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Exploratory procedures of tactile images in visually impaired and blindfolded sighted children: How they relate to their consequent performance in drawing

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A B S T R A C T

The aim of the present study was to compare the types of exploratory procedures employed by children when exploring bidimensional tactile patterns and correlate the use of these procedures with the children's shape drawing performance. 18 early blind children, 20 children with low vision and 24 age-matched blindfolded sighted children aged approximately 7 or 11 years were included in the study. The children with a visual handicap outperformed the sighted children in terms of haptic exploration and did not produce less recognizable drawings than their sighted counterparts. Close relationships were identified between the types of exploratory procedures employed by the children and their subsequent drawing performance, regardless of visual status. This close link between action and perception in the haptic modality indicates the importance of training blind children in exploratory procedures at an early age.

1. Introduction

Paradoxically, the body of research devoted to the way in which the procedures used for the haptic exploration of objects determine the accuracy of perceptual outcomes has, in general, concentrated more on sighted than on blind individuals. However, the haptic system, which deals with kinesthetic and cutaneous information, would appear to be far more crucial to blind than to sighted individuals who need to collect information about the objects in their environment. As has been convincingly shown in the many studies conducted by Lederman and Klatzky (e.g., Klatzky, Lederman, & Reed, 1987; Lederman & Klatzky, 1987, 1993), the haptic system is the only perceptual system that can substitute for vision in providing information about an object's properties such as its shape or size. Although it seems better adapted for the processing of material properties (such as texture or temperature) than of geometrical properties (shape or size, Lederman & Klatzky, 1993), it seems nevertheless able to recover the topology of complex object spaces as precisely as the visual modality, at least in sighted adults (Gaissert, Wallraven, & Bülthoff, 2010). However, the question of whether and how the specific exploratory procedures employed by blind children to explore objects relate to performance levels, and especially to the accuracy of such children's perception of the shapes of these objects (Thinus-Blanc & Gaunet, 1997) remains unresolved.

The aim of the present study is to address this issue by comparing the types of exploratory procedures used by children when exploring bidimensional tactile patterns and correlating the use of these procedures with the children's shape drawing

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performance. As pointed out by Klatzky, Lederman, and Metzger (1985), it is likely that the use of raised bidimensional displays results in an underestimation of subjects' ability to perform the haptic processing of shapes. We nevertheless used bidimensional tactile patterns rather than concrete 3D objects due to the fact that the present study forms part of a more general research project which has the aim of improving the construction of tactile bidimensional images of the type used to illustrate tactile books for blind children. Although these illustrations usually integrate the material properties (texture) that are the most useful for facilitating recognition, a large part of the identification process is still based on the encoding of shape information.

In their seminal works, Lederman and Klatzky (1987, 1993, 2009) categorized six different exploratory procedures and showed how each of these is particularly suitable for providing information about a specific object property and how all of them help subjects gather information about several different properties. As far as the property of shape is concerned, the enclosure procedure (and, incidentally, the static contact procedure) makes it possible to extract global shape information, while the contour following procedure, especially when executed with the two hands, is suitable for the precise extraction of shapes (Lederman, Klatzky, & Reed, 1993). The global enclosure procedure also helps individuals extract information about the size of objects. A number of other classifications have been proposed in the literature, whether in the light of studies examining the processing of specific object properties (for instance, curvature, Davidson, 1972; Davidson & Whitson, 1974; symmetry, Ballasteros, Manga, & Reales, 1997) or studies investigating how age or visual status affect the use of different exploratory movements (Landau, 1991; Morrongiello, Humphrey, Timney, Choi, & Rocca, 1994; Ruff, 1984).

A related study performed in adults found that bimanual exploration led to better performances than unimanual exploration during the tactile detection of the vertical symmetry of bidimensional raised shapes (Ballasteros et al., 1997). Bimanual exploration was found to have similar advantages in a task requiring the recognition of tactile images of familiar objects (Wijntjes, Lienen, Verstijnen, & Kappers, 2008), as well as in a task in which congenitally blind adults had to discriminate elliptical shapes (Russier, 1999). Exploration using several fingers rather than just one finger also seems to improve the recognition of 2D raised line drawings (Klatzky, Loomis, Lederman, Wake, & Fujita, 1993). The benefits of using more fingers to obtain tactile information was pointed out long ago by Hatwell (1959) who ascribed the better performance achieved by blind adults in a length estimation task compared to their blindfolded sighted counterparts to the fact that the former used all the fingers of both hands while the latter used only the index finger of the dominant hand. Davidson (1972; Davidson & Whitson, 1974) argued that blind adults outperformed blindfolded sighted individuals in a curvature discrimination task because their exploratory procedures made use of the whole hand instead of just one or two fingers. Loomis, Klatzky, and Lederman (1991) have confirmed the role played by the size of the tactile field in the recognition of tactile patterns and have shown that performance differences between visual and haptic exploration disappear when both fields are reduced to the area covered by one finger. Consequently, the literature, which has tended to focus on adults, suggests that procedures that mobilize several fingers, such as the enclosure procedure and the bimanual contour-following procedure, should lead to the best performance in terms of the extraction of shape information. We therefore asked ourselves whether the same types of finding might be observed in visually impaired and blindfolded sighted children.

Indeed, children are much less efficient than adults in their haptic exploratory procedures which develop gradually with age. Piaget and Inhelder (1947/1963) reported that up to around 5 years of age, children's manual exploration remains partial and incomplete and is unsuitable for the extraction of shape information. Although the use of the fingers to explore object contours emerges at around 5 years of age, it does not adhere to any systematic method that would determine a reference point around which children could organize their exploratory movements. This type of organized exploratory procedure that permits the extraction of shape information starts to emerge as of 7 years of age. A very similar overall developmental schema was observed in an object localization task in which appropriate planned explorations did not appear before 9 years of age (Hatwell, Osiek, & Jeanneret, 1973) as well as in a length estimation task, in which systematic and appropriate explorations were observed as of 12 years of age (Abravanel, 1968). An improvement in the manual exploratory activities of congenitally blind children has also been found between 4 and 7 years of age (Simpkins, 1979; Simpkins & Siegel, 1979), despite the fact that the exploratory movements of these blind children seemed to be much less organized than might have been expected (Berlà, 1972; Berlà & Butterfield, 1977). Furthermore, the literature also suggests that the nature of the exploratory procedures used by children influences the quality of their perception. For instance, Berlà (1972) reported that unsystematic exploratory movements involving the hands and fingers were associated with a low level of tactual discrimination in blind children. Similarly, it has been shown that the thoroughness of the object exploration performed by blindfolded sighted children or blind children is positively correlated with their recognition scores (Morrongiello et al., 1994). Hatwell, Orliaguet, and Brouty (1990) argued that the increase in the speed of haptic processing between 5 and 9 years of age is at least partly due to the improvement in the quality of the exploratory procedures. Schwarzer, Küfer, and Wilkening (1999) coded the types of exploratory procedures used by young children asked to focus on texture information during a task requiring the haptic classification of 3D objects. These authors observed that despite being asked to focus on texture, the children also employed procedures, such as the contour-following procedure, that are specific to the extraction of shape information. This finding suggests that a fairly loose relationship exists between the exploratory procedure used and the type of information collected. Thus, although some of these findings are encouraging, the information they provide concerning the relationships between the exploratory procedures employed by children, whether blind or not, and their subsequent performance levels remains vague. What specific types of exploratory procedure are executed if children are to extract accurate information about the shape and size of objects? Is the child's visual status relevant when considering these relationships between action and perception?

