Spatial representation and processing in the congenitally blind

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Although there is consistent evidence for a deficit in the manipulation and internal representation of space and spatially located objects by the congenitally blind (e.g. Heller, 1989), explanations for this deficit are disputed. In this chapter, two accounts are examined for their ability to explain the experimental data, and recent data from a comparison of blind and sighted participants' judgements of, and memory for, relative object locations are described, in an attempt to discriminate between these two accounts.

Blind People's Visuo-Spatial Performance

Blind and sighted comparisons have been made on a wide variety of visuo – spatial tasks (e.g., those involving mental rotation, mental scanning, pathway memory and word imagery), always with the same result: the blind group performs either less accurately or more slowly than the sighted control group. However, the surprising finding has been the similar *patterns* of performance that are demonstrated by both sighted participants and the congenitally blind on such tasks. These patterns of results have lead some researchers to suggest that the blind and sighted utilise similar mental representations. Given this assumption, the blind visuo-spatial performance deficit must be explained by less efficient processing of the representations. This is a *processing* account of the blind visuo-spatial deficit. Most perceptual data used by the blind are received and processed sequentially (e.g. haptic and audio information) whereas visual

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data are received and processed in parallel. It has been concluded by some researchers, therefore, that deficits arise because serial processing of sound and touch is slower and more prone to error than the parallel processing of vision (e.g. Aleman, van Lee, Mantione, Verkoijen & de Haan, 2001). However, there are *a priori* reasons to believe that differences between blind and sighted visuo-spatial performance may reflect different or impaired mental *representations* rather than less efficient processing. The argument goes as follows: Mental representations are required for visuo-spatial tasks and are derived from perceptions; the perceptual experience of someone blind from birth must be different to that of a sighted person; it follows that the mental representations of the blind might be profoundly different from those of the sighted. It can then be hypothesised that mental representations based on haptics or auditory perception might be sub-optimal for visuo-spatial tasks, so explaining the consistent performance deficit on such tasks by the congenitally blind.

In summary, the conflict within the literature has been between those who propose processing deficiencies in the blind in relation to the stages of constructing, integrating and manipulating visuo-spatial representations, and those who emphasise differences in the actual format of such representations.

The Representation Account

Representational explanations of blind people's visuo-spatial deficit vary widely. Perhaps the most extreme version of the representation account holds that the blind use 'abstract semantic representations' (Zimler & Keenan, 1983) whereas the sighted use analogue visuo-spatial representations. This claim is based upon evidence that the blind demonstrate the same advantage for concrete, imageable words (e.g., "puppy") over abstract and non-imageable words (e.g., "bonus") as the sighted do.

Zimler and Keenan argued that in the blind the advantage for high-imageability words was not due to visual imagery (as has been argued for the sighted) and therefore must reflect the operation of an effective non-imagery representation based upon propositional encoding of abstract semantic information. However, the contrasting conclusion, that imagery representations rely very little on vision and are cross-modal, has also been drawn from the same evidence (De Beni & Cornoldi, 1988).

The assumption that the blind use abstract semantic representations in visuo-spatial tasks has not been supported by evidence of blind performance at tasks that are widely held to involve analogue representations, such as mental rotation. Mental rotation tasks typically require participants to encode an object, and then recognise whether another object is the same or different in shape, under conditions of rotation or reflection. One study compared mental rotation of tactually presented forms by blind and sighted groups (Marmor & Zaback, 1976). All participants demonstrated longer reaction times for larger rotation angles, in common with previous rotation research (e.g. Shepard & Metzler, 1971). Moreover, all groups showed evidence of employing an analogue representation, because of the clear linearity evident in the increase in response times in proportion to increases in the angle of rotation. However, although this appears to be indicative of an analogue representation, it has been argued by Anderson (e.g., 1978) that evidence from rotation studies may be consistent with propositionally-based abstract semantic representations. Marmor and Zaback (1976) also found evidence of a blind visuo-spatial deficit, with the congenitally blind group being significantly slower and making more errors than both late blind and sighted groups. The authors' claim was not that blind participants employed a propositional rather than analogue representation; instead they made the weaker and more ambiguous claim that the better performance in rotation tasks by sighted people was because

”mental rotation is easier to perform upon visual representations than non-visual ones” (1976, p.520). Nonetheless, the implication is that blind and sighted participants have qualitatively different representations (i.e. visual and non-visual). However, this account has limited explanatory power, and typically leads to a circular argument - those without vision perform worse because their representations lack a visual component, and the lack of a visual component is found in those without vision.

An alternative representational hypothesis has been proposed by Heller (1989), who asserted that blind people's visuo-spatial representations differ from sighted people's because the blind lack experience of external frame or reference cues (e.g. knowledge of the horizontal and vertical) and that these aid in the construction of a more manipulable object-centred representation. (Rock & DiVita, 1987). This claim was supported by evidence of less accurate recognition of rotated unfamiliar stimuli by the early blind and also by sighted groups who had frame of reference cues removed, compared to sighted participants with frame of reference cues available. The similar performance of both the congenitally blind group and the sighted group without frame of references cues suggests that they are accessing the same representational substrate, but it is simply incomplete.

