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Analogue Versus Propositional Representation in Congenitally Blind Individuals

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Abstract

Congenitally blind individuals are generally less accurate at mentally manipulating objects than sighted people. However, they often score higher in tests of short- and long-term verbal memory, and it has been suggested that an enhanced propositional representation compensates for inefficiencies in analogue visuo-spatial representation. Here, congenitally blind, blindfolded and sighted participants recalled descriptions of relative object locations. In contrast to previous findings, congenitally blind participants were as accurate as blindfolded and sighted individuals at remembering the relative locations of objects, but their memory for the verbatim structure of presented descriptions was worse. We propose that, like sighted people, the congenitally blind spontaneously construct and remember analogue representations of object locations, and that the blind performance discrepancies arise from the process of managing and manipulating these analogue representations.

Analogue versus Propositional Representation in Congenitally Blind Individuals

How humans mentally represent spatial information remains controversial Some researchers hold that spatial information is represented analogically (Kosslyn, 1994), while others claim it is represented by a propositional grammar (Pylyshyn, 2002). However, even recent neuroscience research has difficulty discriminating between these representations (Pylyshyn, 2003). One claim is that the underlying functional and anatomical mechanisms for imagery and perception are very similar (Kosslyn, 1994). This view is supported by unilateral spatial neglect patients whose representational deficits on remembered images mirror their perceptual neglect (Bisiach & Luzzati, 1978). Kosslyn, Thompson, Kim, and Alpert (1995) also found evidence of visual area activation with mental imagery. However, double dissociations found since make it untenable to claim *identical* imagery and perceptual systems, although a fair degree of overlap seems likely (see Bartolomeo, 2002, for a review).

Behavioural data are also inconclusive, but increasingly there is evidence that sighted people construct *analogue* representations to mimic structural relations between objects in the external world (Zwaan & Radvansky, 1998). Mani and Johnson-Laird (1982) devised a subtle experimental paradigm that measured participants' ability to recognise verbatim, gist and foil descriptions of spatial locations as indicators of propositional and analogue representational dominance. In this paper, we use this paradigm to examine the representational characteristics of spatial reasoning among the congenitally blind.

In the absence of visual experience, one might expect congenitally blind individuals to derive profoundly different representations of space to sighted individuals. Perception based on haptic or auditory information alone might promote non-analogue representation that would be suboptimal for spatial tasks. This argument has been used to explain slower performance by congenitally blind participants on mental rotation tasks (Marmor & Zaback, 1976). Non-analogue representations may also provide a compensatory strategy for visuo-spatial memory; Vanlierde and Wanet-Defalque (2004) found no differences in blind and sighted individuals' memory for verbal descriptions of 2D matrix patterns, with blind participants reporting use of a coordinate strategy to remember patterns. This strategy could be as effective as mental imagery because the blind may have superior verbal short-term and long-term memory abilities (Hull & Mason, 1995; Röder, Rosler, & Neville, 2001), reflecting apparent use of the visual cortex for verbal tasks (Amedi, Raz, Pianka, Malach, & Zohary, 2003).

However, the congenitally blind may use analogue representations. Perceptual mechanisms, such as those underpinning object recognition, appear to be crossmodal (Amedi, von Kriegstein, van Atteveldt, Beauchamp, & Naumer, 2005); it is possible to have spatial images without visual content (Jeannerod & Jacob, 2005), and the blind have enhanced auditory-spatial abilities (Röder, Teder-Salejarvi, Sterr, Rosler, Hillyard, & Neville 1999). One view of analogue representations in the blind is that they might be different to those of the sighted because the blind lack adequate frame-of-reference cues that aid performance on tasks like mental rotation (Heller, 1989). Recent research suggests that allocentric knowledge plays a role in spatial memory (Burgess, Spiers, & Paleologou, 2004) and that frame of reference is qualitatively different dependent upon early visual experience (Röder, Rosler, & Spence, 2004). Millar (e.g., 1994) has long suggested that the paucity of allocentric knowledge is responsible for worse blind performance in visuo-spatial tasks.