In the present study, we asked blind children, children with low vision and age-matched blindfolded sighted children to perform a detailed exploration of bidimensional tactile patterns so that they could subsequently produce a precise drawing of the corresponding shape. Two age groups were included in the study. One of these consisted of children of approximately 7 years of age and the other of children of approximately 11 years of age. The quality of haptic processing has not often been assessed on the basis of drawings (see, however, Piaget & Inhelder, 1947/1963). However, a recent study has demonstrated that drawing constitutes a very effective way of revealing the understanding of shape since better performances were observed when the participants were required to draw the explored shapes than to name them (Kalia & Sinha, 2011). Indeed, the fact that drawing requires a progressive integration of locally gathered information is likely to be beneficial for the reconstruction of shape. It could be objected that drawing is an unusual and difficult task for children with severe visual impairments. However, several studies have shown that blind children possess genuine drawing abilities (e.g., D'Angiulli & Maggi, 2003; D'Angiulli, Miller, & Callaghan, 2008; Kennedy, 1982, 1993). Furthermore, the fact that blind children without associated disorders are now systematically included in normal classes means that drawing has become a regular activity for these children. In our study, all the visually impaired children were able to draw.

According to the literature, at 7 years of age, exploratory activity should already be quite organized regardless of visual status. However, we expected to find an age-related improvement in the use of the exploratory procedures that are most appropriate for the extraction of shape and size, especially in sighted children who do not regularly perform this type of perceptual exploration. Since haptic perception places a considerable load on both attention and working memory (Hochberg, 1986; Loomis et al., 1991), age effects can be expected. Blind children, and possibly also children with low vision, should use procedures, such as bimanual explorations, that enlarge their tactile field more frequently than sighted children. They should also exhibit a more diversified range of types of haptic exploration and this might be evident in the number of different exploratory procedures employed. More importantly, we expected that, regardless of visual status, when shape extraction-oriented procedures were used (i.e., the contour following procedure, bimanual exploration, symmetrical movements), the resulting drawing of the explored patterns should be accurate. Conversely, the use of procedures that are not appropriate for the encoding of shape information (see Lederman & Klatzky, 1987) should lead to inaccurate drawings.

2. Method

2.1. Participants

Three groups of children participated in the study: 18 early blind children (12 girls and 6 boys), 20 children with low vision (9 girls and 11 boys), and 24 sighted children (13 girls and 11 boys). The children with a visual handicap did not present any other known cognitive or psychiatric disabilities, as reported by parents and teachers. They attended normal classes and were not academically retarded in any way. It should be noted that selecting visually handicapped children without associated disorders greatly restricted the number of participants per group.

The early blind group included 8 totally blind children (no light perception) and 10 children with reduced light perception and no perception of shapes and positions (best corrected visual acuity below 20/70). The causes of blindness were congenital cataracts, congenital glaucoma, retinopathy of prematurity, anophthalmia, optic atrophy and Leber's disease. These children were aged between 6 and 13 years ($M = 9.7$ years, $SD = 2.4$). Fourteen of them drew regularly (at least once a week), while the other four drew less frequently (but at least once a month). They were divided into 2 age groups of 9 children each: one group aged approximately 7 years ($M = 7.7$ years, $SD = 1.25$) and one group aged approximately 11 years ($M = 11.8$ years, $SD = 1.02$).

The low vision group comprised 20 children aged between 6 and 13 years ($M = 10.1$ years, $SD = 2.1$) who were subdivided into two age groups of 10 children each: one group aged approximately 7 years ($M = 7.8$ years, $SD = .95$) and the other aged approximately 11 years ($M = 11.7$ years, $SD = 1.32$). Their corrected visual acuity was between 1/60 and 3/18 ($n = 8$ between 1/60 and 3/60, $n = 8$ between 3/60 and 6/60, $n = 4$ between 6/60 and 6/18). The onset of visual impairment in all of these children had occurred before 18 months of age. The main causes of visual impairment were congenital cataracts, macular degeneration, severe myopia, glaucoma, peripheral vision dysfunction and retinal atrophy. All the children drew regularly.

The sighted group consisted of 12 7-year-old children ($M = 7.2$ years, $SD = .32$) and 12 11-year-old children ($M = 11.3$ years, $SD = .46$). These children had normal or corrected to normal vision and were not educationally advanced or retarded. They also drew regularly.

All the children were tested individually at home or at school. Informed written consent was obtained from the parents of each child participating in the study. The experiment was conducted in accordance with the tenets of the World Medical Association Declaration of Helsinki on Ethical Principles for Medical Research Involving Human Subjects.

2.2. Material

The stimuli consisted of non-meaningful 2D patterns made from a thin foam material (1 mm) that is commonly used for the images present in illustrated tactile books. These stimuli are depicted in Fig. 1. One pattern was employed to demonstrate the task instructions (Fig. 1A), while six patterns were used for training (Fig. 1B) and the other six (Fig. 1C) served as the basis for the analysis of the children's exploratory procedures and drawings. These patterns were glued to curtain cards of identical sizes (12.5 cm × 16.5 cm). The height, length and width of the experimental patterns varied between 4 and 7 cm.

