ("Triangle and Circle"). Hence, there was an additional cost associated with verifying spatial information in an unexpected stimulus. Although we found that the advantage of expected over unexpected stimuli was greater after participants had read a spatial than a non-spatial sentence, we only found this difference between spatial and non-spatial sentences for sentence-picture trials and not for sentence-sentence trials. If participants in our experiment had exclusively formed a propositional representation *or* a pictorial representation, then one would expect an additional cost for both sentence-picture and sentence-sentence trials, in which the second stimulus was unexpected. Yet, we only found these costs for the sentence-picture trials. Therefore, this data fits with the *dual-representational model* that assumes that participants automatically represented the spatial sentence propositionally. In addition, participants formed a pictorial representation strategically dependent on the context (i.e. expecting a sentence or a picture) in which the sentence was read. This was supported by the fact that there were additional costs for unexpected pictures and not for unexpected sentences.

As a secondary result, we looked at the four different possibilities for the second spatial sentence in a sentence-sentence trial. These possibilities were: the second sentence was identical to the first sentence, the spatial expression and the position of the words were changed, the spatial expression was changed, or the position of the words was changed. We found that the more the second sentence differed from the first sentence the slower the participants were at making a verification decision concerning the second sentence. This effect is in line with the notion that both the first and the second sentence were represented as a set of propositions, whereby the differences in propositional components needed to be resolved in a serial fashion. Interestingly, this effect was the same for expected and unexpected sentences. This finding further corroborates the dual-representational model that assumes that even when participants follow a pictorial strategy the sentence is also represented (automatically) as a set of propositions. In line with the foregoing behavioural evidence, the most important findings in the present study follow from the online EEG measurements, because the latter give insight in when representational differences emerge.

We found that there was an interaction between S1 and S2 at the medial parieto-occipital region for the slow wave (SW) following the onset of the first sentence. This interaction indicated that the negative slow wave was larger when participants expected a picture than when they expected a sentence, but only for spatial sentences and not for non-spatial sentences, which nicely accords with the effect found on behavior. Because the spatial sentences are identical, this constitutes neuro-cognitive evidence that they are encoded and represented differently depending on the context (i.e. expecting a sentence or a picture) in which the sentence is read. Previous EEG studies have found a transient negative slow between 600 and 1200 ms at parieto-occipital regions that was associated with spatial operations and imagery processes (Bosch et al., 2001; Mecklinger & Pfeifer, 1996; Rösler et al., 1995). Hence, the processing differences between spatial sentences followed by a sentence or a picture might involve the exclusive involvement of imagery in the condition in which a picture is expected. This claim was further illustrated by results of source analyses, which showed that between 875 and 925 ms after the onset of S1 a posterior occipital source appeared more active when participants read a spatial sentence and expected a picture, than when participants expected a sentence. In addition, a frontal source appeared more active when participants read a spatial sentence and expected sentence, or when they read a non-spatial sentence and expected either a sentence or a picture then when they read a spatial sentence and expected a picture. This pattern of active sources fits nicely with a dual-coding model or strategic model in which a spatial sentence is transformed into a mental image in a visual-spatial context. Interestingly, the interaction between S1 and S2 was only found for the SW and not for the CNV. This provides evidence that the construction of different representations of spatial sentences takes place directly after the initial processing of the visually presented sentence, and not later on, when the participant is preparing for the second stimulus.

Other effects in the SW only pertain to differences between spatial and non-spatial sentences, independent of S2. Of course, these effects related to S1 cannot be completely separated from the fact that spatial and non-spatial sentences were perceptually different for the SW interval. However, because this slow wave is supposed to reflect processes that are closely related to the encoding and storage of information (e.g. Bosch et al., 2001)) it is not likely to reflect merely perceptual differences. We found a larger negative SW for spatial than non-spatial sentences at left and medial parieto-occipital sites. Recently, Tranel and Kemmerer (2004) found that patients with lesions to specific brain areas in the left frontal and parietal cortex had specific problems with several spatial expressions. This suggests that the processing of spatial language and especially locative prepositions (e.g. "left of", "above") is dependent on these areas. Furthermore, in a recent fMRI study (Noordzij, Neggers, Postma, & Ramsey, in preparation), employing the same stimuli as in the present study, higher activation was found in the left supramarginal gyrus (an area in the left inferior parietal cortex) for spatial (e.g. *triangle left of circle*) than non-spatial sentences (e.g. *triangle and circle*). Therefore, the differences between parieto-occipital slow wave activity related to spatial and non-spatial sentences might reflect the additional recruitment of parietal regions for spatial sentences compared to non-spatial sentences.

The CNV is considered to reflect processes associated with motor preparation, but also with the anticipation of S2 and the preparation for a cognitive response (Rockstroh, Elbert, Canavan, Lutzenberger, & Birbaumer, 1989). As mentioned above there were no interaction effects between S1 and S2 for the CNV. We did find an interaction between S2 and the Anterior/Posterior variable, indicating that the CNV was larger at parieto-occipital regions when participants expected a picture than a sentence, while the CNV tended to be larger at frontal regions when participants expected a sentence than a picture. These differences might reflect the general perceptual readiness effects related to the fact that people expect to process a verbal stimulus or a visual stimulus. Important for the present discussion is that this difference in CNV between "picture expected" and "sentence-expected" conditions did not differ for spatial and non-spatial sentences and thus cannot explain the behavioural differences that arise between spatial and non-spatial conditions when participants respond to the second stimulus.

Conclusions

Early brain activation linked to parsing spatial sentences occurs in areas generally associated with mental image processing, and only so when participants are explicitly expecting to compare the verbal information to a pictorial scene. Therefore, this is the first study to provide neuroimaging evidence that different representational formats of spatial sentences arise almost directly when people are reading a spatial sentence. In addition, we replicated previous behavioral findings showing that participants indeed can form different representations of spatial sentences. These findings are in line with the *dual-representational model* (Noordzij et al., in press; Paivio, 1983), which assumes that people automatically represent the spatial sentence as a set of propositions, and strategically form a mental image.

References

Annet, M. (1970). A classification of hand preference by association analysis. *British Journal of Psychology, 61*, 303-321.

Barsalou, L. W. (1999). Perceptual symbol systems. *Behavioral & Brain Sciences, 22*(4), 577-660.

Bosch, V., Mecklinger, A., & Friederici, A. D. (2001). Slow cortical potentials during retention of object, spatial and verbal information. *Cognitive Brain Research, 10*(3), 219-237.

Clark, H. H., & Chase, W. G. (1972). On the process of comparing sentences against pictures. *Cognitive Psychology, 3*(3), 472-517.

Cohen, R., Dobel, C., Berg, P., Koebbel, P., Schoenle, P. W., & Rockstroh, B. (2001). Event-related potential correlates of verbal and pictorial feature comparison in aphasics and controls. *Neuropsychologia, 39*(5), 489-501.

Eley, M. G. (1981). Distinguishing imagery from propositional recoding processes in sentence-picture verification tasks. *Canadian Journal of Psychology, 35*(3), 254-269.

Glushko, R. J., & Cooper, L. A. (1978). Spatial comprehension and comparison processes in verification tasks. *Cognitive Psychology, 10*(4), 391-421.

Gratton, G., Coles, M. G. H., & Donchin, E. (1983). A new method for off-line removal of occular artifacts. *Electroencephalography and Clinical Neurophysiology, 55*, 468-484.

Hagoort, P. (2003). Interplay between syntax and semantics during sentence comprehension: ERP effects of combining syntactic and semantic violations. *Journal of Cognitive Neuroscience, 15*(6), 883-899.

Hunt, E., & MacLeod, C. M. (1978). The sentence-verification paradigm: A case study of two conflicting approaches to individual differences. *Intelligence, 2*(2), 129-144.

Logan, G. D., & Sadler, D. D. (1996). A computational analysis of the apprehension of spatial relations. In P. Bloom & M. A. Peterson & L. Nadel & M. F. Garret (Eds.), *Language and Space* (pp. 493-529). Cambridge, MA: MIT Press.

MacLeod, C. M., Hunt, E. B., & Mathews, N. N. (1978). Individual differences in the verification of sentence-picture relationships. *Journal of Verbal Learning & Verbal Behavior, 17*(5), 493-507.

Mathews, N. N., Hunt, E. B., & MacLeod, C. M. (1980). Strategy choice and strategy training in sentence-picture verification. *Journal of Verbal Learning & Verbal Behavior, 19*(5), 531-548.

Maxwell, S. E., & Delaney, H. D. (1990). *Designing experiments and analyzing data: A model comparison perspective*. Pacific Grove, California: Brooks/ Cole Publishing Company.

Mecklinger, A. (1998). On the modularity of recognition memory for object form and spatial location: A topographic ERP analysis. *Neuropsychologia, 36*(5), 441-460.

Mecklinger, A., & Pfeifer, E. (1996). Event-related potentials reveal topographical and temporal distinct neuronal activation patterns for spatial and object working memory. *Cognitive Brain Research, 4*(3), 211-224.

Noordzij, M. L., Neggers, S. F. W., Postma, A., & Ramsey, N. F. (in preparation). Neural correlates of locative prepositions.

Noordzij, M. L., Van der Lubbe, R. H., Neggers, S. F. W., & Postma, A. (2004). Spatial tapping interferes with the processing of linguistic spatial relations. *Canadian Journal of Experimental Psychology, 58*(4), 259-271.

Noordzij, M. L., Van der Lubbe, R. H., & Postma, A. (in press). Strategic and automatic components in the processing of linguistic spatial relations. *Acta Psychologica*.

Paivio, A. (1983). The empirical case for dual coding. In J. C. Yuille (Ed.), *Imagery, Memory and Cognition*. Hillsdale, New Jersey: Lawrence Erlbaum Associates.

Reichle, E. D., Carpenter, P. A., & Just, M. A. (2000). The neural bases of strategy and skill in sentence-picture verification. *Cognitive Psychology, 40*(4), 261-295.

Roberts, M., Wood, D., & Gilmore, D. (1994). The sentence-picture verification task: Methodological and theoretical difficulties. *British Journal of Psychology, 85*, 413-432.

Rockstroh, B., Elbert, T., Canavan, A., Lutzenberger, W., & Birbaumer, N. (1989). *Slow cortical potentials and behaviour* (2nd ed.). Munich: Urban & Schwarzenberg.

Rösler, F., Heil, M., Bajric, J., Pauls, A. C., & Hennighausen, E. (1995). Patterns of cerebral activation while mental images are rotated and changed in size. *Psychophysiology, 32*(2), 135-149.

Rösler, F., Heil, M., & Röder, B. (1997). Slow negative brain potentials as reflections of specific modualr resources of cognition. *Biological Psychology, 45*, 109-142.

Ruchkin, D. S., Johnson , R., Jr., Grafman, J., Canoune, H., & Ritter, W. (1997). Multiple visuospatial working memory buffers: evidence from spatiotemporal patterns of brain activity. *Neuropsychologia, 35*(2), 195-209.

Ruchkin, D. S., Johnson, R., Jr., Mahaffey, D., & Sutton, S. (1988). Toward a functional categorization of slow waves. *Psychophysiology, 25*(3), 339-353.

Scherg, M. (1990). Fundamentals of dipole source potential analysis. In F. Grandori & M. Hoke & G. L. Romani (Eds.), *Auditory evoked magnetic fields and potentials* (pp. 40-69). Basel: Karger.

Tranel, D., & Kemmerer, D. (2004). Neuroanatomical correlates of locative prepositions. *Cognitive Neuropsychology, 21*(7), 719-749.

Walter, W., Cooper, R., Aldridge, V., McCallum, W., & Winter, A. (1964). Contingent negative variation: An electric sign of sensorimotor association and expectancy in the human brain. *Nature, 230*, 380-384.

West, W. C., & Holcomb, P. J. (2000). Imaginal, semantic, and surface-level processing of concrete and abstract words: an electrophysiological investigation. *Journal of Cognitive Neuroscience, 12*(6), 1024-1037.

Chapter 5 | Neural correlates of locative prepositions

Abstract

The aim of the present fMRI study was to further establish the involvement of left inferior parietal areas with the processing of locative prepositions, and to examine a possible confound that was present in a previous neuropsychological and PET study that examined the neural correlates of locative prepositions. In order to examine these questions we executed an fMRI study with simple spatial sentences that had to be verified against subsequent pictures (visual-spatial context) or sentences (verbal context). As control conditions participants were asked to verify non-spatial sentences that contained a conjunction (e.g. 'triangle and circle'). We found evidence for higher activity for spatial than for non-spatial sentences in the left SMG, and this was not dependent on the context (verbal or visual-spatial) in which the sentence was read. Therefore, we conclude that it appears to be the case that the left SMG is necessarily involved with the processing of locative prepositions and not just when this type of verbal information has to be compared to a visual stimulus.

Noordzij, M. L., Neggers, S. F. W., Postma, A., & Ramsey, N. (*in preparation*).

Introduction

Numerous studies have shown that processes that underlie the understanding and production of language can be dissociated both on a cognitive and a neuronal level from the processes that underlie our visuospatial abilities (Hickok, Say, Bellugi, & Klima, 1996; Kemmerer & Tranel, 2000; Shah & Miyake, 1996). Yet, people are very able to use spatial representations to explain to others what kind of objects they have seen and where these objects were located. Therefore, language and spatial knowledge, although they seem to be dissociated, can and have to be linked. The standard linguistic representation of an object's place requires three elements (Levinson, 2003): The object to be located (or "figure"), the reference object (or "ground") and their relationship. In language this relationship is mostly indicated by a locative preposition such as "above" or "to the left of". Therefore, locative prepositions play a pivotal role in successful communication of spatial knowledge. The aim of the present study was to examine how locative prepositions are processed and represented in the brain.

In an influential paper Landau and Jackendoff (1993) speculated that the semantic aspects of processing locative prepositions are represented in the parietal lobe. Indirect evidence for this claim can be found in studies with agrammatic aphasic patients with specific impairments in the use of closed-class lexical items (including prepositions). Agrammatism is often associated with left frontal and parietal regions. In a neuropsychological study Tranel and Kemmerer (2004) seventy-eight participants with focal, stable lesions to various parts of the telencephalon were examined. The highest region of lesion overlap for participants with impaired knowledge of locative prepositions was in the left frontal operculum and the left supramarginal gyrus (SMG), an area in the inferior parietal cortex. Recently, neuroimaging studies have indicated similar findings. A PET study (Damasio et al., 2001) showed that naming static spatial relationships was associated with activation in the left inferior prefrontal cortex as well as activation in the left SMG. In related studies (PET (Emmorey et al., 2002) & fMRI (MacSweeney et al., 2002)), production and comprehension of sign language sentences with a spatial content resulted in more SMG activation than sentences without a spatial content.

The aforementioned studies point to the left SMG as the crucial area for the representation of linguistic spatial relations. There are also indications that another area in the left inferior parietal lobule, namely the angular gyrus (AG), might play a role. Lesions in the AG are known to result in Gerstmann syndrome, which, among other symptoms, involves a profound left/ right confusion (Gerstmann, 1957; Mayer et al., 1999). Furthermore, in an fMRI study concerning categorical and coordinate spatial relations (Baciu et al., 1999), the left AG was found to be more active than the right AG for the categorical "above/ below" decisions. In addition, Carlson, West, Taylor, and

Herndon (2002) measured event-related brain potentials (ERPs) while participants had to verify "above/ below" relations and found a modulation of a parietal slow wave that was associated with the assessment of "above" and "below" relations in various spatial arrays. However, the precise source of this slow wave could have been either the SMG or the AG, or both, given the poor spatial resolution of ERP measurements. Taken together, these findings suggest that left (inferior) parietal regions are necessary for the understanding and production of locative prepositions.

In a previous study (Noordzij, Van der Lubbe, & Postma, in press) we found evidence that participants followed an imagery strategy when reading a spatial sentence that was followed in 80% of the trials by a picture, while they did not rely on imagery when the spatial sentence was followed in 80% of the trials by a sentence. The above mentioned neuroanatomical studies (Damasio et al., 2001; Tranel & Kemmerer, 2004) concerning the processing of locative prepositions tested the understanding of the spatial prepositions only in relation to visual-spatial material. Furthermore, a recent fMRI study (Just, Newman, Keller, McEleney, & Carpenter, 2004) showed that high imagery sentences (e.g. *On a map, Nevada is to the right of California*) evoked more activation in the left intraparietal sulcus than low imagery sentences (e.g. *Horsepower is the unit for measuring the power of engines or motors)*. Therefore, it might be the case that the parietal activation that was found in previous neuroimaging studies actually reflected an imagery strategy or another type of integrative process between verbal and visual-spatial information.

The aim of the present fMRI study was to establish the involvement of left inferior parietal areas with the processing of locative prepositions, and to examine the possible confound that was present in the previous neuropsychological (Tranel & Kemmerer, 2004) and PET study (Damasio et al., 2001) that examined the neural correlates of locative prepositions. We focused on one type of spatial preposition ("to the left of" and "to the right of") to prevent possible variability related to differences between topological (e.g. "through", "in") and projective (e.g. "above", "right") relations. In addition, we wanted to examine whether this parietal activation reflects either necessary, context independent processes or strategic, context dependent processes.

In order to examine these questions we conducted a rapid event-related fMRI study with simple spatial sentences (e.g. 'triangle left of circle') that had to be verified against subsequent pictures (visual-spatial context) or sentences (verbal context). As control conditions participants were asked to verify non-spatial sentences that contained a conjunction (e.g. 'triangle and circle') against subsequent pictures or sentences. First, we tested whether spatial conditions and sentences did indeed elicit more activation from left inferior parietal regions than non-spatial conditions. As control regions we also investigated these contrasts in classical language areas (i.e. Broca (BA44/ 45) and Wernicke (BA22)). Second, if we did find evidence for more involvement of left inferior parietal regions with spatial than non-spatial conditions then the effect of the context in which the spatial sentence was read will be tested for the activated parietal areas.

Materials and Method

Participants

Eleven healthy participants (4 men, 7 women, aged 19-37 years) were included in this study. All participants were native Dutch speakers and reported normal or corrected-to-normal vision. They were all right handed as assessed with Annet's handedness questionnaire (Annet, 1970). All participants gave written informed consent, and the Medical Ethical Committee (METC) of the Utrecht University Medical Center approved the experiment.

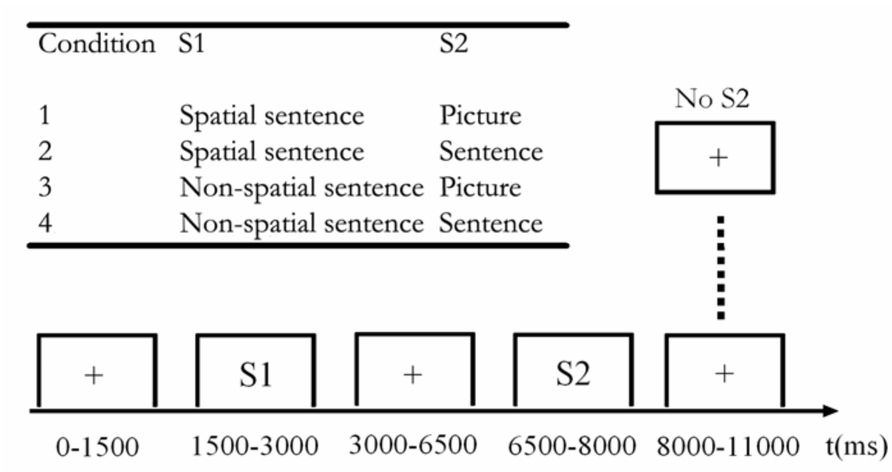

Figure 1.
A depiction of a typical trial for all four conditions, which are described in the table. For every condition no S2 was shown in 6 trials and subjects immediately saw the final fixation cross (this final fixation cross had a red colour, whereas the previous fixation crosses had a black colour).

Experiment, design and procedure

Trials consisted of two sequentially presented stimuli (S1, S2), and four different conditions were included: (1) spatial sentence followed by a picture, (2) spatial sentence followed by another spatial sentence, (3) non-spatial sentence followed by a picture, and (4) non-spatial sentence followed by another non-spatial sentence (see Figure 1). Participants were instructed to indicate whether the information in S2 was the same as the information in S1. In spatial conditions S1 was a sentence that described the left/ right relation between two objects (circle, square, and triangle were the options). S2 was either a correct depiction/ description of the spatial arrangement described in S1, or it was an incorrect depiction/ description because a different object was present or the spatial relation was incorrect in relation to S1. In non-spatial conditions S1 was a sentence that described a conjunction ('and') of two objects (circle, square, and triangle). S2 either depicted/ described the same objects (correct trials) or one different object (incorrect trials). The spatial position of the objects was irrelevant in the non-spatial conditions. For both spatial and non-spatial conditions there were 6 trials in which no S2 appeared and participants were instructed to wait for the next S1. Each condition consisted of 28 trials (22 S1-S2 trials, and 6 S1 only trials) divided over 4 blocks. In between blocks there was a rest period of 11 seconds. The experiment was broken into two sessions (each session had 8 blocks). In between sessions participants saw a green fixation cross. Participants only had to wait about 35 seconds on average before the second session started.

A trial consisted of the following sequence: fixation cross (white colour, 1500 ms), S1 (1500 ms), fixation cross (white colour, 3500 ms), S2 (1500 ms), fixation cross (red colour, 3000 ms). For trials in which no S2 appeared, participants saw a red fixation immediately after the white fixation cross following S1. During functional imaging participants looked at a screen visible through an overhead mirror. A beamer, controlled by a laptop PC running the Presentation software package from Neurobehavioral Systems, projected the stimuli on the screen. Responses were recorded by means of an MR compatible pneumatic button box. Participants responded by pressing the left key for "incorrect" (with their left thumb) and the right key for "correct" (with their right thumb). Before the start of the fMRI experiment participants were instructed to respond as quickly as possible while maintaining high accuracy. In addition, participants were trained for 20 minutes on all conditions and during this training they received feedback on their performance. No feedback was given during the fMRI experiment.

Data acquisition

Functional imaging was performed with a Philips ACSNT 1.5-T clinical scanner with a 6 channel SENSE head receive coil, using the blood oxygen level dependent (BOLD) sensitive, navigated 3D PRESTO-SENSE pulse sequence (Golay et al., 2000; Ramsey et al., 1998; van Gelderen et al., 1995), with the following parameters: TE/TR, 13.5/26.32 ms; flip angle, 9.5°; FOV, 256 x 120 x 92 mm; voxel size 4 x 4 x 4 mm; scan time per fMRI volume, 1.007 s; 704 scans for session 1 and 711 scans for session 2. The SENSE method (Pruessmann, Weiger, Scheidegger, & Boesiger, 1999) is based on sensitivity encoding with multiple receiver coils, which permits reducing the scan time by using information related to the distinct spatial sensitivities of coil array elements. Directly after the functional sequence, an additional functional scan (FA30) was made with a flip angle of 30°, to which functional as well as anatomical images were coregistered. The PRESTO images used as functional time series have low anatomical contrast and wouldn't coregister well with a high-contrast anatomical scan, whereas the FA30 scan has higher anatomical contrast which makes it suitable for coregistration with the anatomical volume, and is otherwise identical to the functional PRESTO images. Finally, an anatomical scan was acquired (TE/TR, 4.6/30 ms; flip angle, 30°; FOV, 256 x 192 x 208 mm; voxel size 1 x 1 x 1.2 mm).

Statistical analysis

Behavioral data (mean RTs and error scores) were analysed using separate 2 (S1: Spatial or Non-Spatial) x 2 (S2: Sentence or Picture) ANOVAs with repeated measures. fMRI data were analyzed with SPM2 (Wellcome Department of Cognitive Neurology, London, http://www.fil.ion.ucl.ac.uk/ spm/spm2.html), using MATLAB 6.5. For each individual subject, the functional time series data were realigned (using the FA30 as first scan) using rigid body transformations, and coregistered to the subjects anatomical T1 weighted image, all without reslicing the volume (only the parameters were saved per volume). The anatomical T1 weighted image was then spatially normalized to the Montreal Neurological Institute (MNI) template based on an average of 152 brains, the same normalization parameters where then applied to the functional time series, which were subsequentially resliced. Finally, the normalized functional time series were smoothed (full width at half maximum= 8mm). Low frequency fluctuations were removed by setting a high-pass filter with a 120 s cut-off. Data-analysis employed a two-stage procedure, implementing a mixed-effect analysis.