Millar (1976) used a rotated drawing task and found that that the totally blind participants were worse than the sighted at oblique rotations but not at orthogonal ones (e.g. 90^0 and 180^0 rotations). She also suggested that congenital blindness reduces access to frame of reference cues and that the representations of the congenitally blind have less well-specified frames of reference than the sighted.

The Processing Account

Processing and representation accounts are not necessarily mutually exclusive. However, processing accounts propose that the majority of evidence for blind visuo-spatial performance deficits is the result of deficits in the processes of constructing, updating, and manipulating a representation, not of deficits in the form of the representation itself

One possibility is that the blind might have difficulty in initially coding the spatial form of an unfamiliar object of the type used in tactual mental rotation tasks. This would result in slower and less accurate performance in visuo-spatial tasks, particularly those tasks with objects irrelevant to the everyday experience of blind people. An example of this would be slower blind performance in a mental rotation task of an unusual tactual form (Marmor & Zaback, 1976). However, once the object is successfully recoded (with the additional time and loss in information that this might involve), the representation would be manipulated in the same way as a sighted person's representation and so a similar pattern of performance would be demonstrated. This account, therefore, cannot readily explain why there is no difference between blind and sighted performance at zero degrees of rotation (Heller, 1989), nor why there are larger blind and sighted performance differences at oblique angles of rotation (Millar, 1976). Finally, this account does not explain why the blind are no different to the sighted in the recall of concrete, imageable words (e.g. 'dragon') which presumably also require recoding.

An alternative account is that the blind have a lower capacity for all 'active' visuo-spatial processing (Vecchi, 1998). 'Active' processing includes encoding, updating and manipulating visuo-spatial objects, but is separate from the 'passive' process of maintaining a representation, once encoded. This processing-capacity account can explain much of the previous data very simply. Word imagery similarities are explained as a result of similar, passively held representations, whilst mental rotation differences are explained as a result of increasing amounts of manipulation required at larger angles, which would slow down blind performance. Underlying this account is the view that the visuo-spatial processing capacity of congenitally-blind participants is lower than that of sighted participants. This hypothesis was tested in a simultaneous comparison of active and passive visuo-spatial memory with blind and sighted groups (Vecchi, 1998). In the experiment, participants tactually explored a matrix of wooden cubes (three cubes long by three cubes wide, or on harder trials a three-dimensional array). Some of the cubes were marked by a coarse surface, and the participants were instructed to remember their positions (passive memory). The participants were then asked to imagine a pathway through the matrix (e.g, "now move left one cube, up one cube, forward one cube…") which entails active memory-updating. The participants were tested on their memory for the coarse-surfaced cubes and for the final cube in the pathway. Although the blind were worse than sighted controls at both tasks, they were significantly less accurate at the more difficult, three dimensional, active pathway recall. This is consistent with the predictions of the processing-capacity theory. Both types of recall require some processing but the pathway tasks require more and so increase the deficit observed with the blind, especially on the harder trials. Blind participants' visuo-spatial processing capacity can cope with easier, two-dimensional matrices, but is insufficient for three-dimensional ones.

Accounting for the Evidence

The processing-capacity hypothesis explains word imagery and mental rotation effects, but it does not readily explain Millar's (1976) finding of worse rotation abilities at oblique angles nor Heller's (1989) evidence of comparably worse rotation abilities among sighted participants with frame of reference cues removed. However, the representational accounts cannot easily explain the pathway memory findings of Vecchi (1998). The differences found between two and three dimensional pathway memory could be explained as an informational difference; the addition of another dimension may require greater specification and so representational accounts would predict reduced accuracy with an added dimension. However, this difference should also extend to memory for fixed passive object locations. The same informational requirements must be represented and no account based on representation seems able to explain this difference. In summary, the blind may use abstract semantic representations, but there is also evidence for both a difference in represented frame of reference information and a difference in processing efficiency. The issue for blind research is which of these accounts underlies the majority of performance differences between congenitally blind and sighted groups.

Recent Research into Visuo-Spatial Processing with a Different Paradigm

Some of our own recent research has examined evidence for the nature of mental representations and the processes carried out upon them in congenitally blind people. Our research is based upon previous investigations of the use of analogue versus propositional representations among the sighted (Mani & Johnson-Laird, 1982; Baguley & Payne, 2000). Examination of underlying representations is problematic. Indeed, as we noted earlier, some have argued that arbitrating between propositional and analogue accounts of representation is impossible because performance in any task can be explained with equal plausibility in terms of either of these formats (Anderson, 1978). Others have argued that performance advantages can accrue from using analogical representations that would not be found if representations were propositional. For example, mental models theory (Johnson-Laird, 1983) offers a detailed theoretical account of the analogical representation of spatial descriptions. Evidence for this account has demonstrated a difference between propositional representations, which can represent unspecified (indeterminate) relations (e.g., “besides”), and analogue representations, which reflect specific (determinate) relations, and so must represent each possibility (in this case 'to the left of' and 'to the right of'). The consequence of this is that propositional representations are equally efficient at maintaining indeterminate and determinate information, whereas analogue representations maintain determinate information better than indeterminate.