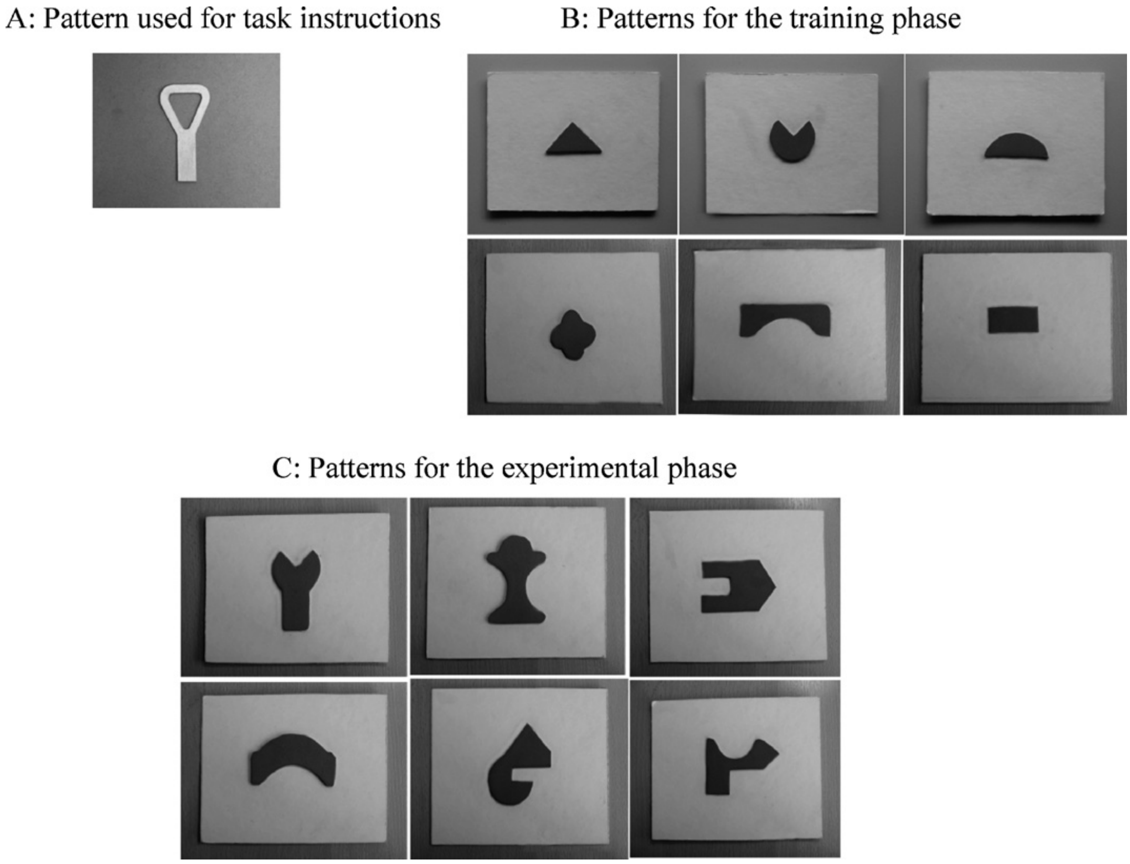

Fig. 1. Illustrations of the patterns.

The children were comfortably seated at a table to which a vertical curtain measuring 50 cm × 32 cm was fixed using two wooden wedges. This curtain was used to prevent the sighted children from seeing the patterns which they were asked to explore haptically. Although this mode of presentation was unnecessary for the blind children, the same experimental setup was used for the different groups. To touch the patterns, the children passed their hands through an opening (32 cm × 6.5 cm) located at the bottom of the curtain.

Each time a child finished exploring a pattern, the masking screen and card were removed in order to allow him or her to draw. Because all the visually impaired children had experience of drawing, they were free to choose the material they were more familiar with. Only eleven children (9 blind children, 2 children with low vision) chose to draw using a raised-line Swedish drawing kit. The drawings were produced using a ballpoint pen on plastic sheets (21.5 cm × 31.85 cm) placed on a rubberized board. The pressure of the ballpoint pen on the plastic sheet produced a raised line which enabled the participants to benefit from haptic feedback during drawing execution. The sighted children, 18 of the visually impaired children and 9 of the blind children selected normal or large black pencils and sheets of paper for drawing. A video camera located above the children's hands recorded their exploratory procedures. We decided not to impose to sighted children to draw in a blindfolded condition, so that all the children produced their drawings in usual and familiar conditions.

2.3. Procedure

The children were told to use their hands to explore patterns located behind the curtain that was positioned in front of them by passing their hands through the opening. When they were comfortably seated with their hands behind the screen, the experimenter gave them the demonstration pattern (Fig. 1A) and explained that all the patterns that they would be asked to explore later would be made of similar material. The experimenter encouraged the children to perform exploratory movements with their two hands and their fingers in order to get "a very good idea of the shape of the pattern so that they would be able to draw it afterwards". The instructions encouraged bimanual exploration because the literature has revealed the importance of this mode of exploration in making shape salient (e.g., Klatzky et al., 1987). The card was held in place by a special glue with its center aligned with the midline of the child's body. If the children did not spontaneously explore the demonstration pattern, the experimenter helped them to move their hands and fingers around the shape. When the children decided that they were ready to draw, the experimenter removed the screen and the demonstration pattern and gave the children the drawing material.

Once the entire procedure had been explained on the basis of the demonstration pattern, the experimenter told the children that they would then practice the operation with different patterns (the training patterns, see Fig. 1B) before moving on to the test phase itself (using the experimental patterns, see Fig. 1C). Given that progressive adaptation of the exploratory activity to the task has been reported in the literature (Richard, Vaz-Cerniglia, & Portalier, 2004), the training phase was important since it familiarized the children with the procedure and the material and gave them the opportunity to establish a relationship between exploration and drawing. The same procedure was used with the training or experimental patterns. The patterns were placed behind the screen one at a time using the same procedure, and there were no time limits for exploring and drawing them. Each time a new pattern was put into position, the experimenter verbally encouraged the children to perform a complete and precise exploration with their hands and fingers so that they could then produce an accurate drawing. The patterns were presented in a random order. No feedback was given to the children concerning their exploratory or drawing performance. They were allowed to produce a new drawing if they were not satisfied with their first attempt. Each drawing was produced on a separate sheet of paper or plastic.

2.4. Data coding

Two pairs of judges working separately coded the use of different exploratory procedures described in the literature (see the related references for a more extensive definition of each procedure and of its coding). The coders were unaware of both the experimental hypotheses and the identity of the participants. Movements that took less than 1 s were ignored. The presence of each individual exploratory procedure was coded, regardless of its duration:

- *Contour following* (Lederman & Klatzky, 1987): dynamic edge following using finger movements.
- *Enclosure of the global shape* (Lederman & Klatzky, 1987): dynamic molding of the palm and/or fingers to the shape's contours.
- *Enclosure of local shapes* (partial enclosure, Reed, Lederman, & Klatzky, 1990): dynamic molding of the fingers to parts of the pattern.
- *Pinch procedure* (Davidson, 1972): holding edges in a pincer grip between the thumb and one or more other fingers.
- *Surface sweeping* (Davidson, 1972; similar to lateral motion, Lederman & Klatzky, 1987): dynamic and usually repetitive movement of one or more fingers or of the palm over the model's surface.
- *Static contact* (Lederman & Klatzky, 1987): stationary contact with the surface without molding.
- *Symmetrical movements* (Ballasteros et al., 1997): symmetrical finger displacements around the pattern's shape during the bimanual execution of the contour following procedure.

