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Pointing with the left and right hands in congenitally blind children

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Abstract

Congenitally blind and blindfolded sighted children at ages of 6, 8, 10 and 12 years performed a pointing task with their left and right index fingers at an array of three targets on a touch screen to immediate (0 s) and delayed (4 s) instructions. Accuracy was greater for immediate than delayed pointing and there was an effect of delay for the orientation of the main axis of the pointing distribution in both groups, indicating distinct spatial representations with development such as ego- and allocentric frames of reference, respectively. The pointing responses of the blind covered less surface area indicating better overall accuracy as compared to the sighted blindfolded.

The hands differed for four of the six precision and accuracy parameters. The right hand performed better and seemed relatively contextually oriented, whereas the responses of the left hand were closer to the body and egocentrically oriented. The elongation of the scatter of the pointing responses was greater for the boys and more allocentrically oriented, indicating gender differences in spatial representation. The study provides a first evidence of ego- and allocentric spatial frames of reference in congenitally blind children and an ability to point at targets with the left and right hands in the total absence of vision.

Keywords: Delay; Self referent; Contextual; Pointing; Blind

1. Introduction

Hand pointing responses are a valuable measure of performance in spatial localization. They indicate different types of spatial representations and the underlying cognitive mechanisms (Paillard, 1987, 1991). Pointing to memorized targets among sighted individuals in accordance to an immediate or delayed instruction has been deemed to be crucial for the manifestation of ego- and exocentric encoding in reachable space (Gaunet & Rossetti, 2006; Rossetti, 1998; Rossetti, Gaunet, & Thinus-Blanc, 1996; Rossetti & Regnier, 1995).

Studies of pointing at targets in space are crucial for assessing the role of vision (Rossetti and Pisella, 2002). Rossetti and colleagues have demonstrated in a series of experiments with sighted adult subjects (Gaunet & Rossetti, 2006; Rossetti, 1998; Rossetti et al., 1996; Rossetti & Pisella, 2002; Rossetti & Regnier, 1995) the effects of delay on the spatial representations of pointing responses and their underlying cognitive mechanisms. In Rossetti's study, the sighted participant sat before a tactile computer screen; the starting and end point of the hand for pointing at targets was located at the bottom of the screen. Pointing movements were executed to a visual target briefly flashed at a random location. Adult participants had to place their index finger on the remembered visual location after variable memory delays (0 or 8 s). It was observed that the main axis of the pointing distribution (i.e., of the scatter) was mainly oriented along movement direction at 0-s delay indicating the involvement of an egocentric frame of reference and along the direction of the target array for 8-s delay showing the involvement of an exocentric frame of reference.

In a recent study (Gaunet & Rossetti, 2006) with early blind, late blind and sighted blindfolded adults, the

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orientation of the main axis of the pointing distribution for the early blind was aligned with movement direction for both delays; that of the sighted blindfolded differed with delay showing an alignment of the main axis to the target display for the longer delay and to movement direction for the shorter delay, whereas the main axis of the late blind group was intermediate to that of the other two groups for the long delay and was aligned with the direction of movement encoding for the short delay. The delay effect was more pronounced in the visually experienced groups than in the congenitally blind indicating that the involvement of two spatial processing systems depends on early visual experience.

Whereas goal-directed pointing has been extensively studied in infants and in adults (Bradshaw & Watt, 2002), no study has investigated pointing without vision in children and the properties of spatial representation. In the present study, we thus applied the memory guided movement paradigm in congenitally blind and blindfolded sighted children. Our goal is to determine when the effect of delay would appear during development in blind and blindfolded sighted children. In theory, the common accepted idea about cognition in space is that there is a shift from ego- to allocentric mode of space encoding in the sighted during development (Piaget & Inhelder, 1967). However, since the early 1970s, an increasing amount of evidence suggests that Piaget's methodology may have underestimated many of the child's abilities (Feldman, 2004). Besides Millar (1994) has indicated that the congenitally blind children are able to perform in both ego- and allocentric space, although they show difficulties for an allocentric frame of reference.

Theorists have attributed the accuracy of object perception and reaching to specific visual pathways involved in the neural control of action (for example, Jeannerod, 1997a). They argue that visual pathways mediating prehension indicate distinct pathways for visual perception and visual control of movements (Milner & Goodale, 1993), and offer suggestions for different visual pathways in the dorsal stream itself which corresponds to the hypothesis of various visuo-motor channels one for reaching and another for grasping.

However, the effects of feed-back with sighted children suggest that visual feed-back is not always afforded the same privileged status during childhood as in adults, particularly for guiding, reaching and pointing movements (Bard, Hay, & Fleury, 1990; von Hofsten & Rosblad, 1988). The 6–10 years range is of particular interest as it spans a period of development in which the reliance on visual feed-back to monitor and correct reaching has been shown to change. Smyth, Peacock, and Katamba (1994) and Smyth, Katamba, and Peacock (2004) for example have shown that during the development of prehension, 5 and 6 year olds displayed no increase in movement time in the absence of vision, though older children (7–10 years) used visual feed-back to improve efficiency. Interestingly, this developmental process has been found to be non-monotonic. For instance, under suppression of visual feed-back during hand movement conditions, Hay, Bard, Fleury, and Teasdale (1991) found that 7- to 8-year-old children make more spatial errors in pointing tasks than either their older or younger counterparts indicating a greater reliance on vision during this period of development (see also Ferrel-Chapus, Hay, Olivier, Bard, & Fleury, 2002; Hay, 1978). Therefore it is of interest in the present study to know the role of vision and the age related differences for pointing between the congenitally blind and sighted blindfolded children.

A further question of interest is the ability of the hands to represent space by pointing at a sagittal plane. Studies with sighted infants have demonstrated early right hand preferences for discriminating features of objects and left hand preferences for contours of objects (Streri, 2002). Streri (2005) observed that at two months of age when prehension–vision coordination is absent the tactile sense is predominantly utilized and touch to vision transfer of information is observed. At five months when reaching and grasping an object is intensive, vision dominates showing successful vision to touch transfer though little touch to vision transfer. Although Streri's tasks involved the manipulation of three dimensional shapes, they resemble pointing and reaching in structure. Furthermore, among blind children that have had no exposure to vision during development, there is a possibility that they rely on convergent information from modalities other than vision (Streri, 2005). Therefore the hands are well utilized for perceptual and motor functions early in development.

Questions concerning the relationship of hand preference and hand ability among adults have for long indicated that the preferred right hand in most individuals is faster and more accurate than the non-preferred hand under visual control and eyes shut conditions (Annett, Annett, Hudson, & Turner, 1979; Honda, 1984; Morange-Majoux, Peze, & Bloch, 2000; Peters, 1980; Woodworth, 1889). Consequently these authors suggested that the superiority of the preferred side is a consequence of lateralized visuo-motor efficiency. However, Ittyerah (1993, 2000) indicated that the hand preferences and hand ability of congenitally blind and sighted children do not differ. Therefore the general lateralization does not affect performance (Ittyerah, 1993) because possibly it is the nature of callosal traffic that underpins lateralities of movement control in humans and not the dominant hemisphere (Derakhshan, 2003), and hence theories of visuo-motor efficiency are insufficient explanations of hand preference (Annett et al., 1979; Honda, 1984; Peters, 1980; Woodworth, 1889). By implication, the expectation in the present study is that there will be no differences in the pointing ability of the left and right hands of neither the congenitally blind nor sighted blindfolded children.

