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Symmetry perception in the blind

Zaira Cattaneo [a,*], Micaela Fantino [b], Juha Silvanto [c], Carla Tinti [d], Alvaro Pascual-Leone [e], Tomaso Vecchi [b]

[a] Department of Psychology, University of Milano-Bicocca, Milano, Italy
[b] Department of Psychology, University of Pavia, Pavia, Italy
[c] Brain Research Unit, Low Temperature Laboratory, Helsinki University of Technology, Espoo, Finland
[d] Department of Psychology, University of Torino, Torino, Italy
[e] Berenson-Allen Center for Noninvasive Brain Stimulation, Harvard Medical School and Beth Israel Deaconess Medical Center, Boston, MA, USA

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A B S T R A C T

Bilateral mirror symmetry, especially vertical symmetry, is a powerful phenomenon in spatial organization of visual shapes. However, the causes of vertical symmetry salience in visual perception are not completely clear. Here we investigated whether the perceptual salience of vertical symmetry depends on visual experience by testing a group of congenitally blind individuals in a memory task in which either horizontal or vertical symmetry was used as an incidental feature. Both blind and sighted subjects remembered more accurately configurations that were symmetrical compared to those that were not. Critically, whereas sighted subjects displayed a higher level of facilitation by vertical than horizontal symmetry, no such difference was found in the blind. This suggests that the perceptual salience of the vertical dimension is visually based.

1. Introduction

Symmetry is a powerful principle in spatial representation of visual shapes (e.g., Royer, 1981). Humans – already in infancy – have an extraordinary capacity to detect bilateral symmetric patterns (where one half of a pattern is a mirror reflection of the other half), especially those symmetrical along the vertical axis (e.g., Pashler, 1990; Wagemans, 1997; Wenderoth, 1994). The processes that give rise to the perceptual salience of symmetry are not well known. It has been argued that symmetry salience might represent a by-product of the need to recognize objects irrespective of their position and orientation in the visual field (Enquist & Arak, 1994). Indeed, symmetry facilitates figure/ground segregation (Palmer, 1991) and it plays a crucial role in computational models of object representation and recognition (e.g., Biederman, 1987). Others have claimed symmetry to play a role even in mate selection, given that symmetric faces are perceived to be more attractive than nonsymmetric ones (Johnstone, 1994; but see Zaidel, Aarde and Baig, 2005, for a discussion). Visual symmetry is thus of clear biological importance.

A few studies have investigated symmetry perception in the haptic modality (e.g., Ballesteros, Manga & Reales, 1997; Ballesteros, Millar & Reales, 1998; Ballesteros & Reales, 2004; Locher & Simmons, 1978; Millar, 1978; Simmons & Locher, 1979). Overall, symmetry seems to play a less prominent role in tactile perception compared to vision, with haptic symmetry detection being modulated by a series of factors such as the mode of exploration (unimanual/bimanual), the size of the stimuli, or their dimensionality (2D or 3D). In particular, it is likely that *vertical*[1] symmetry becomes salient in touch only for stimuli for which a spatial reference frame – as the one related to the observer's own body – is available (e.g., Millar, 1978). According to this "reference hypothesis" (Millar, 1978), it has been shown that the use of two hands in a parallel search mode (rather than using just one finger) enhances the tactile detection of vertical symmetry in 2D raised shapes (cf. Ballesteros et al., 1997; Ballesteros et al., 1998). Critically, as is also the case in vision (Rossi-Arnaud, Pieroni &

[1] Studies investigating symmetry salience in touch have typically used raised-line or raised-dot configurations (see Ballesteros et al., 1997; 1998; Locher & Simmons, 1978; Millar, 1978; Simmons & Locher, 1979) presented on the flat surface of the table at which the subjects were sitting. Therefore, in these studies the *vertical* axis of symmetry has to be intended as perpendicular to the line of the horizon and in direct vertical (tabletop projected) alignment with the midpoint of the subject's body; and the horizontal axis of symmetry has to be intended as parallel to the line of the horizon (and perpendicular to the tabletop projected midsagittal axis of subject's body).