The judges also coded the total exploration time for each pattern as well as whether the exploration was bimanual or unimanual. Before the coding phase, the four judges were jointly trained to identify the different procedures until they reached a level of 80% agreement for the coding of six sequences (here, the term "sequence" refers to the recording of a child's explorations of one pattern). This training was performed using the recordings made during the children's exploration of the training patterns. The 372 sequences involving the experimental patterns were randomly subdivided into two halves and each pair of judges was assigned 186 sequences for coding. The mean percentage agreement was 86% for one pair of judges and 82% for the other pair. The disagreements were settled before analysis.

As far as the drawings are concerned, a variety of criteria were assessed (see Fig. 3 for illustrations):

- The degree of *resemblance* (or *iconicity*) between the drawing and the model (low = 0, medium = .5, high = 1).
- The presence in the drawing of *salient local shape features* present in the model.
- Whether *contour lines* were used to draw the model (if they were not, the drawing was constructional (Freeman, 1980), i.e. made up of an assembly of delineated parts).
- Whether the model was assimilated to a familiar known shape (*assimilation*).
- Whether the model was reproduced as a series of juxtaposed parts rather than as a single integrated shape (*juxtaposition*).
- The *size* of the drawing compared to that of the model (the differences in height and width between the drawing and the model were calculated as absolute values and the mean was computed. The lower this score was, the closer the size of the drawing was to that of the model).
- Whether the drawing was a *closed shape* or not.

The same four judges, still unaware of the purpose of the experiment, were trained to apply these criteria to a selection of drawings obtained with the training patterns. A satisfactory level of convergence between them (80% of agreement) was rapidly achieved. The 372 drawings of the experimental shapes were again subdivided randomly into two halves and each pair of judges saw 186 drawings for coding. The percentage agreements were 91% for one pair of judges and 88% for the other. The disagreements were settled before analysis.

3. Results

The aim of the present experiment was to correlate the use of different exploratory procedures in the 3 groups of children with performance levels as assessed by their drawing performance. However, before examining these correlations, it is

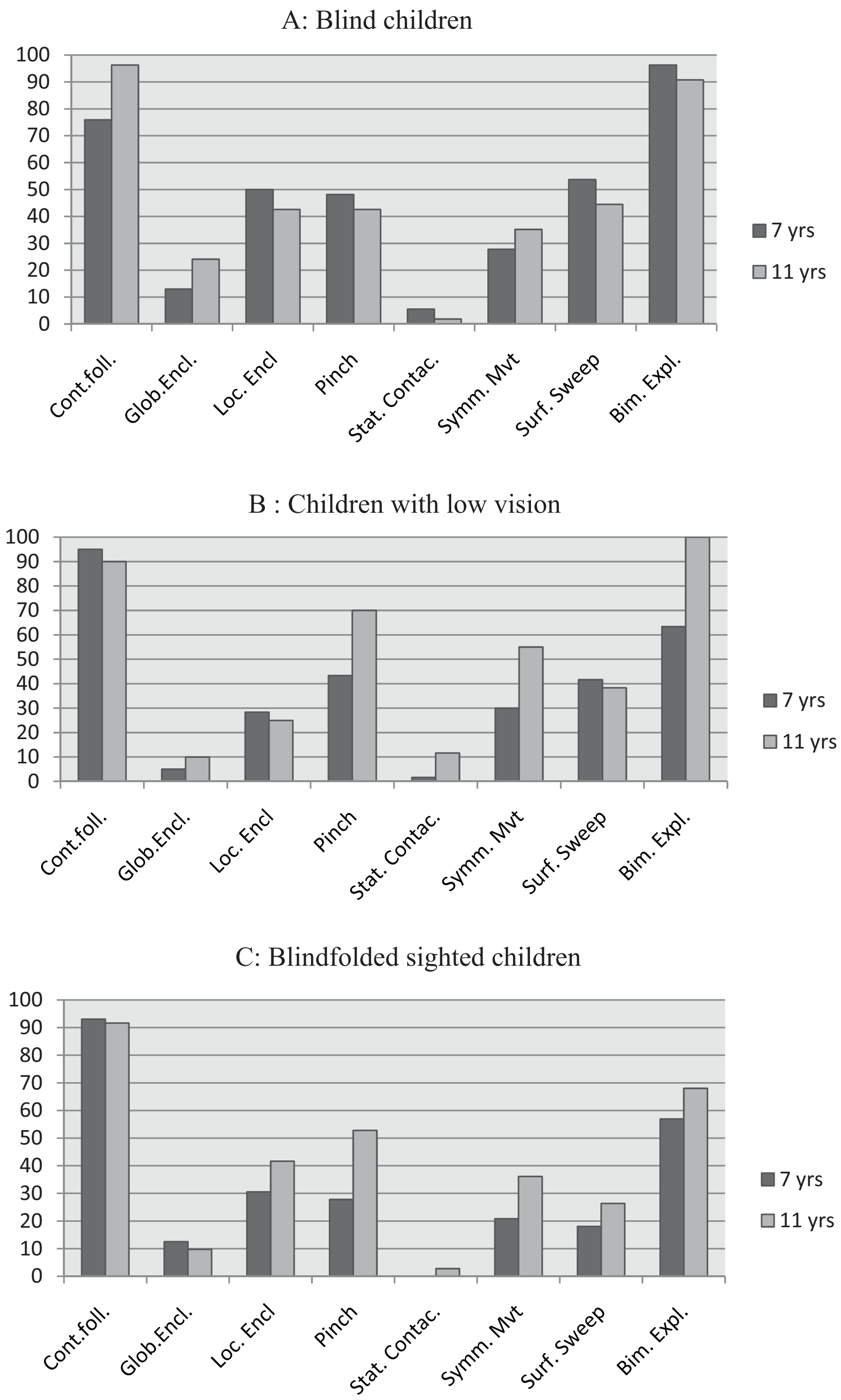

Fig. 2. Frequencies of use of the different exploratory procedures as a function of age and visual status.

interesting to consider the overall distribution of the different procedures as a function of the visual status and age of the children. Fig. 2 presents the relevant data.