In contrast, Vecchi (1998) argues that analogue representations used by sighted and blind people are equivalent, but the *processing* associated with representations is less ‘efficient’ in the case of blind people. A processing-efficiency view holds that visuo-spatial working memory comprises a ‘passive’ storage component (some form of representation) that underpins the recall of previously memorised material, and an ‘active’ processing component by which representations are constructed, updated and manipulated (cf. Logie, 1995). Unsighted individuals are viewed as having more limited abilities in the active component compared to the sighted, but equal abilities in the passive maintenance of encoded representations. In support of these proposals, blind participants recall actively constructed pathways less accurately than sighted participants but are equally accurate in recalling marked points within a matrix (Vecchi, 1998). However, evidence for this processing-efficiency view has been inconclusive; Aleman, van Lee, Mantione, Verkoijen, and de Hann (2001), for example, observed no differential effect of spatial interference (tapping task) on blind and sighted groups and found an equivalent performance decrement on both active and passive tasks.

A strength of the processing-efficiency view is that it explains evidence that patterns of performance by blind and sighted individuals are actually very similar on many visuo-spatial tasks. Blind participants demonstrate the characteristic linear relation between time and distance shown by sighted controls in mental rotation (Marmor & Zaback, 1976) and mental scanning (Kerr, 1983), albeit at a slower rate overall. The blind, like the sighted, are better at remembering concrete (‘imageable’) words than abstract words (Zimler & Keenan, 1983). Landau (1991) showed that a blind child produced similar performance to sighted controls in representing and transforming objects. Heller et al. (2002) found that the Müller-Lyer illusion is equally compelling in the blind and sighted. Gregory (2004) showed that a blind man who was able to see for the first time could read block capitals that he had learned to read by touch, and Intraub (2004) found boundary extension by a blind person in the same way sighted people do when remembering a scene. The latter is possible because of the multi-modal nature of spatial representations.

These previous tasks are all traditionally viewed as requiring analogue representations; they could be carried out using non-analogue information but unless the representations are so equivalent as to be indistinguishable then very different patterns of performance would be expected. Overall, this corpus of evidence suggests that the blind can make use of analogue representations.

In the present study we investigated blind and sighted people's memory for short descriptions of relative spatial relations among objects, exemplified in Figure 1. Researchers (e.g., Baguley & Payne, 2000; Mani & Johnson-Laird, 1982) have used this task to determine the roles of analogue and propositional representations in spatial reasoning by assessing recognition (among foils) of *verbatim* descriptions (ones that replicate the exact verbal form of the originally presented information) and *gist* descriptions (those that capture the meaning of verbal descriptions in different words).

(Figure 1 about here)

Studies employing this paradigm have shown that sighted participants judge gist descriptions as being identical to the originally presented descriptions, suggesting conversion of the verbal descriptions into an analogue representation that fits both versions. Furthermore, Mani and Johnson-Laird (1982) found that people recognise gist descriptions more effectively when spatial relations are *determinate* (i.e., the description allows only one possible layout) than when they are *indeterminate* (i.e., the description allows for more than one possible layout, thereby necessitating multiple analogue representations to capture all layout possibilities). If participants store and manipulate the spatial description in a propositional representation, then determinate and indeterminate layouts should be equally easy to remember. For example, the indeterminate relation 'next to' and the determinate relation 'to the left of' should be similar in their comprehensibility if represented in propositional form. However, the determinate relation can be represented analogically in a single scene, whereas the indeterminate relation brings to mind at least two possibilities and so would be harder to store in this format. The determinacy-indeterminacy distinction applies even in the case of recent formulations of analogue representations that suggest they are not Euclidean (i.e., exact analogues of perceived information) but are instead hierarchically organised (Huttenlocher, Hedges, Corrigan, & Crawford, 2004).

The present experiment compared recognition of spatial location descriptions across three groups: congenitally blind, blindfolded sighted, and sighted controls. The experimenter presented each description aurally, and participants then had to choose which of two layouts matched the description. The layouts were presented tactually, with object names being stated verbally by the experimenter when participants touched each location. This technique was employed in order to make the layouts accessible to the blind and blindfolded-sighted individuals. Participants then ranked four alternative versions of each description (verbatim, gist description and two foils) according to the degree of correspondence with the original description.

If blind participants rely upon propositional (i.e., non-analogue) representations, then they should be more likely than sighted participants to treat gist descriptions as distracters. Moreover, they should perform the same with determinate and indeterminate relations. One might also expect blind participants to be more accurate in the recognition of verbatim descriptions than sighted participants because of their superior verbal memory (e.g., Röder et al., 2001). On the other hand, if blind participants are able to develop analogue representations of spatial descriptions, then they should show an identical pattern of performance to the sighted on the gist measure of recognition memory. As such, they should be susceptible to the same influence of determinate versus indeterminate relations in their recognition of gist descriptions as observed in sighted participants.

