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

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Abstract

The purpose of the present study is twofold: the first objective is to evaluate the importance of visual experience for the ability to form a spatial representation (spatial mental model) of fairly elaborate spatial descriptions. Secondly, we examine whether blind people exhibit the same preferences (i.e. level of performance on spatial tasks) 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 performed better after listening to a route than a survey description, even when the spatial problems that has to be solved explicitly favor the survey description. It seems that people with active vision build up a spatial mental model more efficiently from a survey description, while people with only visual memories (late blind), similar to people with no visual memories (early blind), build up a spatial mental model more efficiently from a route description.

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Keywords: Spatial language; Blindness; Perspective; Spatial mental model

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1. 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. 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. Rinck, Williams, Bower, & Becker, 1996; Bestgen & Dupont, 2003), even when that information is 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 (Taylor & Tversky, 1992; Noordzij & Postma, 2005), that might influence the construction of a spatial mental model and the features it supports. A potentially crucial factor in mental model construction, which has been 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. Early blind individuals may rely more on a representation that requires no spatial 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 many imagery tasks, even tasks that are considered to require active visual imagery processes (e.g. Jonides, Kahn, & Rozin, 1975, for a review see Kaski, 2002). In the present study, we evaluated the importance of visual experience for the ability to form spatial mental models of fairly elaborate spatial descriptions.

Various studies have investigated whether blind people build up spatial representations in order to manipulate objects or find their way in the world. On the one hand, there are studies that have found that people deprived of visual experience are impaired on a number of spatial tasks. These findings (for a review see Warren, 1984) suggest that visual experience plays a crucial role in the development of spatial abilities and representations. Supposedly, spatial integration processes would be impaired or absent in blind individuals because they cannot rely on their proprioceptive memory for these type of processes. On the other hand, many studies have found conflicting evidence that blind participants have good spatial abilities. Klatzky, Golledge, Loomis, Cicinelli and Pellegrino (1995) showed that, for a large number of spatial tasks, differences in the performance of groups with varying visual experience (i.e. congenitally blind, late blind and sighted participants) were minimal and failed to support hypotheses of general or specific spatial deficits among
people who are blind. Furthermore, Landau, Spelke and Gleitman (1984) showed in a series of experiments that a young blind child had a set of capacities that seemed to indicate the presence of a system for spatial knowledge. This system involved complex processes such as spatial inferences that allow travel along new paths. Besides examining the question whether mental model construction is dependent on visual experience, the current study also contributes to the discussion of whether visual experience is of importance for the ability to form spatial representations.

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 employ two tasks that allow us to examine whether blind and sighted participants form 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) that indicate a spatial organization of mental representations when participants have 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 is 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, independent 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 systematically included because this would result in a discontinuous text where certain objects would be skipped over and later returned to. Previous research has shown that such discontinuities make a text harder to process and recall than a continuous description (e.g. Denis and Denhière, 1990; Ehrlich and Johnson-Laird, 1982). 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. the straight-line distance between points A and B), in contrast to the priming/recognition task (described above) that had no reference in the instruction to spatial features of the environment. Denis and Zimmer (1992), elaborating on ideas of Moyer (1973) and Kosslyn, Ball and Reiser (1978), 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 form a spatial mental model based on a description, then their performance (RTs and percentage errors) should improve when the metric difference between bird flight distances increases. If participants form a representation that stays close to the actual words in the text, then they will be faster and more accurate when the distance (in words) between objects in the original text increases. 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 they indicate differences in coding (Millar, 1994) or behavioral (Thinus-Blanc & Gaunet, 1997) strategies between blind and sighted people. Since the distance comparison task requires an explicit use of the representation participants build up from the spatial description, performance could reflect possible differences in strategy-choice (i.e. spatial vs. linguistic) of blind and sighted participants.

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 the same level as sighted people, then the performance on the scale model task should be similar for all groups of participants.

Taken together, the three tasks contrast two hypotheses concerning the influence of visual experience on the ability to form spatial representations in general. (1) Blind participants are not able to construct spatial representations, resulting in findings showing that they perform worse than sighted participants on the scale model task and do not show spatial priming and symbolic distance effects. (2) Blind people construct spatial representations as effectively as sighted people and they perform equally well on the scale model task and they show spatial priming and symbolic distance effects.