On average, at 7 years of age, the blind children employed 2.74 different procedures when exploring a pattern and exhibited a mean exploration time of 23.5 s, whereas at 11 years of age, they used an average of 2.87 procedures across a mean exploration period of 18.8 s. Fig. 2A shows that their explorations were almost always bimanual (M = 93%, SD = 12.9), that they frequently used the contour following procedure (M = 86%, SD = 20), while making less regular use of the surface sweeping (M = 49.1%, SD = 38), local enclosure (M = 46%, SD = 33) and pinch (M = 45%, SD = 26) procedures. Their bimanual movements were symmetrical contour following movements in 31% of cases. The global enclosure procedure did not occur often (M = 18.5%, SD = 18), and the static contact strategy was rarely observed (M = 3.7%, SD = 9).

This profile differed from those observed in the other two groups of children (see Fig. 2A and B). An ANOVA run with Visual Status (3) and Age (2) as between-subjects factors revealed that the blind children and the children with low vision employed more different procedures (M = 2.7, SD = .48) than the sighted children (M = 2.3, SD = .6), $F(2,56) = 1.5$, $p < .05$, $\eta^2 = .05$. By contrast, the exploration times per pattern did not vary significantly as a function of visual status, $F < 1$. However, a just significant interaction revealed that these times decreased with age in both the blind children (from 23.5 s to 18.8 s) and the sighted children (from 26.9 s to 19.1 s), whereas they increased with age in the children with low vision (from 18.5 s to 28.7 s), $F(2,56) = 3$, $p = .05$, $\eta^2 = .10$.

A number of other differences were observed between the three groups of children. The blind children and the children with low vision used the surface sweeping procedure significantly more often ($M = 40\%$, $SD = 35$) than the blindfolded sighted children ($M = 22.\ 2\%$, $SD = 32$), $F(2,56) = 3.2$, $p < .05$, $\eta^2 = .10$. These visually impaired children also explored the shapes bimanually ($M = 81.6\%$, $SD = 32$, for the children with low vision) significantly more often than the sighted children ($M = 62.5\%$, $SD = 40$), $F(2,56) = 5.4$, $p < .01$, $\eta^2 = .16$. Planned comparisons showed that the blind children employed the global enclosure procedure ($M = 18.5\%$, $SD = 17$) more often than the children with low vision ($M = 7.5\%$, $SD = 11$), $F(1,56) = 4.7$, $p < .05$, $\eta^2 = .08$. The same phenomenon was also observed for the local enclosure procedure ($M = 46\%$, $SD = 33$, for the blind children, $M = 26.6\%$, $SD = 24$, for the children with low vision), $F(1,56) = 4.3$, $p < .05$, $\eta^2 = .07$. The use of the contour following procedure increased with age in the blind children (from 76% at 7 years of age to 97% at 11 years of age), while it remained stable across ages in the children with low vision and in the sighted children (between 90 and 95%), $F(2, 56) = 3.6$, $p < .05$, $\eta^2 = .11$. This was the only procedure that evolved significantly with age in the blind children. In the other two groups of children, a significant age-related increase was observed in the use of the pinch procedure, $F(1, 40) = 6.6$, $p < .05$, $\eta^2 = .14$, symmetrical movements, $F(1, 40) = 7.4$, $p < .01$, $\eta^2 = .16$, and bimanual exploration, $F(1, 40) = 4.9$, $p < .05$, $\eta^2 = .11$.

How did these exploratory procedures relate to subsequent drawing performance? We computed Bravais–Pearson correlations between the mean frequency of use of the exploratory procedures and the mean frequency of occurrence of each drawing criterion in each group. Variables that showed either ceiling ($M > 90\%$) or floor effects ($M < 10\%$) were discarded from the analysis. Because age correlated significantly with some of the drawing and exploratory procedure variables, we computed correlations with the effect of age partialled out. Tables 1A, 1B and 1C present the partial correlations (and the associated levels of significance) obtained in the blind group, the group with low vision and in the blindfolded sighted group

Table 1
Partial correlations (with the effect of age partialled out) between children's percentage use of each of the exploratory procedures and the number of drawings meeting each drawing performance criterion.

(A) Blind children

	Recognizable shape	Salient features	Closed shape	Size differences	Contour lines	Assimilation	Juxtaposition
Mean	.37	50.5%	68.3%	.20	77.8%	12%	15.74%
Contour following	.49* $p < .05$	.45 $p = .06$	.21 ns	−.40 ns	.48* $p < .05$	−.08 ns	−.32 ns
Global enclosure	.20 ns	.23 ns	.24 ns	−.01 ns	.20 ns	−.39 ns	−.23 ns
Local enclosure	.29 ns	.36 ns	.44 $p = .07$	−.20 ns	−.45 $p = .06$	−.21 ns	−.42 ns
Pinch	.61* $p < .05$	.58* $p < .05$	.51* $p < .05$	−.40 ns	.34 ns	−.31 ns	−.36 ns
Surface sweeping	−.47 $p = .05$	−.47* $p = .05$	−.31 ns	.34 ns	−.04 ns	.23 ns	.54* $p < .05$
Symmetrical movements	.48* $p = .05$	.35 ns	.25 ns	−.37 ns	.20 ns	.15 ns	−.20 ns
Number procedures	.60* $p < .05$	.55* $p < .05$	.55* $p < .05$	−.39 ns	.25 ns	−.25 ns	−.25 ns
Time	.25 ns	.42 ns	.41 ns	−.46 $p = .06$	.13 ns	−.10 ns	−.13 ns

(B) Children with low vision

	Recognizable shape	Salient features	Size differences	Contour lines	Assimilation
Mean	.44	68.2%	.22	85.8%	14%
Local enclosure	−.01 ns	−.04 ns	−.06 ns	.18 ns	−.27 ns
Pinch	.19 ns	.14 ns	−.08 ns	−.07 ns	.26 ns
Surface sweeping	−.18 ns	−.44* $p = .05$	.60* $p < .05$	−.29 ns	.02 ns
Symmetrical movements	.44* $p = .05$	.39 ns	−.23 ns	.51* $p < .05$	.24 ns

Table 1 (*Continued*)

(B) Children with low vision

	Recognizable shape	Salient features	Size differences	Contour lines	Assimilation
Mean	.44	68.2%	.22	85.8%	14%
Number procedures	.18 ns	.02 ns	.19 ns	.13 ns	.19 ns
Time	−.33 ns	−.31 ns	.38 ns	−.15 ns	.17 ns
Bimanual exploration	.26 ns	.01 ns	−.001 ns	.20 ns	.28 ns