In the first stage, ten event types were defined and included to construct event related regressors. For S1 the following events were defined: a spatial sentence followed by a picture (sp_S1_picture), a spatial sentence followed by a sentence (sp_S1_sentence), a non-spatial sentence followed by a picture (nonsp_S1_picture), and a non-spatial sentence followed by a sentence (nonsp_S1_sentence). For S2 we defined another 4 events: a picture for which a spatial decision was required (sp_S2_picture), a sentence for which a spatial decision was required (sp_S2_sentence), a picture for which only object identification was required (nonsp_S2_picture), and a sentence for which only object identification was required (nonsp_S2_sentence). The moment when no S2 appeared was included (no_S2), and finally the moment of written block instruction (instr) was included. These ten events were modelled by convolving a block function of 1.5 seconds at each stimulus onsets with a canonical hemodynamic response function. Session-specific (the two sessions were replications) parameter estimates were calculated for each voxel, and images of contrasts of these parameters were calculated for each participant. These contrast images were then entered into one-sample *t*-tests, treating participants as a random variable.

The specific contrasts that we investigated were:

[1] sp_S1_picture + sp_S1_sentence - nonsp_S1_picture - nonsp_S1_sentence + sp_S2_picture + sp_S2_sentence - nonsp_S2_picture - nonsp_S2_sentence.
[2] sp_S1_picture + sp_S1_sentence - nonsp_S1_picture - nonsp_S1_sentence
[3] sp_S1_picture - sp_S1_sentence
[4] sp_S1_sentence - sp_S1_picture

Contrast [1] should be significant for voxels with different responses to spatial than non-spatial *conditions*, Contrast [2] should be significant for voxels with different responses to spatial than non-spatial *sentences*. If we find significant activation differences for contrast [1] and/ or [2] then a new ROI will be based on these patterns of activation. Subsequently, contrast [3] should be significant for voxels with different responses to spatial sentences followed by a picture than by spatial sentences followed by a sentence. Finally, contrast [4] should be significant for voxels with different responses to spatial sentences followed by a sentence than by spatial sentences followed by a picture.

The regions of interest were the left inferior parietal lobe, thresholded at $t= 4.91$, $p< .05$ corrected for multiple comparisons, Broca's area (BA44/ 45), thresholded at $t= 3.87$, $p< .05$ corrected, and Wernicke's area (BA 22), $t= 4.22$, $p< .05$ corrected. These ROIs and critical *ts* were computed with the aid of WFU PickAtlas; a number of Matlab functions interfaced to SPM2 which incorporates lobar, anatomic label, hemisphere, tissue type and Brodmann area segmented atlas volumes based on the Talairach Daemon (Maldjian, Laurienti, & Burdette, 2004; Maldjian, Laurienti, Kraft, & Burdette, 2003). Finally to investigate whether the BOLD signal had the shape of a typical Hemodynamic Response (i.e. starting to rise after 2 seconds and having its peak around 6 seconds) time course plots of the average BOLD signal changes were plotted for significantly activated regions. These peri-stimulus-time-histograms (PSTHs) provided important information concerning our data because we modelled neural events with a typical Hemodynamic Response and this might not be correct for the specific ROI's (possibly parietal regions) in this experiment. PSTHs were constructed by a so called finite impulse response (FIR) model, with a first regressor containing the plotted events as delta functions, and the next regressors (as many as time points in the PSTH) contain the same information shifted one volume in time per regressor (see Henson, Rugg, & Friston, 2001)). The regression coefficients of such a FIR model are the time points in the plotted PSTH. Additionally, hemodynamic responses of events of no interest for this PSTH were added to the FIR model to correct the data for these responses. Here, the raw signal was corrected for all other events than those compared in the contrast.

Results

Behavioral data

Table 1 shows mean RTs for correct responses and mean percentage error scores. For reactiontimes, the main effects of S1 and S2 were significant, $F(1, 10) = 159.2$, $p < .001$ and $F(1, 10) = 138.9$, $p < .001$, indicating that responses were faster when the first sentence was non-spatial than spatial and when the second stimulus was a picture than a sentence. The interaction between S1 and S2 was also significant, $F(1, 10) = 83.7$, $p < .001$. Further analysis showed that responses were faster for pictures than for sentences, but this advantage was far greater when the first sentence was spatial, $t(10) = 15.3$, $p < .001$, than non-spatial, $t(10) = 3.4$, $p = .007$. For error scores, the main effect of S1 was significant, $F(1, 10) = 15.7$, $p = .003$, Indicating that participants made more errors when S1 was spatial than non-spatial. The main effect of S2 and the interaction between S1 and S2 were not significant, $F(1, 10) = 1.2$, $p = .28$ and $F(1, 10) = 2.6$, $p = .14$.

Table 1.
Mean RTs (ms) and error scores (%), standard errors in parentheses.

S2	Picture	Sentence
S1	***RTs***	
Spatial	1233 (74.5)	1845 (91.9)
Non-spatial	1116 (68.3)	1297 (69.9)
	error scores	
Spatial	7 (1.8)	7 (1.5)
Non-spatial	3 (.9)	1 (.6)

fMRI data

The main interest of this study was the neural correlates of the processing of locative prepositions, and therefore the contrasts spatial minus non-spatial *conditions* (contrast [1]) and *sentences* (contrast [2]) was tested. Contrast [1] resulted in one significant cluster in the left supramarginal gyrus (BA 40; -36, -52, 36; t(10)= 5.7, p= .00008; see Figure 1A) for the left inferior parietal ROI. PSTHs for this significant cluster were also plotted in Figure 2B, and they clearly showed the shape of a typical HR (onset around 2 s. and peak around 6 s) for the spatial conditions, while the responses for non-spatial stimuli were almost absent. Contrast [2] resulted in significant differences in the left supramarginal gyrus (BA 40; -32, -52, 40; t(10)= 5.1, p= .0002) for the left inferior parietal ROI. PSTHs for this significant cluster were also plotted in Figure 2C, and they approximately showed the shape of a typical HR (onset around 2 s. and peak around 6 s) for the spatial sentences, while the responses for non-spatial sentences were almost absent. Contrast [1] and [2] resulted in no significant voxels for the Broca or Wernicke ROI.

Furthermore, we wanted to test whether possible parietal activation related to spatial language might be modulated by the context in which the sentence is read (Contrast [3] & [4]). Therefore, a new ROI (a cube with the dimension 4 x 4 x 4 mm, origin (-32, -52, 40)) was created based on the activation that was found for contrast [2] between spatial and non-spatial sentences, and the contrasts for this ROI were thresholded at t= 3.15, p< .05 corrected. Contrast [3], a spatial sentence followed by a picture (only S1) minus spatial sentence followed by a sentence (only S1), revealed no significant differences in BOLD responses. The reversed contrast [4] also did not reveal any significant clusters.

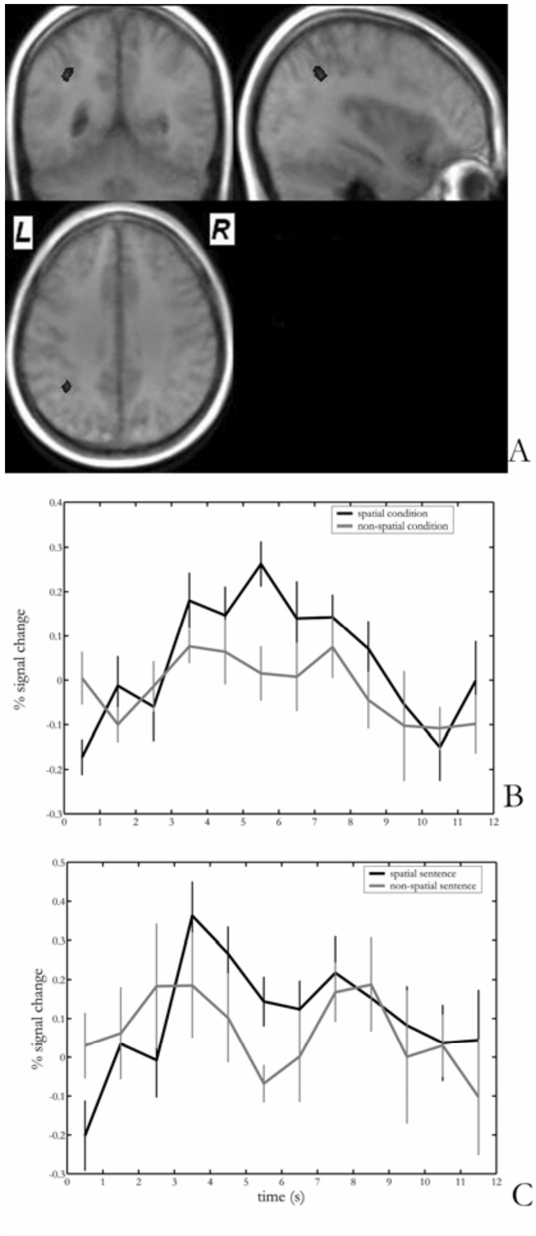

Figure 2.
A. Significant cluster in the left supramarginal gyrus (x= -36, y= -52, z= 36, 7 voxels, Z-score= 3.8) resulting from Contrast [1]. The cluster is superimposed on an average T1 image of the 11 participants.
B. PSTHs extracted from the cluster in the left SMG reflect different HR amplitudes for spatial and non-spatial conditions (Contrast [1]).
C. PSTHs extracted from the cluster in the left SMG reflect different HR amplitudes for spatial and non-spatial sentences (Contrast[2]).

Discussion

The first aim of the present fMRI study was to establish the involvement of left inferior parietal areas with the processing of locative prepositions. Only a recent neuropsychological study (Tranel & Kemmerer, 2004) tested the hypothesis that left inferior parietal regions might be crucial for the processing of locative prepositions. To our knowledge, the present study is the first to employ (event-related) fMRI to specifically study the possible involvement of parietal areas with spatial language. We did indeed find that BOLD responses were significantly larger in an area in the left SMG for spatial conditions than for non-spatial conditions. Furthermore, PSTHs for the spatial stimuli in the area in the left SMG clearly resembled a typical HR, while the PSTHs for non-spatial stimuli were virtually absent. Importantly, because we employed an event-related design, we could also contrast activity related to the processing of only the first stimulus in every trial (i.e. spatial vs. non-spatial sentences). This contrast revealed that BOLD responses were significantly larger in an area in the left SMG for spatial than non-spatial sentences. This area in the left SMG was almost identical to the one we found for the contrast between spatial and non-spatial conditions. Moreover, PSTHs for the spatial sentences in the area in the left SMG clearly resembled a typical HR, while the PSTHs for non-spatial sentences were virtually absent. Therefore, the present fMRI study provides converging evidence for the involvement of left inferior parietal areas, more specifically the left SMG, with the processing of locative prepositions.

One point of concern was the fact that participants were faster and better when S1 was non-spatial than spatial, although participants made very little errors in both conditions (i.e. 7% and 2% errors in the spatial and non-spatial conditions respectively). This difference in difficulty between both conditions might result in a generally higher neural activity in the more difficult spatial condition than in the non-spatial condition. If this were the case then the difference found in the left inferior parietal lobe ROI might simply be a result of this difference in general neural activity. However, the contrast between spatial and non-spatial conditions was not significant for the Broca or Wernicke ROI, while the critical statistical thresholds for these ROIs were (much) lower than the threshold for the parietal ROI. Therefore, it does not seem plausible that the significant activation in the left SMG can be explained by a general difference in neural activity, because then this difference would have resulted in significant activations in the other ROIs as well.

In the Introduction we addressed the possibility that parietal activation associated with locative prepositions only occurs when a spatial relation has to be named or understood in relation to a visual stimulus (visual context) and not in relation to a verbal stimulus (verbal context). Hence, the second aim of the present study was to examine whether the left inferior parietal activation, that has been associated with spatial language and the processing of locative prepositions in particular, might be explained by the context (visual vs. verbal) in which a spatial sentence is read. Contrasts for the abovementioned region in the left parietal cortex between spatial sentences (only S1) followed by sentences or pictures revealed no significant differences. Therefore, the activation in the left SMG was not modulated by the context (i.e. verbal or visual-spatial) in which the sentence was read.

Participants were faster when S2 was a picture than a sentence, and this effect was far stronger when the first sentence was spatial than non-spatial. Although the task for S2 is the same whether it is a picture or a sentence, participants are faster to verify the identity of the objects and the spatial relation between them (for the spatial conditions) in a picture than in a sentence. This finding is a replication of those reported in a very similar behavioral study (Noordzij et al., in press) in which the same stimuli were used. In this behavioral study the advantage for pictures over sentences was only found when participants expected a picture after the spatial sentence. We associated the advantage of pictures over sentences with an imagery strategy in which participants represent the spatial sentence as a mental image that can be quickly compared with a pictorial stimulus. In the present fMRI study participants always knew whether a sentence or a picture would follow the spatial sentence. Therefore, it is likely that they did rely on an imagery strategy in the conditions in which S2 was a picture. However, this imagery strategy does not explain the heightened BOLD response in left inferior parietal cortex because there was no significant difference in BOLD responses in the left SMG for spatial sentences followed by a picture or a sentence.

The present finding concerning the involvement of an area in the left SMG with the processing of sentences with the locative prepositions "to the left" and "to the right" might hold true for all type of locative prepositions, but more research is certainly needed to support this generalization. To summarize even a portion of the semantic differences that exist between locative prepositions is well beyond the scope of this article, especially when the enormous cross-cultural variation is taken into account (for a review see Levinson, 2003)). For example, in Arrernte, an Australian language, terms such as “left” and “right” do not exist, and it only has terms for cardinal direction terms similar to “north”, “south”, “east” and “west”. Even if the area in the left SMG proves to be essential for the understanding of most locative prepositions in languages (i.e. for topological and projective relations) such as English and Dutch, it would still remain unclear how these type of spatial expressions are represented neurally in languages that linguistically carve up space in very different ways. As noted by Tranel and Kemmerer (2004), very little is known about neural systems that are responsible for retrieving the semantic structures and lexical forms for locative prepositions in *any* language. In any case, this study is, to our knowledge, the first fMRI study to examine these neural systems and it seems to provide converging evidence for the findings from the neuropsychological study (Tranel & Kemmerer, 2004) with the same question.

Conclusions

Locative prepositions might be special linguistic modifiers because they form a natural link between verbal and visuospatial information. In the present fMRI study we found evidence that understanding categorical spatial relations expressed in language with locative prepositions such as "to the left of" and "to the right of" is dependent on the supramarginal gyrus located in the left inferior parietal lobe. The evidence for higher activity for spatial than for non-spatial sentences in this region was not dependent on the context (verbal or visual-spatial) in which the sentence was read. Therefore, we conclude that it appears to be the case that the left SMG is necessarily involved with the processing of locative prepositions.

References

Annet, M. (1970). A classification of hand preference by association analysis. *British Journal of Psychology, 61*, 303-321.

Baciu, M., Koenig, O., Vernier, M.-P., Bedoin, N., Rubin, C., & Segebarth, C. (1999). Categorical and coordinate spatial relations: fMRI evidence for hemispheric specialization. *Neuroreport, 10*, 1373-1378.

Carlson, L. A., West, R., Taylor, H. A., & Herndon, R. W. (2002). Neural correlates of spatial term use. *Journal of Experimental Psychology: Human Perception & Performance, 28*, 1391-1408.

Damasio, H., Grabowski, T. J., Tranel, D., Ponto, L. L. B., Hichwa, R. D., & Damasio, A. R. (2001). Neural Correlates of Naming Actions and of Naming Spatial Relations. *Neuroimage, 13*, 1053-1064.

Emmorey, K., Damasio, H., McCullough, S., Grabowski, T., Ponto, L. L., Hichwa, R. D., & Bellugi, U. (2002). Neural systems underlying spatial language in American Sign Language. *Neuroimage, 17*(2), 812-824.

Gerstmann, J. (1957). Some notes on the Gerstmann syndrome. *Neurology, 7*, 866-869.

Golay, X., Pruessmann, K. P., Weiger, M., Crelier, G. R., Folkers, P. J. M., Kollias, S. S., & Boesiger, P. (2000). PRESTO-SENSE: An Ultrafast Whole-Brain fMRI Technique. *Magnetic Resonance in Medicine, 43*, 779-786.

Henson, R. N. A., Rugg, M. D., & Friston, K. J. (2001). The choice of basis functions in event-related fMRI. *Neuroimage, 13*, 683.

Hickok, G., Say, K., Bellugi, U., & Klima, E. S. (1996). The basis of hemispheric asymmetries for language and spatial cognition: Clues from focal brain damage in two deaf native signers. *Aphasiology, 10*(6), 577-591.

Just, M. A., Newman, S. D., Keller, T. A., McEleney, A., & Carpenter, P. A. (2004). Imagery in sentence comprehension: an fMRI study. *Neuroimage, 21*, 112-124.

Kemmerer, D., & Tranel, D. (2000). A double dissociation between linguistic and perceptual representations of spatial relationships. *Cognitive Neuropsychology, 17*(5), 393-414.

Landau, B., & Jackendoff, R. (1993). "What" and "where" in spatial language and spatial cognition. *Behavioral & Brain Sciences, 16*(2), 217-265.

Levinson, S. C. (2003). *Space in language and cognition: Explorations in cognitive diversity*. Cambridge, UK: Cambridge University Press.

MacSweeney, M., Woll, B., Campbell, R., Calvert, G. A., McGuire, P. K., David, A. S., Simmons, A., & Brammer, M. J. (2002). Neural correlates of British Sign Language comprehension: Spatial processing demands of topographic language. *Journal of Cognitive Neuroscience, 14*(7), 1064-1075.

Maldjian, J. A., Laurienti, P. J., & Burdette, J. H. (2004). Precentral gyrus discrepancy in electronic versions of the Talairach atlas. *Neuroimage, 21*(1), 450-455.

Maldjian, J. A., Laurienti, P. J., Kraft, R. A., & Burdette, J. H. (2003). An automated method for neuroanatomic and cytoarchitectonic atlas-based interrogation of fMRI data sets. *Neuroimage, 19*(3), 1233-1239.

Mayer, E., Martory, M. D.-., Pegna, A. J., Landis, T., Delavelle, J., & Annoni, J. M.-. (1999). A pure case of Gerstmann syndrome with a subangular lesion. *Brain, 122*, 1107-1120.

Noordzij, M. L., Van der Lubbe, R. H., & Postma, A. (in press). Strategic and automatic components in the processing of linguistic spatial relations. *Acta Psychologica*.

Pruessmann, K. P., Weiger, M., Scheidegger, M. B., & Boesiger, P. (1999). SENSE: sensitivity encoding for fast MRI. *Magnetic Resonance in Medicine, 42*(5), 952-962.

Ramsey, N. F., van den Brink, J. S., van Muiswinkel, A. M., Folkers, P. J. M., Moonen, C. T., Jansma, J. M., & Kahn, R. S. (1998). Phase navigator correction in 3D fMRI improves detection of brain activation: Quantative assesment with a graded motor activation procedure. *Neuroimage, 8*(3), 240-248.

Shah, P., & Miyake, A. (1996). The separability of working memory resources for spatial thinking and language processing: An individual differences approach. *Journal of Experimental Psychology: General, 125*(1), 4-27.

Tranel, D., & Kemmerer, D. (2004). Neuroanatomical correlates of locative prepositions. *Cognitive Neuropsychology, 21*(7), 719-749.

van Gelderen, P., Ramsey, N. F., Liu, G., Duyn, J. H., Frank, J. A., Weinberger, D. R., & Moonen, C. T. (1995). Three-dimensional functional magnetic resonance of human brain on a clinical 1.5-T scanner. *Proceedings of the National Academy of Sciences of the United States of America, 92*(15), 6906-6910.

Chapter 6 Categorical and metric distance information in mental representations derived from route and survey descriptions

Abstract

Descriptions with a route perspective take the addressee into the environment and give information on position of objects relative to the changing position of the addressee. In contrast, descriptions with a survey perspective adopt a bird's-eye view and describe objects with respect to one another. The objective of the present study was to determine whether the perspective of a spatial description influences the extent to which categorical and metric distance is represented. We studied the characteristics of the representations that were constructed from route or survey descriptions with a recognition/ priming task and a bird flight distance comparison task. Spatial priming and symbolic distance effects were present after participants had studied a verbal description. The spatial priming effect indicated that objects in the environment were spatially organised according to some kind of distance (i.e. categorical or metric) in the representation of the listener. Furthermore, this organisation was not dependent on whether the objects in a given prime-target relation were explicitly mentioned in the same sentence, or instead had to be inferred from the text. The presence of symbolic distance effects indicated that larger differences in metric distance were easier to compare than smaller differences, which is an effect that is also expected if actual metric distances on a visual map have to be compared. Therefore, further evidence was provided that people are able to create map-like spatial representations of verbal descriptions. We replicated previous findings that route and survey descriptions result in representations from which categorical spatial information is equally available This study is the first to find evidence that a mental representation, which contains some analog spatial detail (i.e. metric distance), can be constructed from a description with a route perspective. Importantly, it should be noted that a relative advantage for survey descriptions over route descriptions did exist, suggesting that survey descriptions lead to spatial representations with a more fine-grained localization of the objects than route descriptions.

Noordzij, M. L., & Postma, A. (2005). *Psychological Research, 69(3)*, 221-232.

Introduction

Listening to verbal descriptions, it is clear that people talk about the world surrounding them in many different ways. An important reason for this diversity is the fact that people can describe a situation from different perspectives. Perspective can play a role in describing various aspects of a situation, which include social roles and spatial features of an environment. Although people necessarily write and talk about a given situation from their own perspective, it is very important to recognise and understand other perspectives to be able to interact with other people. For the present study we investigate the influence of different spatial perspectives on the representation of the spatial characteristics of a described environment. It seems to be the case that speakers mostly choose between two types of spatial perspectives, or a mix between the two (Taylor & Tversky, 1996). The first consists of taking listeners on a mental tour, which is termed a route perspective; the second consists of taking a viewpoint that is above the environment, which is termed a survey perspective. Route and survey descriptions have specific characteristics that have their origins in the different reference frames they employ. Route descriptions take the addressee into the environment and give information on position of landmarks and objects relative to the changing position of the addressee. The relative spatial information is conveyed by locative prepositions such as "to the left" and "to the right". In contrast, survey descriptions adopt a bird's-eye view and describe objects with respect to one another in terms of "north", "south", "east" and "west". Finally, the organisation of survey descriptions is often hierarchical. This hierarchical organisation takes shape in a division of an environment in spatial areas, after which each area is described in turn. In contrast, route descriptions have a sequential organisation, whereby each new object is introduced in a linear fashion.

It has been proposed that readers form representations that have a multilevel structure when they are confronted with the assignment to remember information from a text. Researchers have looked into different aspects of this multilevel structure: a surface level of representation, which is associated with the phonetic or graphemic properties of words (e.g. Glanzer, Dorfman, & Kaplan, 1981), a representation associated with the meaning of single words and sentences (i.e. propositional text base, e.g. Mani & Johnson-Laird, 1982), and a representation of the situation described in the text. These latter representations have been called situation models (Van Dijk & Kintsch, 1983) or mental models (Johnson-Laird, 1983). Studies have shown that a mental model can reflect the spatial properties of a description, which include relations between objects (Perrig & Kintsch, 1985; Taylor & Tversky, 1992) and distance information (Morrow, Bower, & Greenspan, 1989; Rinck, Hähnel, Bower, & Glowalla, 1997). A representation that reflects the spatial information in the text is usually referred to as a spatial situation model or spatial mental model.