* Corresponding author.
E-mail address: zaira.cattaneo@unimib.it (Z. Cattaneo).

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Baddeley, 2006), symmetry facilitates tactile processing even indirectly: in a task requiring judgments of 2D shapes closure (rather than the detection of symmetry), bilateral vertically symmetrical open shapes were judged more accurately than asymmetrical open shapes (Ballesteros et al., 1998, Experiment 3). However, from the studies reported above it is not clear whether symmetry salience – and in particular vertical symmetry salience – in haptic perception is independent of exposure to visual symmetry, since symmetry facilitation of tactile processing may derive from the haptic percept being converted into a visuo-spatial image in memory (see Thinus-Blanc & Gaunet, 1997). This issue can be investigated by assessing symmetry perception in congenitally blind observers (who have no prior visual experience) and thus any symmetry perception in such subjects cannot have developed through visual processes. Until now, however, symmetry perception in the blind has not been investigated.

Here we present a study in which a group of early blind subjects and a group of blindfolded sighted subjects were tested on a task requiring them to memorise and reproduce a series of configurations that could be either symmetrical along the horizontal or vertical axis, or non-symmetrical. If symmetry plays a role in haptic perception by reducing the memory load, all participants should remember symmetrical configurations better than non-symmetrical ones. Furthermore, perceptual grouping should facilitate memory to a similar extent regardless of the orientation of the axis of symmetry, as in the horizontal and vertical symmetry conditions the memory load is identical. Nonetheless, studies on symmetry detection in the visual modality have consistently reported an advantage of vertical symmetry over horizontal symmetry detection (e.g., Wagemans, 1997; Wenderoth, 1994), and there is evidence that the vertical axis may be particularly salient even in tactile perception (e.g., Ballesteros et al., 1998). In light of this evidence, one would expect an additional benefit for patterns which are symmetrical along the vertical axis, in other words, memory performance should be superior in the vertical symmetry condition relative to the horizontal symmetry condition. Importantly, if this special salience of vertical symmetry develops through normal visual experience, no specific advantage of the vertical axis of symmetry should be found in the blind group.

2. Method

2.1. Participants

Sixteen congenitally or early blind individuals (6 females), mean age 35.8 years (SD = 7.4, age range 22–48), and 26 sighted control participants (14 females), mean age 27.0 (SD = 5.0, age range 20–40), took part in the experiment. Blindness was never associated with a central neural disorder. In all participants blindness was complete, with no light perception. Table 1 describes blind participants' characteristics.

2.2. Material

Wooden two-dimensional matrices measuring 20 cm by side and consisting of 25 tactilely perceivable cells were used as stimuli. Each matrix cell measured 4 cm by side. In each trial, 7 target cells were covered with sandpaper in order to be easily recognisable at touch. Matrices were presented both in a horizontal and in a frontal plane. In the horizontal plane condition, matrices were presented on a table, the center of the matrix was aligned with the participant's body midline, and the bottom side of the matrix was put at a distance of about 20 cm from the subject. In the frontal plane, the matrix was aligned with the participant's body midline, and the bottom side of the vertical matrix was fixed at a height of about 10 cm from the table's plane (a wooden panel was used to hold the matrices), at a distance of 20 cm from the subject. There were 3 types of configurations: symmetrical along the vertical axis (VS), symmetrical along the horizontal axis (HS) or non-symmetrical (NS). Examples of the three different types of configurations are shown in Fig. 1. For matrices presented in the frontal plane, the vertical axis of symmetry was in the direction of the force of gravity (i.e., parallel to the participants' midbody axis), and the horizontal axis of symmetry was perpendicular to that (i.e., parallel to the horizon). When the matrices were presented in the horizontal plane, the vertical and horizontal axis' orientation referred to the horizontal tabletop: that is, the vertical axis of symmetry was in direct vertical (tabletop projected) alignment with the midpoint of the subject's body (i.e., perpendicular to the horizon), and the horizontal axis of symmetry was parallel to the horizon (see Ballesteros et al., 1998).