Method

Participants

The study involved 15 congenitally blind adults[1] (aged 15-57 years; mean: 38 years) and 32 adults from Lancaster University (aged 19-29 years; mean: 21 years). Blind and sighted individuals were matched for gender and were of a similar educational background and level. All participants were naïve, paid volunteers. The blind participants were totally blind and had no memory of sight (see Table 1).

(Table 1 about here)

Materials

Eight sets of spatial descriptions and diagrams (plus two additional sets for practice trials) were produced using a stimulus-generation program developed by Baguley and Payne (2000). Each set contained four sentences describing spatial relations between five objects in a two-dimensional Euclidean plane. Four description sets were determinate, having only one possible object layout, and four sets were indeterminate with two possible object layouts. Each description set contained object names from a different category (e.g., bird names) matched for frequency, imagery, and concreteness (Kuçera & Francis, 1967; Quinlan, 1992). Descriptions were counterbalanced for category name, configuration and presentation order.

Matching and non-matching tactile diagrams were produced for each description set (see Figure 1); the relative location of two objects described in the sentences was reversed in the non-matching diagram. The tactile boards were 29x38cm plywood sheets with rubber stops (15mm diameter projecting 10mm from the plywood) representing object positions. The rubber stops were 15cm apart.

For the description-recognition task, four versions of each original description set were devised. One contained the original ('verbatim') sentences. The second, a 'gist' version, described the same object array as the original description but in different words. It shared one sentence with the original, with two paraphrase sentences (inverting the objects and the spatial relation) and one inferable sentence that was true of, but not explicit in, the original description. The remaining versions were distracters that shared one sentence with the original description but swapped the relative locations of three objects.

Procedure

Each trial consisted of three phases: presentation of description of object locations, a layout matching task, and an incidental recognition task. The participants were not instructed to memorise descriptions, only to use them for the layout matching task (cf. Mani & Johnson-Laird, 1983). The experimenter read the descriptions to blindfolded and blind participants (participants indicated when they were ready for the next sentence), while sighted participants read descriptions themselves. In the layout matching phase, participants examined two tactile boards, one matching the description, the other not, and were required to identify the matching board. As the participant touched each rubber stop on a board, the object represented at that location was named by the experimenter. Participants received two practice trials followed by eight experimental trials. They received feedback on practice trials only. The reading and layout matching phases were self-paced, and each took approximately one minute for each trial.

The final recognition phase began directly after completion of the eight layout matching tasks. For each recognition trial, participants ranked four versions of a description set given in the first phase on a scale from one to four according to how closely they resembled the original description, ignoring the order of sentences within the description set (cf. Baguley & Payne, 2000).

Results

Errors accounted for 33% of choices in the layout matching phase, a result that mirrors previous findings, such as those of Baguley and Payne (2000), who reported an error rate of 24%. There were no reliable effects of Group (congenitally blind, blindfolded sighted, and sighted controls), $F(2, 44) = 1.21$, $p = .31$, or Determinacy Status (determinate vs. indeterminate descriptions), $F(1, 44) = 2.70$, $p = .11$, on layout matching accuracy (Figure 2). Subsequent analyses excluded data from one blind and one blindfolded-sighted participant, who scored at or below chance across all tasks.

(Figure 2 about here)

Gist recognition (Figure 3), measured as the proportion of responses in which the two descriptions that described the correct layout (i.e., the verbatim and gist versions) were ranked first and second, was greater for determinate than for indeterminate relations, $F(1, 42) = 10.07$, $p < .05$. However, there was neither an effect of Group ($F < 1$), nor an interaction between Group and Determinacy Status ($F < 1$).

(Figure 3 about here)

Verbatim recognition (see Figure 4), measured as the proportion of responses in which the verbatim description was ranked first, differed significantly across groups,

$F(2, 42) = 5.55$, $p < .01$. Planned comparisons show that the congenitally blind group recognised fewer verbatim descriptions than the sighted groups, $F(1, 42) = 7.95$, $p < .01$. The difference between the sighted and blindfold groups was not significant, $F(1, 42) = 2.97$, $p > .05$. Performance in verbatim recognition contrasted starkly with digit spans: On this test, congenitally blind participants achieved scores between 6 and 14 items (mean: 8.64), compared with a range of between 6 and 8 items for sighted participants (mean: 6.44), consistent with the normal range (Smyth & Scholey, 1996).