Furthermore, gender has also been expected to influence spatial cognition. In children's studies of pointing, von Hofsten and Rosblad (1988) observed that in visually and tactually informed conditions, the non-dominant hand of the girls particularly at the youngest ages of 4 and 5 years had more systematic error for manual pointing at table top positions than the dominant or the non-dominant hand of the boys. In a later study, Barral and Debu (2002) found that girls were more accurate than the boys at 5 years for pointing at targets with their left hand, whereas variability in responses was more pronounced among the boys. In view of the general inconsistency of findings in children (Witkins, Goodenough, & Karp, 1967), we expect null effects in the present study between the girls and boys to point at targets.

The present study was designed quite similarly to the previous studies of Rossetti and colleagues, though the question of interest was to know the role of early visual deprivation during development. As there is little work on pointing in blind children and what exists is focused only on quantitative variables, the present study explored pointing movements by groups of congenitally blind and blindfolded sighted children specifically to know the frames of reference used to perform the task. It is also of interest to know whether pointing ability will differ between the hands for immediate and delayed conditions. Two important differences in the experimental set up were introduced with respect to the original paradigm. First, to prevent attention drift (Rossetti, 1998), the longer delay was 4 s instead of 8 s. Rossetti (1998) has observed that the effects of both delay periods are equivalent. Second, the number of targets was 3 instead of 6. Indeed, the use of three targets decreases the duration of the experiment, which is an important factor when working with children. Since the pointing task involves the memorization of one target at a time, the three targets array in the present study with children is considered to be equivalent to the six targets array with adults.

2. Method

2.1. Subjects

Two groups of forty (congenitally blind and blindfolded sighted) right handed children participated in the experiment. Both groups consisted of four age groups (6, 8, 10 and 12 years) of 10 children (five boys and five girls at each age level). All the blind children were totally blind at birth, that is, total congenital blindness, though the etiology of only ten is known (see Table 1 for some information about the children).

Further, each blind child was tested for residual vision and only those who failed the test participated in the study. The experimenter held her hand before the child. A child with residual vision is expected to accurately report the number of fingers before her and a child with none fails the test. For ethical reasons all the sighted children were tested before the blind children to ensure that the blind group will be able to perform the task without difficulty. Incidentally, the blind children were younger than the sighted at ages 8 and 10 by 11 and 8 months. The ages of the blind and sighted children are presented in Table 2. The children were not tested for any other ability since they were pursuing normal curriculum. None had neither functional pattern nor form vision and could not see any hand movements. No child in the sample had any known history of neither central neurological injury nor general mental deficit. The number of subjects by group is double than the number required for a delay dissociation effect (Rossetti, 1998; Rossetti et al., 1996); it compensates for the reduced number of targets and counterbalances any variability among the handicapped children (Thinus-Blanc & Gaunet, 1997).

The blind children were selected at random from the National association for the blind at R. K. Puram, New Delhi, and the sighted children were selected from a Government school at Kingsway camp, Delhi. We ensured their enthusiasm to participate in the experiment, by presenting the task as a game. All the children belonged to middlelower socio-economic groups in Delhi. Before the experiment, the children were informed of the overall method (i.e., pointing to targets) but were naive about the specific hypotheses. The experiment was conducted with the understanding and verbal consent of each child. The sighted children were blindfolded prior to entering the experimental room and all through the experiment. The children were given sweets at the end of the experiment.

2.2. The pointing device

A thick transparent touch panel (Carolltouch, acoustic wave technology) (height near the subject, 45 cm × width at lower end, 42 cm × width at higher end, 43 cm × height further from the subject, 57 cm) was fixed upon a table and aligned to the mid-line of the body of the seated child (Fig. 1, left). The left hand was resting on the table and the right hand on a tactile mark at the bottom of the panel (starting position at 21 cm. from the closer vertical panel toward the subject). Three targets were defined on this panel along an arc centered at the starting position (radius of 20 cm) (Fig. 1, right). One target was spotted right above the starting point and was at the center of the other two targets. The second target was located 30° from that central target toward the participant (−30°) and the last was 30° from that central target away from the participant (+30°). They were spotted on the screen with a pencil mark. The touch screen recorded with custom software, the position of the location that was touched with the very end of the index finger on both sides of the panel with the left or right hand of each subject. The accuracy of the measurements was estimated as better than 5 mm. A computer was used to generate tones for providing the temporal windows to point at targets for both the encoding and test phases of target location.

2.3. Procedure

During the familiarization phase each child was presented with the apparatus. The apparatus was freely

Table 1
Ethiology of blindness

Age	Gender	Onset of blindness	Residual vision	Etiology of blindness
6	F	Congenital	Nil	Unknown
6.5	F	Congenital	Nil	Unknown
6.1	F	Congenital	Nil	Unknown
6.4	F	Congenital	Nil	Coloboma
6.5	F	Congenital	Nil	Unknown
6	M	Congenital	Nil	Unknown
6.7	M	Congenital	Nil	Unknown
6.2	M	Congenital	Nil	Traction retinal detachment
6.3	M	Congenital	Nil	Unknown
6.4	M	Congenital	Nil	Unknown
7.11	F	Congenital	Nil	Unknown
8.2	F	Congenital	Nil	Unknown
7.8	F	Congenital	Nil	Unknown
7.5	F	Congenital	Nil	Congenital cataract
7.4	F	Congenital	Nil	Unknown
7.1	M	Congenital	Nil	Unknown
8	M	Congenital	Nil	Unknown
7.6	M	Congenital	Nil	Unknown
7.9	M	Congenital	Nil	Unknown
8.1	M	Congenital	Nil	Persistent hyper plastic vitreous
9.7	F	Congenital	Nil	Unknown
9.5	F	Congenital	Nil	Unknown
10	F	Congenital	Nil	Unknown
10.2	F	Congenital	Nil	Primary optic atrophy
9.4	F	Congenital	Nil	Unknown
9.7	M	Congenital	Nil	Micro epithelimus with coloboma choroid
9.6	M	Congenital	Nil	Unknown
10.1	M	Congenital	Nil	Unknown
9.3	M	Congenital	Nil	Prematurity and advanced retinopathy
10.4	M	Congenital	Nil	Unknown
11.1	F	Congenital	Nil	Unknown
12.1	F	Congenital	Nil	Unknown
12.2	F	Congenital	Nil	Unknown
12.4	F	Congenital	Nil	Coloboma choroids and optic nerve with nystgamus
12.3	F	Congenital	Nil	Microepithemia
12.4	M	Congenital	Nil	Unknown
12.2	M	Congenital	Nil	Microepithemia
11.9	M	Congenital	Nil	Unknown
12	M	Congenital	Nil	Unknown
12.1	M	Congenital	Nil	Unknown

