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An “Oblique Effect” in Infant’s Haptic Perception of Spatial Orientations

Edouard Gentaz¹,² and Arlette Streri²

Abstract

The present research addresses the question of the “oblique effect” (better discrimination of the vertical orientation than of an oblique orientation) in manual haptic perception of orientations (without visual control) by 5-month-old infants. A familiarization/reaction to novelty procedure was used. The results revealed the occurrence of a haptic oblique effect. These findings are similar to those obtained in infant visual perception. We suggest that 5-month-old infants predominately use vertical orientation as a reference norm to perceive haptically spatial orientations. We discuss the implications of these results for both orientation processing and anatomofunctional level contributing specifically to the haptic oblique effect.

INTRODUCTION

We live in a world organized by the force of gravity that continuously acts on the body. The vertical and horizontal orientations are sensorily reinforced because of the convergence of the various cues provided by the perceptual systems. The visual system codes the numerous vertical and horizontal directions present in the environment. The vestibular system codes the gravitational acceleration. The cutaneous exocaptors record the relative pressure across the soles of the feet. Finally, the muscular and articular endocaptors regulate the balance of muscular tonicity. Thus, the vertical and horizontal orientations may constitute, very early in age, powerful norms for the perceptual systems involved in spatial perception (Gentaz et al., 2001; Marendaz, 1998; Paillard, 1991). The purpose of the present research was to investigate whether vertical orientation is predominately used as a reference norm by the infant haptic system to define oblique orientations.

To study whether vertical orientation is predominately used as a reference norm by the haptic system to define the oblique orientations, we examined the occurrence of an anisotropy in the perception of orientations (i.e., perceptual differences according to the value of the orientation). More specifically, an “oblique effect” (Appelle, 1972) should be observed. This oblique effect reflects the more accurate perception of vertical or horizontal orientations relatively to oblique orientations. In vision, several studies have established the generality of the oblique effect: It is present in a variety of tasks and at all ages (for reviews, see Gentaz & Ballaz, 2000; Gentaz & Tschopp, 2002; Appelle, 1972). The origin and the explanation of the “visual oblique effect” are still debated. Because many cortical structures are involved in visual orientation processing, there is some controversy about the anatomofunctional level contributing specifically to the visual oblique effect (Gentaz & Tschopp, 2002). The first theoretical conception mainly locates the origin of the visual oblique effect early in the visual pathway. This effect could be explained by the axis-dependent changes in the properties of orientation-selective neurons of the visual primary cortex, because neurons tuned to horizontal and vertical orientations are more numerous, sensitive, and narrowly tuned than neurons tuned to oblique orientations (e.g., Furmanski & Engel, 2000; Saarinen & Levi, 1995). The second theoretical position considers both striate and extrastriate explanations (from the V2 area and further up). These studies have led to the conclusion that the origin of the visual oblique effect could imply additional extraretinal cues such as the vestibular and somesthetic ones integrated at a higher level in the visual hierarchy (Heel ey, Buchanan-Smith, Cromwell, & Wright, 1997; Cecala & Garner, 1986). Essock (1980) proposed a distinction between “Class 1 oblique effects”, observed when one is measuring the basic functioning of the visual system (acuity, contrast threshold) and “Class 2 oblique effects” reflecting memory and cognitive processes. Class 1 effects can be consistently explained by the properties of orientation-selective neurons. The explanation of Class 2 oblique effects is less clear. For Essock, Krebs, and Prather (1997), Class 2 oblique effects could be explained by a general bias in the representation of oblique stimulus.