Another interest of the current study, which is inherently related to the construction of mental models from text, concerns the spatial perspective in descriptions. As a second goal, we aim to determine whether blind people exhibit the same level of performance on spatial tasks as sighted people in processing different perspectives of a spatial description. As mentioned by Thinus-Blanc and Gaunet (1997) in their literature review of the representation of space by blind people, the research concerning the influence of visual experience on spatial cognition has mostly neglected an analysis of the specific features of spatial descriptions. Text perspective has received considerable attention in research with sighted individuals. Speakers mostly choose between two types of spatial perspectives in descriptions, or a combination of the two (Taylor & Tversky, 1996). A route perspective consists of taking listeners or readers on a mental tour; the second type, a survey perspective, consists of taking a viewpoint that is above the environment. Route and survey descriptions have specific characteristics that have origins in the different reference
frames they employ: egocentric (route) vs. allocentric (survey). Route descriptions take
the addressee into the environment and give information on the position of landmarks and
objects relative to the changing position of the addressee. The relative spatial information
is conveyed by terms 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 organization of survey
descriptions is often hierarchical. This hierarchical organization divides the environment
into spatial areas, and then each area is described in turn. Route descriptions have a
sequential organization, whereby each new object is introduced in a linear fashion.

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. Taylor &
Tversky, 1992; Ferguson & Hegarty, 1994), suggesting that people use viewpoint
independent mental models (Zwaan & Radvansky, 1998). In contrast, Shelton and McNama-
ra (2004) found that the perspective of the text had an effect on the way the information was
stored in spatial memory whereby participants did not show viewpoint-independent
performance in a scene recognition task. Our recent study (Noordzij & Postma, 2005) used
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 certain strategies might differ from those employed by the sighted
with respect to the preferred reference frame (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 local, sequential representation
based on routes, whereas sighted people mostly code spatial information in the form of a
more global, externally based representation. The choice of blind people for spatial
strategies and representations based on an egocentric frame of reference in spatial tasks
may extend to the realm of spatial description comprehension. Hence, when blind people
read or listen to a spatial description they may predominantly choose to construct a spatial
mental model in the form of a sequential representation (e.g. a set of procedural
instructions). Route descriptions give local information and have a linear (or sequential)
organization, whereas survey descriptions give more global information and have a
hierarchical organization. Therefore, if blind people construct a spatial mental model in
the form of a set of procedural instructions instead of a more global representation, then
the route description may facilitate better and faster spatial mental model construction
than a survey description. The distance comparison task 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 for survey over route descriptions on the 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 that the perspective of a spatial description is processed. According to Millar (1994), efficient and fast coding of spatial relations between objects without considering the position of the body 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 better performance for route than survey descriptions is only present for people with no visual experience at all, and not for people who lost their vision later in life.

2. Method

2.1. Participants

Appendix A contains the list of participants. Thirteen early blind, 17 late blind, and 16 sighted people participated in the experiments. The blind were recruited by announcements in magazines for the visually impaired. The sighted participants either had blind partners or relatives or they 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. 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. 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 (1970); three participants were ambidextrous 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. Participants
had never seen or felt the set-up, were unaware of the experimental purposes, and were never given any feedback.

3. Materials and design

3.1. 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 B for sample texts). The descriptions were made of fictitious maps of either a zoo or a mall (see Fig. 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: the survey description addressed participants in the third person and objects were introduced in relation to previously mentioned objects, 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). New locations were always mentioned in reference to a previous

Fig. 1. An example of a basic configuration for the mall and the zoo (both 12 objects).
location, which ensured that there were no discontinuities in the descriptions, resulting in easier processing and better recall.

### 3.2. 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. The close in text/far in space relation was not included because new locations were always mentioned in reference to a previous location. 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.

### 3.3. Distance comparison

Two lists, one for the zoo and one for the mall, containing 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, 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 follows: small difference (1–29 words), medium difference (30–59 words) and large difference (60–131 words). 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.
3.4. Procedure

All participants were blindfolded during the experiment. First, participants were allowed to feel the outer edge of the environment in a scale model before the start of the descriptions to provide them with a cue for the imaged size of the environment. Participants listened to a description of an environment through headphones. Each description was divided into smaller parts that were repeated twice. In total, participants listened to a specific description six times, which was based on our previous study (Noordzij & Postma, 2005) with the same descriptions that showed that most sighted participants could make accurate drawings of the environment after listening to the descriptions six times. This study phase took approximately 15 min. 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 min after which the other environment was learned, again followed by a priming/recognition task and a distance comparison task. Each participant studied both a route and a survey description. The order of presentation was counterbalanced across participants.

The priming task was preceded by 12 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 two 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 tasks 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. It has been shown that blind people can construct spatial representations from tactile maps (e.g. Espinosa, Ungar, Ochaita, Blades, & Spencer, 1998), and because we were interested in what blind people could represent on the basis of verbal descriptions alone we did not provide a complete (tactile) scale model of the environment at the start of the environment.
3.5. Data analysis

For the Recognition/Priming task, mean RTs, computed over correct trials, and mean percentage error scores were analyzed using separate $2 \times 3 \times 3$ 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 $2 \times 3$ ANOVA with Study Material (Route description and Survey description) as a within subjects variable, and Group (Early Blind, Late Blind, and Sighted) as a 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 six 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 $2 \times 3 \times 3 \times 3$ 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. Planned comparisons were done for the three levels of Metric Distance Difference.