One area of concern is the disparity in ages between the blind and sighted participants. However, when the blind group was subdivided into those under 30 years ($M = 18$) and those over 30 years ($M = 51$) no differences were found between subgroups for gist performance, $t(12) = .000$, $p = 1$, or for verbatim performance, $t(12) = .149$, $p = .884$.

(Figure 4 about here)

Discussion

In contrast to previous findings (e.g., Aleman et al., 2001), congenitally blind participants showed no decrement in a visuo-spatial task relative to sighted and blindfold participants. Similarly, there were no group differences in gist recognition performance, with superior gist recognition for determinate than indeterminate descriptions. Despite apparently above average digit spans (8.64 vs. 6.44 for sighted), the verbatim recognition of congenitally blind participants was worse than that of sighted and blindfold participants.

The key question is how were congenitally blind participants able to match the spatial reasoning performance of blindfolded participants and sighted controls, when previous studies have shown a decrement among the congenitally blind in tasks that require the mental manipulation of objects? The answer appears to be that the blind use analogue representations similar to sighted people. Their memory for object layouts was equivalent to sighted controls, a finding consistent with the use of analogue representations sensitive to determinacy and effective at retaining gist information, rather than abstract propositional representations that retain verbatim information only and are not sensitive to determinacy.

This equivalence of representations among sighted and blind groups is supported by recent research indicating that spatial knowledge *can* be acquired from non-visual modalities (e.g., Shelton & McNamara, 2001; Amedi et al., 2005). This suggests that the blind and sighted construct and access crossmodal representations of objects and space. Vanlierde and Wanet-Defalque (2004) propose that blind people's visuo-spatial performance reflects the use of a compensatory verbal strategy based on a coordinate model. However, gist recognition in the present study required the identification of non-explicit locations which could not be inferred using a coordinate model without a performance decrement. Furthermore, verbatim recognition was, in fact, worse in the blind than in the sighted groups, which would be very unlikely to arise if the blind relied on a verbal strategy. It seems likely that the blind can form representations that reflect their perceptions as can the sighted (Bartolomeo, 2002) and that the blind do not need to rely on a verbally-based compensatory representation different to sighted representations.

An ancillary question is why did congenitally blind participants perform worse than other groups in verbatim recognition, when studies of verbal memory ability in the blind suggest the opposite (Hull & Mason, 1995; Röder et al., 2001)? We propose that the relatively poor verbatim performance of our blind participants is, paradoxically, unlikely to be the result of inherent deficiencies in verbal memory. Blind people tend to have equivalent (or better) verbal capabilities than sighted individuals. Our blind participants' poor verbatim recognition is also unlikely to result from a lack of frame-of-reference information or the use of a verbal strategy. Instead, we suggest that poorer verbal performance on visuo-spatial tasks by non-sighted individuals may be a reflection of their difficulty in carrying out these tasks: Visuo-spatial tasks are simply more difficult for the congenitally blind.

Our proposal can be clarified as follows: Creating an analogue representation (e.g., mental model) requires verbal working memory resources simply to retain the information and so free up general working memory resources to construct the model, as evidenced by correlations between digit span and gist recognition (but not verbatim recognition) in our study[2] (cf. Morra, 1989). Therefore, blind participants' better verbal memory abilities may aid them in the creation of analogue models. By contrast, verbatim recognition is held to be a measure of the 'episodic trace' of model construction processes (Baguley & Payne 2000). Since the blind are believed to be less effective at active processing (i.e., manipulating and constructing) spatial representations in the first place (Vecchi, 1998), then this would offset their verbal span advantage and lead to a degraded episodic trace and worse verbatim-recognition performance. Previous research has indicated deficits in blind task performance compared to sighted participants. Such poor task performance may, we argue, reflect a cost associated with the sheer cognitive burden of visuo-spatial processing.

In support of this latter view we also note that research has shown that an increased cognitive burden in a visuo-spatial task can, indeed, lead to a specific decrement in verbatim memory. Barshi and Healy (2002) asked participants to repeat navigation instructions for an array that was perceived in either two or three dimensions, although the stated directions were informationally equivalent. It was found that participants' immediate verbal memory was far worse on the more complex three-dimensional matrix-navigation task. This phenomenon mirrors that found in this experiment: the blind group have to do more to achieve the task and the blind group have worse verbatim recall.