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The study of the visual oblique effect in infants allowed a better understanding of this phenomenon. The Class 1 visual oblique effect has been demonstrated in infants by Leehey, Moszkowicz-Cook, Brill, and Held (1975). Using contrast sensitivity, Leehey et al. tested the oblique effect in infants aged from 6 to 50 weeks. The stimulus was a circular grating consisting of light and dark bars uniformly alternated. Bars were of five different widths. When spatial frequency was above threshold discrimination, the pattern appeared contrasted, whereas when spatial frequency was below threshold, the pattern looked like a homogeneous gray field. Two gratings of the same spatial frequency differing in orientations were simultaneously proposed. Each trial consisted of an oblique grating ($45^\circ$ or $135^\circ$) and a vertical or a horizontal grating presented in a random fashion. As infants looked longer at the more contrasted of two patterns, a forced-choice judgment was used to determine which grating the young subject preferred. Given that the two stimuli have the same spatial frequency, an oblique effect would be present if, for a specific bar width, infants could discriminate the vertical or the horizontal lines but not the oblique lines. For this particular spatial frequency, infants should look preferentially at vertical or horizontal gratings rather than at oblique gratings. Results revealed an oblique effect. If the critical value of spatial frequency progressively decreased with age according to the development of visual acuity, an oblique effect was systematically observed at all ages. These findings were replicated by Gwiazda, Brill, Mohindra, and Held (1978). According to Gwiazda et al., findings suggest that the visual oblique effect depends on endogenous maturation rather than exposure to a carpentered world, as assumed by other authors (Ross, 1992; Annis & Frost, 1973).

In the same perspective, Jouen (1985) studied the nature of spatial reference frame in which the orientations and the oblique effect are mapped (for recent discussions, see Luyat, Gentaz, Corte, & Guerraz, 2001; Luyat & Gentaz, 2002). If the visual oblique effect is mapped in a retinotopic reference frame, its origin could be located at a low level of visual processing where the retinotopic mapping of most orientation-selective neurons is preserved. By contrast, if the visual oblique effect is defined in gravitational reference frame, its origin could be located at a high level of visual processing of orientation. To study this question, the authors examined the effect of body position on the perception of orientations in 5-month-old infants. In the upright position, infants showed the classical oblique effect, looking longer at the vertical and horizontal gratings than at the $45^\circ$ and $135^\circ$ gratings. By contrast, in a tilted position, infants looked longer at oblique stimuli aligned with body orientation. These results showed that the visual oblique effect in infants is not defined in gravitational reference frame but rather in retinotopic reference frame. The author suggests that the visual oblique effect is directly related to the properties of orientation-selective neurons of the low levels of the visual system.

The Class 2 visual oblique effect has been demonstrated in infants by Essock and Siqueland (1981). Using an operant-amplitude-sucking paradigm and successive suprathreshold gratings in 2-month-old infants, the authors showed discrimination between vertically and horizontally oriented gratings. However, infants failed to discriminate mirror-image obliques ($45^\circ$ and $135^\circ$) from each other and nonmirror-image obliques ($22.5^\circ$ and $112.5^\circ$). The authors suggest that the occurrence of the Class 2 oblique effect in infants stems from a greater confusability in memory of oblique orientations, which is also the case in children (Bryant, 1973; Rudel & Teuber, 1963) and in adults (Essock, 1980).

In haptics, the oblique effect has not yet been investigated in infants. The haptic oblique effect (“Class 2” in Essock’s 1980 terminology) has been little explored (for a review, see Gentaz, 2000), and the available studies examined only adults (Kappers, 2002; Gentaz & Hatwell, 1995, 1996, 1999; Gentaz, Badan, Luyat, & Touil, 2002; Appelle & Gravetter, 1985; Appelle & Countraman, 1986; Lechelt, Eliuk, & Tanne, 1976; Lechelt & Verenka, 1980) and children (Gentaz & Hatwell, 1995, 1997). Gentaz and Hatwell (1998) revealed the existence, in some exploratory conditions, of a purely haptic oblique effect, independent of visual experience and representations because this effect was observed in adults blind since birth. In addition, Gentaz and Hatwell (1996, 1997, 1998) showed, in blindfolded and blind adults and in blindfolded children, that the occurrence of the haptic oblique effect was influenced by the conditions of manual exploration of the rod stimulus because these conditions changed the gravity constraints during scanning. The gravitational cues provided by the antigravitational forces developed by the scanning arm–hand system could partially determine the presence of the oblique effect because these cues reinforced the vertical orientation relatively to the oblique orientations. For example, the oblique effect was present in the three planes of space (horizontal, frontal, and sagittal) when the shoulder–forearm–hand system was free (unsupported) in the air. In this condition, antigravitational forces were elicited during the scanning. By contrast, the oblique effect was absent in the horizontal plane when the shoulder–forearm–hand system was supported while remaining in physical contact with the surface of the device. In this condition, minimal antigravitational forces were required to move the forearm–hand system.