Table 2
Mean ages and *SD* of the blind and blindfolded sighted children

Congenitally blind		Blindfolded sighted		Statistics	
Mean	*SD*	Mean	*SD*	*t*	*p*
6.3	0.23	6.3	0.49	0.26	0.8
7.7	0.39	8.6	0.26	−8.45	<0.001
9.8	0.37	10.4	0.29	−4.57	<0.001
12	0.37	12.1	0.14	−0.67	>0.5

explored with both hands and the dispositions of the three targets were presented to the child with the following procedure. Target location encoding was performed by a passive demonstration with the left target-index finger raised from the table and left on target location. The child was then instructed to perform a right hand movement to the target location. The left-target hand was then moved back to the table by the experimenter and the child had to return his right hand to the tactile mark fixed at the bottom of the panel (starting position). The order of presentation of the targets was from the closer target to the further and the three targets were tested 10 times (30 trials). These pointing responses only tested to know if the ability for raising the arm was intact and were excluded from the data analysis. A similar procedure was followed for the left hand.

During the test phase, the same procedure was applied, except that there was a delay between target encoding and the right hand movement towards the target. Target location encoding was performed by a passive demonstration with the left index finger raised from the table and left on the target location for 300 ms and then immediately moved back to the table. A 300 ms computer-generated low tone allowed the investigator to keep this duration constant. Following this demonstration, the child was instructed by a high tone when s/he had to perform a right hand movement to the target location. The task consisted of pointing

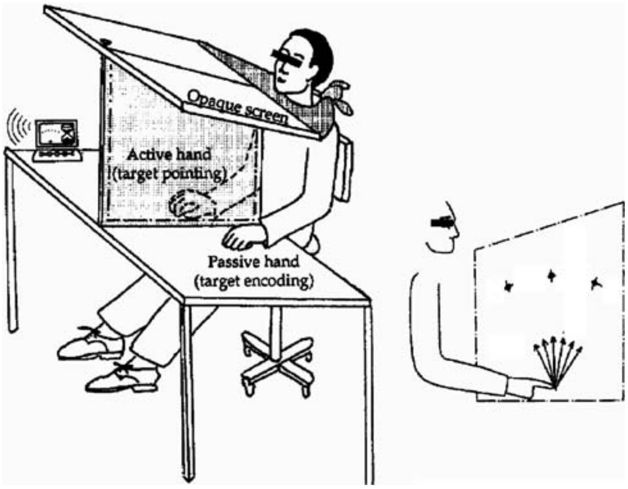

Fig. 1. The experimental setup.

with the right index finger and touching the vertical plane in the most accurate position. Pointing had to be performed during a 1.5 s temporal window; the maximum trial duration (1.5 s) was indicated by a second high tone. No correction had to be done after the finger touched the screen. Two delays between target demonstration and go signal were presented in a random order: 0 and 4 s. The vertical plate was thick enough to prevent tactilo-tactile cues. The three target positions and the two delays were randomly presented. Each child made ten pointing responses for each combination of target position and delay. Each pointing response was recorded on the touch screen. A similar procedure was followed for the left hand and hand order was counterbalanced between subjects.

There were 10 pointing trials for each target. Since there were three targets and two delays, there was a total of $10 \times 3 \times 2 = 60$ pointing responses for each hand. In all there were 120 pointing responses for both hands together for each child. No recording failure was observed. However, the plotting of individual pointing revealed a few aberrant pointing responses (i.e., from a circle area of 200 mm diameter on the panel). The coordinates of aberrant pointing responses were replaced by the individual average coordinates of the corresponding experimental condition (e.g., if for child $n°2$, data to target $n°1$ for delay 0 was missing, we averaged the x-axis location and the y-axis location of this child for the particular target and delay and replaced the missing data by the mean performance of that particular target and delay). These replacements did not affect the experimental conditions because they were a few (i.e., not more than 3 out of 60 pointing responses). The endpoint recording of each individual movement was used to compute constant, variable and absolute errors. Unattempted or missed trials were detected automatically and were presented just after the end of the 60 pointing trials during the session; their number was not recorded, but it did not reach more than 6 trials out of 60 on an average in all groups (10%). An experimental pointing session lasted 15 min. A stop or pause in the experiment for about 30 s to a minute at the most was provided for a few children, at request.

2.4. Scoring procedure and assumptions about the nature of errors

The coordinates of endpoint recording of each individual movement was used to compute several constant, variable and absolute errors (see below). Fig. 2, left, describes parameter d (absolute distance error), the constant errors R_o (*movement amplitude errors*) and α (direction amplitude errors); Fig. 2, right, describes the constant errors, x (errors along the horizontal axis) and y (errors along the vertical axis) and the variable errors which are the *scatter surface* (in gray), minor and major axes lengths of the pointing distribution (i.e., smaller and larger dimensions of the pointing distribution, respectively, used to compute the *ratio of lengths of the major–minor axes*) and (orientation of the *major axis of the scatter*). Constant errors are over shooting and undershooting errors with respect to the target locations, whereas variable errors are of three types that depict the surface area of pointing, the lengths of the major and minor axes of the pointing distribution and the orientation of the main axis of the scatter.

We provide below descriptions of these parameters and formulate predictions about the effects of age, group and delay factors on the parameters.

2.4.1. Absolute error

The absolute distance error or d (in millimeters) is the unsigned mean distance between pointing and the target.

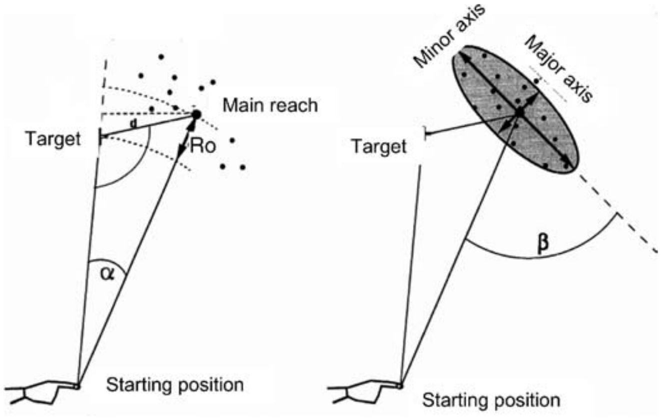

Fig. 2. Computation of dependent variables. The large dark dot represents the target and the smaller dots represent attempts to proprioceptively match the target. Left: d, absolute distance error between pointing distribution and target; α, movement direction error of the pointing distribution; R_o, movement amplitude error of the pointing distribution; x, error of pointing in the horizontal plane; y, error of pointing in the vertical plane. Right: minor axis length of pointing distribution, smaller dimension of the pointing distribution scatter; major axis length of pointing distribution, greater dimension of the pointing distribution scatter; β, major axis orientation of the scatter.

Although the so-called absolute error (mean distance to the target) is a non-specific parameter affected by both constant and variable factors (Schutz & Roy, 1973), its value was computed to allow comparisons with previous studies. Because this parameter is affected by both constant and variable parameters, it is difficult to predict its effect with children in the present study.