Both our current findings and those of Barshi and Healy (2002) suggest that the supposedly verbal recall measure employed by researchers in the context of navigation tasks may not actually reflect a genuine measure of verbal memory, but rather may be an index of a propositional memory for the active processing that underpins the construction of analogue mental representations (Baguley & Payne, 2000; Barshi & Healy, 2002). Thus, although the blind are worse at spatial processing (which produces a decrement in verbal recognition in this study) they are still able to build analogue representations, and, having built them, are effective at maintaining them.

In summary, the present study provides support for the view that the sighted and blind can make similar use of analogue representations when tackling visuo-spatial tasks. The consistent performance deficits observed in the blind on such tasks are not, necessarily, the result of the deployment of different representations, but instead may reflect differences in processing effectiveness.

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Footnotes

[1]We classified participants as congenitally blind based upon their self-reports, although we note that the medical histories of three individuals suggested they might have had some early visual experience. Data re-analysis excluding these participants produced an identical pattern of results.

[2]This is supported by our blind participants' data showing a trend for a correlation between digit span and gist recognition, $r = .303$, but not between digit span and verbatim recognition, $r = .088$.

Table 1

Characteristics of Early Blind Participants

Sex	Age	Years of Higher Education	Age of onset of blindness	Aetiology
M	55	0	Birth	Retrolental fibroplasia
M	57	3.5	Birth	Retrolental fibroplasia
M	51	5	Birth	Retrolental fibroplasia
F	42	3	3 months-2 years	Bilateral retinoblastoma
F	48	5	1 year	Bilateral retinoblastoma
M	52	4	Birth	Retrolental fibroplasia
M	54	10	Birth	Congenital rubella
M	17	0	Birth	Retrolental fibroplasia
M	16	0	Birth	Retrolental fibroplasia
M	56	0	Birth	Retrolental fibroplasia
M	16	0	Birth	Retrolental fibroplasia
F	20	1	Birth	Retrolental fibroplasia
F	15	0	3-4 years	Bilateral retinoblastoma
M	50	4	Birth	Retrolental fibroplasia
F	24	3	Birth	Retrolental fibroplasia

Notes: Retrolental fibroplasias (also termed retinopathy of prematurity) affects prematurely born babies, and is thought to be caused by disorganised growth of retinal blood vessels resulting in scarring and retinal detachment. Oxygen toxicity may also contribute to its development. Retinoblastoma is a cancer of the retina that occurs mostly in children before the age 5 years. The tumor may begin in one or both eyes.

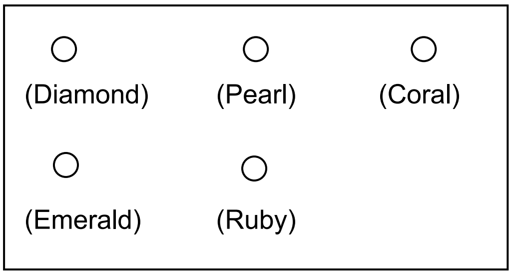
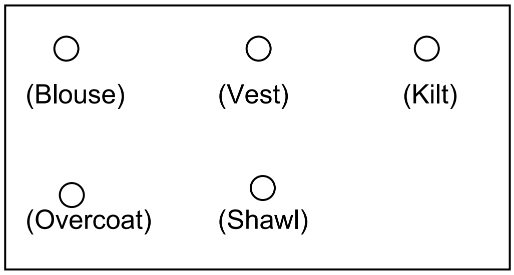
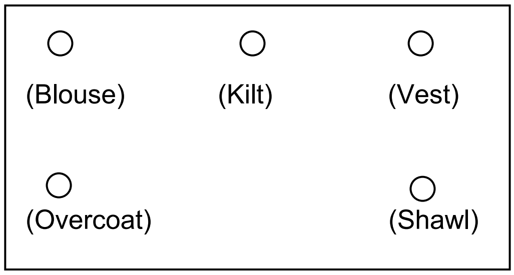
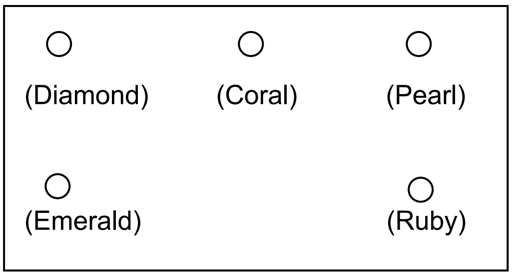
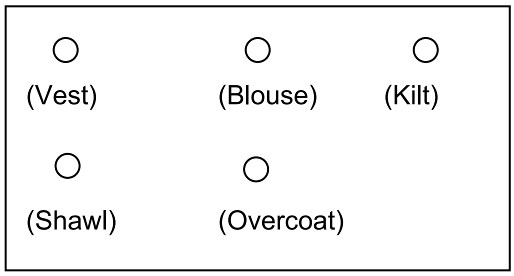
Figure Captions