The haptic tasks proposed to adults and children in the above studies required movements of the shoulder–arm–hand system that were different from those required in the haptic tasks proposed to 5-month-old infants. The infants’ exploratory movements were smaller and less frequent than those of adults and children. However, it is well established today that the hand ability to intake and process perceptual shape information is
already efficient (for reviews, see Hatwell, Streri, & Gentaz, 2000, in press; Streri, 1993). For example, Streri and Pècheux (1986) showed that 5-month-old infants are able to discriminate haptically various shapes without visual control. The object shapes were a plain square versus a square with a hole and a flower versus a star. Recently, Gentaz and Streri (2002) showed that 5-month-old infants are also able to discriminate haptically (without visual control) between vertical (defined gravitationally) and 45° oblique rod orientations. Moreover, Van Hof and Lagers-van Haselen (1994) observed in adults an oblique effect in a static proprioceptive coding of rod orientation. The authors asked blindfolded participants to grasp two rods simultaneously, one with each hand, and to judge whether these rods were parallel or not. More accurate performances were observed in the vertical and horizontal orientations than in the 45° and 135° oblique orientations. These results showed that a proprioceptive oblique effect was present even when no exploratory movements were required. Taking these two general arguments into account, we hypothesized that the haptic oblique effect could be present in infants when their shoulder–arm–hand system is free in the air to hold and to slightly explore a fixed rod stimulus positioned in the frontal plane.

In the present study, we used the familiarization/reaction to novelty procedure to test the haptic discrimination of two orientations and the occurrence of an oblique effect (without visual control) in 5-month-old infants. Thus, we proposed a familiarization phase (with a 90-sec fixed-duration procedure) and a test phase in which the duration of manual holding of the stimulus was the main dependent variable. A haptic discrimination between two orientations could be inferred if, in the test phase, there is a difference between the holding times of the familiar rod orientation (presented during the familiarization phase) and the novel rod orientation. To study the occurrence of a haptic oblique effect, we adopted a method based on “a critical angular value” using the principle of Leehey et al.’s method presented previously. A haptic oblique effect occurs when the discrimination between two orientations does not only depend on their angular difference but also on the orientation value tested. In this case, we predicted that, with the same angular difference (10°; this value was chosen from performances observed both in young children by Gentaz & Hatwell, 1995 and in a pilot study), a successful haptic discrimination would be observed between vertical and 10° left oblique rods, whereas a failure of discrimination would occur between 55° left oblique and 45° left oblique rods.

RESULTS

Test Phase

The data analyses were carried out on the holding times (in seconds) of stimuli during the test phase for each experimental condition. Holding times were verified a posteriori from the video recordings by the two observers. The interobserver reliability in all sessions was very high (Pearson correlation; \( R = .93 \)).

The means and standard deviations of the holding times in the test phase for each experimental condition are shown in Table 1. A preliminary ANOVA on the holding times in seconds showed that the factor “order of test trial” had no effect and did not interact with any other factor. Consequently, results were collapsed across order condition. A 2 (familiarized stimulus) \( \times 2 \) (test trial pair) \( \times 2 \) (test stimulus) ANOVA (with repeated measures on the last two factors) on the holding times in seconds revealed a main effect of test stimulus, \( F(1,22) = 10.11, p < .01 \), with longer holding time for the familiar orientation \( (M = 13.1) \) than for the novel orientation \( (M = 6.4) \). The main effect of familiarized stimulus was significant, \( F(1,22) = 7.7, p < .01 \), with longer holding time for the vertical orientation \( (M = 14.2) \) than for the 45° oblique orientation \( (M = 5.2) \). The main effect of test trial pair was not significant, \( F(1,22) = 0.18, p > .25 \).