2.4.2. Constant errors

The output of a sensorimotor transformation may indicate a bias in the internal representation of movement encoding and target position, i.e., the coordinate system used. Constant errors were measured along movement direction (in degrees) and along movement amplitude (R_o in millimeters), relative to the ideal reach that would hit the target. Angular errors were negative when the reach was closer to the body than the aimed target (undershooting in direction) and amplitude errors were negative when movement distance was shorter than the ideal reach (undershooting in amplitude).

The constant error along the horizontal (or x in millimeters) and along the vertical (or y in millimeters) axes is the mean of the algebraic errors in pointing movements to the center of the target. Errors along the horizontal axis were negative when pointing projections on the x-axis were below the projection of the ideal reach (undershooting along horizontal); errors along the vertical axis were negative when pointing projections on the y-axis were under the projection of the ideal reach (undershooting along vertical). The covariation of errors along the horizontal axis and movement direction and errors along the vertical axis and movement amplitude is predicted. Therefore errors along the x and y axes will not be analyzed. If the children perform like adults (Gaunet & Rossetti, 2006), group and delay factors are expected to affect these four parameters. Indeed the blindfolded sighted adults under evaluated targets in movement direction and amplitude whereas the congenitally blind group over evaluated movement direction and amplitude. However, it is difficult to predict these effects for constant errors in children. A comparison between blind and sighted blindfolded groups tells whether visual experience accounts for movement calibration.

2.4.3. Variable errors

The 2D variable errors were assessed by the computation of confidence ellipse parameters. Confidence ellipses (i.e., two-dimensional mean ±1.96 SE of pointing responses) were derived for each subject, each delay and each target position. They were basically characterized by the length of the two orthogonal axes computed by orthogonal regressions between x and y coordinates of each scatter endpoint. When comparisons are made between two groups of ellipses, an increase of the length of the major axis implies that the pointing distribution is more elongated along the main axis of the scatter, whereas an increase of the minor axis of the ellipse implies that more pointing variability is observed along the direction orthogonal to the main axis of the scatter. The ratio between these two measures specifically describes the elongation of the ellipse. In addition, the total ellipse surface (minor × major × Pi) provides a precise estimate of the two-dimensional variability of the pointing performance, which depicts the surface of the probability zone (95%) where the endpoint mean is likely to be. The *scatter surface* (in mm^2) provides an estimate of the global pointing variability, and is thus expected to increase with the longer memory delay (Gaunet & Rossetti, 2006; Rossetti et al., 1996).

These parameters allow only for a quantitative assessment of the pointing variability, whereby systematic trends within the global variability are masked, that is, the scatter may vary in shape. Two additional parameters were computed in order to describe the qualitative spatial (and not the quantitative) aspects of each pointing scatter. First, the *ratio* of the two axes lengths provides a description of the ellipse shape, ranging from a circle (ratio = 1) to a more or less thin distribution around the main axis. According to previous studies, no effects of group or delay are expected to affect the ratio (Gaunet & Rossetti, 2006; Rossetti et al., 1996). Second, the orientation of the major axis of the ellipse (β) was analyzed in polar coordinates centered on the starting location. To this aim the orientation of the main axis of each ellipse was computed with respect to the average pointing direction. The angle between the mean movement direction (from the starting position to the average pointing location) and the major axis of the scatter of each target was calculated. The resulting angle could range between −360° and +360°. As each β could appear as either a positive or a negative value, these angles were then converted to modulo PI (i.e., a constant) within a half trigonometric circle. According to previous studies, values were expressed in angles ranging from 45° to 225° (a range of 180°) in order to obtain unimodal distributions of β. As a matter of fact, previous studies (Gaunet & Rossetti, 2006; Rossetti et al., 1996; Rossetti & Pisella, 2002; Rossetti & Regnier, 1995; Rossetti, Pisella, & Pilisson, 2000) have shown that values of β are typically distributed around 90° and 180° within the circumscribed range.

In addition the chosen half trigonometric circle was such that these values lie symmetrically within this interval, i.e., 45° from the edge rather than at 0°. The interpretation of this parameter is straight-forward. When β values are close to 180°, they indicate that the scatter is elongated in the direction of the pointing movement. When β is close to 90°, it indicates that the scatter elongation is orthogonal to the pointing direction. For example, if an arc-shaped target array centered on the starting location is used, this implies that the pointing distributions are primarily aligned with the target array if β values are close to 90°. Note that this parameter was neither a measure of pointing variability nor a measure of constant pointing error. Instead, it provided a cue to the spatial frame of reference used by the subjects to perform the task.

To show the strength of local distortion (or the involvement of ego- or exocentric representations) the analysis of both the ratio of the two main axes lengths, and the orientation of the main axis, have to be considered. For β to be meaningful the ratio of the two axes has to be different from 1, otherwise the distribution is too circular for its orientation to mean anything reliable. According to previous findings in adults (Gaunet & Rossetti, 2006; Rossetti et al., 1996, 2000; Rossetti & Regnier, 1995), this orientation should be affected by the delay in blindfolded sighted children. In theory, β should be aligned with movement direction at 0-s delay as is observed for visual targets (e.g., Rossetti, 1998; Rossetti et al., 2000). Our most crucial test will be to analyze the pointing performance in the delayed condition. As suggested by Newcombe and Huttenlocher (2000), if exocentric representation develops in children and the blind like the sighted children are able to perform in allocentric space (Millar, 1994), then β can be expected to become aligned with the target array in the delayed condition for both groups of children.

3. Results

Overall, the children failed very few trials. The means and *SD* of the left and right hands for groups and delays are presented in Tables 3 and 4.

The values of the three targets for the two delays were averaged and the data were subjected to a (2) Gender × (2) Group × (4) Age × (2) Delay × (2) Hand mixed analysis of variance (Statistica, 1997, version 5.5) with repeated measures on delay and hand. The ANOVA results for the three error outcomes are presented below. All the main effects and the significant interaction effects of the six parameters are reported. Some abbreviations are used for the means: b, blind; s, sighted; g, girls; b, boys; 0, 0-s delay; 8, 8-s delay; rt, right hand; lt, left hand.

3.1. Absolute error

The ANOVA indicates that neither the main effect of gender ($F(1,64)=1.23$, $MSE=380$, $p>.05$), nor group is significant ($F(1,64)=.549$, $MSE=169.5$, $p>.05$). The main effect of age is significant ($F(3,64)=4.79$, $MSE=1478$, $p<.01$) indicating an effect of development for both hands (M.6yrs = 78.5; M.8yrs = 85.47; M.10yrs = 88.39; M.12yrs = 81.5). The main effect of hand is significant ($F(1,64)=1521.59$, $MSE=6636$, $p<.0001$), (M.lt. = 129.13; M.rt. = 37.81) indicating lower accuracy for the left than the right hand, and immediate pointing is more accurate than delayed pointing ($F(1,64)=5.45$, $MSE=160$, $p<.02$), (M.d.0 = 82.76; M.d.4 = 84.18) (See Fig. 3). The hand × delay interaction is significant ($F(1,64)=22.48$, $MSE=1029$, $p<.05$). Newman Keul's post hoc test showed that the right and the left hands at delay 0 s are more accurate than at delay 4 s ($p<.05$).