An interesting question is whether the spatial perspective of a description has an influence on the spatial mental model. Spatial description research provided evidence for both the similarities and differences in the representations constructed from route or survey descriptions. Perrig and Kintsch (1985) found that subjects were able to answer effectively to spatial inference statements after reading a route or survey description, but the perspective of the statement and the sex of the subject modulated the performance on these statements. Female subjects were always better if the perspective of the statement was the same as the perspective of the studied text. Male subjects were always better when the statement had a survey perspective than when the statement had a route perspective. Perrig and Kintsch (1985) concluded that the nature of the spatial representation depends on the perspective of the text and the bias of the reader; a route perspective would give rise to a spatial representations in the shape of a set of procedural instructions, while a survey perspective would lead to a spatial representation in the shape of a mental map; male readers would prefer the latter representation irrespective of the perspective of the studied text. However, the Perrig and Kintsch (1985) study presented participants with descriptions that were long and detailed, which resulted in an overall poor performance on the verification statements. This low accuracy concerning spatial features of the learned environment made it unlikely that participants had been able to form a spatial representation at all. Furthermore, the coherence of the route texts was far better than of the survey texts

In contrast to Perrig and Kintsch (1985), Taylor and Tversky (1992) found that participants were equally accurate when answering to inference statements with a same or a different perspective from the studied text. They concluded that participants formed a spatial mental model that was not directly linked to the specific characteristic (e.g. perspective, organisation) of the original text. They suggested that this spatial mental model would have the properties of an architect's 3D model that can be viewed or visualized from many perspectives, but cannot be viewed as a whole. They stressed that this representation only contains information concerning categorical spatial relations that can be easily conveyed by spatial descriptions. By emphasising the nature of the information actually present in spatial descriptions they reconciled their findings with those from studies that contrasted exploration of an environment (route perspective) with map learning (survey perspective). In these studies (e.g. Taylor, Naylor, & Chechile, 1999; Thorndyke & Hayes-Roth, 1982) the mode of learning did influence which characteristics were easily accessible in the representation. Learning a map facilitated Euclidian or bird flight distance estimates, whereas learning an environment by exploration facilitated route distance estimates. Taylor and Tversky (1992) argued that in those cases, the information that was easily accessible was directly obtainable from the respective learning perspectives and not easily derived from the other perspective. In contrast, the critical information in the inference statements (categorical spatial information) was obtainable directly from both perspectives.

The fact that most spatial descriptions only mention the categorical spatial relations and not the metric distance between objects does not necessarily mean that people are incapable of constructing a representation from the text that does contain metric information. Denis and Zimmer (1992) examined the spatial properties of representations constructed from a verbal description or a map with three tasks: spatial priming, distance comparison and mental scanning. These three tasks had been previously used (e.g. Kosslyn, Ball, & Reiser, 1978; McNamara, 1986) to establish whether certain characteristics such as spatial proximity and distance were present in representations based on perceptual experience (i.e. maps). Denis and Zimmer (1992) found similar results for participants who studied a map or a verbal description and they argued for the map-like properties and structural isomorphism of representations based on spatial descriptions. This idea, of similar structural properties for perceptually and verbally based representations, was further supported by a number of mental scanning studies (e.g. Cocude, Mellet, & Denis, 1999; Denis & Cocude, 1989; Denis, Goncalves, & Memmi, 1995). The mental scanning paradigm resulted in positive correlations between response times and corresponding distances between two objects in an environment that was learned by means of a verbal description. In the aforementioned studies participants read spatial descriptions that were very simple and somewhat artificial (using the conventional hour-dial terms of flight navigation to indicate the spatial location of six objects). Furthermore, the position of objects was described as being placed on a (visually) well known geometrical shape: a circle. If a perspective had to be assigned to such a description it would have to be a survey perspective because of the allocentric point of view that is used to describe the positions and the overall shape. This leaves the question unanswered whether a spatial representation with metric properties can also be constructed from a description with a route perspective.

The objective of the present study was to determine whether the perspective of a spatial description influences the extent to which categorical and metric distance is represented. Although it seems to be the case that the spatial representations based on route and survey descriptions contain similar information regarding categorical spatial information, this study is the first to examine the possibility that the spatial perspective of the description does influence the availability of metric spatial information. In the current study participants listened to route and survey descriptions, after which they were presented with a priming/ recognition and a bird flight distance comparison task. Both these tasks are associated with typical response patterns (i.e. spatial priming effect and symbolic distance effect), which have been found after participants studied a visual map. When participants learn a simple visual configuration of a number of objects you expect items spatially close to each other to prime one another (McNamara, 1986). When a spatial configuration is learned by means of a verbal description different kinds of priming may occur depending on the nature of the representation that is formed. If people represent only the actual text (surface representation), only sentence priming should occur and no priming by spatial proximity should be expected. If participants build a spatial representation from a descriptive text that resembles a representation of a visual image, then items proximal in space should prime the target more than items remote in space, independently of whether they were mentioned in the same or different sentences. In order to examine whether participants formed a spatial representation of the information in the route and survey texts we presented them with an old/new recognition task, in which different prime-target relations (i.e. *close in text/ close in space*, *far in text/ close in space* and *far in text/ far in space*) were present. The fourth option, close in text/ far in space, could not be included because this would result in a highly incoherent text. One of the strong points of examining spatial priming effects is that they are supposedly insensitive to conscious choices and strategies. Therefore, the presence of a spatial priming effect would be a good indication of implicit spatial memory processes. The type of distance relations we examined, namely *near* and *far*, only allowed us to examine whether the representations contained information about categorical distance information. Similar to Taylor and Tversky (1992), we expected that route and survey descriptions result in representations from which categorical spatial information is equally available.

The second task, bird flight distance comparison, could also be used to distinguish between a representation on a textual level and a spatial representation. Participants were instructed to adopt a survey perspective during the task, whereas the priming/ recognition task allowed a more neutral instruction. However, the manipulation of the differences in metric distance could be more fine-grained for the distance comparison task, thereby allowing a specific test of the metric qualities of the spatial representations. Moyer (1973) argued that participants, who had to compare two animals and indicate which one is larger, converted animal names to analogue representations that preserved animal size and then compared these analogues by making an "internal psychophysical judgement". Moyer wanted to make the claim that the time required to answer any question "Which is /X/, /A/ or /B/?" will vary inversely with the difference between /A/ and /B/ on the dimension designated by /X/ (see also Moyer & Bayer, 1976). Denis and Zimmer (1992), elaborating on this idea, asked participants to compare pairs of bird flight distances between objects in an environment that had been previously studied (map or verbal description). They reasoned that if representations constructed from maps or descriptions represent distances then an inverse relationship between response times and distance differences should be observed. This was exactly what they found for both participants who had studied a map and a verbal description: the greater the distance difference between two object pairs the faster and better participants were at classifying the difference. Apparently, the information about bird flight distances can be inferred from a description that does not explicitly mention metric distances between objects. Thus, if participants in our experiment formed a spatial representation based on a description, then their performance (RTs and percentage errors) should have become better when the metric difference between bird flight distances increased. If participants formed a representation that stayed close to the actual words in the text, then their performance (RTs and percentage errors) should become better when the distance (in words) between objects in the original text increased.

In addition, we also examined possible effects of categorical distance in the bird flight distance comparison task by taking into account the number of objects and walls in-between two objects. In this way the term "categorical distance" does not refer to an ordinal level of distance measurement (i.e. "near" vs. "far"), but rather to the number of spatial units in between two target objects. If a spatial representation has metric qualities then symbolic distance effects should be independent of this type of categorical distance. In contrast, if a spatial representation only has categorical qualities related to the number of spatial units in between objects then symbolic distance effects should only be a result of this type of categorical distance, independent of metric distance.

Metric bird flight distance estimations have been found to be easier when the study material contained a survey perspective (map learning) than a route perspective (learning by exploration). Participants in the present study were asked to make bird flight distance comparisons after they had learned an environment from a survey description or a route description. If the route and survey descriptions were transformed into representations that retained the spatial perspective of the text, then we expected, similar to studies that contrasted actual navigation and map learning, participants who studied a survey description to be better at the bird flight distance comparison task than participants who studied a route description.

Method

Participants

Thirty undergraduates (9 male and 21 female, mean age ± 21 years) from Utrecht University participated and were paid € 7 per hour. All participants were right-handed, with normal or corrected-to-normal vision. They all gave informed consent and were naive with respect to the hypotheses.

Materials & Design

Descriptions

Fictitious maps of either a zoo or a mall (see Figure 1) were drawn using the software Paint. The environments measured 20 by 20 cm, containing 12 objects of 3 by 3 cm. Two types of descriptions of the zoo and the mall were created: one with a route perspective and one with a survey perspective (see Appendix A for sample texts). The descriptions differed on a number of points related to the perspective of the text. The survey description first introduced the four major quadrants of the environment after which the individual objects were mentioned (i.e. hierarchical organisation). In contrast, the route description started immediately with the first object revealing information about the overall layout of the environment in a step-wise fashion (i.e. linear organisation). Furthermore, the survey description employed canonical spatial terms such as *north*, *south* and *southwest corner*, while the route description used relative spatial terms such as *on your left* and *right*. Additionally, the grammatical person differed for the descriptions: objects were introduced in relation to previously mentioned objects in the survey description, whereas the route description addressed participants in the second person and introduced objects in relation to the reader's suggested position in the environment. A number of factors, which were not related to perspective, were held constant for both descriptions. All objects were mentioned twice in both descriptions. The descriptions approximately had the same amount of words, 260 (survey description) and 283 (route description). Continuous descriptions with high connectivity have been shown to result in easier processing and better recall than discontinuous descriptions with low connectivity (e.g. Denis & Denhiere, 1990; Ehrlich & Johnson-Laird, 1982). Therefore, new locations were always mentioned in reference to a previous location, which ensured that there were no discontinuities in the descriptions. A pilot study showed that participants could make accurate drawings (correct objects in their correct relative locations) of the environment after studying the description for ten minutes.

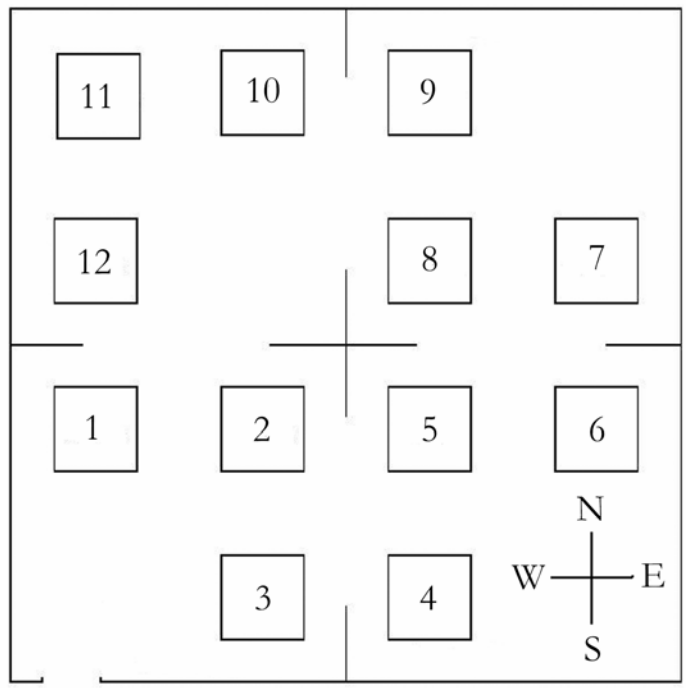

Figure 1.
An example of a basic configuration for the mall and the zoo (both 12 objects).

Recognition/ Priming

Lists of object names (animals or shops) were constructed for the priming task. The spoken object names were recorded and the duration of the individual sound files was 1200 ms. Names were presented to participants through headphones with E-Prime software running on a Pentium III computer. Half of the names were old (i.e. mentioned in one of the descriptions) and half were new (i.e. not previously learned). New items were selected from the same object categories as the old items. The old items were used to examine three priming relations: *close in text/ close in space*, *far in text/ close in space* and *far in text/ far in space*. For both *close in space* relations the prime was directly next to the target in the environment (spatial proximity). *Close in text/ close in space* relations were also mentioned in the same sentence in the descriptions, while *far in text/ close in space* relations were mentioned in different sentences. The prime-target relation was termed *far in text/ far in space* when a prime and a target were divided by at least one intermediate object and were not mentioned in the same sentence. Every priming relation was repeated seven times. Object names were repeated two or three times, but priming involving the repetition of a name was not confounded with the prime-target relation.

Distance comparison

Two lists, one for the zoo and one for the mall, of 48 pairs of two spoken object names were made and these pairs were all based on a common first object name (e.g. "Giraffe-Hyena"/ "Giraffe-Chimpanzee"). Two other lists were made with reversed presentation of the first and second pair (i.e. "Bonobo-Arctic Fox"/ "Bonobo-Rabbit" vs. "Bonobo-Rabbit"/ "Bonobo-Arctic Fox"). Presentation of distance pairs was randomised for both lists. Differences were divided in three categories based on the actual difference on the drawing of the environment: small difference (0-3 cm.), medium difference (3-6 cm) and large difference (6-11 cm). Small, medium and large differences all were repeated 16 times. In addition, the categorical distance between each object pair was determined by counting the number of objects and walls that were encountered on a straight line between the centres of the two objects. Participants were allowed to see the outer edge of the environment in a drawing before the start of the distance comparison task to provide them with a cue for the imaged size of the environment. A response box was used to collect participants' choices both in the Priming and Distance Comparison task.

Procedure

First, participants listened to a description of an environment through headphones. Each description was divided in smaller parts, which were repeated twice. In total, participants listened to a specific description six times. This study phase took approximately 15 minutes. Participants were asked to listen carefully and to memorise as much as possible. After the study phase they were presented with a priming/ recognition task and a distance comparison task. Next, they were given a rest for 45 minutes after which the other environment was learned again followed by a priming/ recognition task and a distance comparison task. Hence, each participant studied a route and a survey description, and the order of presentation was counterbalanced over participants.

The priming task was preceded by twelve practice trials that required province-no province judgements. Names of Dutch provinces (requiring a right button-press) and names of foreign countries (requiring a left button-press) were displayed, one name at a time. These practice trials allowed participants to get used to the procedures, especially pressing as fast and accurately as possible on the buttons. Subsequently, the priming task was started and object names were presented acoustically. Participants had to decide as fast and as accurately as possible whether an object had been present in the learned environment or not. They pressed the left button of the response box for *new* names and the right button for *old* names. The next object name was presented 250 ms after a response had been made.

The distance comparison task consisted of 2 practice trials with feedback and 48 experimental trials without feedback. During a trial, participants constantly looked at a fixation cross on the screen. A warning tone indicated the start of the trial. Two spoken names of objects were presented shortly (300 ms gap) after one another. Participants were asked to picture a map of the environment and mentally focus on the bird flight distance that separated the two objects. In addition they were instructed that this distance needed to be used as a reference to make a judgement about a second distance; after a delay of 2000 ms participants again heard two object names, and they had to visualise the bird flight distance between the objects. Finally they had to make a decision whether this second distance was longer or shorter than the first distance. Participants were to press the left button for "shorter" and the right button for "longer", as fast and as accurately as possible. The next trial started 2000 ms after the response was made.

At the end of the experiments belonging to a specific description participants were asked to make a drawing of the environment. They were given no time constraint, but they were told to make the drawing as accurately as possible by including all the objects they could remember in their correct relative locations. Only participants who could accurately draw the environment were included in the data analysis.

Data analysis

The data of the practice trials were discarded, as were trials on which the RT was either 2 standard deviations above or below the mean of the condition. For the Recognition/ Priming task, mean RTs, computed over correct trials, and mean percentage error scores were analysed using separate 2 x 3 repeated measures ANOVAs with Study Material (Route description and Survey description) and Prime-Target Relation (Close in Text/ Close in Space, Far in Text/ Close in Space and Far in Text/ Far in Space) as within-subjects variables. Planned comparisons were done for the three levels of Prime-Target-Relation. For the Distance comparison task, data (RTs and errors) were analysed using separate 2 x 3 x 3 repeated measures ANOVAs with Study Material (Route description and Survey description), Metric Distance Difference (Small, Medium, Large), and Categorical Distance Difference (0 units, 1 unit, 2 units[4]) as within subjects-variable. In addition, the predicted inverse relationship between the magnitude of the distance difference and the

[4] A unit refers to an object or wall. There were three trials in which there was a categorical distance difference of three units between the two target objects. However, this categorical distance difference did not occur for trials with Small Metric Distance Differences, and therefore these three trials had to be discarded for the ANOVAs.

RTs and the percentage error scores was tested with a contrast for a linear component in the Metric Distance Difference variable. Planned comparisons were done for the three levels of Metric Distance Difference, and correlations were also computed between RTs/ error scores and the precise metric distance differences. These correlations were computed for the whole set of metric distances (cm). Next, an analysis was carried out for the distance comparison task after the elimination of those items in which the first or the second distance was either the largest or the smallest of all possible differences. If participants discovered that these items represented the smallest or the largest possible difference, then they could have realised that there is no need for any mental comparison.

Subsequently, we also wanted to test whether the distance between the words in the route and survey descriptions influenced the RTs and error scores. Text distance differences were divided in three categories based on the number of words between two objects in a distance pair in the route and survey description. For the route description this resulted in the following subdivision: small difference (1-45 words), medium difference (46-90 words) and large difference (91-200 words). For the survey descriptions the subdivision was as followed: small difference (1-29 words), medium difference (30-59 words) and large difference (60-131 words). Mean RTs, computed over correct trials, and mean percentage error scores were analysed using separate 2 x 3 repeated measures ANOVAs with Text Distance Difference (Small, Medium and Large) and Study Material (Route description and Survey description) as within-subjects variables.

Six participants (three male and three female) were excluded from the analysis because they were not able to produce accurate drawings of the environments or scored at chance level on both the priming/ recognition task and the distance comparison task.

Results

Recognition/ priming

Reaction times

Table 1 shows mean RTs for correct responses for the spatial priming experiment. The main effect of Study Material was not significant, $F(1, 23) < 1$, $\eta_p^2 < .001$. The main effect of Prime-Target Relation was significant, $F(2, 46) = 7.5$, $p = .001$, $\eta_p^2 = .25$. Planned comparisons showed that RTs for primes and targets Close in Text/ Close in Space and Far in Text/ Close in Space were shorter than RTs for Far in Text/ Far in Space, $F(1, 23) = 5.0$, $p = .04$ and $F(1, 23) = 19.3$, $p < .001$. The RTs for primes and targets close in space but either close or far in text did not differ significantly from each other, $F(1, 23) = 1.6$, p= .22. The interaction effect between Study Material and Prime-Target Relation was not significant, $F(2, 46) < 1$, $\eta_p^2 < .01$.

Table 1.
Mean RTs (ms) for the priming/ recognition experiment, standard errors in parentheses.

Prime-Target Relation	Close in space/ Close in text	Close in space/ Far in text	Far in space/ Far in text
Perspective			
Route description	1018 (43.8)	1002 (31.7)	1066 (31.7)
Survey description	1023 (45.8)	999 (40.6)	1063 (39.7)

Error scores

There were no significant effects related to the error scores, all $Fs < 1.3$, $p > .27$, $\eta_p^2 < .06$.

Distance comparison

Reaction times

Table 2 shows mean RTs for correct responses and mean percentage error scores for the distance comparison experiment. The main effect of Study Material was not significant, $F(1, 23) < 1.2$, $\eta_p^2 = .05$. The main effect of Metric Distance Difference was significant, $F(2, 46) = 15.5$, $p < .001$, $\eta_p^2 = .4$. Planned comparisons showed that RTs for Small differences were higher than the RTs for Medium (marginally significant) and Large differences, $F(1, 23) = 3.9$, $p = .059$, and $F(1, 23) = 29.2$, $p < .001$. Participants were slower with Medium differences than with Large differences, $F(1, 23) = 15.1$, $p = .001$. In addition, a significant linear trend effect was found for Metric Distance Difference, $F(1, 23) = 29.2$, $p < .001$, $\eta_p^2 = .56$. This linear trend followed the expected direction and indicated the inverse relationship between RTs and the magnitude of the distance difference. The main effect of Categorical Distance Difference was not significant, $F(1, 23) < 1$, $\eta_p^2 = .04$. No interactions among Study Material, Metric and Categorical Distance Differences were significant, all $Fs < 1.6$, $p > .22$, $\eta_p^2 < .065$.

Table 2.
Mean RTs (ms) and error scores (%) based on categorical and metric distance differences for the distance comparison experiment.

Categorical Distance	Zero Units			One Unit			Two units		
Metric Distance	Small	Medium	Large	Small	Medium	Large	Small	Medium	Large
	RTs								
Perspective									
Route	2606	2228	2010	2392	2360	2123	2501	2274	2112
Survey	2494	2301	2118	2298	2385	2059	2267	2104	1851
	error scores								
Route	39	21	9	40	21	11	13	33	14
Survey	36	22	16	43	26	8	26	19	11

A number of trials included distance pairs that were the smallest or largest of the entire set of metric distances. A further analysis excluded trials in which such an extreme pair occurred. This analysis resulted in similar results as mentioned above. Next, reaction times were averaged over participants for each individual metric distance and correlations between RTs and differences were calculated for both Study Materials. A coefficient of $r(14)= -.66$, $p= .01$, was found for route descriptions and a coefficient of $r(14)= -.72$, $p= .004$, was obtained for survey descriptions (see Figure 2).

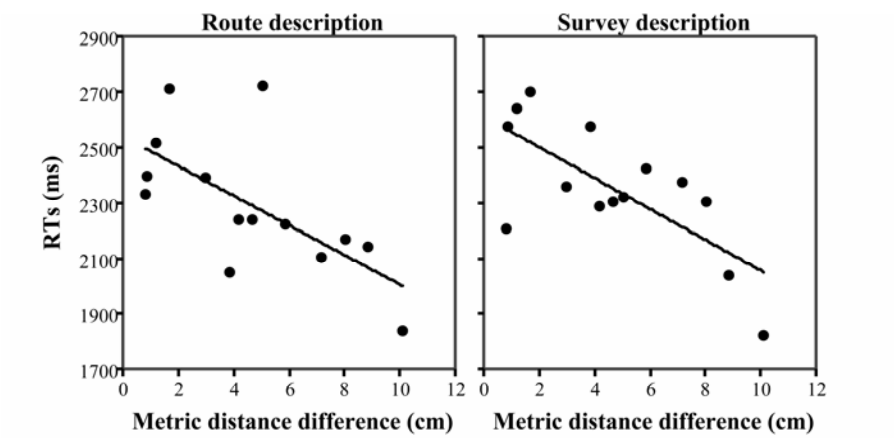

Figure 2.
RTs (ms) as a function of metric distance differences (cm), including regression lines for route descriptions, $y= 2540 - 54x$, $r= -.66$, and survey descriptions, $y= 2613- 56x$, $r= -.72$.

An additional ANOVA was carried out with Text Distance Difference and Study Material as within-subjects variable. The main effect of Text

Distance Difference was significant, $F(2, 44)= 3.2$, $p= .049$, $\eta_p^2= .13$, see Table 3. Further analysis showed that the difference between Small and Large Text Distance Differences was significant, $F(1, 22)= 5.9$, $p= .03$. The difference between Small and Medium, and Medium and Large differences were not significant, $F(1, 22)= 1.4$, $p= .25$, and $F(1, 22)= 2.1$, $p= .16$. All other effects were not significant, all $Fs< 1$, $\eta_p^2< .04$.

Table 3.

RTs (ms) and error scores (%) based on text distance differences for the distance comparison experiment, standard errors in parentheses.

Text Distance Difference	Small	Medium	Large
Perspective		RTs	
Route description	2421 (181.1)	2308 (141.5)	2172 (109.3)
Survey description	2267 (141.1)	2217 (143.4)	2151 (162.0)
		error scores	
Route description	43 (5.0)	35 (5.0)	36 (5.0)
Survey description	46 (3.6)	39 (4.6)	39 (3.6)

Error scores

The main effect of Study Material was not significant, $F(1, 23)< 1$, $\eta_p^2= .003$. The main effect of Metric Distance Difference was significant, $F(2, 46)= 40.6$, $p< .001$, $\eta_p^2= .64$. Planned comparisons showed that more errors were made for Small than for Medium and Large differences, $F(1, 23)= 13.8$, $p= .001$ and $F(1, 23)= 66.8$, $p< .001$. Furthermore, the percentage error score for Medium differences was greater than for Large differences, $F(1, 23)= 37.4$, $p< .001$. In addition, a significant linear trend effect was found for Metric Distance Difference, $F(1, 23)= 66.8$, $p< .001$, $\eta_p^2= .74$. This linear trend followed the expected direction and indicated the inverse relationship between percentage error scores and the magnitude of the distance difference comparison. The main effect of Categorical Distance Difference was not significant, $F(1, 23)= 2.6$, $p= .08$, $\eta_p^2= .10$.