The Familiarized Stimulus \( \times \) Test Stimulus interaction was significant, \( F(1,22) = 9.43, p < .05 \). It means that, after a familiarization with a vertical rod, the holding time was longer for the familiar (vertical) orientation \( (M = 20.85) \) than for the novel \( (10° \) oblique; \( M = 7.65 \) ) orientation, \( F(1,22) = 19.5, p < .001 \). By contrast, after a familiarization with a 45° oblique rod, there was no

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*Gentaz and Streri*
difference between the familiar (45° oblique rod; $M = 5.3$) orientation and the novel (55° oblique rod; $M = 5.1$) orientation, $F(1,22) = 0.05$, $p > .25$. No other interactions were significant: Familiarized Stimulus x Test Trial Pair, $F(1,22) = 0.007$, $p > .25$; Test Trial Pair x Test Stimulus, $F(1,22) = 0.04$, $p > .25$, and Familiarized Stimulus x Test Trial Pair x Stimulus Test, $F(1,22) = 0.7$, $p > .25$.

**Familiarization Phase**

In order to examine whether the results observed in the test phase could be due to the biomechanical constraints of the task during the familiarization phase, data analyses were carried out on the number of times that the infant let go of the rod and self-regrasped the rod during the 90-sec familiarization phase for each orientation. These two types of numbers were verified a posteriori from the video recordings by the two observers. The interobserver reliability in all sessions was very high (Pearson correlation; $R = .91$). A first $t$ test compared the mean number of times that all infants let go of the rod in each familiarized orientation. There was no significant difference ($p > .25$) between the vertical rod (mean = 29/12 = 2.4) and the 45° oblique rod (mean = 31/12 = 2.6). A second $t$ test compared the proportion of the number of times that infants self-regrasped the rod in each orientation. No significant difference ($p > .25$) was observed between the vertical rod (20 of 29, i.e., 0.68) and the 45° oblique rod (23 of 31; i.e., 0.74).

**DISCUSSION**

The haptic oblique effect (without visual control) in 5-month-old infants was demonstrated with a technique based on the discrimination of angular difference. If the haptic perception of orientation was not anisotropic (i.e., was independent of orientation value), the discrimination of two orientations in infants should depend only on the angular difference between the two orientations tested. In this case, whatever the orientation tested, the discrimination of two orientations would be possible with fixed angular differences and would not be possible for other angular differences. By contrast, if the haptic perception of orientation was anisotropic and if a haptic oblique effect was observed, the discrimination of two orientations should depend on both the angular difference and the orientation value tested. The results of the present test phase are consistent with this hypothesis. Indeed, with the same angular difference (10°), a haptic discrimination was observed between vertical and +10° left oblique orientations, whereas no discrimination was evidenced between 55° left oblique and 45° left oblique orientations.

An additional point concerns the direction of preference revealed by the holding times observed in the present experiment: Infants preferred the familiar orientation rather than novel orientation. However, it should be noted that a novelty preference was sometimes observed in other infant studies. Nevertheless, both preferences provided evidence of discrimination, because in both instances infants showed differential responsiveness to two stimuli based on prior exposure to one of them. Such difference in preferences has often been observed in infant studies and its explanation is still in debate (for a recent review, see Pascalis & de Haan, in press). Complementary analyses carried out on the number of times that infants let go of the rod and self-regrasped the rod during the familiarization phase showed that the infant’s holding and exploration of the fixed rod with the shoulder–arm–hand system did not differ according to its spatial orientation. Therefore, the findings observed in the test phase could not be due to the biomechanical constraints of the task during the familiarization phase.