Figure 1. Examples of determinate and indeterminate description sets and corresponding diagrams.

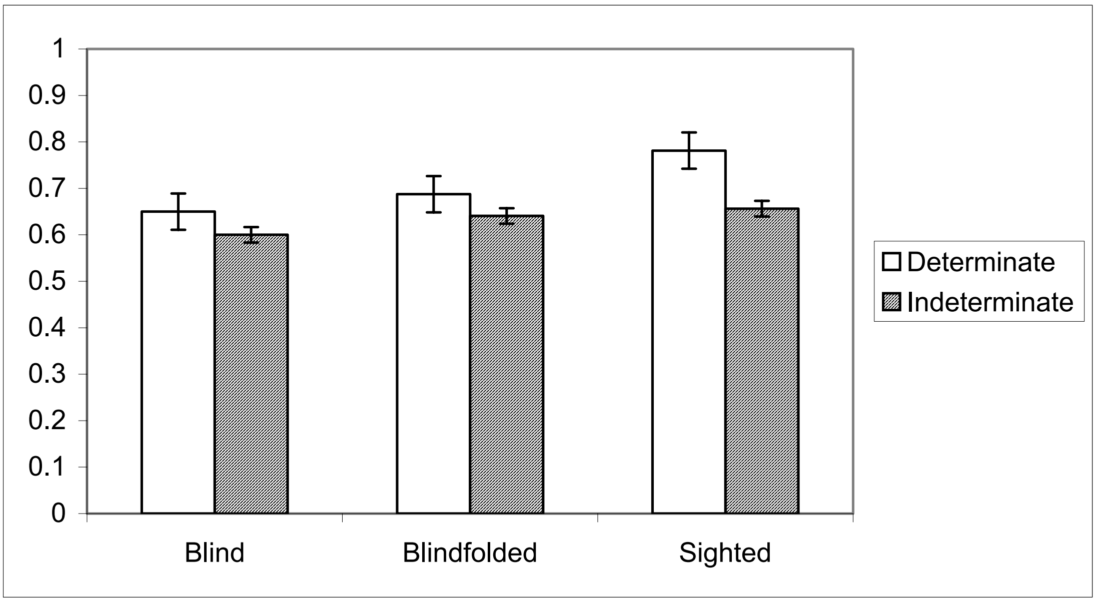
Figure 2. Proportion of correct judgements of the matching diagram by Group for determinate and indeterminate description sets. Vertical lines depict standard errors of the means.