(C) Blindfolded sighted children

	Recognizable shape	Salient features	Size differences
Mean	.39	49.4%	.32
Global enclosure	.45* $p < .05$	.47* $p < .05$	−.10 ns
Local enclosure	.03 ns	.17 ns	−.01 ns
Pinch	.25 ns	.40* $p = .05$	.03 ns
Surface sweeping	−.27 ns	−.37 $p = .07$	−.001 ns
Symmetrical movements	.49* $p < .05$	.49* $p < .05$	−.10 ns
Number procedures	.37 $p = .07$	.45* $p < .05$	−.09 ns
Time	.06 ns	−.01 ns	−.13 ns
Bimanual exploration	.46* $p < .05$	.43* $p < .05$	−.08 ns

* Significant correlations.

respectively. Each drawing criterion is reported in the tables together with its mean percentage of occurrence. An analysis of the drawing performance lies beyond the scope of the present paper and would also require too much space. However, a few comments are worth making (Fig. 3). The drawings produced by the sighted children did not globally look more similar to the models ($M = .39$, $SD = .25$) than those collected from the blind children ($M = .37$, $SD = .33$), $t(40) = .28$, *ns*, or the children with low vision ($M = .44$, $SD = .23$), $t(42) = -.71$, *ns*. It is interesting to note that at the descriptive level, the children with low vision achieved the best performance in terms of resemblance to the model. Although drawing performance was not very good at 7 years of age (the resemblance scores were around .28–.30), it improved with age (the scores reached .50–.60 at 11 years of age). Only the blind group produced juxtaposed drawings and drawings with open shapes. In the other two groups, these types of drawings were very rare (occurrence of between 0 and 6%).

Table 1A shows that five procedures correlated positively with the drawing variables that indicated the correct reproduction of the patterns in the blind group. The contour following procedure was associated with the production of recognizable shapes ($r = .49$, $p < .05$) made of contour lines ($r = .48$, $p < .05$) and tended to be associated with the production of drawings with salient features ($r = .45$, $p = .06$). The greater the use made of the global enclosure strategy, the less likely the patterns were to be assimilated to familiar objects ($r = -.45$, $p = .05$). The pinch procedure was associated with the drawing of recognizable shapes ($r = .61$), containing salient features ($r = .58$, $p < .05$), and drawn as closed shapes ($r = .51$, $p < .05$). The use of symmetrical movements was also beneficial for the production of recognizable shapes ($r = .48$, $p < .05$). Furthermore, the larger the number of different procedures used by the blind children, the more recognizable the drawings were ($r = .60$, $p < .05$), and the more likely they were to be characterized by salient features ($r = .55$, $p < .05$) and closed shapes ($r = .55$, $p < .05$). Exploration times tended to correlate positively with the size of the produced drawings, with size being more accurate when exploration times were longer (size differences between the produced drawing and the model tended to decrease as exploration time increased, $r = -.46$, $p = .06$). By contrast, one procedure had a negative impact on drawing performance. Increased use of the surface sweeping strategy resulted in a lower probability of recognizable productions ($r = -.47$, $p < .05$), the reduced presence of salient features ($r = -.47$, $p < .05$), and the more frequent production of drawings with juxtaposed parts ($r = .54$, $p < .05$). Finally, the local enclosure procedure led to more ambiguous results. On the one hand, it tended to be negatively correlated with the production of drawings with contour lines ($r = -.45$, $p = .06$), while, on the other, it tended to be positively correlated with the production of closed shapes ($r = .44$, $p = .07$).

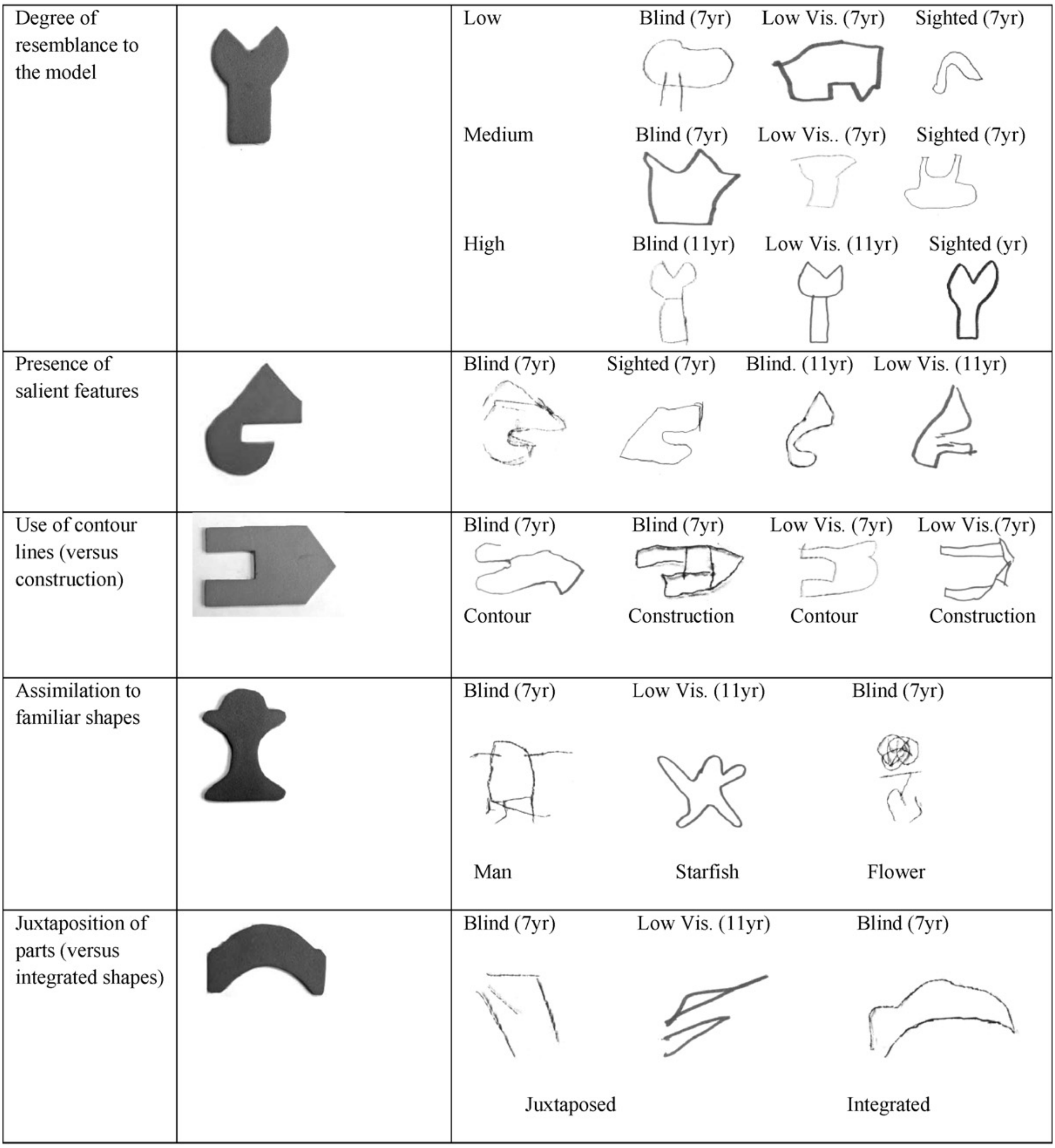

Fig. 3. Illustrations of the different drawing performance criteria.