Moreover, the results of the present experiment also confirmed that 5-month-old infants are able to discriminate haptically between two orientations without visual control (Gentaz & Streri, 2002). The efficiency of these haptic abilities is high because the 5-month-olds are able to discriminate an angular difference of 10° when the vertical rod is tested. These findings show that the 5-month-old infants are able to discriminate a spatial property varying on one dimension only. These results extend the findings evaluating the efficiency of the haptic abilities in infants (for reviews, see Hartwell et al., 2000; Streri, 1993). This result was also consistent with visual studies that revealed that from 2 months of age, infants are able to discriminate gratings differing in orientation (for a review, see Kellman & Arterberry, 1998).

Taken together, the results showed that a haptic oblique effect exists in 5-month-old infants. These results were consistent with our hypothesis assuming that the haptic oblique effect could be present when the shoulder–arm–hand system of the infants could move freely in the air to hold and to explore the rod stimulus positioned in the frontal plane. These results confirm the generality of the oblique effect because this effect is present in adults, in children, and now in infants in both the visual and haptic systems. The haptic oblique effect could be explained by both general factors. First, this effect may be related to the properties of orientation-selective neurons of the somesthetic system. Indeed, Warren, Hamalainen, and Gardner (1986) found orientation-selective neurons (with a preference for stimuli oriented proximally–distally on the finger) in the primary somatosensory cortex of awake monkeys. Second, the haptic oblique effect could be explained partially by the presence of the gravitational cues provided by the arm–hand system during holding and scanning. These cues could reinforce gravitational (vertical) direction as an important axis and that it is used by infants as a reference norm to define spatial orientations in haptics, as is the case in children and adults. In this perspective, the haptic oblique effect could stem from the fact that any oblique
orientation could be encoded in relation to the vertical and horizontal norms defined by gravity constraints, whereas the vertical or horizontal orientations would be encoded directly. The indirect encoding of the oblique orientations, which implies the integration of the parameters computed on the two norms, may require higher costs of processing than the direct encoding of vertical or horizontal orientations, which refers to one norm only. The difference between these two modes of encoding and processing could explain the oblique effect observed in the haptic tasks (Foster & Westland, 1998; Gentaz & Hatwell, 1996; Gentaz, 2000; Gentaz et al. 2001; Regan & Price, 1986). In this context, the occurrence of an oblique effect in infants’ visual and haptic systems may suggest that an amodal reference norm could be at work across perceptual systems. However, Gentaz et al. (2001) showed in adults that although vertical orientation appears to be used as a reference norm by the visual, haptic, and somatovestibular systems to define orientations, modality-specific mechanisms seem to be at work in each perceptual system. This suggests that if the infants and adults share the same mechanisms, vertical reference norm used by the infants in haptic perception of orientations would be a modal reference norm, i.e., a norm specific to the haptic system. Moreover, to examine whether the infants and children share similar haptic orientation processing, further study should investigate whether the haptic oblique effect disappears when the exploratory conditions change, as is the case in children and adults when gravitational cues are lowered (Gentaz & Hatwell, 1996, 1999; see the Introduction).

Finally, the present research raises a question about the anatomofunctional level contributing specifically to the haptic oblique effect. As in vision, the remaining problem is to determine the level(s) where this haptic effect is generated. Neurophysiological studies do not seem to exclude any level in somesthetic processing. On one hand, the direction of gravity could be coded very early in somesthetic processing. Some authors have assumed the existence of body graviceptors, which could be linked to the Golgi tendon organs (Dietz, 1994). Thus, the haptic oblique effect could take root in the low level of somesthetic processing. On the other hand, Brandt, Dieterich, and Danek (1994) have isolated a multisensory cortical area (the parieto-insular cortex) in human adults involved in the perception of verticality. Thus, the haptic oblique effect can be generated at this high anatomofunctional level. It is also possible that the haptic oblique effect could occur at this high level of multisensory processing, although somesthetic primary mechanisms can also be at work in the observed haptic performances.