2.3. Procedure

Subjects were seated at a table. Sighted subjects were blindfolded throughout the entire experiment. The experimenter positioned the participant's hands in the middle of the matrix, parallel to the midbody axis, as the starting position on each trial. Subjects were instructed to tactilely explore the matrices in their preferred order and to memorise the position of the target cells. Symmetry was not mentioned. The exploration phase lasted 16 s. At test, subjects were required to indicate (by pointing with their hands) the position of the memorised target cells on a corresponding blank matrix. There was no time limit in the response. For each plane (horizontal and frontal) there were 6 trials for the 3 types of configurations (VS, HS, NS), for a total of 36 trials. The matrices in the horizontal and frontal plane were

Table 1
Characteristics of blind participants.

Gender	Age (years)	Job activity	Blindness aetiology	Blindness onset	Mobility devices
M	39	Call operator	Optic nerve damage	Birth	White cane
F	34	Call operator	Optic nerve damage	Birth	White cane
M	26	Employee	Oxygen therapy	Birth	White cane
F	36	Call operator and university student	Congenital glaucoma	Birth	White cane
M	37	Call operator	Optic nerve damage	Birth	White cane
M	33	Physiotherapist	Trauma	4 months	White cane
M	40	Physiotherapist	Oxygen therapy	Birth	White cane
M	46	Call operator	Optic nerve damage	Birth	White cane
F	29	English teacher	Retrolental fibroplasias	Birth	White cane
M	48	Call operator	Optic nerve damage	Birth	Dog
M	46	Call operator	Optic nerve damage	Birth	White cane
M	32	Employee	Trauma	Birth	White cane
M	22	University student	Bilateral retinoblastoma	10 months	White cane
F	39	Physiotherapist	Optic nerve damage	Birth	White cane
F	28	Call operator	Trauma	8 months	White cane
F	38	Call operator	Optic nerve damage	Birth	White cane

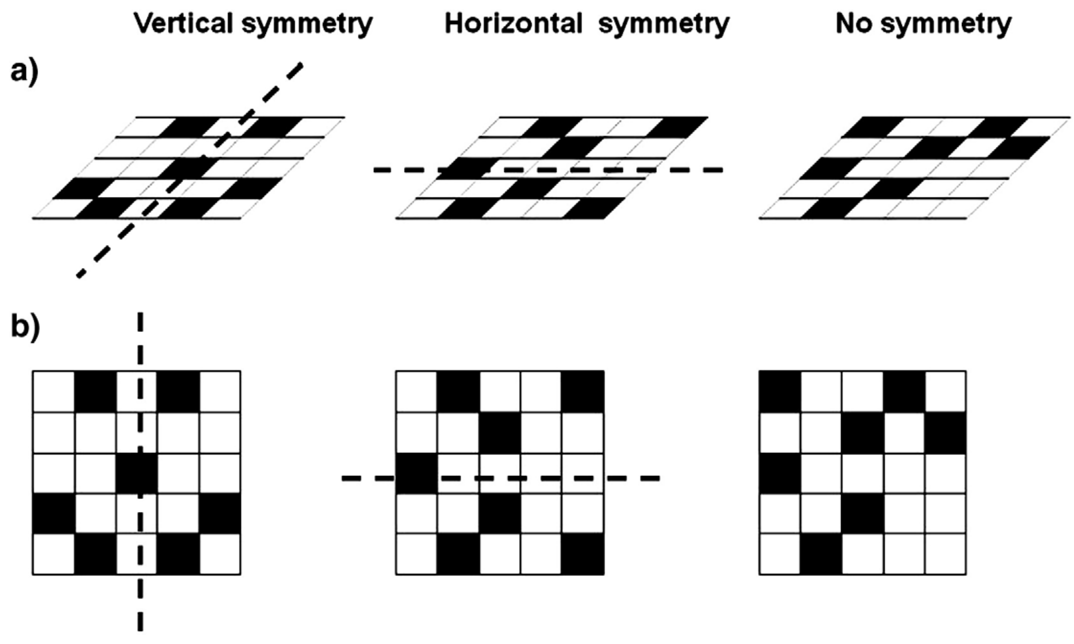

Fig. 1. A schematic representation of the three types of configurations (VS, HS and NS) as presented in the a) horizontal (tabletop) and b) frontal plane. The vertical and horizontal symmetry axes (dashed lines) have been superimposed to the figures for representational purposes.