The interaction between Metric Distance Difference and Categorical Distance Difference was significant, $F(4, 92)= 8.4$, $p< .001$, $\eta_p^2= .27$. Further analysis showed that for Small Metric Distance Differences the effect of Categorical Distance Difference was significant, $F(2, 46)= 12.0$, $p< .001$, while for Medium and Large Metric Distance Differences the effect of Categorical Distance Difference was not significant, both $Fs< 1$. The significant effect of Categorical Distance Difference for Small Metric Distance Differences indicated that participants made more errors for Small and Medium than for Large Categorical Distance Differences, $F(1, 23)= 13.9$, $p= .001$ and $F(1,23)= 23.5$, $p< .001$. In addition, the interaction between Study Material, Metric Distance Difference and Categorical Distance Difference was significant, $F(4,$

92)= 2.8, p= .03, η_p^2= .11. Analysis of the component interactions showed that the interaction between Metric and Categorical Distance Differences was significant, but only when participants had studied a Route Description and not when they had studied a Survey Description, F(4, 92)= 10.6, p< .001 and F(4, 92)= 1.5, p= .22. More precisely, when participants had studied a Route Description an effect of Categorical Distance Difference was only found for Small Metric Distance Differences, F(2, 46)= 13.1, p< .001, whereas when participants had studied a Survey Description no effect of Categorical Distance Difference was found for Small (or any other) Metric Distance Differences, F(2, 46)= 2.2, p= .13. All other interactions were not significant, all Fs< 1.1, η_p^2< .05.

The analysis, without trials in which an extreme distance difference occurred, produced similar results as those reported above. Subsequently, error scores were averaged over participants for each individual metric distance and correlations between RTs and differences were calculated for both Study Materials. A coefficient of r(14)= -.64, p= .02, was found for route descriptions and a coefficient of r(14)= -.82, p< .001, was obtained for survey descriptions (see Figure 3). The difference between these two coefficients was not significant, χ^2(1)< 1 (see Olkin & Finn, 1990).

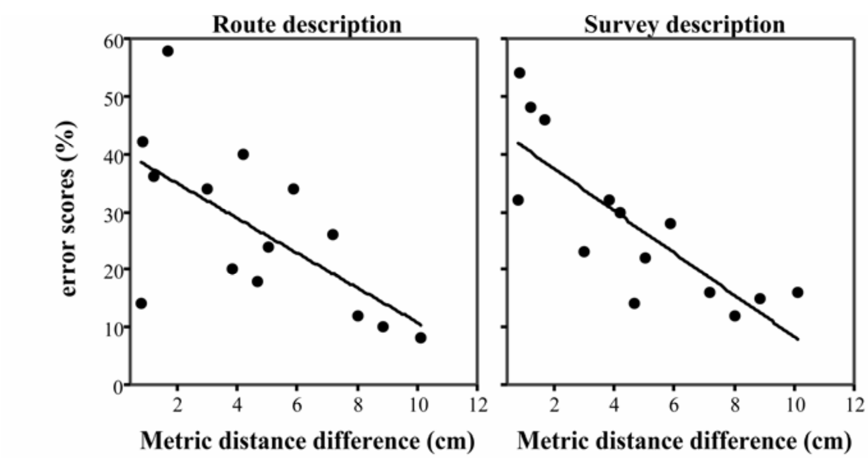

Figure 3.
Error scores (%) as a function of metric distance differences (cm), including regression lines for route descriptions, y= 41 - 3x, r= -.64, and survey descriptions, y= 45 – 3.6x, r= -.82.

An additional ANOVA was carried out with Text Distance Difference and Study Material as within-subjects variable. The main effect of Study Material was not significant, F(1, 23)= 1.8, p= .20, η_p^2= .07. The main effect of Text Distance Difference was significant, F(2, 46)= 8.2, p= .001, η_p^2= .26. Further analysis showed that more errors were made for Small than Medium and Large Text Distance differences, F(1, 23)= 10.6, p= .004 and F(1, 23)= 9.8, *p*= .005 (see Table 3). The same amount of errors was made for Medium and Large Distance differences, *F*< 1. Importantly, the percentage error scores that resulted from fitting the data to correct responses according to text distance differences was much higher than fitting the data to correct responses according to metric distance differences (see Figure 4). In addition, Figure 4 clearly shows that participants were able to compare even the smallest Metric Distance Differences at a performance level (i.e. mean= 33 % errors, standard error= 2.1) that was well above chance level.

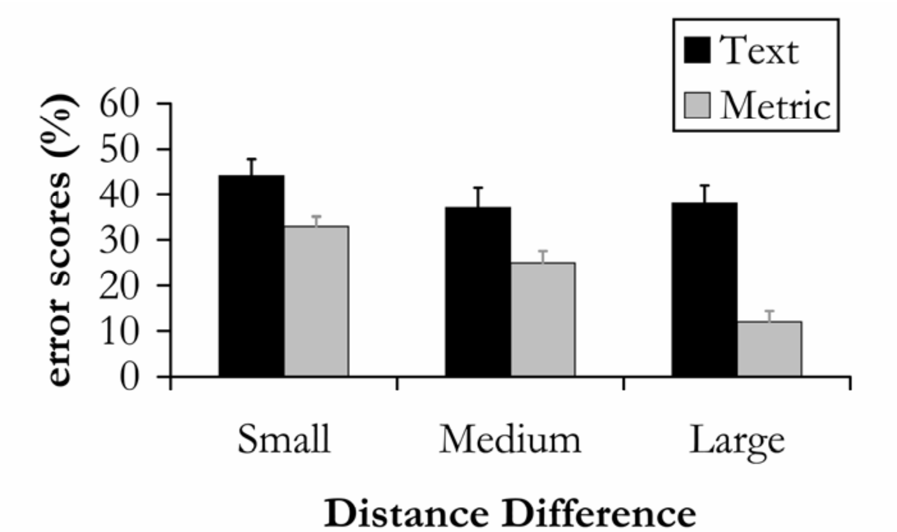

Figure 4.
Error scores (%) as a function of text (words) or metric distance differences (cm).

Discussion

The purpose of the present investigations was to determine whether the perspective of a spatial description influences the extent to which categorical and metric distance is represented. We found spatial priming and symbolic distance effects after participants had listened to a route or survey description of an environment. In the recognition/ priming task primes close in space resulted in significantly faster RTs for the target than primes far in space, while primes close in text and far in text resulted in similar RTs. This spatial priming effect indicates that objects in the environment were spatially organised in the representation of the listener. Furthermore, this organisation was not dependent on whether the objects in a given prime-target relation were explicitly mentioned in the same sentence, or instead had to be inferred from the text. Apparently, participants formed a spatial representation of the route and survey descriptions in which the distance between individual objects was encoded. In this experiment we only distinguished between primes that were directly next to the target and primes that were not directly next to the target. Therefore, the spatial priming effect only reflected an organisation of spatial memory according to any kind of distance (i.e. categorical or metric). The precise detail of the distance information that was present in the spatial representation could not be deduced from the findings of the priming/ recognition task. In order to be able to pronounce upon the possible metric qualities of the spatial representation we turn to the findings of the second task in this study.

For the bird flight distance comparison task we found that participants performed faster and better with increasing distance differences. A significant inverse linear relation was found between RTs/ percentage error scores and the magnitude of the difference between two bird flight distances. Furthermore, the percentage errors that participants made were well below chance level, even for the smallest distance differences. Evidently, participants formed a representation that allowed them to infer bird flight distance information. In addition, regardless of whether participants had listened to a route or a survey description, negative correlation coefficients were found between the metric distance differences and the performance (RTs and percentage errors) of participants. The presence of such symbolic distance effects indicated that larger differences in distance were easier to compare than smaller differences, which is an effect that is also expected if actual metric distances on a visual map have to be compared. A number of the trials included distances between object pairs that were the smallest or largest metric distance on the map. These distances might have been recognised by participants as being a minimum or a maximum, thereby allowing them to answer without making a mental comparison to the other distance in the trial. However, after eliminating these trials from the data analysis we found the same results regarding the relation between distance differences and the performance of participants. Until now, these symbolic distance effects have only been found after people listened to or read verbal descriptions with a survey perspective. The finding that symbolic distance effects were present after participants studied a survey *or* a route description further supports the notion that people build up spatial representations from both types of descriptions. These spatial representations appear to have structural properties (i.e. metric distance) that are isomorphic to the properties of representations that are constructed from actual visual-spatial configurations such as maps.

An alternative explanation for the symbolic (metric) distance effects might be that people relied on differences in categorical distance, such as the number of objects and walls, that were present in-between the objects. Overall we found that the effect of metric distance was independent of this type of categorical distance, with one exception: categorical distance did have an effect for the smallest metric distance differences. Participants got better as the categorical distance between the objects increased for these subtle metric differences. This suggested that participants did rely on categorical distance differences for the most difficult metric comparisons. However, we only found this effect to be significant for route descriptions and not for survey descriptions, as evidenced by a three-way interaction between study material, metric distance differences and categorical distance differences.

Route and survey descriptions can be seen as the textual equivalents of on the one hand actual traversal of an environment and on the other hand studying a map. Previous research showed *relative* advantages for certain spatial estimations depending on the way knowledge had been acquired about the environment. For example, metric bird flight distance estimations were better after map study than after navigation in the environment. The present study required participants to infer metric bird flight distances, which are more available from a survey than a route representation. Although participants were able to perform metric bird flight distance comparisons after they studied a route or a survey description, we did find that for very small differences in metric distance participants seemed to rely on categorical distance differences when they had studied a route description and not when they had studied a survey description. This finding is consistent with the idea that survey descriptions lead to spatial representations with a more fine-grained localization of the objects than route descriptions.

Another alternative explanation for the symbolic distance effects might be that participants did not rely on imagining metric distances, but instead relied on the (temporal) distance between words in the original spatial description. If participants did use text distance instead of metric distance, then their performance would be better explained by fitting text distances than by fitting metric distances to the data. Moreover, if a route description would have led to a representation that is in the form of a linear path through an environment, and a survey description would have led to a more map-like representation, then the distance in text should have influenced the performance of participants more after listening to route than a survey description. Importantly, our results do not support this alternative explanation for either the route or survey description conditions. First, correct responses according to metric distance differences corresponded more often to the responses given by participants than the correct responses according to text distance differences. This indicates that participants did follow the instructions and tried to imagine the bird flight distances. Second, the inverse relation between differences (either bird flight distances or distances in number of words in the text) and performance were much stronger after fitting the metric distances than after fitting the text distances. The inverse relation for text distance can probably be explained by the trials in which the answer according to text distance and metric distance was the same. Finally, we found no significant differences between route and survey descriptions with respect to how well metric or text distances explained the data.

The results from this study replicated and extended the findings of previous studies concerning the characteristics of representations of spatial descriptions. A number of studies (Denis & Zimmer, 1992; Wagener & Wender, 1985; Wagener-Wender & Wender, 1990) found similar priming effects as those reported here. In all these studies participants learned a short text describing a spatial configuration after which primes located near the target produced a stronger priming effect than did those located far from it, even if the prime and target had been in different sentences. The presence of a symbolic distance effect in the present study resembles the findings from mental scanning studies (e.g. (Denis & Cocude, 1992) where relative distances between objects influence the time necessary to scan from one object to the other. Furthermore, as mentioned in the introduction, (Denis & Zimmer, 1992) obtained similar symbolic distance effects after participants had studied a map or a verbal description of a fictitious island. However, these previous studies examined spatial descriptions that were simple and which employed uncommon terms (e.g. clock times) to indicate spatial information. In the current study we created spatial descriptions, which employed common locative prepositions to indicate the relative spatial location of objects. Moreover, the spatial descriptions in our study did not describe a canonical spatial arrangement such as a circle or a square, which was previously learned visually. Participants had to learn a new arrangement through a spatial description. Hence, the present study adds to the growing evidence in support of the idea that people can build up detailed spatial representations from verbal descriptions. In addition, we can conclude that the construction of such spatial representations can not only be achieved for simple descriptions of well-known spatial arrangements, but also for more complex, common descriptions of previously unknown configurations.

The spatial representations that result from reading a verbal description have been hypothesized to be abstract (perspective free) spatial mental models or mental images. Spatial mental models indicate a representational level of text that reflects the spatial properties of a description. These mental models have been theorised to be like an architect's 3D model, which can be viewed from many different perspectives, but can never be viewed as a whole (Taylor & Tversky, 1992). In contrast, mental images are thought to be perception-like and viewed from a constant (allocentric) point of view. Although an extensive comparison between these two types of representations is beyond the scope of the present article (for a detailed discussion see for instance (De Vega, Intons-Peterson, Johnson-Laird, Denis, & Marschark, 1996), we would like to argue for the idea that participants in the present study formed mental images instead of more abstract mental models. The fact that we found spatial priming and symbolic distance effects, which also would be expected when this task had to be executed after studying a visual map, seemed to indicate that the spatial representation had at least some structural properties that were the same as those from an actual perceptual experience. However, (Rinck et al., 1997) found evidence that metric distance can be represented in situation models, but this precise information is only used when a given task cannot be performed by means of categorical distance information. Therefore, it might be that the difference between a situation model and a mental image should not be decided upon by examining whether metric distance information was present or not in the spatial representation.

In conclusion, spatial priming and symbolic distance effects were found after participants studied verbal descriptions. Both categorical and metric distance information seems to be represented after people listen to a description with a route or a survey perspective. Our finding that similar priming effects related to categorical distance occurred after participants listened to a route or survey description is in line with previous studies that indicated that information concerning the relative positions of objects was equally available from representations based on either description perspective. This study is the first to find evidence that a mental representation, which contains some analog spatial detail (i.e. metric distance), can be constructed from a description with a route perspective. Importantly, it should be noted that a relative advantage for survey descriptions over route descriptions did exist, suggesting that survey descriptions lead to spatial representations with a more fine-grained localization of the objects than route descriptions.

References

Cocude, M., Mellet, E., & Denis, M. (1999). Visual and mental exploration of visuo-spatial configurations: Behavioral and neuroimaging approaches. *Psychological Research, 62*(2-3), 93-106.

De Vega, M., Intons-Peterson, M. J., Johnson-Laird, P. N., Denis, M., & Marschark, M. (Eds.). (1996). *Models of visuospatial cognition*. New York: Oxford University Press.

Denis, M., & Cocude, M. (1989). Scanning visual images generated from verbal descriptions. *European Journal of Cognitive Psychology, 1*(293-307).

Denis, M., & Cocude, M. (1992). Structural properties of visual images constructed from poorly or well-structered verbal descriptions. *Memory & Cognition, 20*, 497-506.

Denis, M., & Denhiere, G. (1990). Comprehension and recall of spatial descriptions. *European Bulletin of Cognitive Psychology, 10*(2), 115-143.

Denis, M., Goncalves, M.-R., & Memmi, D. (1995). Mental scanning of visual images generated from verbal descriptions: Towards a model of image accuracy. *Neuropsychologia, 33*(11), 1511-1530.

Denis, M., & Zimmer, H. D. (1992). Analog properties of cognitive maps constructed from verbal descriptions. *Psychological Research, 54*(4), 286-298.

Ehrlich, K., & Johnson-Laird, P. N. (1982). Spatial descriptions and referential continuity. *Journal of Verbal Learning & Verbal Behavior, 21*, 296-306.

Glanzer, M., Dorfman, D., & Kaplan, B. (1981). Short-term storage in processing text. *Journal of Verbal Learning & Verbal Behavior, 20*, 656-670.

Johnson-Laird, P. N. (1983). *Mental models*. Cambridge, MA: Harvard University Press.

Kosslyn, S. M., Ball, T. M., & Reiser, B. J. (1978). Visual images preserve metric spatial information: Evidence from studies of image scanning. *Journal of Experimental Psychology: Human Perception & Performance, 4*(1), 47-60.

Mani, K., & Johnson-Laird, P. N. (1982). The mental representation of spatial descriptions. *Memory & Cognition, 10*(2), 181-187.

McNamara, T. P. (1986). Mental representations of spatial relations. *Cognitive Psychology, 18*(1), 87-121.

Morrow, D. G., Bower, G. H., & Greenspan, S. L. (1989). Updating situation models during narrative comprehension. *Journal of Memory & Language, 28*(3), 292-312.

Moyer, R. S. (1973). Comparing objects in memory: Evidence suggesting an internal psychophysics. *Perception and Psychophysics, 13*(2), 180-184.

Moyer, R. S., & Bayer, R. H. (1976). Mental comparison and the symbolic distance effect. *Cognitive Psychology, 8*(2), 228-246.

Perrig, W., & Kintsch, W. (1985). Propositional and situational representations of text. *Journal of Memory & Language, 24*(5), 503-518.

Rinck, M., Hähnel, A., Bower, G. H., & Glowalla, U. (1997). The metrics of spatial situation models. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 23*(3), 622-637.

Taylor, H. A., Naylor, S. J., & Chechile, N. A. (1999). Goal-specific influences on the representation of spatial perspective. *Memory & Cognition, 27*(2), 309-319.

Taylor, H. A., & Tversky, B. (1992). Spatial mental models derived from survey and route descriptions. *Journal of Memory & Language, 31*(2), 261-292.

Taylor, H. A., & Tversky, B. (1996). Perspective in spatial descriptions. *Journal of Memory & Language, 35*(3), 371-391.

Thorndyke, P. W., & Hayes-Roth, B. (1982). Differences in spatial knowledge acquired from maps and navigation. *Cognitive Psychology, 14*(4), 560-589.

Van Dijk, T. A., & Kintsch, W. (1983). *Strategies of dicourse comprehension*. New York: Academic Press.

Wagener, M., & Wender, K. F. (1985). Spatial representations and inference processes in memory for text. In G. Rickheit & H. Strohner (Eds.), *Inferences in text processing* (pp. 115-136). Amsterdam: Elsevier Science Publishers B.V.

Wagener-Wender, M., & Wender, K. F. (1990). Expectations, mental representations, and spatial inferences. In A. C. Graesser & G. H. Bower (Eds.), *The psychology of learning and motivation* (Vol. 25, pp. 137-157). New York: Academic Press.

Appendix A

Route description example (English translation of Dutch text)

In the shopping centre are stores and these stores are all squares of the same size. You enter the shopping centre in the first area with in front of you the toy store. You walk towards the toy store and in front of the toy store you turn to the right with an angle of 90 degrees, and then you walk straight on. Next, the furniture shop is to your left and the jewellery is to your right.

You walk straight on in between the furniture shop and the jewellery and then the postal office is to your left and the shoe shop is to your right. You are now in the second part of the shopping centre. You walk straight on with to your right the shoe shop and then you turn left with an angle of 90 degrees. Now the postal office is still to your left and the chemist's is to your right.

You walk straight on with to your right the chemist's and then the video store is to your right and the kitchen shop is to your left. You are now in the third part of the shopping centre. You walk straight on with to your right the video store and then you turn left with an angle of 90 degrees. Now the kitchen shop is still to your left and the department store is to your right.

You walk straight on with to your right the department store and then the perfumery is to your right. You are now in the fourth part of the shopping centre. You walk straight on with to your right the perfumery and with in front of you to the right the pet shop. Next you turn left with an angle of 90 degrees and now the pet shop is behind you to the right and the restaurant is directly to your right. You walk straight on with to your right the restaurant. If you keep walking straight on you are back at the entrance.

Survey description example

The shopping centre is a square and is divided in four parts. The first part is the southwest corner of the shopping centre, the second part is the southeast corner of the shopping centre, the third part is the northeast corner of the shopping centre, and the fourth part is the northwest corner of the shopping centre. There are three stores in each part, and these stores are all squares of the same size. The entrance is on the west side of the south wall and the entrance is pointed to the north.

The toy store is in the northwest corner of the first part. To the east of the toy store is the furniture shop, in the northeast corner of this part. To the south of the furniture shop is the jewellery, in the southeast corner of the first part.

To the east of the jewellery is the shoe shop, in the southwest corner of the second part. To the north of the shoe shop is the postal office, in the northwest corner of this part. To the east of the postal office is the chemist's, in the northeast corner of the second part.

To the north of the chemist's is the video store, in the southeast corner of the third part. To the west of the video store is the kitchen shop, in the southwest corner of this part. To the north of the kitchen shop is the department store, in the northwest corner of the third part.

To the west of the department store is the perfumery, in the northeast corner of the fourth part. To the west of the perfumery is the pet shop, in the northwest corner of this part. To the south of the pet shop is the restaurant, in the southwest corner of the fourth part. To the south of the restaurant is the first part again

Chapter 7 The influence of visual experience on the ability to form spatial mental models based on route and survey descriptions

Abstract

The objective of the present study was twofold: first, to evaluate the importance of visual experience for the ability to form a spatial representation (spatial mental model) of fairly elaborate spatial descriptions. Second, to examine whether blind people exhibit the same preferences as sighted people in processing the type of perspective that is employed in a spatial description. Early blind, late blind, and sighted participants listened to a route and a survey description of two environments. Next, they had to execute a recognition/ priming task, a bird flight distance comparison task, and a scale model task. Spatial priming and symbolic distance effects were found for all participants. These findings suggest that early and late blind people can form spatial mental models on the basis of route and survey descriptions. Interestingly, in contrast with sighted people, blind people seem to prefer route to survey descriptions, even when the spatial problems that have to be solved explicitly favor the survey description. Apparently, only people with active vision prefer a survey description to build up a spatial mental model, whereas people with visual memories only (late blind), similar to people with no visual memories (early blind), prefer a route description to build up a spatial mental model.

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Introduction

Most theories concerning language comprehension (e.g. Graesser, Singer, & Trabasso, 1994; Johnson-Laird, 1983; Van Dijk & Kintsch, 1983; Zwaan & Radvansky, 1998) predict that readers and listeners will try to construct a mental representation of the referential situation. This mental representation is generally referred to as a situation or mental model. A mental model can incorporate information about temporal, spatial, causal, person- and object-related features of a particular event. The spatial aspects of mental models have been studied most extensively. For example, a consistent finding is that people can build up a spatial mental model that contains information about spatial relations and distances between objects (e.g. Bestgen & Dupont, 2003; Rinck, Williams, Bower, & Becker, 1996), even while that information was not explicitly mentioned in the text. Researchers have examined many factors, such as the structure of the description (Mani & Johnson-Laird, 1982), the specific (non)-spatial strategy instruction given to participants (Zwaan & Van Oostendorp, 1993), and the perspective (route or survey) of the text (Noordzij & Postma, 2005; Taylor & Tversky, 1992), that might influence the construal of a spatial mental model and the features it supports. A potentially crucial factor in mental model construction, which has been mostly ignored in previous research, is the visual experience of an individual. Mental model construction requires an ongoing integration and transformation of several pieces of information (Zwaan & Radvansky, 1998). It has been suggested that early blind people (people who lost their vision before the age of three) perform normally with respect to the passive storage of visual-spatial information, while they have specific problems with processes that require active integration and transformation (Cornoldi & Vecchi, 2000). Therefore, it could be that the level of abstraction that a mental model represents might be unattainable for them. In turn, early blind people could rely more on a representation that requires less integration and is more closely linked to the text (i.e. propositional text base; Mani & Johnson-Laird, 1982). However, other studies have also shown that early blind people perform equally well or only slightly worse than sighted people in a great number of spatial tasks, even tasks that are considered to require active visual imagery processes (for a review see Kaski, 2002). The present study was designed to evaluate the importance of visual experience for the ability to form spatial mental models of fairly elaborate spatial descriptions.

There is a good reason for examining the spatial domain in order to find out whether people form a linguistic representation or a mental model of a description. Namely, space can be perceived in many instances to be non-linear, which forms a contrast with the linear nature of language. For example, if a number of objects on a circle are described then the object mentioned first and the object mentioned last may be directly next to each other on the circle. This contrast between space and language can be employed experimentally to dissociate between a linguistic (i.e. propositional text base) and spatial representation (i.e. spatial mental model) of a spatial description. In the present study we employed two tasks that allowed us to examine whether blind and sighted participants had formed a linguistic or spatial representation of a text: a priming/ recognition and a bird flight distance comparison task. Both these tasks are associated with typical response patterns (i.e. spatial priming effect and symbolic distance effect), which indicate a spatial organization of mental representations and have been found after participants studied a visual map. When participants learn a simple visual configuration of a number of objects you expect items spatially close to each other to prime one another (McNamara, 1986). When a spatial configuration is learned by means of a verbal description different kinds of priming may occur depending on the nature of the representation that is formed. If people represent only the actual text, only sentence priming should occur and no priming by spatial proximity should be expected. If participants build a spatial representation from a descriptive text, then items proximal in space should prime the target more than items remote in space, independently of whether they were mentioned in the same or different sentences. In order to examine whether blind and sighted participants formed a spatial mental model of the information in the texts, we presented them with an old/new recognition task, in which different prime-target relations (i.e. *close in text/ close in space*, *far in text/ close in space* and *far in text/ far in space*) were present. The fourth option, close in text/ far in space, could not be included because this would result in a highly incoherent text. One of the strong points of examining spatial priming effects is that they are supposedly insensitive to conscious choices and strategies. Therefore, the presence of a spatial priming effect would be a good indication of implicit spatial memory processes.