3.2. Constant errors

The direction error is only affected by the main effect of hand ($F(1,64)=40.47$, $MSE=144.7$, $p<.001$) (M.lt. = −3.72; M.rt. = −2.37), indicating that the reach of the left hand was closer to the body than the aimed target with an underestimation of the targets by the left hand. The other main effects are not significant for gender ($F(1,64)=.001$, $MSE=.0037$, $p>.05$), nor group ($F(1,64)=3.33$, $MSE=116$, $p>.05$), nor age ($F(3,64)=1.4$, $MSE=48.56$, $p>.05$), nor delay ($F(1,64)=2.34$, $MSE=35.93$, $p>.05$). The gender × group × delay interaction is significant ($F(1,64)=4.48$, $MSE=73.3$, $p<.05$). Newman Keul's post hoc analysis indicates that the sighted girls at delay 0 s ($p<.05$), and the blind boys at delay 4 s ($p<.05$) are more accurate than the blind girls or the sighted boys.

For amplitude, neither the main effects of gender ($F(1,64)=1.73$, $MSE=1931$, $p>.05$) nor group ($F(1,64)=3.24$, $MSE=3620$, $p>.05$) nor hand ($F(1,64)=.708$, $MSE=533$, $p>.4$) is significant. The main effect of delay is significant ($F(1,64)=30.36$, $MSE=1645$, $p<.001$), indicating more accuracy for immediate than delayed

Table 3
Mean error and *SD* for parameters of the left hand

Parameters/group		Congenitally blind		Sighted blindfolded	
Delay		0-s Delay	4-s Delay	0-s Delay	4-s Delay
Absolute distance	Mean	128.46	131.97	125.59	130.48
	SD	13.18	15.72	10.85	13.56
Direction error	Mean	−3.26	−4.8	−2.26	−3.2
	SD	3.04	3.9	3.34	4.1
Amplitude error	Mean	44.52	72.18	−24.8	31.57
	SD	17.24	18.59	20.54	20.31
Surface scatter	Mean	1205.75	1538.6	1622.59	2325.66
	SD	492.37	602.91	711.3	863.89
Main axis orientation	Mean	159.83	161.11	153.2	155.71
	SD	42.72	62.96	59.01	46.93
Ratio of axis	Mean	1.76	1.77	1.77	1.76
	SD	.32	.33	.28	.36

Table 4
Mean error and *SD* for parameters of the right hand

Parameters/group		Congenitally blind		Sighted blindfolded	
Delay		0-s Delay	4-s Delay	0-s Delay	4-s Delay
Absolute distance	Mean	35.47	41.43	34.71	38.85
	SD	15.39	16.9	13.21	13.68
Direction error	Mean	−2.35	−4.15	−1.4	−2.79
	SD	3.07	3.39	3.54	4.15
Amplitude error	Mean	3.48	5.68	−5.05	2.37
	SD	21.15	21.71	23.39	25.65
Surface scatter	Mean	1066.86	1448.55	1434.96	1918.88
	SD	401.19	607.13	526.96	668.84
Main axis orientation	Mean	126.83	116.12	126.57	118.22
	SD	30.23	25.6	20.55	21.97
Ratio of axes	Mean	1.87	1.79	1.85	1.77
	SD	.39	.36	.43	.24

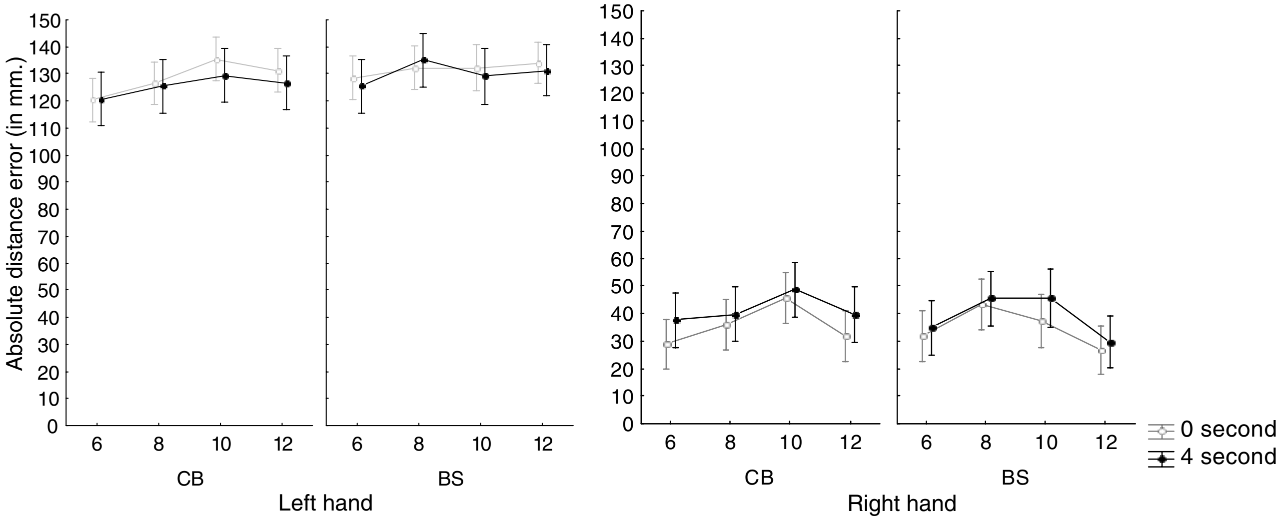

Fig. 3. Absolute error for the left and right hands of the blind and sighted blindfolded groups.

pointing (M.d.0 = .29; M.d.4 = 4.84). There is an effect of development for amplitude ($F(1,64) = 3.24$, $MSE = 3620$, $p < .03$), (M.6yrs = −2.32; M.8yrs = 1.7; M.10yrs = 12.5; M.12yrs = −1.63) showing an underestimation to the ideal reach in the youngest and the oldest children, whereas the 8 year olds slightly overestimate the targets and the 10 year olds well overestimate the targets. The group × delay interaction is significant ($F(1,64) = 4.31$; $MSE = 233.47$, $p < .05$). Post hoc tests indicate that the blind overestimate the ideal reach to the target and this overestimation is greater at 4-s delay, whereas the sighted blindfolded underestimate the ideal reach and this underestimation is greater at 4-s than 0-s delay ($p < .05$).