presented in blocks (blocks' order was counterbalanced across participants). VS, HS and NS matrices in each block were presented in random order. The experiment started with 4 practice trials (not included in the analyses), two in the horizontal and two in the frontal plane, to familiarise participants with the task. The experiment took approximately 45 min. The spontaneous encoding strategy adopted by each participant was noted by the experimenter.

3. Results

Results are reported in Fig. 2. A repeated measures ANOVA was carried out on accuracy (%) with Configuration (VS, HS, NS) and Plane (horizontal vs. frontal) as within-subjects variables and with Group (blind vs. sighted) as between-subjects variable. The analysis revealed a significant effect of Configuration, $F(2,80)=55.69$, $p<.001$, $\eta^2=.58$: VS configurations (mean = 77.98%, SD = 12.76) were remembered better than both HS (mean = 70.92%, SD = 14.37) ($p=.001$) and NS configurations (mean = 60.35%, SD = 15.48) ($p<.001$), and HS configurations were remembered better than NS configurations ($p<.001$) (Bonferroni correction for multiple comparisons applied). A significant effect of Group, $F(1,40)=6.57$, $p=0.014$, $\eta^2=.14$, was also reported, due to blind participants (mean = 75.84%, SD = 14.48) overall performing better than sighted ones (mean = 66.00%, SD = 10.40). Finally, the analysis reported a significant effect of the interaction Configuration by Group, $F(2, 80)=6.$, $p=.002$, $\eta^2=.14$. No other factors or interactions reached significance.

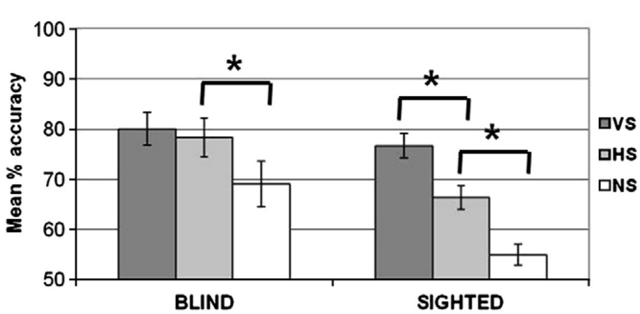

Fig. 2. Mean percentage accuracy of blind and blindfolded sighted individuals with configurations symmetrical along the vertical axis (VS), configurations symmetrical along the horizontal axis (HS), asymmetrical configurations (NS). Error bars represent standard errors of the mean.

An analysis of the main effect of Group for each Configuration showed that blind were significantly more accurate than sighted individuals with HS configurations, $t(40)=2.85$, $p=.007$, and with NS configurations, $t(40)=3.19$, $p=.003$, whereas the two groups performed similarly with VS configurations ($p=.41$). An analysis of the main effect of Configuration within each Group showed that the sighted remembered VS significantly better than HS configurations, $t(25)=5.85$, $p<.001$, VS significantly better than NS configurations, $t(25)=10.28$, $p<.001$; and HS significantly better than NS configurations, $t(25)=7.07$, $p<.001$. Conversely, blind participants' performance did not significantly differ with VS and HS configurations ($p=.51$), whereas it was better with VS compared to NS stimuli, $t(15)=4.37$, $p=.001$, and with HS compared to NS stimuli, $t(15)=3.23$, $p=.006$.