In the second task, bird flight distance comparison, participants were explicitly instructed to imagine and use spatial information (i.e. bird-flight distances), in contrast to the above described priming/ recognition task that employed an instruction without any reference to possible spatial features of the environment. Both Thinus-Blanc and Gaunet (1997) and Millar (1994) state that problems of blind people with spatial tasks do not reflect a deficiency of the blind person, but rather that it indicates differences in coding (Millar, 1994) or behavioral (Thinus-Blanc & Gaunet, 1997) strategies between blind and sighted people. Thus, because the distance comparison task required an explicit use of the representation participants had build up from the spatial description, performance could reflect more clearly possible differences in strategy-choice (i.e. spatial vs. linguistic) of blind and sighted participants. Denis and Zimmer (1992), elaborating on an idea of Moyer (1973), asked participants to compare pairs of bird flight distances between objects in an environment that had been previously studied (map or verbal description). If participants convert the spatial descriptions into analogue representation and make some kind of internal psychophysical judgment then an inverse relationship between response times and distance differences should be observed. This was exactly what they found for both participants who had studied a map and a verbal description: the greater the distance difference between two object pairs the faster and better participants were at classifying the difference. Thus, if participants (blind and sighted) in our experiment formed a spatial mental model based on a description, then their performance (RTs and percentage errors) should have become better when the metric difference between bird flight distances increased. If participants formed a representation that stayed close to the actual words in the text, then their performance (RTs and percentage errors) should become better when the distance (in words) between objects in the original text increased.

A third task was also included to get a more general measurement of the ability of blind participants to form spatial mental models. After the priming/recognition and distance comparison task had been finished, participants were presented with a scale model of the described environment. Next, they were asked to name each of the objects in the scale model according to the description that was given. If blind participants can form spatial mental models to a same level as sighted people, then the performance on the scale model task should be similar for all groups of participants.

Another interest of the current study, which is inherently related to the construction of mental models from text, concerns the perspective in descriptions. As a second goal, we aimed to examine whether blind people exhibit the same preferences as sighted people in processing the type of perspective that is employed in a spatial description. As mentioned by Thinus-Blanc and Gaunet (1997) in their review of the literature on the representation of space by blind people, the research concerning the influence of visual experience on spatial cognition has so far mostly neglected an analysis of the specific features of spatial descriptions. Text perspective has received considerable attention in research with sighted individuals. Speakers mostly seem to choose between two types of spatial perspectives in descriptions, or a mix between the two (Taylor & Tversky, 1996). The first consists of taking listeners or readers on a mental tour, which is termed a route perspective; the second consists of taking a viewpoint that is above the environment, which is termed a survey perspective. Route and survey descriptions have specific characteristics that have their origins in the different reference frames they employ: egocentric (route) vs. allocentric (survey). An interesting question is whether the spatial perspective of a description has an influence on the spatial mental model. Several studies have found no difference between spatial mental models of sighted people based on route or survey descriptions (e.g. Ferguson & Hegarty, 1994; Taylor & Tversky, 1992), suggesting that people were using viewpoint independent mental models (Zwaan & Radvansky, 1998). In contrast, Shelton and McNamara (2004) did find that the perspective of the text had an effect on the way the information was stored in spatial memory, because the participants did not show viewpoint-independent performance in a scene recognition task. Our recent study (Noordzij & Postma, 2005) employed a task (bird-flight distance comparison; see above) that required participants to adopt a specific perspective (i.e. birds-eye view) that was congruent with one type of description (survey) and incongruent (route) with the other. In this situation we found a relative advantage for survey over route descriptions. This finding corroborates previous findings that showed relative advantages for certain spatial estimations depending on the way knowledge had been acquired about the environment. For example, metric bird flight distance estimations were better after map study than after actual navigation in the environment (e.g. Thorndyke & Hayes-Roth, 1982).

Interestingly, research on the coding of space by blind people in haptic and locomotor tasks has shown that these processes might differ from those employed by the sighted with respect to the reference frame that is preferred (Millar, 1994; Zuidhoek, Kappers, Noordzij, Van der Lubbe, & Postma, 2004). Millar argues that blind people tend to code spatial information (especially of large spaces) in the form of a sequential representation based on routes, whereas sighted people mostly code spatial information in the form of a cognitive map. The preference of blind people for spatial strategies and representations based on an egocentric frame of reference in spatial tasks might extend to the realm of spatial description comprehension. Route descriptions employ an egocentric frame of reference and a linear organization (similar to a sequential representation), whereas survey descriptions employ an allocentric frame of reference and a hierarchical organization (similar to a cognitive map). Therefore, when blind people read or listen to a spatial description they might always construct a spatial mental model in the form of a sequential representation (e.g. a set of procedural instructions). Moreover, if blind people construct a spatial mental model in the form of a set of procedural instructions instead of a cognitive map, then the route description might allow better and faster spatial mental model construction than a survey description. The distance comparison task described above requires participants to infer bird-flight distances, after they have studied a route or a survey description. If the blind construct a spatial mental model more effectively from a route than a survey description, then the performance on the bird-flight comparison task should be better after they studied a route description. In contrast, Noordzij and Postma (2005) found that sighted people had a relative advantage of a survey over a route description on this bird-flight distance comparison task. Therefore, if the blind show similar coding strategies as the sighted concerning text perspective, then a relative advantage is to be expected after they studied a survey description.

A final point that needs to be addressed is whether the age of onset of blindness has an influence on the way in which the perspective of a spatial description is processed. According to Millar (1994), an efficient and fast coding of spatial relations between objects without considering the position of the body (i.e. within an allocentric reference frame) almost certainly needs vision, or at least memories of visual experiences. It could be that vision is only important during a critical period in life, after which the ability for certain spatial processing mechanisms, such as coding within an allocentric reference frame, is functional and no longer dependent on vision. Therefore, we included both early blind and late blind participants in the present study to examine whether the hypothesized preference for egocentric reference frames in spatial descriptions (i.e. route description) is only present for people with no visual experience at all, and not for people who lost their vision later in life.

Method

Participants

Appendix A contains the list of participants. Thirteen early blind, seventeen late blind and sixteen sighted people participated in the experiments. The blind were recruited by announcements in magazines for the visually impaired. The sighted participants had blind partners or relatives, or worked (paid or on voluntary basis) in institutions for the blind. None of the participants had neurological or motor deficits. Participants were considered early blind when they had no memory of vision whatsoever. The early blind group consisted of congenitally blind and early blind individuals that had become blind before the age of three. Those that were not blind from birth had no memory of vision whatsoever. All participants in the late blind group had rich vivid visual memories, and reported to have used vision as a primary spatial modality. The blindness of participants had different etiologies (see Appendix A). Some late blind participants were born visually impaired and had gradually become blind during life. Others had lost their sight due to accidents. A minority of the blind participants had diffuse light sensations, but denied being able to use this in any form of spatial behavior. Sighted control participants where blindfolded.

Early blind, late blind and sighted control participants were matched for sex, and approximately matched for age and education. Importantly, Verbal IQ as measured with two sub-scales (Vocabulary and Similarities) of the Dutch version of the WAIS-III (Wechsler, 1997) showed no significant difference the three groups, $F(2, 43) = 1.4$, $p = .3$. Almost all participants were right-handed as assessed with Annett's handedness questionnaire (Annet, 1970); three participants were ambi-dexter or left handed (see Appendix A).

All participants gave their informed consent for inclusion in this study and received payment for their participation. They were naive to all aspects of the tasks, that is, they had never seen or felt the set-up, were unaware of the experimental purposes, and were never given any feedback.

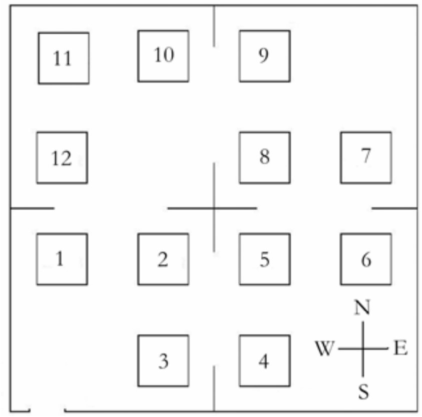

Figure 1.
An example of a basic configuration for the mall and the zoo (both 12 objects).

Materials & Design

Descriptions

Two types of descriptions of a zoo and a mall were created: one with a route perspective and one with a survey perspective (see Appendix A of Chapter 6 for sample texts). The descriptions were made of fictitious maps of either a zoo or a mall (see Figure 1). The descriptions differed on a number of points related to the perspective of the text. The survey description first introduced the four major quadrants of the environment after which the individual objects were mentioned (i.e. hierarchical organization). In contrast, the route description started immediately with the first object revealing information about the overall layout of the environment in a step-wise fashion (i.e. linear organization). Furthermore, the survey description employed canonical spatial terms such as *north*, *south* and *southwest corner*, while the route description used relative spatial terms such as *to your left* and *right*. Additionally, the grammatical person differed for the descriptions: objects were introduced in relation to previously mentioned objects in the survey description, whereas the route description addressed participants in the second person and introduced objects in relation to the reader's suggested position in the environment. A number of factors, which were not related to perspective, were held constant for both descriptions. All objects were mentioned twice in both descriptions. The descriptions approximately had the same amount of words, 260 (survey description) and 283 (route description). Continuous descriptions with high connectivity have been shown to result in easier processing and better recall than discontinuous descriptions with low connectivity (e.g. Denis & Denhiere, 1990; Ehrlich &

Johnson-Laird, 1982). Therefore, new locations were always mentioned in reference to a previous location, which ensured that there were no discontinuities in the descriptions.

Recognition/ Priming

Lists of object names (animals or shops) were constructed for the priming task. The spoken object names were recorded and the duration of the individual sound files was 1200 ms. Names were presented to participants through headphones with E-Prime software running on a Pentium III computer. Half of the names were old (i.e. mentioned in one of the descriptions) and half were new (i.e. not previously learned). New items were selected from the same object categories as the old items. The old items were used to examine three priming relations: *close in text/ close in space*, *far in text/ close in space* and *far in text/ far in space*. For both *close in space* relations the prime was directly next to the target in the environment (spatial proximity). *Close in text/ close in space* relations were also mentioned in the same sentence in the descriptions, while *far in text/ close in space* relations were mentioned in different sentences. The prime-target relation was termed *far in text/ far in space* when a prime and a target were divided by at least one intermediate object and were not mentioned in the same sentence. Every priming relation was repeated seven times. Object names were repeated two or three times, but priming involving the repetition of a name was not confounded with the prime-target relation.

Distance comparison

Two lists, one for the zoo and one for the mall, of 48 pairs of two spoken object names were made and these pairs were all based on a common first object name (e.g. "Giraffe-Hyena"/ "Giraffe-Chimpanzee"). Two other lists were made with reversed presentation of the first and second pair (i.e. "Bonobo-Arctic Fox"/ "Bonobo-Rabbit" vs. "Bonobo-Rabbit"/ "Bonobo-Arctic Fox"). Presentation of distance pairs was randomized for both lists. Differences were divided in three categories based on the actual difference on the drawing of the environment: small difference (0-3 cm.), medium difference (3-6 cm) and large difference (6-11 cm). Small, medium and large differences all were repeated 16 times. In addition, next distance differences were divided in three categories based on the number of words between two objects in a distance pair in the route and survey description. For the route description this resulted in the following subdivision: small difference (1-45 words), medium difference (46-90 words) and large difference (91-200 words). For the survey descriptions the subdivision was as followed: small difference (1-29 words), medium difference (30-59 words) and large difference (60-131 words). Participants were allowed to feel the outer edge of the environment in a scale model before the start of the distance comparison task to provide them with a cue for the imaged size of the environment. The "c" and "m" keys on a standard keyboard were made more prominent with a tactile marking and were used to collect participants' choices both in the Priming and Distance Comparison task.

Procedure

All participants were blindfolded during the experiment. First, participants listened to a description of an environment through headphones. Each description was divided in smaller parts, which were repeated twice. In total, participants listened to a specific description six times. This study phase took approximately 15 minutes. Participants were asked to listen carefully and to memorize as much as possible. After the study phase they were presented with a priming/ recognition task and a distance comparison task. Next, they were given a rest for 45 minutes after which the other environment was learned, again followed by a priming/ recognition task and a distance comparison task. Hence, each participant studied both a route and a survey description. The order of presentation was counterbalanced over participants.

The priming task was preceded by twelve practice trials that required province-no province judgments. Names of Dutch provinces (requiring a right key-press) and names of foreign countries (requiring a left key-press) were mentioned, one name at a time. These practice trials allowed participants to get used to the procedures, especially pressing as fast and accurately as possible on the keys. Subsequently, the priming task was started and object names were presented acoustically. Participants had to decide as fast and as accurately as possible whether an object had been present in the learned environment or not. They pressed the left key ("c") for *new* names and the right key ("m) for *old* names. The next object name was presented 250 ms after a response had been made.

The distance comparison task consisted of 2 practice trials with feedback and 48 experimental trials without feedback. A warning tone indicated the start of the trial. Two spoken names of objects (1200 ms) were presented shortly (300 ms gap) after one another. Participants were asked to picture a map of the environment and mentally focus on the bird flight distance that separated the two objects. In addition they were instructed that this distance needed to be used as a reference to make a judgment about a second distance. After a delay of 2000 ms participants again heard two object names, and they had to visualize the bird flight distance between the objects. Finally they had to make a decision whether this second distance was longer or shorter than the first distance. Participants were to press the left key for "shorter" and the right key for "longer", as fast and as accurately as possible. The next trial started 2000 ms after the response was made.

At the end of the experiments belonging to a specific description participants were asked to name the objects in a scale model of the environment. They were given no time constraint, and they were told to name all the objects they could remember in their correct relative locations.

Data analysis

For the Recognition/ Priming task, mean RTs, computed over correct trials, and mean percentage error scores were analyzed using separate 2 x 3 x 3 ANOVAs with Study Material (Route description and Survey description) and Prime-Target Relation (Close in Text/ Close in Space, Far in Text/ Close in Space and Far in Text/ Far in Space) as within-subjects variables, and Group (Early Blind, Late Blind, and Sighted) as between subjects variable. Planned comparisons were done for the three levels of Prime-Target-Relation. The data of the practice trials (province-no province judgments) showed no difference between the groups, both for RTs, $F(2, 43)= 2.3$, $p= .12$, and for error scores, $F(2, 43)= 1.8$, $p= .17$.

For the scale model task, data (number of objects remembered in their correct location) were analyzed using a 2 x 3 ANOVA with Study Material (Route description and Survey description) as within subjects variable, and Group (Early Blind, Late Blind, and Sighted) as between subjects variable. Furthermore, the performance on the scale model task was used to determine whether a participant could be included in the analysis of the Distance Comparison task. Some participants reported that they were not able to perform the Distance Comparison task, and that they had been guessing. These participants were also very poor on the scale model task. Therefore, only participants who could name at least 6 objects in the right location on both scale models were included in the analysis. For the Distance Comparison task, data (mean RTs and errors) were analyzed using separate 2 x 3 x 3 x 3 ANOVAs with Study Material (Route description and Survey description), Metric Distance Difference (Small, Medium, Large) and Text Distance Difference (Small, Medium, Large) as within subjects variables, and Group (Early Blind, Late Blind, and Sighted) as between subjects variable. In addition, the predicted inverse relationship between the magnitude of the distance difference and the RTs and the percentage error scores was tested with a contrast for a linear component in the Metric Distance Difference variable. Planned comparisons were done for the three levels of Metric Distance Difference.

Results

Recognition/ priming

Reaction times

Table 1 shows mean RTs for correct responses for the spatial priming experiment. The main effect of Study Material was not significant, $F(1, 43) < 1$. The main effect of Prime-Target Relation was significant, $F(2, 86) = 8.6$, $p < .001$. Planned comparisons showed that RTs for primes and targets Close in Text/ Close in Space and Far in Text/ Close in Space were shorter than RTs for Far in Text/ Far in Space, $F(1, 66) = 10.3$, $p = .002$ and $F(1, 66) = 16.8$, $p < .001$. The RTs for primes and targets close in space but either close or far in text did not differ significantly, $F(1, 66) = 1.8$, $p = .18$. The main effect of Group was not significant, $F(2, 33) = 1.3$, $p = .29$. No interaction effect between Study Material, Prime-Target Relation, and Group was significant, all $Fs < 1.2$, $p > .29$.

Table 1.
Mean RTs (ms) for the priming/ recognition experiment, standard errors in parentheses.

	Prime-Target Relation	Close in space/ Close in text	Close in space/ Far in text	Far in space/ Far in text
Group	**Perspective**			
Early Blind				
	Route description	997 (51.1)	1010 (67.4)	1032 (63.2)
	Survey description	1066 (69.7)	1012 (61.5)	1185 (84.1)
Late Blind				
	Route description	1032 (44.7)	1075 (58.9)	1101 (55.3)
	Survey description	1084 (60.9)	1030 (53.8)	1119 (73.6)
Sighted				
	Route description	1149 (46.1)	1080 (60.8)	1182 (57.0)
	Survey description	1121 (62.8)	1078 (55.4)	1144 (75.8)

Error scores

There were no significant effects related to the error scores, all $Fs < 1.3$, $p > .26$.

Scale model

Table 2 shows the amount of correctly named objects in the right location on the scale model by the congenitally blind, late blind and sighted participants. The main effects of Study Material and Group were not significant, $F(1, 43) = 1.0$, $p = .32$, and $F(2, 43) < 1$. The interaction effect between Study Material and Group was marginally significant, $F(2, 43) = 2.9$, $p = .06$. A contrast comparing blind (early and late) with sighted participants showed that after studying a route description blind participants (mean = 8.3) remembered the same amount of object locations as sighted participants (mean= 7.7), $t(43) < 1$, in contrast after studying a survey description blind participants (mean= 7.0) tended to remember less object locations than sighted participants (mean= 9.6), $t(43) = 1.9$, $p = .06$.

Table 2.
The division of participants by the amount of correctly named objects in the right location.

	Perspective					
	Route description			Survey description		
	Group					
Amount of objects	Early blind	Late blind	Sighted	Early blind	Late blind	Sighted
10-12	6	11	9	5	8	11
7-9	1	3	-	1	3	2
4-6	-	2	1	3	-	2
0-3	6	1	6	4	6	1

Only participants who could name at least 6 objects in the right location for both scale models were included in the analysis of the Distance Comparison task. This criterion resulted in a group of 7 early blind, 12 late blind and 11 sighted participants.

Distance comparison

Reaction times

Figure 2 shows mean RTs for correct responses for the distance comparison experiment. The main effect of Study Material was not significant, $F(1, 27) < 1$. The main effect of Metric Distance Difference was significant, $F(2, 54) = 27.1$, $p < .001$. RTs for Small differences were higher than the RTs for Medium and Large differences, $t(29) = 3.7$, $p = .001$, and $t(29) = 6.7$, $p < .001$. In addition, participants were slower with Medium differences than with Large differences, $t(29) = 4.4$, $p < .001$. Furthermore, a significant linear trend effect was found for Metric Distance Difference, $F(1, 27) = 41.8$, $p < .001$. This linear trend followed the expected direction and indicated the inverse relationship between RTs and the magnitude of the distance difference. The main effects of Study Material, Text Distance Difference and Group were not significant, $F(1, 27) < 1$, $F(2, 54) = 1.4$, $p = .25$, and $F(2, 27) = 2.1$, $p = .14$.

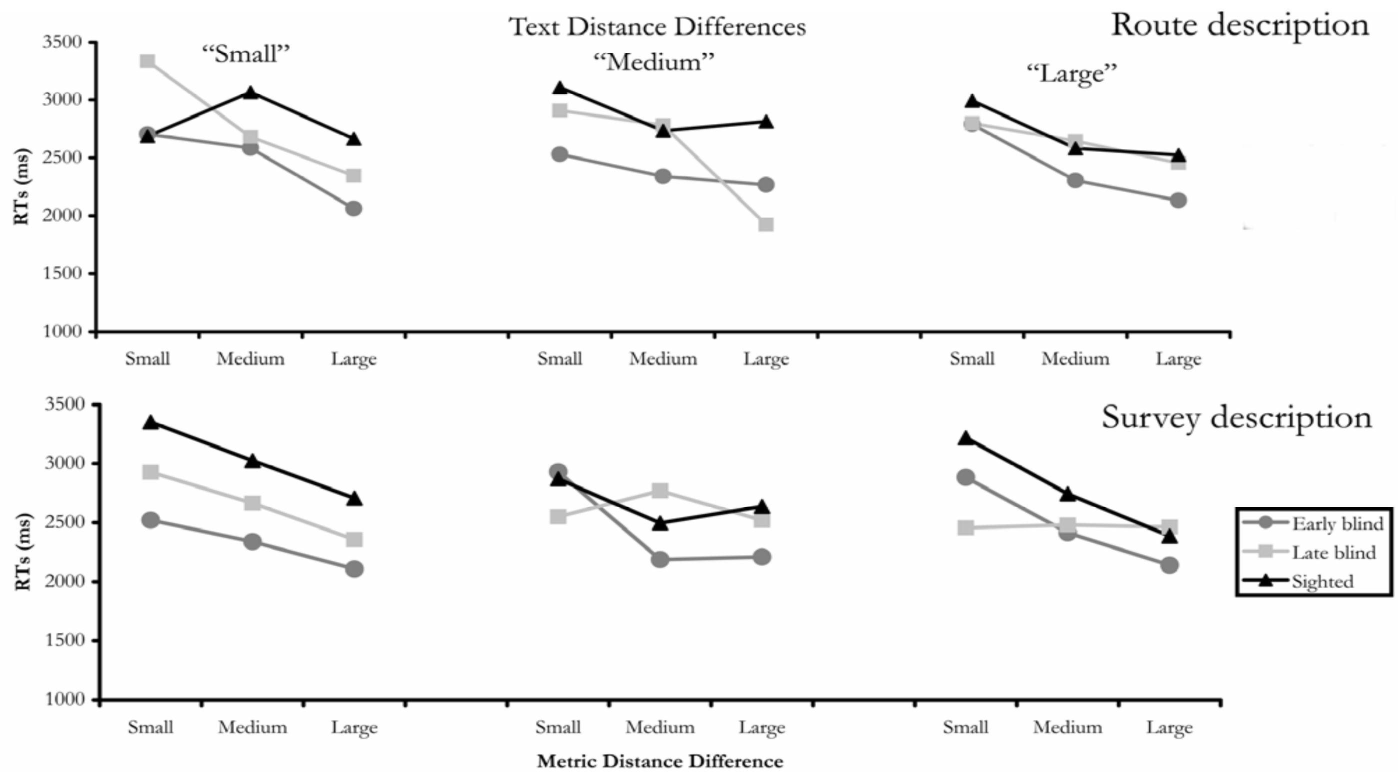

Figure 2.
RTs (ms) for the distance comparison task.