3.3. Variable error

The scatter surface is smaller for the blind children ($F(1,64) = 20.51$, $MSE = 20256$, $p < .001$), (M.b = 1315.13; M.s = 1819.63). The surface area increased with delayed than immediate pointing ($F(1,64) = 143.9$, $MSE = 178165$, $p < .001$), (M.d.0 = 1330.81; M.d.4 = 1803.95), and the left hand pointing responses have more surface area than that of the right hand ($F(1,64) = 6.68$, $MSE = 356103$, $p < .001$) (M.lt. = 1673.15; M.rt. = 1461.62) (see Fig. 4). The effects of gender ($F(1,64) = .33$, $MSE = 323565$, $p > .05$), and age ($F(3,64) = 1.76$, $MSE = 1737428$, $p > .05$) are not significant. The gender × delay ($F(1,64) = 4.85$, $MSE = 600807$, $p < .05$) and the group × delay ($F(1, 64) = 8.576$; $MSE = 1061725$, $p < .005$) interactions are significant. Newman Keul's post hoc analysis indicates that the girls have lesser surface area than the boys ($p < .05$) and the surface area increases with delay ($p < .05$). Furthermore, the blind have lesser surface area than the sighted ($p < .05$) and the surface area increases with delay ($p < .05$).

Only the main effect of gender is significant for scatter elongation or the ratio of the lengths of the major and minor axes ($F(1,64) = 7.92$, $MSE = 1.55$, $p < .005$)

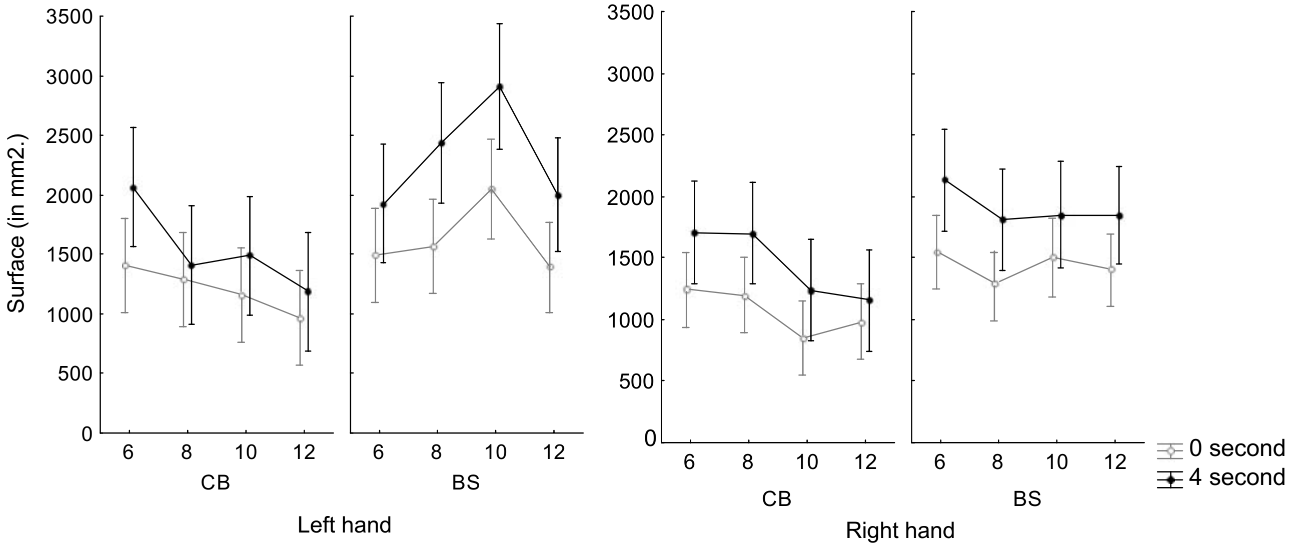

Fig. 4. The surface area of pointing distributions for the left and right hands for the blind and sighted blind folded groups.

(M.g = 1.73; M.b = 1.87) showing greater elongation for the boys than the girls. The effects of group ($F(1,64) = .05$, $MSE = .0098$, $p > .05$), age ($F(3,64) = .26$, $MSE = .0516$, $p > .05$), hand ($F(1,64) = 1.8$, $MSE = .1566$, $p > .05$) and delay ($F(1,64) = 1.065$, $MSE = .1017$, $p > .05$) are not significant.

Only the effect of hand is significant for the orientation of the major axis of the scatter ($F(1,64) = 44.89$, $MSE = 100741$, $p < .001$), indicating that while the right hand seems more allocentric or context oriented (M.rt. = 121.88), the left hand is more egocentric (M.lt. = 157.46), see Fig. 5. The other effects are not significant for gender ($F(1,64) = 1.258$, $MSE = 2707.5$, $p > .27$), nor group ($F(1,64) = .251$, $MSE = 540.7$, $p > .62$), nor age ($F(3,64) = 2.607$, $MSE = 5612.7$, $p > .06$) nor delay ($F(1,64) = .658$, $MSE = 1141.8$, $p > .42$).

In general, we observe that the groups do not differ for most parameters, though the hands differ for four of the six parameters, that is, the absolute error, the direction error, the surface area of pointing and the orientation of the main axis of the pointing distribution. Therefore it was considered relevant to examine the effects of orientation and elongation of the main axis of the pointing scatter for the two hands separately because they are an index of the frame of reference.

3.4. Left hand

A (2) group × (2) gender × (4) age × (2) delay mixed ANOVA with repeated measures on the last factor indicates that the scatter elongation (ratio of the major and minor axis) is affected only by gender ($F(1,64) = 4.23$, $MSE = .601175$, $p < .05$), showing that the girls have a lower ratio (1.73) than the boys (1.87). This indicates that the pointing distribution of the left hand for the boys is more elongated than that of the girls.

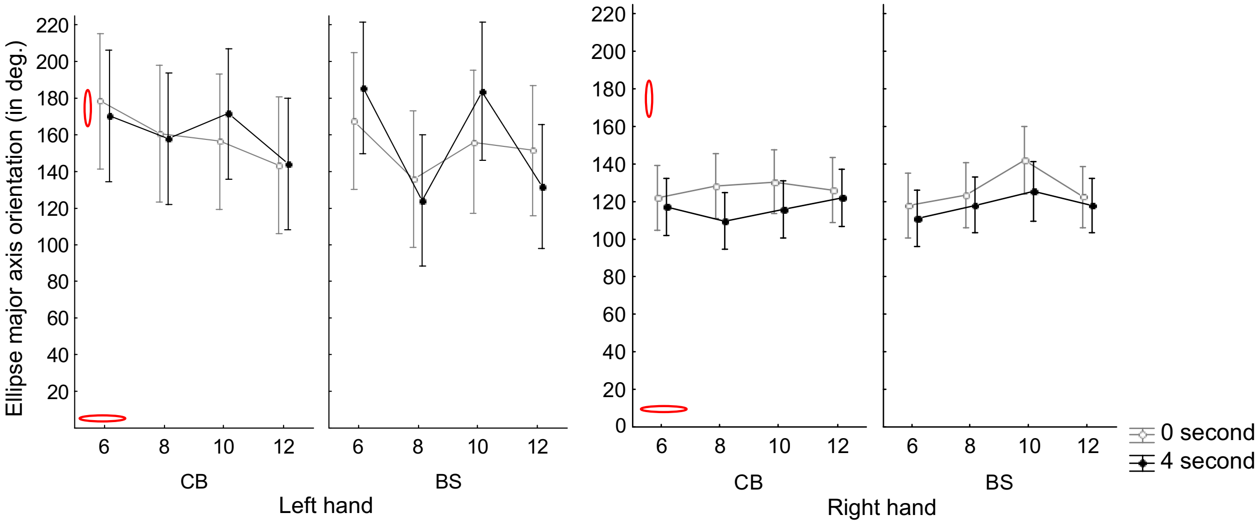

Fig. 5. The main axis of the scatter for the left and right hands for the blind and sighted blindfolded children.