4. Results

4.1. Recognition/priming

4.1.1. 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, $F(2, 33) = 1.3, P = .29$. There was no significant interaction between Study Material, Prime-Target Relation, and Group, all $Fs < 1.2, P > .29$. 
4.1.2. Error scores

There were no significant effects related to the error scores, all $F$s < 1.3, $P$ > .26.

4.2. Scale model

Table 2 shows how many participants of each group remembered a certain amount of objects in their correct location (these amounts were divided in 0–3, 4–6, 7–9, and 10–12). 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 fewer object locations than sighted participants (mean = 9.6), $t(43) = 1.9$, $P = .06$.

Only participants who could name at least six 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.

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

<table>
<thead>
<tr>
<th>Group</th>
<th>Perspective</th>
<th>Prime-target relation</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Close in space/close</td>
<td>Close in space/far</td>
<td>Far in space/ far in text</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>in text</td>
<td>in text</td>
<td>in text</td>
<td></td>
</tr>
<tr>
<td>Early Blind</td>
<td>Route description</td>
<td>997 (51.1)</td>
<td>1010 (67.4)</td>
<td>1032 (63.2)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Survey description</td>
<td>1066 (69.7)</td>
<td>1012 (61.5)</td>
<td>1185 (84.1)</td>
<td></td>
</tr>
<tr>
<td>Late Blind</td>
<td>Route description</td>
<td>1032 (44.7)</td>
<td>1075 (58.9)</td>
<td>1101 (55.3)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Survey description</td>
<td>1084 (60.9)</td>
<td>1030 (53.8)</td>
<td>1119 (73.6)</td>
<td></td>
</tr>
<tr>
<td>Sighted</td>
<td>Route description</td>
<td>1149 (46.1)</td>
<td>1080 (60.8)</td>
<td>1182 (57.0)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Survey description</td>
<td>1121 (62.8)</td>
<td>1078 (55.4)</td>
<td>1144 (75.8)</td>
<td></td>
</tr>
</tbody>
</table>

Table 2
The number of participants of each group that remembered a certain amount of objects in their correct location (these amounts were divided in 0–3, 4–6, 7–9, and 10–12)

<table>
<thead>
<tr>
<th>Amount of objects</th>
<th>Perspective</th>
<th>Route description (Group)</th>
<th>Survey description (Group)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Early blind</td>
<td>Late blind</td>
</tr>
<tr>
<td>10–12</td>
<td>6</td>
<td>11</td>
<td>9</td>
</tr>
<tr>
<td>7–9</td>
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<td>3</td>
<td>–</td>
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<tr>
<td>4–6</td>
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<td>1</td>
</tr>
<tr>
<td>0–3</td>
<td>6</td>
<td>1</td>
<td>6</td>
</tr>
</tbody>
</table>
4.3. Distance comparison

4.3.1. Reaction times

Fig. 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, $t(29) = 4.4, P < .001$. Thus, a significant linear trend was found for Metric Distance Difference that followed the expected direction and indicated an 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 $F(2, 27) = 2.1, P = .14$.

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 borderline 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 indicated that 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 showed 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 \( Fs < 2.3, P > .07 \).

4.3.2. Error scores

Fig. 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, \( t(29) = 3.4, P = .002 \). Thus, a significant linear trend was found for Metric Distance Difference that 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 Fig. 4). All other interactions were not significant, all \( Fs < 2.3, P > .065 \).

![Fig. 3. Error scores (%) for the distance comparison task.](image-url)
5. 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 performance 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 faster and more accurately with increasing metric distance differences. Thus, 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 accurately 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 formed 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 relate to previous 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. 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 on the basis of verbal descriptions. Visual experience does not seem necessary in order to be able to form these integrated representations.

In this study, we explicitly asked congenitally blind participants to imagine an environment and we found evidence that indicated that they are capable of constructing a spatial mental model. The fact that early blind people are actually capable of executing a task such as imagining bird-flight distances between objects might be considered surprising. Many studies have examined 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 earlier, 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 performance 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 the early blind people had the lowest score for both the scale model tasks based on the route and the survey description. 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 previously, 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 efficient on both the scale model tasks 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 (2005): sighted people appear to have a relative advantage of a survey over a route description on the 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 perform better following spatial strategies and representations based on local, route based information. Our findings are consistent with the hypothesis that the better performance of blind people employing local, route based information does indeed extend to the domain of spatial description comprehension. However, the advantage of route based information has been predominantly found for early blind people and not for late blind people. In our study, both early and late blind people performed better after listening to a route rather than a survey description. Apparently, only people with active vision build up a spatial mental model more efficiently from a survey description, whereas people with visual memories only (late blind), similar to people with no visual memories (early blind), build up a spatial mental model more efficiently from a route description.