The second order interaction between Study Material, Metric Distance Difference and Group was significant, $F(4, 76)= 2.8$, $p= .03$. Further analysis of the component interactions showed that the interaction between Study Material and Metric Distance Difference was not significant for early blind and sighted participants, $F(2, 12)< 1$ and $F(2, 22)= 1.5$, $p=.24$, in contrast, this interaction was almost significant for late blind participants, $F(2, 20)= 3.3$, $p= .06$. Late blind participants showed a significant effect for Metric Distance Difference, indicating decreasing RTs with larger distance differences, however this effect of metric distance was only present after the late blind participants had studied a route description and not after a survey description, $F(2, 22)= 14.9$, $p< .001$ and $F(2, 22)= 1.0$. The Interaction between Metric Distance Difference, Text Distance Difference and Group was significant, $F(8, 108)= 2.6$, $p= .01$. Analysis of the component interactions showed that for Medium Text Distance Differences there was a significant interaction between Metric Distance Difference and Group, $F(4, 54)= 2.5$, $p= .05$, while this interaction was not significant for Small and Large Differences, both $Fs< 1.6$. Sighted Participants did not show an effect of Metric Distance Difference, $F(2, 20)= 1.6$, $p= .23$ when the Text Distance Difference was Medium. In contrast, both the early and late blind participants did show an effect of Metric Distance Difference for this particular Text Distance Difference, $F(2, 12)= 4.2$, $p= .04$ and $F(2, 22)= 13.8$, $p< .001$. No other interactions among Study Material, Metric and Text Distance Differences were significant, all $Fs< 2.3$, $p> .07$.

Error scores

Figure 3 shows mean percentage error scores for the distance comparison experiment. The main effect of Metric Distance Difference was significant, $F(2, 54)= 42.2$, $p< .001$. Error scores for Small differences were higher than the error scores for Medium and Large differences, $t(29)= 6.3$, $p< .001$, and $t(29)= 9.2$, $p< .001$. In addition, participants were worse with Medium differences than with Large differences, $t(29)= 3.4$, $p= .002$. Furthermore, a significant linear trend effect was found for Metric Distance Difference, $F(1, 27)= 79.7$, $p< .001$. This linear trend followed the expected direction and indicated the inverse relationship between error scores and the magnitude of the distance difference. The main effects of Study Material, Text Distance Difference and Group were not significant, all $Fs< 1.4$. The interaction between Study Material and Group was significant, $F(2, 27)= 5.5$, $p= .01$. A contrast comparing blind (early and late) participants with sighted participants showed that blind subjects made more errors after studying a survey description, while sighted participants made more errors after studying a route description, $t(27)= 2.5$, $p= .02$ (See Figure 4). All other interactions were not significant, all $Fs< 2.3$, $p> .065$.

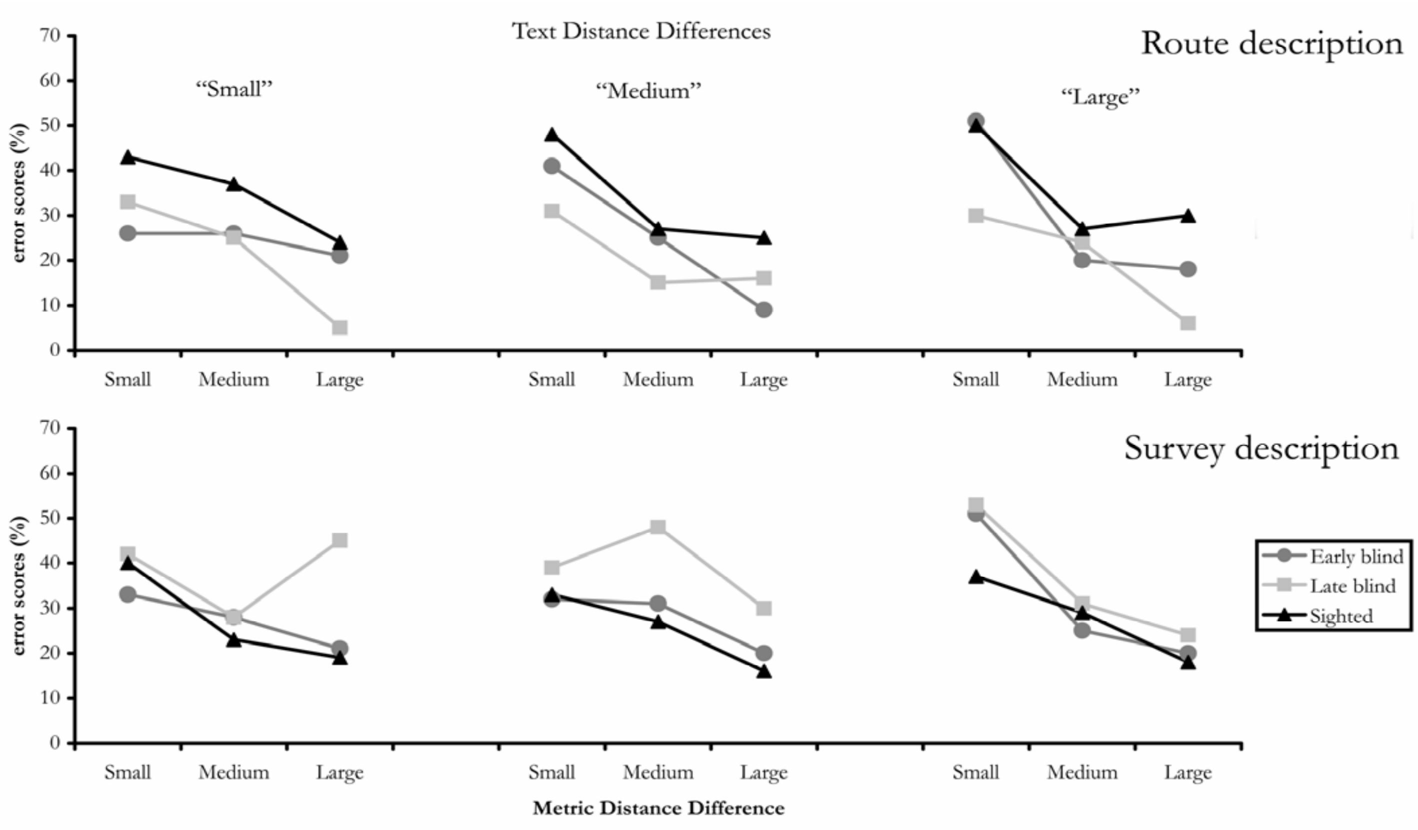

Figure 3.
Error scores (%) for the distance comparison task.

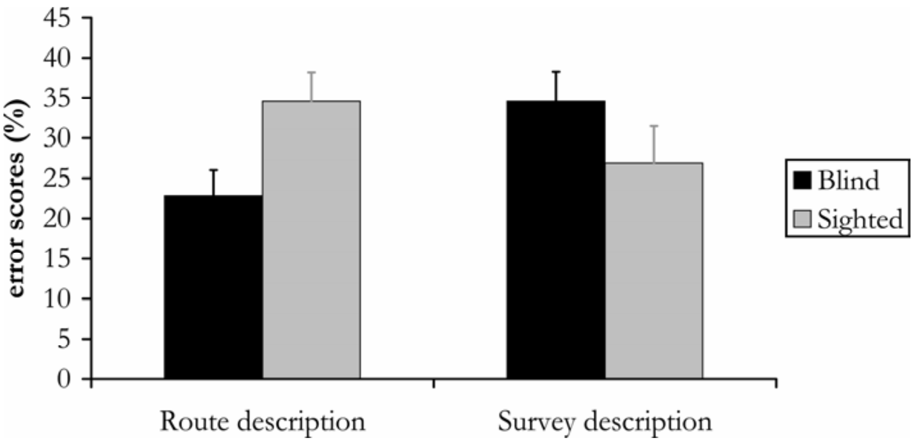

Figure 4.
Overall error scores (%) for the distance comparison task for the blind and sighted participants after studying a route or a survey description

Discussion

The goals of the present study were to determine whether visual experience plays a crucial role in the construction of spatial mental models and whether blind people exhibit the same preferences as sighted people in processing the type of perspective that is employed in a spatial description. Firstly, in the priming/ recognition task we found a spatial priming effect indicating that primes close in space resulted in significantly faster RTs for the target than primes far in space, while primes close in text and far in text resulted in similar RTs. This spatial priming effect indicates that objects in the environment were spatially organized in the mental models of the listeners. There was no difference between the early blind, late blind and sighted subjects with respect to the spatial priming effect. These findings suggest that participants both with and without visual experience formed a spatial mental model of the descriptions in which the distance between individual objects was encoded. Secondly, in the scale model task blind and sighted participants were able to name similar amounts of objects in their correct locations. This again would suggest that there are no differences in the ability to form spatial mental models between blind and sighted participants. However, there was a difference in the amount of object- locations that was remembered as a function of the perspective of the spatial description. We will return to this finding later. Thirdly, in the bird flight distance comparison task all participants performed better (i.e. faster and with less errors) with increasing metric distance differences. In addition a significant inverse linear relation was found between performance and the magnitude of the difference between two bird flight distances. The presence of such symbolic distance effects indicated that larger differences were easier to compare than smaller differences, which is an effect that is also expected if actual metric distances on a visual map have to be compared. These effects of metric distance differences could not be explained by differences in text distance differences, because this last variable had no significant effect on the performance of participants. This again provides evidence that both blind and sighted participants formed spatial mental models that allowed them to infer bird flight distances. Moreover, the second order interaction that involved both the metric and text distance difference variable actually indicated that sighted participants, in contrast to blind participants, did not show an effect of metric distance difference for medium text distance differences. This finding even suggests that metric distance was represented more accurate in mental models of the blind than the sighted. However, the strength of this interaction was relatively weak and overall the effect of metric distance difference on the performance of participants was far stronger and hardly modulated by any interaction.

Importantly, the results from the priming/ recognition and bird flight distance comparison task indicate that the representation blind and sighted people form on the basis of spatial descriptions had spatial characteristics that resembled those of the described environment and not the exact wording of the text. How do these findings concerning the blind people relate to other research? Numerous studies with sighted people have shown that people can build up representations from simple verbal descriptions that contain some form of spatial information (e.g. Cocude, Mellet, & Denis, 1999; Denis, Goncalves, & Memmi, 1995; Wagener-Wender & Wender, 1990). In our recent study (Noordzij & Postma, 2005) we showed that spatial representations can also be constructed from more complex descriptions of previously unknown configurations (i.e. objects not described as being placed on a well-known visual shape such as a circle). The present results corroborate those from the latter study and extend them to blind participants. Thus, this study is, to our knowledge, the first to provide evidence for the ability of early and late blind people to construct spatial mental models. In other words, visual experience does not seem necessary in order to be able to form these integrated representations.

For our study we explicitly asked congenitally blind participants to imagine an environment and we found evidence that indicated that they are capable of constructing some kind of visual-spatial representation. The fact that early blind people are actually capable of constructing a representation with visual-spatial qualities might be considered surprising. Moreover, how could someone who has never seen execute such a visual task as imagining bird-flight distances between objects? Many studies have considered the question whether visual imagery and perception are strongly associated (for a review, see Kaski, 2002), and the results have not been clear at all. However, there have been consistent findings that congenitally blind people show only slightly poorer performance than sighted people on visual imagery tasks (e.g. Aleman, van Lee, Mantione, Verkoijen, & de Haan, 2001; Hollins, 1985). Therefore, it is likely that visual imagery and perception retain unique components, besides sharing some common elements. As mentioned in the Introduction, Cornoldi and Vecchi (2000) hypothesized that early blind people might only have specific problems with the active integration and transformation of several pieces of visual-spatial information. This could be a severe problem for the formation of spatial mental models. Although we found that early blind people tended to score lower on the scale model task than the late blind and sighted participants, there was no evidence that early blind people were unable to form spatial mental models.

The second goal of the present study concerned the possible differences in the preferences of blind and sighted participants with respect to the perspective of a spatial description. There was no effect of perspective in the recognition/ priming task, but this can probably be explained by the fact that this is a very easy task and not as sensitive for detecting differences concerning route and survey descriptions as the more difficult scale model and distance comparison tasks. In the scale model task, sighted participants remembered more locations of objects than blind participants, but only after studying a survey description and not after studying a route description. Although it has to be mentioned that for both the scale model tasks based on the route and the survey description the early blind people had the lowest score. Furthermore, almost half of the early blind people were not able to mention some or even any object at the right location in the scale model. As mentioned before, most participants that had great difficulty with the scale model task also reported that they had been guessing on the bird flight distance comparison task. Therefore, for the analysis of the bird flight distance comparison only those participants that were able to mention at least 6 objects in both the scale models were included. In the bird flight distance comparison task we found that there was a difference between participant groups with respect to the type of description that was studied and the subsequent amount of errors. Blind participants made more errors after studying a survey description than a route description. In contrast, sighted participants made more errors after studying a route than a survey description. Furthermore, late blind participants tended not to show an effect of metric distance in their reaction times after studying a survey description, while they always showed this effect after studying a route description.

These differences on the bird flight distance comparison task between blind and sighted people suggest that blind people construct less effective spatial mental models than sighted people on the basis of survey descriptions. In contrast, blind people actually seem to construct spatial mental models more effectively than sighted participants on the basis of route descriptions. The findings concerning the sighted participants in our study replicated those found in Noordzij and Postma (in press): sighted people appear to have a relative advantage of a survey over a route description on this bird-flight distance comparison task. Notably, the blind participants in the present study showed the opposite pattern: a relative advantage of a route over a survey description. Millar (1994) and Thinus-Blanc and Gaunet (1997) have both argued that blind people prefer spatial strategies and representations based on an egocentric frame of reference. Our findings are consistent with the hypothesis that the preference of blind people for egocentric strategies and representations does indeed extend to the domain of spatial description comprehension. However, the preference for egocentric strategies has been predominantly found for early blind people and not for late blind people. In our study, both early and late blind people seemed to prefer a route rather than a survey description. Apparently, only people with active vision prefer a survey description to build up a spatial mental model, whereas people with visual memories only, similar to people with no visual memories, prefer a route description to build up a spatial mental model.

There has not been much research on the way in which blind people understand and communicate spatial language. Loomis, Lippa, Golledge, and Klatzky (2002) showed that blind individuals were capable of spatial updating to a similar level as sighted individuals on the basis of 3D-sound and on the basis of spatial language. Their early blind participants performed equally well as sighted participants on a task that required spatial inferences. Brambring (1982) asked blind and sighted people to give spatial descriptions about relevant information with respect to certain routes. The difference between descriptions given by the blind and by sighted persons was indicated by the fact that sighted persons gave environment-oriented descriptions whereas the blind tended to use descriptions related to their own position. Therefore, sighted persons seem to give allocentric descriptions and blind people tend to convey egocentric descriptions. This pattern of spatial language communication fits nicely with the preferences we found in spatial language comprehension. Clearly more research is needed on the way in which blind people understand spatial descriptions and how they consequently use this knowledge for their own way finding.

In sum, the present study is the first to provide evidence that early and late blind can form spatial mental models on the basis of route and survey descriptions. Interestingly, in contrast with sighted people, blind people seem to prefer route to survey descriptions, even when the spatial problems that have to be solved explicitly favor the survey description. At present, the current findings may have direct relevance for the way in which spatial information is communicated towards blind people. If people use an egocentric reference frame consistently in spatial descriptions (i.e. route description) to the blind, spatial information is probably communicated more effectively than when a mixed or purely allocentric perspective (i.e. survey description) is chosen.

References

Aleman, A., van Lee, L., Mantione, M. H., Verkoijen, I. G., & de Haan, E. H. (2001). Visual imagery without visual experience: evidence from congenitally totally blind people. *Neuroreport, 12*(11), 2601-2604.

Annet, M. (1970). A classification of hand preference by association analysis. *British Journal of Psychology, 61*, 303-321.

Bestgen, Y., & Dupont, V. (2003). The construction of spatial situation models during reading. *Psychological Research, 67*, 209-218.

Brambring, M. (1982). Language and geographic orientation for the blind. In R. J. Jarvella, and Klein, W. (Ed.), *Speech, Place, and action* (pp. 203-218): John Wiley & Sons Ltd.

Cocude, M., Mellet, E., & Denis, M. (1999). Visual and mental exploration of visuo-spatial configurations: Behavioral and neuroimaging approaches. *Psychological Research, 62*(2-3), 93-106.

Cornoldi, C., & Vecchi, T. (2000). *Visuo-spatial working memory and individual differences*. Hove and New York: Psychology Press.

Denis, M., & Denhiere, G. (1990). Comprehension and recall of spatial descriptions. *European Bulletin of Cognitive Psychology, 10*(2), 115-143.

Denis, M., Goncalves, M.-R., & Memmi, D. (1995). Mental scanning of visual images generated from verbal descriptions: Towards a model of image accuracy. *Neuropsychologia, 33*(11), 1511-1530.

Denis, M., & Zimmer, H. D. (1992). Analog properties of cognitive maps constructed from verbal descriptions. *Psychological Research, 54*(4), 286-298.

Ehrlich, K., & Johnson-Laird, P. N. (1982). Spatial descriptions and referential continuity. *Journal of Verbal Learning & Verbal Behavior, 21*, 296-306.

Ferguson, E. L., & Hegarty, M. (1994). Properties of cognitive maps constructed from texts. *Memory & Cognition, 22*(4), 455-473.

Graesser, A. C., Singer, M., & Trabasso, T. (1994). Constructing inferences during narrative text comprehension. *Psychological Review, 101*, 371-395.

Hollins, M. (1985). Styles of mental imagery in blind adults. *Neuropsychologia, 23*(4), 561-566.

Johnson-Laird, P. N. (1983). *Mental models*. Cambridge, MA: Harvard University Press.

Kaski, D. (2002). Revision: is visual perception a requisite for visual imagery? *Perception, 31*(6), 717-731.

Loomis, J. M., Lippa, Y., Golledge, R. G., & Klatzky, R. L. (2002). Spatial Updating of Locations Specified by 3-D Sound and Spatial Language. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 28*(2), 335-345.

Mani, K., & Johnson-Laird, P. N. (1982). The mental representation of spatial descriptions. *Memory & Cognition, 10*(2), 181-187.

McNamara, T. P. (1986). Mental representations of spatial relations. *Cognitive Psychology, 18*(1), 87-121.

Millar, S. (1994). *Understanding and representing space: Theory and evidence from studies with blind and sighted children*. Oxford: Oxford University Press.

Moyer, R. S. (1973). Comparing objects in memory: Evidence suggesting an internal psychophysics. *Perception and Psychophysics, 13*(2), 180-184.

Noordzij, M. L., & Postma, A. (2005). Categorical and metric distance information in mental representations derived from route and survey descriptions. *Psychological Research, 69*(3), 221-232.

Rinck, M., Williams, P., Bower, G. H., & Becker, E. S. (1996). Spatial situation models and narrative understanding: Some generalizations and extensions. *Discourse Processes, 21*(1), 23-55.

Shelton, A. L., & McNamara, T. P. (2004). Orientation and perspective dependence in route and survey learning. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 30*(1), 158-170.

Taylor, H. A., & Tversky, B. (1992). Spatial mental models derived from survey and route descriptions. *Journal of Memory & Language, 31*(2), 261-292.

Taylor, H. A., & Tversky, B. (1996). Perspective in spatial descriptions. *Journal of Memory & Language, 35*(3), 371-391.

Thinus-Blanc, C., & Gaunet, F. (1997). Representation of space in blind persons: Vision as a spatial sense? *Psychological Bulletin, 121*(1), 20-42.

Thorndyke, P. W., & Hayes-Roth, B. (1982). Differences in spatial knowledge acquired from maps and navigation. *Cognitive Psychology, 14*(4), 560-589.

Van Dijk, T. A., & Kintsch, W. (1983). *Strategies of dicourse comprehension*. New York: Academic Press.

Wagener-Wender, M., & Wender, K. F. (1990). Expectations, mental representations, and spatial inferences. In A. C. Graesser & G. H. Bower (Eds.), *The psychology of learning and motivation* (Vol. 25, pp. 137-157). New York: Academic Press.

Wechsler, D. (1997). *Wechsler Adult Intelligence Scale, Third Edition*. San Antonio, TX: The Psychological Corporation.

Zuidhoek, S., Kappers, A. M. L., Noordzij, M. L., Van der Lubbe, R. H., & Postma, A. (2004). Frames of reference in a haptic parallelity task: Temporal dynamics and the possible role of vision. In S. Ballesteros & M. A. Heller (Eds.), *Touch, blindness and neuroscience* (pp. 155-164). Madrid, Spain: UNED Press.

Zwaan, R. A., & Radvansky, G. A. (1998). Situation models in language comprehension and memory. *Psychological Bulletin, 123*(2), 162-185.

Zwaan, R. A., & Van Oostendorp, H. (1993). Do readers construct spatial representations in naturalistic story comprehension? *Discourse Processes, 16*, 125-143.

Appendix A: Sample description of participants

Early blind

Subject number	*Occupation*	*Education level*	*Sex*	*Age*	*Etiology and further characteristics*	*Age of onset (years)*
1	Sports masseuse	Secondary school	F	41	Leber's amarosis, Ambidexter	0
2	Policy worker	University	M	41	Retino blastoma	0
3	Computer programmer	Higher education	M	33	Macula degeneration	0
4	Office assistant	Vocational Education	F	49	Rubella (mother)	0
5	Retired operator	Secondary school	M	58	Glaucoma, Ambidexter	2
6	Office assistant	Secondary school	F	34	Retrolental fibroplasias	0
7	Operator	Secondary school	M	38	Rubella (mother)	2-3
8	Translator	Higher education	F	30	Retrolental fibroplasias	0
9	Retired	Vocational Education	M	64	Retino blastoma	2-3
10	Teacher	Higher education	M	46	Leber's amarosis	0
11	Systems designer	Higher education	M	46	Retino blastoma	0-1
12	Consultant	Secondary school	F	55	Retino blastoma	0-1
13	Sound technician	Higher education	M	49	Retrolental fibroplasias	0

Late blind

Subject number	*Occupation*	*Education level*	*Sex*	*Age*	*Etiology and further characteristics*	*Age of onset (years)*
1	Physiotherapist	Higher education	M	52	Accident	10
2	IT-employee	Higher education	M	57	Born partially blind in one eye, other eye glaucoma	25
3	Social worker	Vocational Education	M	57	Usher's syndrome and an accident	25
4	Piano tuner	Vocational Education	M	40	Accident, Left-handed	19
5	Volunteer	Higher education	M	54	Macular degeneration	10
6	Office assistant	Secondary school	M	64	Congenital glaucoma	7
7	Operator	Secondary school	F	59	Accident	9
8	Music teacher	Higher education	M	64	Retinitis pigmentosa	40
9	Correspondence clerk	Vocational Education	M	60	Congenital glaucoma	49
10	Civil servant	Higher education	M	38	Brain tumour	4
11	Employment-finding for the blind	Higher education	M	59	Leber opticus artrosa and glaucoma	32
12	Social worker	Vocational Education	M	53	Aniridi and glaucoma	20
13	Operator	Vocational Education	F	58	Retinitis pigmentosa	14
14	Therapist	Secondary school	F	52	Born blind in one eye Glaucoma and inflammation of the cornea of the other eye	30
15	School teacher	Higher education	F	53	Congenital glaucoma	22
16	Psychologist	University	F	51	Congenital glaucoma	40
17	Social worker	Higher education	F	39	Unknown	35

Sighted controls

Subject number	*Occupation*	*Education level*	*Sex*	*Age*
1	Editor	Higher education	F	32
2	Editor	University	F	30
3	Retired	University	M	58
4	Research	University	M	37
5	Retired	Vocational Education	F	58
6	Ergotherapist	Higher education	F	36
7	Ergotherapist	Higher education	F	46
8	Journalist	Higher education	M	56
9	Musician	Higher education	M	53
10	Volunteer	Vocational Education	F	60
11	Personnel coordinator	Higher education	F	54
12	Administration	Higher education	M	67
13	Housewife	Secondary school	F	63
14	Ortho-pedagogue	University	F	40
15	Service manager	Higher education	M	48
16	Editor	University	M	51

Chapter 8 The influence of visual experience on visual and spatial imagery

Abstract

In the present experiment differences were found between blind and sighted participants on a visual and a spatial imagery task, but not on an auditory imagery task. Interestingly, there was a dissociation for early and late blind participants on the visual and the spatial imagery task: late blind participants made more errors on the visual imagery task, while early blind participants made more errors on the spatial imagery task. This dissociation suggests that for visual (form) imagery people use the channel currently available (i.e. haptic for the blind; visual for the sighted). In contrast, for spatial imagery reliance on haptic processing does not suffice, and people would benefit from visual experience and ability.