METHODS

Participants

Twenty-four infants (13 females and 11 males) aged from 4 months 22 days to 5 months 8 days (mean age: 4 months 28 days) participated in this experiment. All infants came from middle socioeconomic backgrounds and were observed at our laboratory. Informed consent was obtained from all parents. Additional infants were eliminated from the study because of fussiness (four) or maternal interventions (three) during the experiment.

Apparatus

The haptic apparatus was composed of a Plexiglas disk (diameter, 30 cm) equipped with a handle-shaped rod (18 cm × 15 cm; Figure 1). This rod (0.5 cm in diameter) was chosen because it was easily handled and explored by the 5-month-old infants. The rod, which was mounted on the center of the disk, could be rotated 360° around its central axis. The rod could be maintained in the desired orientation to prevent involuntary deviation from its position during haptic scanning. The disk was graduated in degrees (the sensitivity threshold of this display was equal to 0.5°). The rod and the disk were positioned in the frontal plane and were centered on the midline of the infant’s body. The height of the disk was adjusted so that the center of the rod was at the level of the infant’s shoulders.

Experimental conditions and procedure

Each infant was placed in a small experimental room and was seated in a semireclining canvas chair in front of an 80 × 80-cm white wooden screen, at a distance of 50 cm.

Figure 1. Infants’ display used to discriminate haptically the orientation of a rod. Note: A = a large white cloth bib was attached around the baby’s neck at one side and to the apparatus at the other.
A large white cloth bib (Figure 1) was attached around the baby’s neck at one side and to the screen at the other. The bib prevented infants from seeing their shoulder-hand systems, even laterally, but left them free to move. It also allowed the infants’ hands to be video recorded with a TV camera, the lens of which was located in a hole in the screen under the bib level. During this procedure, the first experimenter, located behind the screen, controlled the video recording. The second experimenter sat under the bib and to the right of the infant. The experimenter put the rod in the infant’s hand, then recorded holding time by pressing a key on the microprocessor, which stored all the data. The infant’s right hand was used in all experimental conditions because previous studies provided evidence that the right hand is preferentially used for moving an object in space, as compared to the left hand (e.g., Streri & Gouarin, 1996). The experiment included a familiarization phase and a test phase.

**Familiarization Phase**

In the familiarization phase, a fixed-duration procedure was adopted in which the stimulus was presented until each infant accumulated a 90-sec amount of holding time. In the present research, the infant’s right hand was put on the rod fixed upon the apparatus. When the infant let go of the rod for more than 2 sec before 90 sec were up and did not self-regrasp the rod, the experimenter put the infant’s hand on the rod again until she/he accumulated 90-sec duration of familiarization. The familiarized orientation was either the vertical (defined gravitationally) or the 45° left oblique. Twelve infants were familiarized with the vertical rod and 12 with the 45° left oblique rod.

**Test Phase**

The test phase began immediately after the familiarization phase. For each trial, an infant-controlled procedure was used. The test phase differed according to the familiarized orientation. In the test phase, after the familiarization to the vertical orientation, the vertical rod or the 10° left oblique rod was placed in the right hand of the infant. These two orientations were presented alternately during four trials (two test trial pairs) in a counterbalanced order (Order 1: 0°/10°/10°, Order 2: 10°/0°/10°/0°) between subjects. After the familiarization to the 45° oblique orientation, the 45° left oblique rod or the 55° left oblique rod was placed in the right hand of the infant. These two orientations were presented alternately during four trials (two test trial pairs) in a counterbalanced order (Order 1: 45°/55°/45°/55° and Order 2: 55°/45°/55°/45°) between subjects. It should be noted that the angular difference of 10° was chosen from performances observed both in young children by Gentaz and Hatwell, 1995 and in a pilot study. The within-subjects method of test, initiated by Kellman and Spelke (1985) and further used systematically by Streri, Gentaz, Spelke, and Walle (in press) and Streri and Spelke (1988, 1989) allows more reliable results than a between-subjects test of the reaction to novelty. There was a 2-sec delay between test trials in both experimental conditions.

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