An explanation for the fact that blind participants in this study were better able to construct a mental model on the basis of a route than a survey description might be directly related to the orientation and mobility training they receive. Obviously, blind people are trained on navigational skills in relation to their own body. They do not learn things on the basis of cues such as “go to other side of the park and end up between the wooden bench and the large chestnut tree”. Instead, it makes more sense to specify a route through
the park on the basis of intermittent landmarks in relation to their own body position. Therefore, the difference in performance between the two types of descriptions might also be the result of the way in which navigational skills are learned by blind people. An interesting next step would be to find out whether blind participants can actually show the same pattern of results as sighted people (i.e. better performance for the survey description) if they know beforehand that the final task includes judging spatial relationships among objects and the inference of distances. This could indicate that although blind individuals are more used to route descriptions, they might very well understand that a survey description is more suitable for certain types of spatial processing.

The present findings add to the growing evidence that visual experience is not an essential feature in the development of spatial representations. Studies (see Warren, 1984) that suggest that spatial integration is not an option for people without, especially early, visual experience are contradicted by the current and other studies (e.g. Klitzky et al., 1995; Landau, 1988; Loomis, Lippa, Golledge, & Klitzky, 2002; Loomis et al., 1993). A reason for the contradicting results might be the individual differences between the samples of blind participants that have been included in the different studies. As mentioned by Loomis et al. (1993) many studies comparing the spatial abilities of blind and sighted people have included blind participants that were not able to travel independently. It is important to note that we included blind participants who traveled, without exception, independently towards the nearest train station from our lab, or even to our lab itself. If experience with independent travel actually is a major factor in the development of spatial abilities then the conclusions that are drawn on the basis of studies with samples of blind participants from either group (i.e. able vs. not able to travel independently) might be completely different.

There has not been much research on the way in which blind people understand and communicate spatial language. Loomis et al. (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 as 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. Sighted persons gave environment-oriented descriptions, while the blind tended to use descriptions related to their own position. Therefore, sighted persons seem to give global, externally based descriptions and blind people tend to give local, internally based descriptions. This pattern of spatial language communication fits nicely with the performance differences 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 summation, 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 performed better after listening to a route than a survey description, even when the spatial problems that has 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 a local, internally based perspective consistently in spatial descriptions (i.e. a route description) to the blind, spatial information is probably communicated more effectively than when a mixed or purely global, externally based perspective (i.e. a survey description) is chosen.

Acknowledgements

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Appendix A. Sample description of participants

A.1. Early blind

<table>
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<tr>
<th>Subject number</th>
<th>Occupation</th>
<th>Education level</th>
<th>Sex</th>
<th>Age</th>
<th>Etiology and further characteristics</th>
<th>Age of onset (years)</th>
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<td>41</td>
<td>Leber’s amaurosis, Ambidextrous</td>
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<td>University</td>
<td>M</td>
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<tr>
<td>3</td>
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<td>33</td>
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<td>F</td>
<td>49</td>
<td>Rubella (mother)</td>
<td>0</td>
</tr>
<tr>
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<td>Retired operator</td>
<td>Secondary school</td>
<td>M</td>
<td>58</td>
<td>Glaucoma, Ambidextrous</td>
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<td>6</td>
<td>Office assistant</td>
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<td>F</td>
<td>34</td>
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</tr>
<tr>
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<td>Operator</td>
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<td>M</td>
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<td>Retired</td>
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### A.2. Late blind

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### A.3. Sighted controls

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<td>Editor</td>
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<td>Editor</td>
<td>University</td>
<td>F</td>
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<td>Retired</td>
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<td>Musician</td>
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<td>Volunteer</td>
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**Appendix B**

**B.1. 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 and in front of you is 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. Next, the furniture shop is to your left and the jeweler is to your right.

You walk straight in between the furniture shop and the jeweler 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 and to your right is 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 is to your right.

You walk straight with to your right the chemist 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 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 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 with to your right the perfumery and in front of you to the right is 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 with to your right the restaurant. If you keep walking straight you are back at the entrance.

**B.2. Survey description example**

The shopping centre is a square and is divided into 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 jeweler, in the southeast corner of the first part.

To the east of the jeweler 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, in the northeast corner of the second part.

To the north of the chemist 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.

References