3.1. Encoding strategies

Encoding spontaneous strategies were also analysed. Overall, blind subjects were quite consistent in their exploration strategies. In particular, 15 out of the 16 blind participants used the two hands in exploring the matrices in all experimental trials. One blind subject kept his left hand anchored to the matrix left side and explored the matrix with his right hand, and did so in all experimental trials. Notably, the performance of this participant was quite poorer compared to the mean accuracy of the other 15 blind individuals, being equal to 53.57% for VS configurations (vs. 81.83% of the other 15 blind), 48.81% for HS configurations (vs. 80.32% of the other 15 blind) and 39.29% for NS configurations (vs. 71.11% of the other 15 blind). Blind participants also tended to be very consistent in the direction of the first exploration of the matrices throughout the experiment. In particular, 14 blind participants always started scanning from the upper row of the matrix, keeping the two hands approximately parallel with the left hand exploring the left portion of the row and the right hand exploring the right portion of the row, hence descending down to the next row and going down to the bottom row (one of these participants started exploration from the bottom row in 2/3 of the trials). The other two blind subjects (one of which was the same that used just one hand for exploration), adopted a reading-like strategy in all the trials, by starting the exploration from the upper left corner and proceeding row by row in a reading-style fashion. Twenty-one sighted subjects used two hands in all the experimental trials. The remaining 5 participants used the right hand only in all trials, while keeping the left hand anchored to the left side of the matrix. Interestingly, the exploration strategies were different between sighted subjects that used two hands in the exploration and those that used one hand. In particular, 20 out of the 21 sighted participants that used 2 hands followed the "up–down search in parallel" strategy described above in all the trials. One sighted participant used two hands but adopted a "down–up search in parallel" strategy in 15 of the 18 trials in the horizontal plane and in 1 trial in the vertical plane; in the rest of the trials he relied upon an "up–down search in parallel" strategy. The 5 sighted subjects that only scanned with the right hand followed a reading-like strategy of exploration in all the trials, reporting a score of 80.00% (SD = 7.64) for VS configurations (vs. 75.91%, SD = 13.53, of participants that used two hands), and of 73.81% (SD = 7.38) and 62.62% (SD = 7.65) for HS and NS configurations respectively (sighted participants that used two hands scored 64.57%, SD = 12.09 for HS and 53.12%, SD = 10.69 for NS matrices). Overall, the use of one rather than two hands did not significantly affect memory, although there was a trend with HS and NS configurations toward a better performance with unimanual exploration, $t(24) = .65$, $p = .53$ for VS configurations; $t(24) = 1.62$, $p = .12$ for HS configurations, and $t(24) = 1.86$, $p = .08$ for NS configurations.

To verify whether differences in scanning strategies, and in particular the use of one rather than two hands, might be responsible for the difference reported in the pattern of performance of blind and sighted individuals, we carried out a further repeated measures ANOVA on percentage accuracy with Configuration (VS; HS; NS) and Plane (Horizontal vs. Vertical) as within-subjects variables and Group (Blind vs. Sighted) as between-subjects variable, including only subjects that used two hands for exploring the matrices. Hence, 15 blind participants and 21 sighted participants were included in the analysis. The ANOVA revealed a significant main effect of Configuration, $F(2,68) = 48.34$, $p < .001$, $\eta^2 = .59$, a significant main effect of Group, $F(1,34) = 11.29$, $p = 0.002$, $\eta^2 = .25$, and a significant interaction Configuration by Group, $F(2, 68) = 6.98$, $p = .002$, $\eta^2 = .17$. No other factors or interactions reached significance. VS configurations (mean = 78.37%, SD = 12.90) were remembered better than both HS (mean = 71.13%, SD = 14.84) ($p = .001$) and NS configurations (mean = 60.61%, SD = 16.14) ($p < .001$), and HS configurations were remembered better than NS configurations ($p < .001$) (Bonferroni correction for multiple comparisons applied). As it was the case when considering the whole participants' sample, blind participants outperformed sighted ones, mean = 77.75% (SD = 12.74) and mean = 64.53% (SD = 10.81), respectively. T-tests showed that this was specifically the case with HS and NS configurations ($p = .001$ and $p < .001$, respectively), whereas blind and sighted performances did not differ with VS configurations ($p = .18$). Critically, when analysing how the two groups performed in the different conditions, the 21 sighted subjects using two hands to explore the matrices were found to remember better VS than HS configurations ($p < .001$), VS than NS configurations ($p < .001$) and HS than NS configurations ($p < .001$). The 15 blind subjects that used two hands remembered better VS than NS configurations ($p = .001$) and HS than NS configurations ($p = .009$), whereas no difference was reported for memory of VS and HS configurations ($p = .59$).