Researchers have found an advantage for determinate stimuli in sighted people consistent with an analogue representational account of spatial description (Mani & Johnson-Laird, 1982). A development of this experimental paradigm was used by Payne (1993; see also Baguley & Payne, 2000) to demonstrate that, not only do participants remember analogue representations, they also have a memory trace for the construction of the 'mental model'. This additional representation contains information on the *processes* of model construction. The memory trace can be defined propositionally, and contains information on the starting state of the representation, the relationship of 'new' information to already held information, and therefore the order in which the mental model is constructed. As a result it is sensitive to the order of the spatial descriptions. Evidence in support of the so-called 'Episodic Construction Trace' has demonstrated reduced recognition of reordered spatial descriptions compared to originally-ordered spatial descriptions.

In our recent research this paradigm was adjusted to be accessible for blind participants (for a more detailed account, see Fleming, Ormerod, Collins & Ball, 2002). Determinate and indeterminate descriptions of the spatial relations of five objects in two dimensions were presented to congenitally blind participants, and their performance was compared with blindfold sighted participants and also with sighted controls. The participants first had to judge whether a presented tactual diagram was a correct layout of the described objects, or whether it was a different layout of the same objects. A surprise recognition task was then given to participants, in which four alternative versions of each original description had to be ranked for similarity to the original: the original (same-ordered/reordered), an alternative description of the correct layout, and two distractor descriptions. Gist recognition was measured as a participant correctly ranking the two correct layout descriptions as first and second. Using this measure, determinate descriptions were correctly recognised more often than indeterminate descriptions, $F(1, 42) = 10.07$, $p < 0.05$. This supports the hypothesis that visuo-spatial representation among all participant groups is analogue. There was no effect of group ($F < 1$), which, suggests a functional equivalence in blind and sighted representation of relative object location on this task. Original description recognition, which was measured as the proportion of responses in which the original sentence was ranked first, differed significantly across groups, $F(2,42) = 5.55$, $p < 0.01$. Planned comparisons showed that the congenitally blind group recognised *fewer* original sentences than either the blindfolded or the seeing sighted groups, $F(1,42) = 7.95$, $p < 0.01$. There was no difference between the seeing and blindfolded groups ($F(1, 42) = 2.97$, $p > 0.05$.

The blind participants' poor performance at recognition of original descriptions in our experiment contrasts with evidence reported in the literature on verbal memory, which typically shows that the blind have superior verbal memory to sighted controls (Hull & Mason, 1995; Röder, Rosler & Neville, 2001). The congenitally blind participants in our study also achieved significantly higher digit spans than sighted controls, so it seems unlikely that the worse memory for the original descriptions was due to worse verbal memory in the blind. Instead, this finding probably reflects worse memory of mental model construction (the Episodic Construction Trace). This memory trace includes the start position of the mental model and the order in which it is built up; information that is manifested in memory for the original description. Worse blind performance at trace recognition of the model building process supports the processing account hypothesis that blind processing is more limited.

A key element of this paradigm was the opportunity to discriminate between analogue and propositional representations. Participants had to demonstrate understanding of the layout of the objects described to them by recognising two different descriptions of the same objects. Blind performance was consistent with the analogue representations of the sighted and not with the deployment of abstract semantic representations. Furthermore, in contrast to previous research, blind and sighted memory for object layout was equally accurate.

Two accounts of blind visuo-spatial performance deficits have been considered in this chapter: differences in representation, and differences in processing. Representational accounts do not predict the functional equivalence found in the study reported by Fleming et al. (2002). We suggest that there is little evidence for the blind relying upon a different (abstract and propositional) representation of visuo-spatial information to sighted people. Both blind and sighted representations of spatial information appear to be analogue, and both groups are equally effective at retaining 'gist' information about the analogue forms they represent.

Instead, evidence has been presented suggesting that most blind visuo-spatial deficits are the result of processing differences between the sighted and the blind. Our results are more consistent with work that suggests the blind are equally able to remember spatial patterns when they are engaged in a task that does not require their manipulation or elaboration through active processing (Vecchi, 1998). However, the results raise the question of whether it is a deficiency in processing *capacity.* In our study, blind participants were equally effective as sighted participants in diagram judgement and memory for gist representation, yet sighted participants were not at ceiling in either measure. This suggests that the tasks exceed visuo-spatial processing capacity for all participants. Thus, a deficit in capacity should have resulted in impaired performance for blind participants on these measures as well as on the original description recognition measure.

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