The orientation (β) of the main axis of the scatter is affected only by age ($F(3,64) = 2.86$, $MSE = 10589.57$, $p < .05$), (M.6yrs = 175.49; M.8yrs = 144.80; M.10yrs = 166.83; M.12yrs = 142.73). Post hoc Duncan's multiple range test shows that the 6 year olds differ from the 8 year olds ($p < .04$) and the 12 year olds ($p < .03$). By implication, the 6 years old children being the youngest are most egocentric, whereas the overall performance of the 10 years old children is also egocentric.

3.5. Right hand

A (2) group × (2) gender × (4) age × (2) delay ANOVA with repeated measures on delay indicates that the scatter elongation (ratio) is again only affected by gender ($F(1,64) = 4.63$, $MSE = .975996$, $p < .05$), the ratio being greater for the boys (M.b = 1.83) than the girls (M.g = 1.71). The orientation (β) of the main axis of the scatter is not affected by age but the delay is significant ($F(1,64) = 6.83$, $MSE = 3569$, $p < .01$), (M.d.0 = 126.62; M.d.4 = 117.15). Gender effects show β reach lower values for the boys; the boys are therefore more allocentric (M.b = 116.5) than the girls (M.g = 127.26) ($F(1,64) = 6.62$, $MSE = 4607.86$, $p < .01$). The group × gender interaction is significant ($F(1,64) = 4.87$, $MSE = 3390.4$, $p < .05$). Post hoc test reveals that the blind boys ($M = 111.49$) ($p < .05$) are more allocentric than the rest of the children (M.s.b = 121.52; M.b.g = 131.48; M.s.g = 123.05). Overall, the girls are not as context oriented as the boys.

In summary the results indicate an effect of the visual status for surface, an effect of gender for ratio and an effect of age for absolute error and amplitude (though U reversed in shape). However the delay increases absolute error, movement amplitude error and surface area. Results indicate a difference between the hands, with the direction error, absolute error, surface area and β being greater for the left hand. Moreover, as β is sensitive to age for the left hand, it seems that the use of frames of reference for the left hand is egocentric, though decreasing with age, whereas the right hand seems to be sensitive to delay (context). For both the left and right hands, scatters are more elongated in boys indicating that boys are more sensitive to the available frames of reference.

4. Discussion

The present study addressed the processing of space in a task that required differentiation between immediate and memorized representation of targets. Congenitally blind and blindfolded sighted children were required to point at targets on a sagittal screen with their left and right index fingers. Although the non-pointing hand proprioceptively defines the target location in every trial, the emphasis was on the analysis of several parameters of pointing distributions, reflecting properties of spatial representation. It is of interest to note that the endpoint distributions observed in congenitally blind children have been found to become contingent upon the target array during the longer delay for the right hand, like that of the blindfolded sighted children. We shall discuss these findings according to the effects of hand, development, gender, instruction delays and visual status. For purposes of discussion we have regrouped the parameters, in three sets. Both the ratio of the lengths of the major and minor axes and the orientation of the main axis of the scatter give some insight about the local distortion (egocentric- vs. allocentric encoding) of pointing distributions (first set of parameters). Movement direction and amplitude provide information about movement encoding bias (second set of parameters). Absolute distance errors and scatter surface (third set of parameters) provide an index of global performance and the dispersion of the endpoints around the mean revealing random noise added at any stage of a sensorimotor transformation.

The first set of parameters (ratio and β) show that the elongation (ratio) of the scatters was only affected by gender, scatter elongation being more for the boys. In both the blind and blindfolded sighted groups, scatter orientation of the main axis for delay 0 s tends to move toward 180° and toward 90° at 4-s delay for the right hand. This indicates that the main axis is aligned with the movement encoding direction for immediate delay and with the target arc for the longer delay, respectively. The fact that elongation is important reinforces these conclusions (the ratio values were far from 1 and almost reach the value 2). The responses of the left hand indicate an egocentric orientation, which however decreases with age. More precisely, in both groups, the greater elongation of scatters for gender (boys) reveals that the boys are more sensitive to movement and context (landmark) orientation than the girls.

Analyses performed on movement integration parameters (direction and distance, second set of parameters) lead to the conclusion that there are no distortions in movement in accordance with the visual status of the children. Errors were larger for the left than the right hand suggesting differences between the hands for estimating depth. Though the delay increased amplitude errors, effects of age reveal that the ability to reach the target was evident with development in both blind and blindfolded sighted children. The absolute error '*d*', (third group of parameters) indicates that both the blind and blindfolded sighted children performed comparably. There is an overall age effect (U-reversed shape) in absolute distance errors from 6 to 12 years indicating a trend of general development for pointing at targets in space, regardless of the visual status of the children (Bradshaw, Watt, Elliott, & Riddell, 2004). Though the absolute error was greater for delayed pointing, there was an effect of development for both hands. The blind children occupied lesser surface area than the sighted, showing better accuracy of pointing at the targets. This finding reveals a steady tactile development in the blind during infancy (Streri, 2005), and suggests the development of some parts of the brain that may undergo significant postnatal development.

However, an absence of early visual experience has often been considered to be a limitation in the construction of a cognitive map in which locations are inter-related (Dodds & Carter, 1983; Thinus-Blanc & Gaunet, 1997). The present experiment shows that early visual deprivation does not prevent the integration of a global spatial arrangement of target locations in children (Millar, 1994) whereas it was found that the lack of early visual experience disrupts allocentric pointing during adulthood in the congenitally blind (Gaunet & Rossetti, 2006). Thus, this ability may not be sustained with time. This divergence in ability between congenitally blind children and adults may be explained by the long-term experience of the adults in space without vision for processes that rely on an egocentric frame of reference (Gaunet, Martinez, & Thinus-Blanc, 1997) such as a greater necessity to avoid static and dynamic objects in locomotor space.