3.2. Effect of blindness onset

Blindness occurring within the first few months of life is usually considered (at least regarding its impact on cognitive abilities, see Cattaneo and Vecchi, 2010, for review) in the same vein as congenital blindness. Nonetheless, it may be that even a brief exposure to visual symmetrical environmental stimuli, such as faces, might induce a specific sensitivity for vertical symmetry. Therefore, we repeated the same analysis reported above excluding from the blind group the three subjects that were not congenitally blind (see Table 1). The ANOVA revealed the same pattern of results as with the whole sample of subjects, that is a significant effect of Configuration ($p < .001$, $\eta^2 = .59$), a significant effect of Group, ($p = 0.014$, $\eta^2 = .15$) and a significant interaction Configuration by Group, ($p < .001$, $\eta^2 = .19$). In particular, the 13 blind subjects included in the analysis were less accurate with NS than with VS ($p = .005$) and HS ($p = .002$) configurations, whereas no difference in performance was reported between VS and HS configurations ($p = .48$). Nonetheless, the three blind subjects affected by early but not congenital blindness remembered overall better VS (mean accuracy = 82.94%, SD = 16.25) than HS (mean = 67.06%; SD = 19.06) and NS (mean = 69.84%, SD = 14.88) configurations (all these three subjects used two hands in scanning the matrices).

4. Discussion

Vertically and horizontally symmetrical configurations were overall remembered better than non-symmetrical configurations by both blind and blindfolded sighted participants. This suggests that symmetry worked as a gestalt principle of perceptual organization (see Machilsen, Pauwels & Wagemans, 2009) reducing the memory load and making the task more simple, even if symmetry was an incidental feature and participants were not informed that some configurations were symmetrical and others were not. There was, however, one important difference between the two groups: whereas the blindfolded sighted subjects were more accurate in retrieving patterns which were symmetrical along the vertical axis than along the horizontal axis, there was no such additional benefit of vertical salience in the blind. This shows that the exceptional salience of vertical symmetry in haptic perception is dependent on prior visual experience.

Symmetrical configurations contain overall less amount of information than non-symmetrical patterns, and are thus easier to remember. Critically though, the facilitation due to perceptual grouping is potentially the same for vertically and horizontally symmetrical configurations. Hence, the better performance of blindfolded sighted participants in retrieving vertically symmetrical compared to horizontally symmetrical configurations cannot be entirely attributable to some gestalt perceptual grouping but is likely to be "hard-wired" in the visual system. Indeed, the visual system detects vertical symmetry more easily than horizontal symmetry (e.g., Palmer & Hemenway, 1978; Royer, 1981; Wagemans, 1997; Wenderoth, 1994) and it has been suggested that the vertical symmetry preference may depend on the bilateral symmetry of the brain itself (see Mach, 1886/1959; Julesz, 1971). According to this view, vertical symmetry detection results from a point-by-point matching process between symmetrical opposite loci in each cortical hemisphere that would be subtended by fibers crossing over through the corpus callosum (e.g., Desjardins, Braun, Achim & Roberge, 2009; Herbert & Humphrey, 1996). Our study demonstrates that the advantage of vertical symmetry over horizontal symmetry is based on visual experience, as such advantage was not present in the blind subjects.