The data obtained from correlations observed in the children with low vision were consistent as indicated in Table 1B, even though only a small number of exploratory procedures were found to correlate significantly with certain drawing variables. As was observed for the blind participants, the use of symmetrical movements was positively associated with variables indicating good drawing performance (recognizable shapes, use of contour lines). Again, in the same way as in the blind participants, the surface sweeping procedure was related to negative aspects of performance. The more this strategy was used, the greater the difference in size between the model and the production was ($r = .60$, $p < .05$), and the fewer salient features the drawings contained ($r = -.44$, $p < .05$). In the blind group, by contrast, neither the use of the local enclosure procedure or the pinch procedure nor the exploration times correlated significantly with any drawing variables in the group with low vision.

To what extent were these patterns of correlations specific to the visually handicapped children? The drawings produced by the sighted children were almost always drawn in contour lines ($M = 97.2\%$, $SD = 9.4$) and were very rarely assimilated to familiar objects ($M = 2.8\%$, $SD = 9$). Consequently, there were fewer variables attesting to the drawing performance of the sighted children. Table 1C shows that three exploratory procedures had the same positive relationships with drawing performance in the sighted controls as in the two groups with visual handicaps, i.e. the pinch procedure, symmetrical movements and the use of multiple strategies. The greater the value measured for these variables, the more recognizable the reproduction of the shape of the model was and the more salient features it possessed. The use of two other procedures was beneficial for drawing in the sighted controls. Both bimanual exploration of the models and the use of the global enclosure procedure correlated positively with the production of recognizable drawings and of shapes with salient features. Finally, in the same way as in the other groups, the surface sweeping procedure tended to correlate negatively with the production of salient features in the drawings, while the local enclosure procedure and the exploration times did not correlate with any of the three drawing variables used for this analysis of the drawings produced by the sighted children, as was also the case for the children with low vision.

4. Discussion

It is not easy for blind individuals to access shape information. The only perceptual system that they can use to process this object property, i.e. the haptic system, collects sequential, fragmented information and a further step involving its integration is therefore required in order to complete the perception process. However, the complexity of this processing is clearly due to the very specific way in which the information is gathered. The types of manual procedure employed by blind children when they explore patterns could indeed determine, at least in part, the accuracy of their shape perception. The aim of the present study was to investigate these relationships between action and perception in children exhibiting different degrees of visual impairment. Identifying which of the exploratory procedures spontaneously employed by blind children are beneficial for or, to the contrary, detrimental to the extraction of shape information might help us define a pedagogy of tactile image exploration which will make it easier for such children to understand the tactile books available to them. At the same time, the present study provides interesting findings relating to the types of exploratory procedures used by children with different visual statuses when asked to extract shape information in order to draw the explored pattern as accurately as possible.

The haptic explorations of both the sighted and visually impaired children seemed to be performed actively and were generally adapted to the task demands, as the very low level of use of the static contact procedure by all the children testifies. Contrary to what might have been expected on the basis of Berlà's findings (1972, 1974, 1981), the children with a visual handicap exhibited greater expertise during their haptic explorations than the sighted children, as their more frequent use of bimanual exploration and the greater number of different procedures employed by them when exploring patterns indicate. This result echoes those reported in a recent study which found that blind adolescents employed both hands and used multiple strategies more often than sighted adolescents in mental rotation tasks (Rovira, Deschamps, & Baena-Gomez, 2011; see also Heller, 1989). In our study, although all the children were encouraged to explore the patterns bimanually, only the blind children systematically did this from an early age. This may be due to the fact that they had received specific instruction in haptic exploration and had thus discovered that bimanual activity helps enlarge the receptive tactile field (Ballasteros et al., 1997; Wijntjes et al., 2008). The greater diversity of procedures employed by visually impaired children, including strategies oriented toward the extraction of information about the pattern as a whole (contour following, surface sweeping), on the one hand, and about local features (pinch, local enclosure), on the other, suggests that they may alternate more systematically than sighted children between coarse and specific information extraction steps as defined by Klatzky and Lederman (1987).

With increasing age, a larger number of procedures emerge in sighted children and in children with low vision than in blind children. The use of the pinch procedure (suitable for the processing of salient local features such as edges or spikes, Davidson, 1972), as well as of bimanual and symmetrical contour following movements (suitable for the processing of precise global shape information, Ballasteros et al., 1997; Lederman & Klatzky, 1987) has been found to develop with age in sighted children and children with low vision, thus confirming the view that haptic exploration becomes more complete and task-appropriate with age (Piaget & Inhelder, 1947/1963; Morrongiello et al., 1994). Only the use of the contour following procedure increased with age in the blind children. This later development of the contour following procedure in blind children, together with their more extensive use of the surface sweeping procedure, could indicate that the awareness of which procedure is most appropriate for the accurate extraction of shape information emerges later in these children. One surprising finding was that the children with a visual handicap employed the surface sweeping procedure more often than the sighted children since this procedure seems to be inappropriate for the encoding of shape information but optimal for the processing of texture information (Lederman & Klatzky, 1987). We suggest that this procedure, used in combination with the contour following procedure, makes it possible to avoid the confusion between foreground and background that is likely to be induced by the presence of the shape contour lines (Kennedy & Domander, 1984), since it enables participants to explore the filled internal region. Finally, the blind children employed the global and local enclosure procedures more often than the children with low vision. This indicates that a total lack of vision may encourage children to use their hands to apprehend larger portions of the pattern than are accessible to them using the contour following procedure.

Exploration times decreased with age in both the blind and sighted children, as might have been expected on the basis of studies that have revealed an improvement in haptic processing speed with development (Berger & Hatwell, 1995, 1996). By contrast, they increased with age in the children with low vision. There is no clear way to account for this result, and replications are obviously needed in order to determine whether it can be considered meaningful. It may be due to the fact that the older children with low vision tended to employ slower local procedures, such as symmetrical contour following movements and the pinch procedure, more frequently than their age-matched counterparts.