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Introduction

It is frequently assumed that visual imagery and perception share similar processing mechanisms and neural systems (Kosslyn, 1994). A litmus test for this assumption has been the examination of the performance of people who have no or little visual experience (i.e. congenitally and early blind people) on tasks that are classically considered to require visual imagery. Even though findings from studies on visual imagery in the blind are rather mixed, several studies, surprisingly, have shown that congenitally blind people are able to perform these tasks equally well or only slightly worse than sighted people (Kaski, 2002). Because it is highly unlikely that someone who has never seen could form purely visual representations, it seems that what is considered to be visual imagery actually depends on more general representations instead of comprising purely visual representations. In line with this, it has been suggested that (blind) people rely on spatial (Farah, Hammond, Levine, & Calvanio, 1988) or haptic (Hollins, 1985) imagery to solve tasks that supposedly require visual imagery. In contrast, other researchers (Thinus-Blanc & Gaunet, 1997) have argued that visual experience is necessary for certain spatial processing mechanisms (including spatial imagery) to operate correctly. In sum, the association between imagery and perception still produces controversy, and the conflicting results from studies with blind and sighted individuals demand further experiments. The present study is the first to compare in a single experiment the performance characteristics of early blind, late blind and sighted participants on similar imagery tasks based on either auditory, visual, or spatial task demands.

For the present experiment we included: (1) a visual form imagery task (Aleman, van Lee, Mantione, Verkoijen, & de Haan, 2001; Mehta, Newcombe, & de Haan, 1992), which required participants to compare the form of three named objects and consequently name the odd one out, (2) an auditory imagery task which required participants to compare the sound of three named objects and consequently name the odd one out, (3) a spatial imagery task (Paivio, 1978; Trojano et al., 2000), which required participants to mentally compare clock times and indicate which clock time had the largest angle between the two hands. In a previous study (Aleman et al., 2001) congenitally blind participants performed worse than sighted participants on the above mentioned visual form imagery task, but the blind participants did score well above chance. The present study tries to extend this finding by including a group of late blind participants, who are blind, yet report to employ their visual memories to solve all kinds of visual-spatial tasks. If the difference between congenitally blind and sighted participants on the visual form imagery task is indeed a result of lack of visual experience then the late blind should perform better than the early blind, because the former have more visual experience than the latter. Furthermore, the auditory imagery task was included to examine whether the possible differences on the visual imagery task were not a result of the task demands, namely keeping three object names in working memory and consequently choosing one of these objects. If the participant groups differed in terms of their general working memory capacity, then this would show on the auditory imagery task, which had very similar task demands as the visual imagery task.

The spatial imagery task used was the mental clock test, in which participants are presented with two spoken clock times and have to decide which of the two times would show the greater angle between the clock hands on an analogue clock face. Paivio (1978) found that fast and accurate average responses, which showed an inverted relationship with the angular difference between the two angles, correlated with good performance on other spatial imagery tasks. Participants who did not show such a "symbolic distance effect", in which the decision becomes faster and better when the difference in angle becomes greater, were likely to have used strategies other than spatial imagery. A recent fMRI study (Trojano et al., 2000) has provided evidence that this task is indeed a spatial task and not a visual task, by showing that similar brain regions were active in the parietal lobe for a perceptual and an imagery version of the task, and, importantly, no areas in the primary visual cortex were active for either version of the task. In the present study we analyzed the possible symbolic distance effects of blind and sighted participants in order to give us insight in how far visual experience can modulate the availability and effectiveness of spatial imagery.

Method & Materials

Participants

Appendix A (Chapter 7) contains the list of participants, although four participants from these lists were excluded because they did not participate in these imagery tasks. Twelve early blind (nr. 9 excluded), fifteen late blind (nr. 6 & 8 excluded) and fifteen sighted (nr. 10 excluded) individuals participated in the experiments. None of the participants had neurological or motor deficits. Participants were considered early blind when they had no memory of vision whatsoever. The early blind group consisted of congenitally blind (8) and early blind (4) individuals that had become blind before the age of three. Those that were not blind from birth had no memory of vision whatsoever. All participants in the late blind group reported to have rich vivid visual memories.

Early blind, late blind and sighted control participants were matched for sex, and approximately matched for age (*mean*= 43, *SD*= 9; *mean*= 52, *SD*= 8; *mean*= 49, *SD*= 11) and education. Verbal IQ as measured with two sub-scales (Vocabulary and Similarities) of the Dutch version of the WAIS-III (Wechsler, 1997) showed no significant difference between the groups, $F(2, 41) = 1.1$, $p = .34$. All participants gave their informed consent for inclusion in this study and received payment for their participation. A local ethics committee approved the experiments.

General procedure

Sighted control participants were blindfolded during the experiment. The order of the three imagery tasks was counterbalanced over participants. In between the imagery tasks the verbal IQ was measured with subscales of the WAIS-III. Taken together, participants were tested for approximately an hour.

Visual and auditory imagery tasks

These imagery tasks were based on the tasks described by Mehta et al. (1992). In the visual form imagery task participants had to mentally compare the shape of the outline (independent of size) of three named common objects and identify the odd-one-out. For example, the words 'book', 'ball', and 'shoebox' were verbally presented to participants. Next, they were asked which of the three items was most deviant in terms of form characteristics (i.e.'ball').

In the auditory imagery task participants had to mentally compare the prototypical sounds produced by three named objects or living creatures and identify the odd-one-out. For both tasks, the odd-one-out could not be determined correctly on the basis of semantic information alone, and both tasks consisted of 23 triads. Participants were not given any time restraints. Error scores were measured.

Spatial imagery task

Forty-eight pairs of clock times were presented in a fixed-random order, involving only half-hours and whole hours. The clock faces were balanced for the side on which the hands had to be imagined: left (12), right (12), and left/right (24). All times were mentioned four times, two times as the first clock and two times as the second clock. In half of the conditions the correct answers corresponded to numerically greater times (i.e. 3:00 versus 1:00), and in the other half to numerically smaller times (i.e. 8:30 versus 11:00). The angular size differences between the pairs of clock times were calculated by subtracting the angular separation between the hour and minute hand of one time from the angular separation of the other. These angular differences (AD) were divided in three main AD-levels; small AD when the angular size difference between the pairs of clock times was 15, 30 or 45 degrees, corresponding to time-unit differences ranging from 2.5 to 7.5 minutes; medium AD when the angular size difference was 60, 75, 90 or 105 degrees, corresponding to time-unit differences ranging from 10 to 17.5 minutes and large AD when the angular size difference included 120, 135, 150, 165 or 180 degrees, corresponding to time-unit differences ranging from 20 to 30 minutes. All pairs of clock times were sound-files of a recorded male voice of the same length (2.48 s).

Participants were asked to imagine pairs of spoken clock times that were presented through earphones. Next, they were to judge which of the two clock times showed the greater angle between the hour and minute hands of the clock. Only angles smaller than 180 degrees were to be considered. Participants had to push the left key ('c') with the left index finger if the hands of the first clock time formed the greater angle, or the right key ('m') with the right index finger for the second clock time. The response keys on a standard keyboard were made more prominent with a tactile marking. Participants were asked to respond as accurately and as fast as possible.

Data analysis

For both the visual and auditory imagery task mean percentage error scores were analyzed using a one way ANOVA with Group (Early Blind, Late Blind and Sighted) as between subjects variable. For the spatial imagery task, mean RTs, computed over correct trials, and mean percentage error scores were analyzed using separate 3 x 3 ANOVAs with Angular Difference (Small, Medium and Large) as within-subjects variable, and Group (Early Blind, Late Blind and Sighted) as between subjects variable. Planned contrasts were done for all tasks comparing blind (early and late) and sighted participants. Bonferroni correction of the significance criterion was applied for post hoc testing.

Results

Visual and auditory imagery tasks

Table 1 shows error scores for both the visual and auditory imagery task. A contrast comparing the performance of blind participants (early and late) with sighted participants revealed a marginally significant effect, $t(39) = 2.0$, $p = .05$. Blind participants tended to make more errors than the sighted participants on the visual task. The effect of Group was almost significant for the visual task, $F(2, 41) = 3.2$, $p = .05$. Furthermore, post-hoc tests (Bonferroni correction results in an α of .05/ 3= .0167) revealed that on the visual imagery task late blind participants made more errors than sighted participants, $t(28) = 3.0$, $p = .006$, whereas there was no difference between late blind and early blind, $t(25) = 1.2$, $p = .23$, and early blind and sighted participants, $t < 1$. No effects concerning the Group variable were significant for the auditory imagery task, all $ps > .56$. On both tasks all participants performed much better than chance level (67% errors).

Table 1.
Mean error scores (%) for the visual and auditory imagery tasks, standard errors in parentheses.

	Task	
Group	Visual	Auditory
Early Blind	18 (3)	26 (3)
Late Blind	23 (2)	26 (3)
Sighted	15 (2)	24 (3)

Spatial imagery task

Figure 1 shows mean RTs and error scores for the mental clock test. The main effect of Angular Difference was significant for both RTs and error scores, $F(2, 78)= 40.9$, $p< .001$, and $F(2, 78)= 17.0$, $p< .001$. In addition, a linear trend was significant for Angular Difference on the RTs, $F(1, 39)= 58.8$, $p< .001$, and on the error scores, $F(1, 39)= 26.4$, $p< .001$. These main effects and the linear trends followed the expected direction and showed the inverse relationship between performance and the magnitude of the angular difference, indicating the presence of symbolic distance effects.

A contrast comparing the performance of blind participants (early and late) with sighted participants showed a significant effect, $t(39)= 2.8$, $p= .008$. This contrast indicated that blind participants made more errors than the sighted participants on the mental clock test. For error scores the main effect of Group was significant, $F(2, 39)= 4.8$, $p= .01$. Furthermore, post-hoc tests ($\alpha= .0167$) revealed that early blind participants made more errors than sighted participants, $t(25)= 2.9$, $p= .007$, whereas there was no difference between early blind and late blind, $t(25)= 1.2$, $p= .23$, and late blind and sighted participants, $t(28)= 2.2$, $p= .03$. All other effects concerning RTs and error scores were not significant, all $Fs< 1.1$.

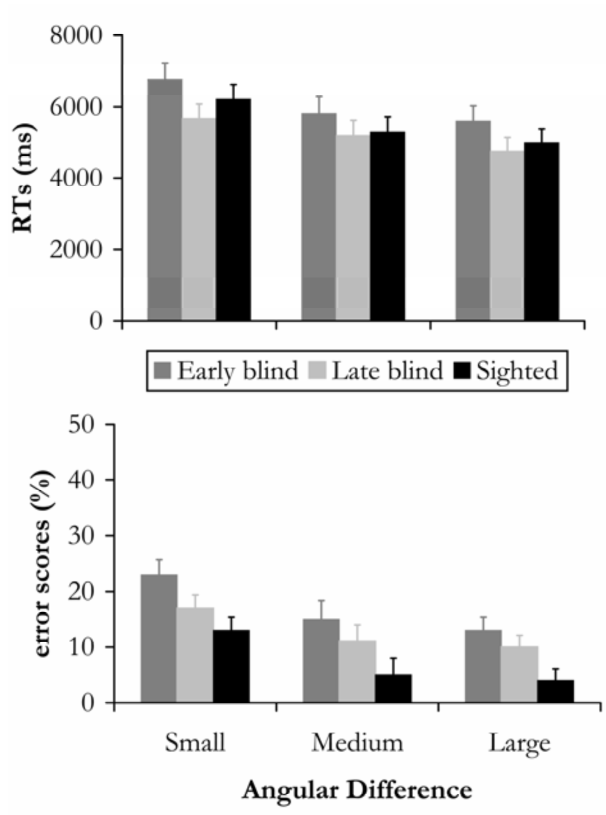

Figure 1.
Mean RTs (ms) and error scores (%) for the mental clock test

Discussion

The main goal of the present study was to investigate the visual, spatial and auditory imagery capabilities of blind and sighted participants by including three similar imagery tasks. In the visual form imagery task we found that blind participants made more errors than sighted participants. Surprisingly, only the late blind group suffered more errors than sighted group, whereas the early blind group showed no difference with the sighted group. Apparently, the fact that blind people performed worse than sighted people on this visual imagery task cannot be explained by differences in visual experience. If this were the case then late blind people should have performed better than early blind people. The difference between blind and sighted participants is probably better explained by differences in strategies. This visual imagery task required participants to compare object forms, which were all well-known small utensils or types of fruit. It is likely that both early and late blind participants relied on a form of haptic imagery to solve this task, whereas sighted people relied on visual imagery. The visual imagery strategy seems to be more effective than the haptic imagery strategy, but the haptic strategy was still highly accurate and well above chance level. Given that early blind participants have more experience with haptic information processing than late blind people (Millar, 1994) it is not surprising that the former group tended to perform better than the latter when both groups applied a haptic imagery strategy. Our findings concerning this visual form imagery task extend the findings of Aleman et al. (2001), by showing that the difference between blind and sighted people is best interpreted as a difference in strategies (haptic vs. visual), because especially late blind participants scored lower than sighted participants on this task. Importantly, this result is not likely to stem from a difference in general cognitive ability or working memory capacity because the groups performed equally on an auditory imagery control task.

The third task that was included in this study was a spatial imagery task that required participants to mentally compare two clock times and decide which of the two times has the greater angle between the hour and the minute hand. All participants performed better (RTs and error scores) when the angular difference between the two clock times increased. These symbolic distance effects provide evidence that both blind and sighted participants relied on spatial imagery to solve this task. Interestingly, blind participants made more errors than sighted participants. In addition, a post hoc test revealed that the early blind participants scored lower than specifically the sighted participants. Therefore, it seems that although all groups employed spatial imagery, the sighted participants did this more effectively than the blind, and especially the early blind participants. These results concerning the mental clock test are in line with previous studies that have found that blind (and especially early blind) people perform worse than sighted people on tasks requiring spatial imagery (Cornoldi, Bertuccelli, Rocchi, & Sbrana, 1993; Herman, Chatman, & Roth, 1983).

It has been suggested that differences between blind and sighted individuals on imagery tasks can only be studied when the tasks are sufficiently difficult (Cornoldi et al., 1993). In our study participants made comparable amount of errors on the visual, auditory and spatial imagery task. In addition, we employed a same verbal description format in all three imagery tasks. The similar level of difficulty of the three tasks and the similarity between the input format allowed us to directly compare the performance patterns of the early blind, late blind, and sighted participants over the three tasks.

As noted above, we found clear differences between the blind and sighted participants on the visual and the spatial imagery tasks, but not on the auditory imagery task. It seems to be the case that being able to see is beneficial for both visual and spatial imagery, yet in different ways. In theory late blind people could have used their visual memories to carry out a task that requires form comparisons. However, we found that early blind people tended to be better at this task than late blind participants. Therefore, it can be argued that late and early blind people relied on haptic imagery for this tasks and that this haptic imagery was less effective than the visual imagery employed by the sighted. Interestingly, our late blind participants had lost their vision a long time ago (on average 30 years). It could be that a late blind group with more recent visual memories might have performed better than the early blind, indicating that they used visual imagery based on their more recent visual experience.

Notably, late blind participants performed the same as sighted participants on the spatial imagery task, while early blind participants performed worse than sighted participants. The differences in performance of late blind and early blind participants relative to sighted participants seem to indicate that spatial imagery benefits from visual experience. This is in line with a suggestion made by Thinus-Blanc and Gaunet (1997) that a critical period (before the age of seven) exists in which vision is crucial in order to develop complete spatial abilities. All of our late blind participants (except one) lost their vision after they were nine years old, suggesting that they had a chance to set up spatial imagery processes that were relatively spared after they had become blind. The specific difference between early blind and sighted people indicates that this spatial imagery task, different from the visual form imagery task, cannot be effectively solved on the basis of haptic imagery alone. Apparently, spatial imagery becomes more efficient because of (some) visual experience.

Conclusion

Taken together, the present study is the first to compare the visual, spatial and auditory imagery abilities of early blind, late blind and sighted individuals in one experiment. Blind people performed worse than sighted people on visual and spatial imagery tasks, but not on the auditory task. Interestingly, we found a dissociation for early and late blind participants between the visual and the spatial imagery task: late blind participants produced more errors than any other group on the visual imagery task, while early blind participants produced more errors than any other group on the spatial imagery task. This dissociation suggests that visual imagery on the form imagery task is actually dependent on the dominant input channel for form information: haptic input for the blind and visual input for the sighted. In contrast, for spatial imagery reliance on haptic processing does not suffice, and people would benefit from visual experience.

References

Aleman, A., van Lee, L., Mantione, M. H., Verkoijen, I. G., & de Haan, E. H. (2001). Visual imagery without visual experience: evidence from congenitally totally blind people. *Neuroreport, 12*(11), 2601-2604.

Cornoldi, C., Bertuccelli, B., Rocchi, P., & Sbrana, B. (1993). Processing capacity limitations in pictorial and spatial representations in the totally congenitally blind. *Cortex, 29*(4), 675-689.

Farah, M. J., Hammond, K. M., Levine, D. N., & Calvanio, R. (1988). Visual and spatial mental imagery: Dissociable systems of representation. *Cognitive Psychology, 20*, 439-462.

Herman, J. F., Chatman, S. P., & Roth, S. F. (1983). Cognitive mapping in blind people: acquisition of spatial relationships in a large-scale environment. *Journal of Visual Impairment & Blindness, 77*, 161-166.

Hollins, M. (1985). Styles of mental imagery in blind adults. *Neuropsychologia, 23*(4), 561-566.

Kaski, D. (2002). Revision: is visual perception a requisite for visual imagery? *Perception, 31*(6), 717-731.

Kosslyn, S. M. (1994). *Image and brain: The resolution of the imagery debate*. Cambridge, Massachusetts: MIT Press.

Mehta, Z., Newcombe, F., & de Haan, E. (1992). Selective loss of imagery in a case of visual agnosia. *Neuropsychologia, 30*(7), 645-655.

Millar, S. (1994). *Understanding and representing space: Theory and evidence from studies with blind and sighted children*. Oxford: Oxford University Press.

Paivio, A. (1978). Comparisons of mental clocks. *Journal of Experimental Psychology: Human Perception & Performance, 4*(1), 61-71.

Thinus-Blanc, C., & Gaunet, F. (1997). Representation of space in blind persons: Vision as a spatial sense? *Psychological Bulletin, 121*(1), 20-42.

Trojano, L., Grossi, D., Linden, D. E. J., Formisano, E., Hacker, H., Zanella, F. E., Goebel, R., & Di Salle, F. (2000). Matching two imagined clocks: The functional anatomy of spatial analysis in the absence of visual stimulation. *Cerebral Cortex, 10*(5), 473-481.

Wechsler, D. (1997). *Wechsler Adult Intelligence Scale, Third Edition*. San Antonio, TX: The Psychological Corporation.

Chapter 9 Summary and conclusions

Summary

The topic of the present thesis is how people represent spatial information when it is communicated through language. When they listen to or read spatial descriptions do they consequently form spatial mental models or even mental images, which resemble representations from direct perceptual experience? We have first studied this issue with respect to simple spatial sentences, such as *triangle left of circle* (Chapters 2, 3, 4 & 5). Subsequently, we have examined more complex spatial descriptions and studied the influence of various variables, such as the perspective of the spatial description and whether the listener can see or is blind, on the characteristics of spatial representations (Chapters 6 & 7). Finally, we described an experiment with blind and sighted people in which we presented a more general discussion of the relation between mental imagery and perception (Chapter 8). In this chapter the main findings for simple and complex spatial sentences from this thesis are summarized, and we present some conclusions with respect to the representation of spatial descriptions.

Simple spatial sentences

In the first half of this thesis we have described experiments that made use of the classic sentence-picture verification task (e.g. Chase & Clark, 1972) in various forms. Participants read a simple spatial sentence such as *the square is right of the triangle* and after a delay they see a picture of two objects and they have to decide whether this pictorial information corresponds to the information in the spatial sentence. In Chapters 2 and 3 we contrasted two models concerning the representation of spatial sentences: a spatial sentence is always represented as a verbal code (a set of propositions) (*propositional model*; Chase & Clark, 1972; Logan & Sadler, 1996), or the spatial sentence is represented as either a set of propositions or as a mental image (*strategic model*; MacLeod, Hunt, & Mathews, 1978). First, we examined the effect of an articulatory suppression and a spatial tapping dual task on the encoding of simple spatial sentences and pictures in sentence-picture and picture-picture verification tasks (Chapter 2). Articulatory suppression did not interfere, while spatial tapping lowered performance in both tasks. Furthermore, in the sentence-picture verification experiments spatial tapping only hampered performance of participants who were classified as having used a visual-spatial strategy, while it had no effect for those who were classified as having applied a verbal strategy. Therefore, this study provided converging evidence, using a dual-task methodology, that both separate verbal and visual-spatial strategies exist for the processing of simple spatial sentences. Second, we examined the effect of the probability of the modality of the second stimulus in "(non)-spatial sentence-sentence" and "(non)-spatial sentence-picture" verification trials (Chapter 3). The probability of the second stimulus was varied in the following way: either 80% of the stimuli were pictures and 20% were sentences, or 80% of the stimuli were sentences and 20% were pictures. We found that people were slower on unexpected than expected stimuli, especially for the spatial sentences. However, this difference between spatial and non-spatial sentences was only present when the second stimulus was a picture and not when the second stimulus was a sentence. Because these data did not fit very well with either the *propositional* or the *strategic* model we suggested a *dual-representational* model in which participants automatically represent the spatial sentence propositionally, and participants form a mental image when they expect a picture, but not when they expect a sentence.

Further evidence for the *dual-representational model* and an answer to the question *when* a mental image of the spatial sentence is formed was provided on the basis of an EEG study (Chapter 4). The same behavioural task was employed as mentioned before (Chapter 3) and we replicated the behavioural results that were described above. We measured EEG while participants were executing the sentence-picture and sentence-sentence trials. A negative slow wave (550-1100 ms after sentence onset) was larger at parieto-occipital sites when participants read a spatial sentence and expected a picture than when they expected a sentence. This difference was not observed for non-spatial sentences. To further illustrate this finding, source analyses indicated that a posterior occipital source was more active when participants read a spatial sentence and expected a picture, while a left frontal source appeared more active when participants read a spatial sentence and expected a sentence. Therefore, we concluded that early brain activation linked to processing spatial sentences (and not non-spatial sentences) occurred in areas generally associated with perceptual and mental image processing (Knauff, Mulack, Kassubek, Salih, & Greenlee, 2002; Kosslyn, 1994; West & Holcomb, 2000), and only so when participants were explicitly expecting to compare the verbal information to a picture.

In Chapter 5 we further focussed on neural correlates of the processing of spatial sentences, and specifically on the building blocks of simple spatial sentences: locative prepositions (e.g. *above*, *on*, *right of*). A similar behavioural experiment as described in Chapter 3 and 4 was employed while using a rapid event-related fMRI design. We found evidence for higher activity for spatial than for non-spatial sentences in the left supramarginal gyrus. This was consistent with previous neuropsychological findings in which patients with lesions in this area in the left inferior parietal cortex had specific problems with understanding the meaning of locative prepositions (Tranel & Kemmerer, 2004). The activity in the left supramarginal gyrus did not differ between trials in which participants expected a picture or a sentence. Therefore, it appears to be the case that the left SMG is necessarily involved with the processing of locative prepositions, irrespective of the context in which the sentence is written. The dual-representational model does predict that mental imagery plays a role in the processing of spatial sentences. The EEG evidence presented in this thesis suggests that these mental imagery processes during the encoding of a spatial sentence occur mostly in parieto-occipital regions. Therefore, it would be interesting to perform additional fMRI analyses in which the occipital lobe is included as a region of interest.

Complex spatial sentences

Given that the first half of the thesis has provided considerable evidence that people are capable of forming a spatial representation or even a mental image on the basis of simple spatial descriptions, the next question is what the exact nature is of representations people can construct on the basis of more complex and everyday spatial descriptions. In Chapter 6 experiments are described in which participants listened to spatial descriptions with either a route or a survey description. After listening to the description they executed a recognition/ priming and a bird flight distance comparison task. Both these tasks are associated with typical response patterns (i.e. spatial priming effect and symbolic distance effect), which indicate a spatial organization of mental representations and have been found after participants studied a visual map. Spatial priming and symbolic distance effects were found after participants studied verbal descriptions. Both categorical and metric distance information seems to be represented after people listened to a description with a route and survey descriptions. Our finding that similar priming effects related to categorical distance occurred after participants listened to a route or a survey description is in line with previous studies indicating that information concerning the relative position of objects was equally available from representations based on either description perspective (Taylor & Tversky, 1992). This study is one of the first to find evidence that a mental representation, which contains analog spatial detail (i.e. metric distance), can be constructed from a description with a route perspective. Importantly, it should be noted that a relative advantage for survey descriptions over route descriptions did exist, suggesting that survey descriptions lead to spatial representations with a more fine-grained localization of the objects than route descriptions.