In light of this, it is remarkable that the three blind subjects that were not congenital but could see for a few months (<10), showed higher accuracy in remembering vertically than horizontally symmetrical configurations, thus resembling sighted subjects' behaviour. Although the small sample size ($n = 3$) does not allow to make any statistical analysis, we may speculate that even a very brief exposure to visually symmetric stimuli (such as faces) can induce a particular sensitivity to vertical symmetry. Future studies may directly assess this issue by investigating haptic symmetry perception in a sample of late blind individuals. Incidentally, it is worth mentioning that in this study blind individuals overall outperformed blindfolded sighted subjects (even when controlling for scanning strategies). Previous studies on haptic perception have often reported similar level of accuracy of early blind and sighted subjects (e.g., Heller, 2003; Vecchi, Tinti & Cornoldi, 2004), nonetheless both the specific nature of the task used and the specific characteristic of the examined blind individuals – such as Braille proficiency, education, mobility skills – likely play a major role in determining blind participants' performance (e.g., Loomis, Klatzky, Golledge, Cicinelli, Pellegrino & Fry, 1993; Thinus-Blanc & Gaunet, 1997).

Previous studies have shown that haptic detection of vertical symmetry was facilitated by bimanual exploration conditions when the stimulus' axis of symmetry was aligned to the midaxis of the subject's body in the midtransverse plane (see Ballesteros et al., 1997, 1998; Millar, 1978). In our experiment, the midaxis of the matrices was aligned to the midline of each subject's body, and the majority of participants used two hands, adopting a parallel-mode of exploration. Nevertheless, symmetry benefited memory even in those subjects who used only their right hand to explore the configurations while keeping their left hand anchored to the left side of the matrix as a spatial reference (critically, in the sighted participants using one hand, the level of accuracy was comparable, and almost higher, than that of sighted subjects using two hands). Hence, haptic symmetry detection does not seem to be mediated by a point-by-point matching between the information coming from each hand, with such matching process likely occurring at the level of the corresponding mental representation generated (that in sighted participants is likely to be visually based, see Thinus-Blanc & Gaunet, 1997).

No differences were reported in memory for configurations presented on the frontal and flat/horizontal planes, neither in the sighted nor in the blind. We decided to present stimuli in both planes because vertical symmetry might be more evident in the frontal plane (visual symmetrical objects are mainly viewed in the frontal plane), and it has been found that haptic judgments of bars orientation in the blind are affected by the plane (horizontal vs. frontal) in which bars are represented (Gentaz & Hatwell, 1998). However, regardless of the presentation plane, the vertical axis of symmetry in our study was always perpendicular to the line of the horizon and either parallel to the participants' body midline (for the frontal presentation) or perfectly aligned with the projection of the participants' body midline on the tabletop (for the flat presentation). Accordingly, regardless of the frontal or flat plane presentation, the horizontal axis of symmetry was always perpendicular to the body midline and parallel to the horizon. Previous research on haptic perception of symmetry indicates the body midline as the critical reference for vertical symmetry detection (e.g., Ballesteros et al, 1997, 1998). According to this, the lack of any effect of plane of presentation on performance may be explained by the fact that in our study the two axes of symmetry maintained a constant position with respect to both the horizon and the participants' body midline regardless the (frontal or flat) plane in which stimuli were presented.

Finally, it is worth mention that future research may investigate whether blind participants detect vertical and horizontal symmetry more easily than oblique one, as it has been reported in the visual modality with sighted individuals (e.g., Wagemans, Van Gool & d'Ydewalle, 1992; Wenderoth, 1994). On one hand, the presence of the so-called "oblique effect" (i.e., the perceptual preference for vertical and horizontal orientations compared to oblique orientations, see Gentaz, Baud-Bovy and Luyat, 2008, for review) in the blind (e.g., Gentaz & Hatwell, 1998; Postma, Zuidhoek, Noordzij & Kappers, 2008) suggests that this is likely to be the case. On the other hand though, previous studies also suggest that the preference for specific axes in visual symmetry detection does not completely coincide with the predictions made on the basis of the oblique effect (e.g., Barlow & Reeves, 1979; Herbert & Humphrey, 1996; Wenderoth, 1994), hence, in blind subjects vertical, horizontal and oblique symmetry may be found to facilitate memory to a similar extent.

In conclusion, our data show that symmetry works as a spatial organizational principle regardless of any prior visual experience, but that a normal visual experience is necessary for the salience of the vertical axis to manifest.

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