Of interest is the unexpected difference in pointing accuracy ('*d*' and surface area) with each hand. The left hand in both groups of children is greater in absolute error and surface area. The left hand also differs from the right hand in its orientation to the major axis of the scatter of pointing responses. This indicates that the hands tend to differ such that the left hand is more egocentrically oriented while the right hand comparatively context oriented. These differences seem to have increased the surface area and the absolute error of the left hand. This may explain why in some studies, fine motor skills that are context oriented, are better performed by the right hand (Healey, Lederman, & Geschwind, 1986; Steinhuis & Bryden, 1989, 1990; Ittyerah, 1996; Streri, 2002), whereas less lateralized tasks such as lifting objects (Steinhuis & Bryden, 1989, 1990) showing actions of strength are better performed by the left hand (Healey et al., 1986; Ittyerah, 1996; Peters, 1990). Besides there are suggestions (Lea, 1984) that the pre-existing asymmetry of the human brain may have perhaps evolved under the elective pressure of tool use in which the stronger left hand holds the work while the right hand skillfully wields the tool. Very recently Gurd, Schulz, Cherkas, and Ebers (2006) correlated the hand used for writing with other actions of skill in monozygotic twins with discordant handedness. Gurd et al. observed that although the right handed sisters were more strongly lateralized than their left handed sister, there is no evidence to indicate that twins who wrote with their left hand showed poorer performance than their right handed twin sister. However, certain tasks such as the peg moving, did not successfully show evidence of differences between the writing and non-writing hands in the left handed group of mono zygotic twins. All this evidence in sum indicates that the general lateralization does not affect ability (Ittyerah, 1993, 2000).

4.1. Development of pointing in the absence of vision

The pointing distributions of the two groups of children in the absence of vision indicate that pointing is not affected by the visual status but for the finding that the congenitally blind group has a smaller surface area of pointing than the blindfolded sighted children. Therefore by not restricting the spatial experience only to vision, a more consistent representation (global pointing variability measured by the scatter surface) of the target location is obtained as a consequence of converging sensory experience (Rossetti, 1998). Overall these results indicate that vision is not necessary for a spatial framework since consistent effects of development have been found in blind children as in their blindfolded sighted peers. The present findings suggest that congenital blindness may not be detrimental to the development of spatial representations, neither self referent nor contextual since there is evidence that people who are totally blind from birth can perform as well (Millar, 1994) or more proficiently (Hollins, 1986) than the sighted on spatial tasks. Casteillo, Bennett, and Mucignat (1993) for example observed that experience of vision is not necessary for the coordination or patterning of the basic reach to grasp movement in blind adults. A recent case study provides a possible explanation for the lack of performance differences between the blindfolded sighted and congenitally blind children in the present study. A blind born lady (Ostrovsky, Andalman, & Sinha, 2006) who underwent surgery for the removal of dense congenital cataracts at the age of twelve years revealed that she exhibited a high level of proficiency on most form and face perception tests twenty years later, with a visual acuity of 20/200. While this finding does not rule out residual impairments, it suggests that significant functional recovery is possible even after several years of congenital visual deprivation. Recent evidence (Millar & Al-Attar, 2005) indicates that vision improves performance in a haptic spatial task only in so far as it adds cues that are potentially relevant to spatial discrimination and reference. Therefore vision does not affect haptic processing if it does not add task relevant information.

Although much evidence about the role of vision in hand use reveals a coordination between eye and hand for reaching or pointing at objects (Jeannerod, 1997b; Johansson, Westling, Baeckstrom, & Flanagan, 2001; von Hofsten, 1982, etc.), studies indicate that processes underlying pointing are early and that infants do not need to see their hand to reach and contact a toy (Clifton, Muir, Ashmead, & Clarkson, 1993; McCarty, Clifton, Ashmead, Lee, & Goubet, 2001). These empirical findings indicate that visual guidance of the hand is not necessary to establish object contact about the onset of reaching and therefore proprioception is sufficient for pointing very early in development. Furthermore, before 7 years of age, perception of positions is predominantly based upon proprioception (Bard & Hay, 1983; Hay, 1978).

Fraiberg (1968) observed that totally blind infants are able to reach to sounding objects located in their prehension space and that reaching is a critical skill for locomotion. Fraiberg (1968) indicated that blind infants reached at their chest for toys because the body mid-line was the first place to have subjective reality for them and subsequent research has demonstrated that such self referent cues are reliable (Millar, 1994; Stelmach & Larish, 1980). According to Bigelow (1986) when blind infants reach, this behaviour may be related to their conceptual development. For example, the ear hand coordination for reaching objects in blind children is attained at 8 months, whereas eye hand coordination in sighted children is attained by four months. Nevertheless sighted children are not able to reach a hidden object they hear until they are about 8 or 9 months of age, and this is at par with the ages of the attainment of object permanence in blind children. Thus the development of reaching and pointing is not dependent on vision.

4.2. *Effects of delay*

The present findings indicate that the delay effect was similarly pronounced in the blind as well as the blindfolded sighted children and this suggests the involvement of the two processing systems (Rossetti, 1998), and that they are not dependent on early visual experience. We also found that at 4-s delay, the scatter surface was larger than that at 0-s delay for both groups of children confirming that a delay between memorization and the output deteriorates the concentration of the pointing distribution. This is also in conformity with previous studies in which delay-dependent effects were found for location memory in sighted subjects (Chieffi & Allport, 1997; Chieffi, Allport, & Woodin, 1999). Furthermore a dissociation of performance was observed with delay in sighted subjects during a haptic spatial matching task (Zuidhoek, Kappers, Van der Lubbe, & Postma, 2003) as well as in a task on the verbal judgment of haptically perceived orientation (Zuidhoek, Kappers, & Postma, 2005) indicating a shift from ego- to allocentric frame of reference with delay. The present data confirm that a given system of information processing is involved only in immediate stimulus driven movement and that another system takes over after a short delay. Consequently, these pathways are also related to ego- and allocentric encoding (Goodale & Milner, 1992; Milner & Goodale, 1993; Rossetti, 1998). According to the present results, the former system devoted to action is self referent and the latter system (perceptual identification) is allocentric and performs according to a global representation of the spatial design involved in the task. The present study shows that the above visuo-motor (pragmatic) representations expressed within a longer delay relying on allocentric representation is evident at 6 years and is independent of early visual experience. This study provides crucial descriptive data and a theoretical perspective concerning the development of cognitive processes in pointing without vision. Both movement (self referent) and target array (contextual) frames of reference are present in young children. The dissociation of spatial encoding processes according to memory delay in young children, as well as in children totally congenitally blind (independent of visual experience) suggests that the double system relies on convergent information from different sense modalities (Rossetti, 1998).

Furthermore there is a difference in the strength of the frame of reference for boys in both groups with a larger scatter elongation than the girls, suggesting a gender advantage for spatial representation. Recent studies continue to show that boys have an advantage for spatial tasks (Lowe, Mayfield, & Reynolds, 2003) and this is evident during adulthood for mental spatial rotation tasks on paper (Parson, Larson, Kratz, & Thiebeux, 2004) and spatial memory (Postman, Jager, Kensels, & Koppenschaar, 2004). We conclude that since the boys were more able to distribute their responses along an arc particularly for the longer delay with larger scatter ratios, they are more contextually oriented than the girls regardless of their visual status.

In summary, the blind like the sighted children are able to adopt an allocentric frame of reference with delay and these effects are evident across development. Both groups of children at all ages are able to point with their left and right hands, indicating differences between the hands in proclivity or tendency rather than in ability. Thus early in development congenital blindness does not prevent the ability to point at a memorized target neither in immediate self referent nor context oriented external space.

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