Spatial mental model construction requires an ongoing integration and transformation of several pieces of information (Zwaan & Radvansky, 1998). It has been suggested that early blind people (people who lost their vision before the age of three) perform normally with respect to the passive storage of visual-spatial information, while they have specific problems with processes that require active integration and transformation (Cornoldi & Vecchi, 2000). Therefore, it could be that the level of abstraction that a spatial mental model represents might be unattainable for them. In Chapter 7 early blind, late blind and sighted control participants listened to route and survey descriptions, after which they were tested with the same tasks as mentioned above. Similar to Chapter 6, we found spatial priming and symbolic distance effects for all participants. Therefore, it is very likely that early and late blind people can form spatial mental models on the basis of verbal descriptions. Interestingly, in contrast with sighted people, blind people seem to prefer route to survey descriptions, even when the spatial problems that have to be solved explicitly favor the survey description. Apparently, only people with active vision prefer a survey description to build up a spatial mental model, whereas people with visual memories only (late blind), similar to people with no visual memories (early blind), prefer a route description to build up a spatial mental model.

Finally, in Chapter 8 we examined the question to what extent blind, and especially early and congenitally blind, people are able to engage in several types of mental imagery on the basis of verbal instructions. Differences were found between blind and sighted participants on a visual and a spatial imagery task, but not on an auditory imagery task. Interestingly, we found a dissociation for early and late blind participants between the visual and the spatial task: late blind participants produced more errors than any other group on the visual imagery task, while early blind participants produced more errors than any other group on the spatial imagery task. This dissociation suggests that only spatial imagery benefits from visual experience. In contrast, for visual form imagery the early blind people can probably rely on haptic imagery to reach similar performance levels as the sighted participants.

Conclusions

In this thesis we have presented several findings that support the idea that people can construct mental images and spatial representations on the basis of spatial descriptions. People seem very able to form a mental image of a simple spatial sentence such as *triangle left of circle,* and subsequently use the representation to verify the spatial information in a visual scene. However we would like to argue that people do not always form a mental image or a spatial representation. Only when they expect to use the verbal information to complete a certain visual task, such as find something in a visual scene, do they form a spatial representation. Therefore we do not support models concerning language representation that assume that a spatial sentence can only be represented as a set of propositions (Clark & Chase, 1972) or as a perceptual simulation (Barsalou, 1999). Instead we propose a model, inspired by the dual code theory (Paivio, 1983), in which a spatial sentence is always represented as a set of propositions, and additionally can be represented as a mental image or spatial representation. Future research should focus on how people use this dual coded spatial information to find objects and places based on spatial descriptions.

In line with recent neuropsychological findings (Tranel & Kemmerer, 2004) we found fMRI evidence that spatial language might be processed in a specific area in the brain. The left supramarginal gyrus seems to be necessarily involved with the processing of spatial sentences and more specifically, locative prepositions such as *left of* and *under*. An interesting next question is whether the connection between this area in the parietal cortex and spatial language might result from people learning to connect the meaning of spatial terms to spatial relations in the outside world. An answer to this question might be found by examining people who have never seen (i.e. congenitally or early blind) in whom this connection between the visual world and spatial terms could have never taken place.

Findings from this thesis also contribute to the growing evidence that people can form elaborate spatial mental models on the basis from spatial descriptions (Zwaan, in press; Zwaan & Radvansky, 1998). Importantly, the dominant idea that spatial perspective in verbal descriptions has no significant influence on the spatial mental model seems to be up for revision based on the evidence presented in this thesis (Chapter 6 & 7) and a recent study from Shelton and McNamara (2004). We showed that metric distance information probably is present in the spatial mental model from listeners, but the availability of this information was dependent on the perspective of the spatial description and the visual experience of the listener. Sighted people build up more accurate spatial mental models from survey descriptions whereas blind people perform better after listening to a route description. This last finding could also have important implications for how spatial information should be communicated to blind people. First, it is crucial to realize that blind people can construct accurate spatial representations of their environment on the basis of verbal descriptions. This implicates that training this aspect of spatial cognition could be very beneficial for the general capacity of blind people to find their own way in the world. Second, when providing spatial information to blind people it is probably best to only mention the information in relation to their own position and movement.

To conclude, the phrase "*a picture's worth a thousand words*" hints at the idea that a picture's meaning can inspire thousands of words. Based on this thesis it also seems to be the case that "*a spatial sentence's worth at least one picture*".

References

Barsalou, L. W. (1999). Perceptual symbol systems. *Behavioral & Brain Sciences, 22*(4), 577-660.

Chase, W. G., & Clark, H. H. (1972). Mental operations in the comparison of sentences and pictures. In L. W. Gregg (Ed.), *Cognition in learning and memory*. New York: Wiley.

Clark, H. H., & Chase, W. G. (1972). On the process of comparing sentences against pictures. *Cognitive Psychology, 3*(3), 472-517.

Knauff, M., Mulack, T., Kassubek, J., Salih, H. R., & Greenlee, M. W. (2002). Spatial imagery in deductive reasoning: a functional MRI study. *Cognitive Brain Research, 13*(2), 203-212.

Kosslyn, S. M. (1994). *Image and brain: The resolution of the imagery debate*. Cambridge, Massachusetts: MIT Press.

Logan, G. D., & Sadler, D. D. (1996). A computational analysis of the apprehension of spatial relations. In P. Bloom & M. A. Peterson & L. Nadel & M. F. Garret (Eds.), *Language and Space* (pp. 493-529). Cambridge, MA: MIT Press.

MacLeod, C. M., Hunt, E. B., & Mathews, N. N. (1978). Individual differences in the verification of sentence-picture relationships. *Journal of Verbal Learning & Verbal Behavior, 17*(5), 493-507.

Paivio, A. (1983). The empirical case for dual coding. In J. C. Yuille (Ed.), *Imagery, Memory and Cognition*. Hillsdale, New Jersey: Lawrence Erlbaum Associates.

Shelton, A. L., & McNamara, T. P. (2004). Orientation and perspective dependence in route and survey learning. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 30*(1), 158-170.

Taylor, H. A., & Tversky, B. (1992). Spatial mental models derived from survey and route descriptions. *Journal of Memory & Language, 31*(2), 261-292.

Tranel, D., & Kemmerer, D. (2004). Neuroanatomical correlates of locative prepositions. *Cognitive Neuropsychology, 21*(7), 719-749.

West, W. C., & Holcomb, P. J. (2000). Imaginal, semantic, and surface-level processing of concrete and abstract words: an electrophysiological investigation. *Journal of Cognitive Neuroscience, 12*(6), 1024-1037.

Zwaan, R. A. (in press). The immersed experiencer: Toward an embodied theory of language comprehension. In B. H. Ross (Ed.), *The Psychology of Learning and Motivation* (Vol. 44). New York: Academic Press.

Zwaan, R. A., & Radvansky, G. A. (1998). Situation models in language comprehension and memory. *Psychological Bulletin, 123*(2), 162-185.

Samenvatting in het Nederlands

Communicatie tussen mensen is moeilijk. Een bekend voorbeeld hiervan is het vragen van de weg in een onbekende stad aan een toevallige voorbijganger. Deze voorbijganger kan dan vaak uitweiden over alle opvallende gebouwen die men zal tegenkomen en het aantal afslagen dat men moet nemen. Echter, wanneer vervolgens het eerste kruispunt zich voordoet heeft de verdwaalde geen flauw idee of hij of zij linksaf of rechtsaf moet slaan. Dit soort problemen in de (ruimtelijke) communicatie roept bepaalde vragen op. Kunnen mensen zich beschreven routes eigenlijk wel goed voorstellen? Of meer algemeen hoe representeren mensen ruimtelijke informatie wanneer deze "slechts" wordt overgebracht door middel van verbale beschrijvingen?

Eenvoudige ruimtelijke zinnen

Wanneer mensen ruimtelijke informatie aan elkaar beschrijven dan bestaat dit meestal uit categorische beschrijvingen zoals *de autosleutels liggen op het kleine tafeltje links van de grijze bank*. Wat opvalt aan een dergelijke beschrijving is dat er geen gedetailleerde of metrische informatie wordt gegeven waaruit de exacte positie van een bepaald object kan worden afgeleid. De positie wordt alleen grofweg aangeduid ten opzichte van andere voorwerpen of ten opzichte van een persoon. Het is dan echter niet meteen duidelijk hoe iemand deze ruimtelijke beschrijving verwerkt en representeert. Enerzijds, is het immers mogelijk dat een ruimtelijke zin wel degelijk een duidelijke en precieze mentale verbeelding oproept, ondanks het feit dat veel van die informatie ontbreekt in de zin. Anderzijds zou het ook zo kunnen zijn dat mensen ruimtelijke zinnen alleen representeren als een abstracte code (propositionele code) en dat mentale plaatjes wellicht slechts bijproducten zijn die geen rol van betekenis spelen in de manier waarop mensen ruimtelijke informatie verwerken en begrijpen. Deze tegenstelling tussen mentale plaatjes en propositionele codes speelt een belangrijke rol in het eerste deel van dit proefschrift.

Een taak die veelvuldig is gebruikt om te onderzoeken hoe mensen een ruimtelijke zin representeren is de *zin-plaatje verificatie taak*. Tijdens een dergelijke taak lezen mensen eerst een zin als *de driehoek is links van de cirkel* en vervolgens verschijnt na een korte pauze een plaatje van (meestal) een driehoek en een cirkel en moeten mensen aangeven of de ruimtelijke relatie klopt met wat in de zin werd aangegeven. In *hoofdstuk 2 en 3* werden twee modellen aangaande de representatie van eenvoudige ruimtelijke zinnen binnen een *zin-plaatje verificatie taak* beschreven en gecontrasteerd. Het ene model veronderstelt dat ruimtelijke zinnen altijd worden gerepresenteerd als een propositionele code (propositionele model) terwijl het andere model veronderstelt dat een propositionele code of een mentaal plaatje mogelijk zijn (strategisch model). In *hoofdstuk 2* lazen mensen een ruimtelijke zin terwijl ze soms tegelijkertijd een andere "dubbel"-taak moesten uitvoeren: ofwel het opzeggen van een simpele reeks cijfers (*1, 2, 3, 4, 1, 2, enz…*) ofwel het tegen de klok in aantikken van vier blokjes in het patroon van een vierkant. Deze twee dubbeltaken worden verondersteld het verbale werkgeheugen (opzeggen cijfers) of het visuo-spatiele werkgeheugen (ruimtelijk patroon aantikken) te belasten. Het bleek dat het merendeel van de mensen langzamer werd op de *zin-plaatje verificatie taak* door het natikken van een ruimtelijk patroon en niet door het opzeggen van de cijfers. Dit doet vermoeden dat de meeste mensen altijd een representatie opbouwen van een ruimtelijke zin die afhankelijk is van het visuo-spatiele werkgeheugen. Deze bevinding ondersteunde het strategische model en niet het propositionele model. *In hoofdstuk 3* werd vervolgens aangetoond dat de rol van de context waarin een ruimtelijke zin wordt gelezen van grote invloed kan zijn op hoe mensen een ruimtelijke zin representeren. Alleen wanneer mensen een ruimtelijke zin lezen en tegelijkertijd verwachten deze te moeten vergelijken met een plaatje leken zij een mentaal plaatje te vormen. Wanneer ze verwachten dat ze de ene ruimtelijke zin met een andere ruimtelijke zin moeten vergelijken dan vonden we geen bewijs voor mentale plaatjes vorming bij de proefpersonen. Deze bevindingen passen niet goed in het strategische of het propositionele model. Daarom stelden wij in hoofdstuk 3 een nieuw model voor: *het dubbel representationeel model*. Dit model veronderstelt dat mensen een ruimtelijke zin altijd representeren als een propositionele code en dat ze daarnaast alleen in sommige omstandigheden (zoals een visuele context) een mentaal plaatje vormen.

Verdere ondersteuning voor dit *dubbel representationeel model* werd geleverd in *hoofdstuk 4* waarin een *elektro-encefalogram* (EEG) studie werd beschreven. Met de EEG techniek is het mogelijk om voortdurend een signaal te meten op de schedel dat een afgeleide is van de snelle elektrische ontladingen tussen hersencellen. We vonden verschillen in EEG (d.w.z. in een slow wave 550-1100 ms na de presentatie van de eerste zin) wanneer mensen een ruimtelijke zin lazen en een plaatje verwachten ten opzichten van wanneer mensen een (ruimtelijke) zin lazen en een zin verwachten. Dit verschil leek vooral te vinden boven de parieto-occipitaal kwab, een gebied dat wordt geassocieerd met visuele mentale voorstelling. Dit werd ook ondersteund door verdere bron-analyses. De betrokkenheid van hersenactiviteit in "visuele voorstellings-" gebieden bij het lezen van een ruimtelijke zin, maar alleen in een visuele context, bevestigde het *dubbel representationeel model*.

In *hoofdstuk 5* onderzochten we de neurale basis van de bouwstenen van een ruimtelijke zin: de ruimtelijke voorzetsels (bijvoorbeeld *links van*, *rechts van*, *onder*, *boven*). Dit hebben we gedaan met behulp van functionele magnetische resonantie beeldvorming (fMRI). Met deze techniek gebruikt men als maat voor hersenactiviteit een afgeleide van de langzame metabolische veranderingen door het brein heen die ontstaan als het gevolg van verschillen in de toevoer van zuurstofrijk bloed. Deze techniek stelt onderzoekers in staat om met behoorlijke ruimtelijke precisie (in de orde van grootte van een aantal millimeters) "blokjes" van activatieverschillen te lokaliseren. We vonden dat wanneer mensen ruimtelijke zinnen (bijvoorbeeld *driehoek links van cirkel*) lazen dit resulteerde in meer activatie in een gebied in de linker parietaal kwab (*gyrus supramarginalis*) dan wanneer ze niet-ruimtelijke zinnen lazen (bijvoorbeeld *driehoek en cirkel*). Deze bevinding kwam overeen met eerder neuropsychologisch onderzoek (Tranel en Kemmerer, 2004) waarin werd gevonden dat mensen met laesies in de linker *gyrus supramarginalis* specifiek moeite hadden met het begrijpen van ruimtelijke voorzetsels en niet met andere soorten woorden.

Complexe ruimtelijke beschrijvingen

Gezien het feit dat het eerste deel van het proefschrift aanzienlijk bewijs opleverde dat mensen wel degelijk in staat zijn om ruimtelijke voorstellingen of zelfs mentale plaatjes op te bouwen op basis van eenvoudige ruimtelijke zinnen werd in het tweede deel onderzocht of dit ook het geval was voor meer alledaagse en complexere beschrijvingen (zoals een route beschrijving). De meeste ruimtelijke beschrijvingen hebben of een vogelvlucht perspectief of een route perspectief. Bij gebruik van een vogelvlucht perspectief worden ruimtelijke relaties ten opzichte van elkaar beschreven, terwijl bij een route perspectief ruimtelijke relaties ten opzichte van een bewegende hoofdpersoon worden uitgelegd. *In hoofdstuk 6* vonden we bewijs dat (ziende) mensen in staat zijn om op basis van behoorlijk uitgebreide, ruimtelijke beschrijvingen (met een vogelvlucht of een route perspectief) een ruimtelijke representatie op te bouwen die het mogelijk maakte om relatieve afstanden te vergelijken en een kaart te tekenen van de beschreven omgeving. Het bleek wel dat proefpersonen beter waren in het vergelijken van afstanden na het horen van een beschrijving met een vogelvlucht perspectief. Dit in tegenstelling tot de bevindingen van *hoofdstuk 7* waaruit bleek dat vroeg en laat blinde mensen juist relatief beter waren in het vergelijken van afstanden na het horen van een beschrijving met een route perspectief. Overigens was het merendeel van de blinde mensen in staat om de ruimtelijke taken uit te voeren na het horen van de ruimtelijke beschrijvingen met een vogelvlucht of een route perspectief. Deze bevinding staat in sterk contrast met de populaire en ook wetenschappelijke opvatting dat blinde mensen niet of in veel mindere mate dan ziende mensen in staat zijn tot taken die ruimtelijke integratie vereisen.

In hoofdstuk 8 tot slot onderzochten we de vraag in welke mate er verschillen zijn tussen bepaalde vormen van mentaal voorstellingsvermogen op basis van verbale beschrijvingen tussen vroeg blinde, laat blinde en ziende mensen. We vonden verschillen tussen blinde en ziende mensen voor visuele en ruimtelijke taken maar niet voor een auditieve taak. Het bleek dat vooral voor ruimtelijk voorstellingsvermogen mensen voordeel lijken te hebben van visuele ervaring. Op een taak waarbij de mentale voorstelling van visuele vormen werd gevraagd leek het erop dat vroeg blinde mensen zeer effectief konden terugvallen op de vorm informatie die zij op basis van tast en haptische informatie hebben verkregen.

Conclusies

In dit proefschrift hebben we verschillende bevindingen naar voren gebracht die het idee ondersteunen dat mensen in staat zijn om mentale plaatjes en ruimtelijke voorstellingen op te bouwen op basis van ruimtelijke beschrijvingen. We willen benadrukken dat deze ruimtelijke representaties waarschijnlijk niet in alle situaties worden opgebouwd. Alleen wanneer mensen verwachten de informatie uit de ruimtelijke beschrijving nodig te hebben in een visuele context (bijvoorbeeld het zoeken van een object in een bepaalde omgeving) zullen ze een mentaal plaatje genereren. We stellen voor dat in alle andere gevallen alleen de automatische abstracte, propositionele code zal worden gebruikt. Dit patroon behorende bij het representeren van een eenvoudige ruimtelijke zin past binnen het *dubbel representationeel model* (Noordzij, Van der Lubbe & Postma, in press). We vonden verder bewijs voor dit model met behulp van de EEG techniek die aantoonde dat hersengebieden die geassocieerd zijn met het visuele voorstellingsvermogen betrokken zijn bij het verwerken van een ruimtelijke zin, maar alleen als mensen deze zin lazen in een visuele context.

In dit proefschrift is verder bewijs geleverd dat een gebied in de linker parietaal kwab (de *gyrus supramarginalis*) noodzakelijk betrokken is bij het begrijpen van ruimtelijke voorzetsels zoals *links van* en *rechts van*. Eerder neuropsychologisch onderzoek had aangetoond dat een hersenbeschadiging in dit gebied het begrip van dergelijke voorzetsels ernstig verminderde. In ons fMRI onderzoek vonden we een grotere activiteit in de linker *gyrus supramarginalis* bij het lezen van ruimtelijke zinnen dan bij het lezen van een niet-ruimtelijke zin.

Een andere belangrijke bevinding van dit proefschrift is dat ziende *en* blinde mensen ruimtelijke voorstellingen op kunnen bouwen op basis van uitgebreide, realistische ruimtelijke beschrijvingen. Verder lijken ziende mensen een voorkeur te hebben voor "vogelvlucht beschrijvingen" en blinde mensen een voorkeur voor "route beschrijvingen".

Op basis van deze laatste bevindingen willen we ook een tweetal aanbevelingen doen voor de ondersteuning van de training van blinde mensen. (1) Voor het trainen van de oriëntatie- en mobiliteitsvaardigheden van blinde mensen is het van groot belang om te beseffen dat verbale (ruimtelijke) beschrijvingen een nuttig en effectief hulpmiddel kunnen zijn. (2) Bij het aanbieden van ruimtelijke beschrijvingen aan blinde mensen kan het beste consistent worden gekozen voor een route of egocentrisch perspectief.

Publications

Noordzij, M.L., & Postma, A. (2005). Categorical and metric distance information in mental representations derived from route and survey descriptions. *Psychological Research, 69(3)*, 221-232

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(4),* 259-271.

Noordzij, M. L., Van der Lubbe, R.H.J., & Postma, A. (in press). Strategic and automatic components in the processing of linguistic spatial relations. *Acta Psychologica*.

Noordzij, M.L., Zuidhoek, S., Van Meggelen, C., Petersen, R., Prinsen,G., & Postma, A. (2004). The influence of perspective on the properties of spatial mental models. Ballesteros, S., & Heller, M. A. (Eds.). *in: Touch, blindness and neuroscience (pp.281-292).* Madrid, Spain: UNED Press.

Zuidhoek, S., Kappers, A.M.L., Noordzij, M.L., Van der Lubbe, R.H.J., & Postma, A. (2004). Frames of reference in a haptic parallelity task: temporal dynamics and the possible role of vision. Ballesteros, S., & Heller, M. A. (Eds.). *In: Touch, blindness and neuroscience (pp.155-164)* . Madrid, Spain: UNED Press.

Manuscripts under revision

Noordzij, M. L., Zuidhoek, S., & Postma, A. (accepted, pending minor revisions). The influence of visual experience on the ability to form spatial mental models based on route and survey descriptions. *Cognition*.

Noordzij, M. L., Zuidhoek, S., & Postma, A. (accepted, pending revisions). The influence of visual experience on visual and spatial imagery. *Perception*.

Manuscript submitted or in preparation

Noordzij, M. L., Neggers, S. F. W., Postma, A., & Ramsey, N. (in preparation). Neural correlates of locative prepositions.

Noordzij, M. L., Van der Lubbe, R.H.J., & Postma, A. (in preparation). Electrophysiological support for the existence of different strategies in the processing of spatial sentences.

Rouw, R., Noordzij, M., Kuo, N., Hung, D., & De Gelder, B. (in preparation). Categorization vs. recognition of own-race and other-race faces.

Zuidhoek, S., Noordzij, M. L., Kappers, A.M.L., & Postma, A. (submitted). Haptic orientation benefits from visual experience: evidence from early blind, late blind and sighted people.

Zuidhoek, S., Noordzij, M. L., Kappers, A.M.L., & Postma, A. (in preparation). Differences between early blind, late blind and blindfolded sighted people in implicit haptic spatial configuration learning and resulting memory traces.

Conference abstracts

Noordzij, M. L., Zuidhoek, S., & Postma, A. (2003). The influence of perspective on the properties of spatial mental models of blind and sighted people. *Proceedings of the 9th EWIC, Pavia*, 96.

Noordzij, M. L., Van der Lubbe, R., & Postma, A. (2003). Strategic and automatic components in the processing of linguistic spatial relations. *Proceedings of the XIII ESCOP, Granada*, 277.

Noordzij, M., Van der Lubbe, R., & Postma, A. (2001). Effects of interference tasks on the judgement of linguistic and perceptual representations of categorical spatial relations.*Poster presented at the XII ESCOP conference in Edinburgh.*

Zuidhoek, S., Kappers, A.M.L., Noordzij, M.L., & Postma, A. (2003). Visual imagery and the coding of haptic space: Performance by early blind, late blind and blindfolded sighted subjects. *Proceedings of the XIII ESCOP, Granada,* 314.

Zuidhoek, S., Noordzij, M.L.,Kappers, A. M. L., & Postma, A (2003). Visual Imagery and the representation of haptic space. *Proceedings of the 9th EWIC, Pavia,* 55.

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Curriculum vitae

Matthijs Noordzij werd in Ede geboren op 10 september 1977. Na het behalen van zijn diploma aan het Stedelijk Gymnasium te Apeldoorn begon hij in 1996 zijn propedeuse psychologie aan de universiteit van Tilburg. Deze rondde hij een jaar later cum laude af om vervolgens zijn psychologie studie te vervolgen in de richting van de cognitieve neuropsychologie. Zijn scriptieonderzoek naar gezichtsherkenning deed hij in het lab van Prof. Bea de Gelder en op de Yang-Ming Universiteit in Taipei, Taiwan bij Prof. Daisy Hung. In 2000 studeerde hij af en het volgende jaar begon hij zijn promotieonderzoek aan de capaciteitsgroep Psychonomie van de Universiteit Utrecht, binnen het Pionier project "ruimtelijke cognitie" van Prof. Albert Postma. Vanaf januari 2005 is hij werkzaam als post-doc onderzoeker bij het F.C. Donders Centre for Cognitive Neuroimaging binnen het Europese project Joint Action Science and Technology.