More importantly, regardless of visual status, strong relationships were revealed between the types of exploratory procedures employed by the children and their consequent performance in drawing. This confirms similar findings in the literature which have not however, been obtained in connection with drawing or in children (Gaunet & Thinus-Blanc, 1996; Lederman & Klatzky, 2004). Our results are consistent with a recent study conducted by Kalagher and Jones (2011) who demonstrated that the production of two specific hand movements by sighted children aged younger than 5 years in a haptic task predicted their subsequent choice of a same shape match in an object matching task. In our experiment involving older children with different visual statuses, the greater the number of procedures appropriate for shape encoding that were used (Davidson, 1972; Lederman & Klatzky, 1987, 1993; Wijntjes et al., 2008), whether global (i.e., contour following, symmetrical movements, global enclosure, bimanual exploration) or local (pinch) in nature, the greater the number of employed strategies was, the more the drawings resembled the model and/or were characterized by salient features and/or were produced using contour lines (Freeman, 1980). The ability to interpret contours therefore seems to be present even in the absence of visual inputs as claimed by Kennedy (1993) even though the generally poor level of drawing performance observed suggests that the processing shape information in the haptic modality is an intrinsically difficult task (Lederman & Klatzky, 1987). It appears that the possibility of translating haptic information into visual information did not confer any clear-cut advantage on the sighted children in the drawing task, possibly because the patterns represented unknown shapes (Heller, 1989; Lederman & Klatzky, 1990). However, as has already been reported in a number of studies, the children with low vision tended to outperform the blind and sighted children in the drawing task. This suggests that a residual visual capacity associated with haptic skills leads to the best performance in spatial recognition tasks (Heller, 2002; Passini, Proulx, & Rainville, 1990; Ungar, Blades, Spencer, & Morsley, 1994).

The importance of observing a positive correlation between the contour following procedure and correct drawing performance in children should not be underestimated. Although this procedure permits the precise encoding of shape, Lederman and Klatzky (1987) have also shown that it is slow and therefore easily induces inaccuracies due to its cost in terms of memory and information integration processes. Bimanual exploration and the use of symmetrical movements undoubtedly help reduce this cost by speeding up the haptic information encoding process (Craig, 1985). The pinch procedure correlated with shape drawing accuracy in our blind children, while the local enclosure procedure did not. This latter procedure mobilizes the thumb and the index or middle fingers, i.e. the fingers with the highest functional and discriminative capacity (Moberg, 1958; Tubiana & Thomine, 1990). In our study, the more frequently the blind children used the local enclosure and pinch procedures, the more likely the drawings they produced were to depict closed shapes. Since this specific characteristic of drawing in blind children at the ages studied here correlated with the execution of specific exploratory procedures, the tendency to draw open shapes may very well not be due solely to the difficulty they experience in monitoring the drawing execution process itself, but also to the way the corresponding information is gathered.

Interestingly, in the blind children, the use of certain exploratory procedures was clearly detrimental to the quality of drawing production. The surface sweeping procedure led to poorly recognizable drawings, containing few salient features and produced as juxtaposed elements. In the children with low vision, this procedure was prejudicial to size accuracy and to the inclusion of salient features. In the sighted children, it again tended to be associated with drawings that possessed few salient features. These results confirm the idea that the surface sweeping (or lateral motion) procedure is not suitable for shape extraction (Lederman & Klatzky, 1987). The fact that its use is associated with the drawing of patterns as juxtaposed parts and without salient features suggests that this procedure provides rudimentary geometrical-level information indicating the presence of something undetermined at the various points covered by the participants' lateral hand movements over the surface of the pattern. The resulting fragmentary representations of the patterns tended to be depicted as illustrated in Fig. 2, i.e. as a combination of segments. Children who have even a restricted visual experience are unlikely to draw juxtaposed elements, possibly because their experience has helped them to formulate an a priori hypothesis of "shape uniqueness" which leads them to draw a single closed shape. This illustrates how the resulting representation of the explored pattern could be the product of complex top-down (a priori knowledge) and bottom-up (the method used to extract information) influences. The close coupling between action and perception in the haptic field clearly implies both top-down and bottom-up information processing (Alexander, Johnson, & Schreiber, 2002; Kalia & Sinha, 2011; Lederman & Klatzky, 2009).

Exploration times tended to have an impact on subsequent drawing performance in blind children. It takes time to encode spatial properties in the haptic modality. However, it was only in the blind children that longer durations were associated with better size reproduction, as might have been expected on the basis of other findings revealing that longer exploration times lead to improved global shape encoding (Berger & Hatwell, 1993; Lakatos & Marks, 1999). It is possible that sighted children, and possibly also children with low vision, process haptic information as described in the image mediation model (Klatzky & Lederman, 1987), i.e. by translating the sequentially collected haptic information into visual images, while blind children operate in accordance with the direct haptic apprehension model (Klatzky & Lederman, 1987) and make use of the processing mechanisms available to the haptic system. Exploration time would have a positive impact only in the case of direct haptic apprehension since, when haptic information is translated into visual images, errors or difficulties can arise at any moment during exploration.

Finally, one drawing variable was never significantly associated with an exploratory procedure: the production of drawing errors due to the assimilation of the explored pattern to familiar shapes. Such assimilation-based errors were noted by Piaget and Inhelder (1947/1963) in young children exploring tactile patterns. Such errors indicate that a hypothesis testing process is undertaken during haptic exploration, with the children making guesses about the identity of the pattern (Kennedy & Bai, 2002; Klatzky & Lederman, 1987). Our results suggest that the visually impaired children also analyzed the haptic information in accordance with a hypothesis testing process and that this process may be mobilized independently of the type of exploratory procedure executed. It is likely that the children made their guesses on the basis of rudimentary information that could be gathered whatever the procedure.

In conclusion, this study suggests that certain exploratory strategies are optimal for the encoding of the shape and size of bidimensional patterns, and especially in blind children. Since it has been found to be effective to train blind children to perform specific exploratory procedures (e.g. Berlà & Butterfield, 1977; Berlà & Murr, 1974), a specific educational program of exploratory activities could be designed for young blind children when they are introduced to illustrated tactile books. This educational training should intervene early in development given that Berlà (1981) has revealed that training older blind children in specific new exploratory procedures might have a negative impact on their performance, at least initially. Achieving a high level of expertise in the haptic exploration of bidimensional patterns at the earliest possible age might well help compensate for the deficits in spatial representation resulting from the absence of visual experience. This suggestion is consistent with the proposal made by D'Angiulli, Kennedy, and Heller (1998) that graphic expertise in general (reading and drawing) could assist progress in blind children.

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