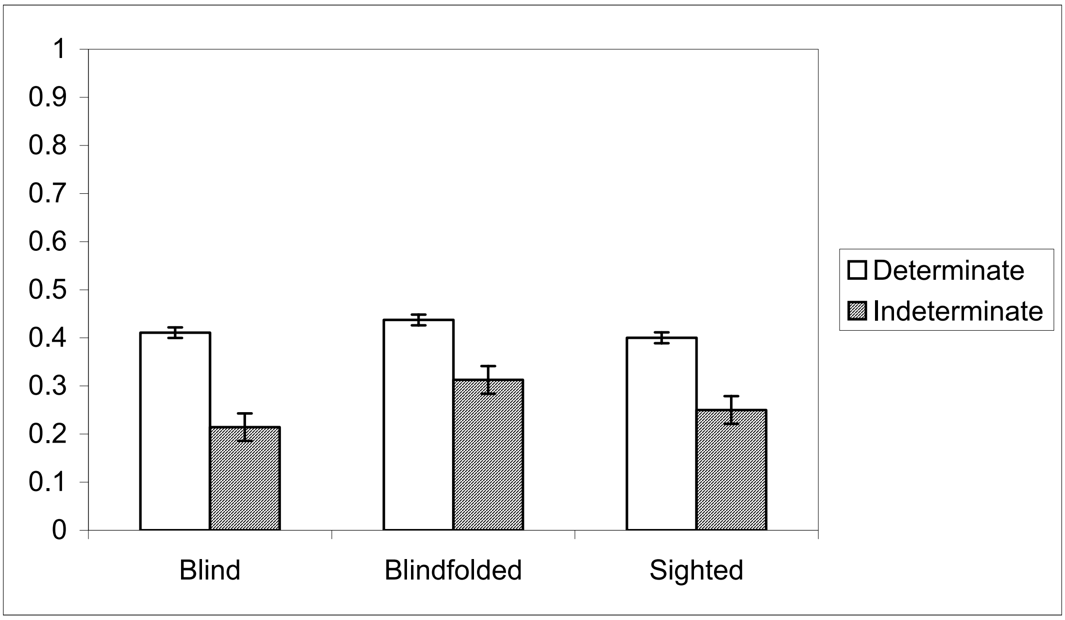
Figure 3. Proportion of correct ‘gist’ ranking by Group for determinate and indeterminate description sets. Vertical lines depict standard errors of the means.

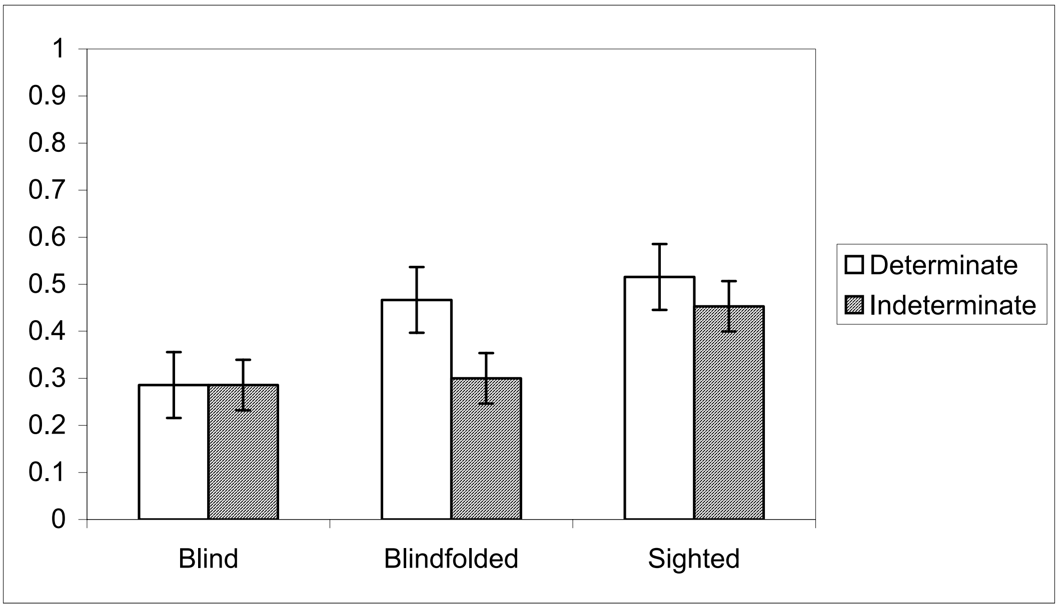
Figure 4. Proportion of correct ‘verbatim’ ranking by Group for determinate and indeterminate. Vertical lines depict standard errors of the means.

Determinate description set	Indeterminate description set
The pearl is behind the ruby The pearl is to the left of the coral The pearl is to the right of the diamond The diamond is behind the emerald	The shawl is in front of the vest The vest is to the right of the blouse The blouse is behind the overcoat The kilt is to the right of the blouse
 (matching)	  (both matching)
 (non-matching)	 (non-matching)

Notes: The determinate description set matches only a single diagram, whereas the indeterminate description set matches two diagrams (although only one would be presented as a matching diagram in the initial recognition task of the experiment). The circles represent tactile markers on the diagrams that were presented to participants.


1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Blind
Blindfolded
Sighted
Determinate
Indeterminate


1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Blind
Blindfolded
Sighted
Determinate
Indeterminate


1
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Blind
Blindfolded
Sighted
Determinate
Indeterminate