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Vertical–horizontal illusion present for sighted but not early blind humans using auditory substitution of vision

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This experiment was undertaken to investigate the effect of sensory modality (vision vs. audition) and of visual status (early blind vs. sighted) on susceptibility to the vertical–horizontal illusion. Early blind volunteers and blindfolded sighted subjects explored variants of the vertical–horizontal illusion using a device that substituted audition for vision, whereas sighted subjects from an independent group inspected the same stimuli visually. Sensitivity to the vertical–horizontal illusion, including an illusion of moderate strength when using the sensory substitution device, was observed only in the two sighted groups. The existence of an illusion effect when using such a device supports the idea of a visual perception provided by sensory substitution, whereas the attenuation of the vertical–horizontal illusion strength is consistent with the visual field shape theory (Künnapas, 1955a). The absence of the illusion effect in early blind subjects suggests that the sensory experience influences the nature of perception and that the visual experience plays a crucial role in the vertical–horizontal illusion, in accordance with the size-constancy scaling theory (Gregory, 1963).

The vertical–horizontal illusion (VHI) is the tendency for observers to overestimate the length of a vertical line relative to a horizontal one of equal length (Prinzmetal & Gettleman, 1993). This illusion occurs both in vision and touch (see, e.g., Burtt, 1917; Coren & Girgus, 1978), and its theoretical significance has been a matter of debate (see Révész, 1950). Two main theories have been proposed to explain this perceptual phenomenon in vision: (1) according to the theory based on the shape of the visual field, the perceived length depends on the proportion of the visual field covered by the stimulus (Künnapas, 1955a, 1955b, 1957a, 1957b, 1957c). Since the visual field is larger horizontally than vertically in healthy humans, a vertical extent is systematically overestimated. (2) According to the size-constancy scaling hypothesis (Girgus & Coren, 1975; Gregory, 1963) and the other theories involving apparent distance (see, e.g., Day, 1972; Fisher, 1970; Tausch, 1954; Thiéry, 1896), illusory figures would be (unconsciously) interpreted by the perceptual system as flat projections of 3-D displays; this would prompt the brain to make specific corrections to the sizes of the perceived lines (Robinson, 1972/1998). In the case of the VHI, the vertical line would be considered to be shortened by a perspective effect, which would lead to a compensatory correction to its perceived length.

Additionally, some factors, such as the bisection of one of the lines in the vertical–horizontal figure, modulate the magnitude of the illusion (see Coren & Girgus, 1978). This modulation has been attributed to the influence of another illusion, the Oppel–Kundt illusion (also called the divided-line illusion or bisection illusion): When a line is divided in two parts, the bisected line is usually underestimated (Obonai, 1954). Therefore, when a line is bisected in a vertical–horizontal figure, the bisection illusion would interact with the VHI effect (Deregowski & Ellis, 1972; Finger & Spelt, 1947; Harris, Hayes, & Gleason, 1974). This would explain why the inverted T figure produces the strongest illusion effect; both effects (bisection and VHI) are combined.

Many authors (see, e.g., Appelle & Gravetter, 1985; Frisby & Davies, 1971) have hypothesized that most haptic illusions depend on the same causal mechanisms as in vision and are mediated by visualization. However, the VHI has also been demonstrated to depend on haptic determinants such as the scanning strategies (radial vs. tangential movements) used to explore the stimuli (Cheng, 1968; Day & Wong, 1971; Deregowski & Ellis, 1972; Gentaz & Hatwell, 2004; Heller, Calcaterra, Burson, & Green, 1997; Heller & Joyner, 1993; Millar & Al-Attar, 2000; von Collani, 1979, 1985; Wong, 1977). It is worth noting that when a sensory substitution device with a

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head-mounted camera is used, the sensorimotor contingencies (i.e., the sensory changes produced by various motor actions—here, the head movements) are similar to those with vision, which is not true for haptic perception (O'Regan & Noë, 2001). Therefore, if the VHI occurs with such a vision substitution device, we could hypothesize that this illusion is caused by visual mechanisms, since similar exploratory methods are used.

The purposes of the present study were (1) to test the sensitivity to the VHI using a device substituting audition for vision and (2) to evaluate both the effect of sensory modality (vision vs. audition) and of visual status (early blind vs. sighted) on the susceptibility to this illusion. Additionally, in order to assess the susceptibility to the bisection illusion, we used different variants of the VHI, presenting a bisection of one, two, or none of the lines. Demonstrating the possibility of experiencing a visual phenomenon, such as a visual illusion, with a sensory substitution device would indicate that perceptions obtained by sensory substitution contain visual properties. In addition, the present study was intended to get a better insight into the causal mechanisms of the VHI by testing two explanatory theories: the visual shape theory (Künnapas, 1955a) and the size-constancy scaling theory (Gregory, 1963). In line with the visual shape theory, suppression, or at least a diminution of the illusion effect when using the sensory substitution device, was expected, because the stimuli (VHI figures) would be explored and perceived through a nonvisual and orthogonal perceptual field. In line with the size-constancy scaling theory, an absence of the illusion effect was expected in the early blind subjects because of their lack of visual experience. Visual depth, and visual perspective, in particular, are often considered to be acquired through visual experience (Arditi, Holtzman, & Kosslyn, 1988; Gregory & Wallace, 1963). It has been shown that congenitally blind subjects can learn about visual depth perception from a theoretical point of view, allowing them to understand linear perspective, in some cases (Kennedy, Gabias, & Nicholls, 1991; Kennedy & Juricevic, 2003). However, they often face difficulties in applying such knowledge (see, e.g., Heller, Calcaterra, Tyler, & Burson, 1996).

METHOD

Subjects

The study was carried out with 49 subjects, including 9 early blind individuals. All of the subjects were involved in a previous experiment testing the Ponzo illusion, using the same sensory substitution device as in the present study (Renier, Laloyaux, et al., 2005). Twenty sighted subjects worked blindfolded, with a prosthesis for substitution of vision by audition (PSVA) (mean age = 26.9; SD = 9.3 years; 12 males, 8 females). The 20 other sighted subjects performed the experiments visually, as an independent control group (mean age = 35.2; SD = 11.1 years; 8 males, 12 females). Early blind subjects (mean age = 33.8 years; SD = 15.8 years; 7 males, 2 females) were totally blind since birth or lost sight completely (including sensitivity to light) before the 20th month of life, well before the completion of visual development. These individuals were considered to be early blind subjects, because they had no history of normal vision and did not remember any visual experience. Furthermore, most early blind volunteers involved in the present study had participated in previous PET experiments and demonstrated high metabolic activity in the occipital cortex in the resting state condition, as previously described (Veraart et al., 1990; Wanet-Defalque et al., 1988). This is considered to be a physiological indicator of early blindness (see, e.g., Büchel, Price, Frackowiak, & Friston, 1998; Sadato et al., 1998). All of the early blind subjects were well integrated socially. They traveled, lived independently, and were active professionally and/or socially. Table 1 provides details about gender, age, educational level, age at which subjects became totally blind, and etiology of blindness. The subjects underwent an audiometry test, to allow the amplitudes of the auditory prosthesis to be optimized for each individual's spectral sensitivity curve. All of the subjects were without any recorded history of neurological or psychiatric problems. The subjects were told the purpose of the study only at its conclusion, and each gave informed, written consent beforehand. The protocol had been approved by the Biomedical Ethics Committee of the School of Medicine of the Université Catholique de Louvain.

The age difference was significant only between visual control and blindfolded sighted subjects [$F(1,38) = 6.85$, $p < .05$; blindfolded sighted vs. early blind subjects: $F(1,27) = 2.25$, $p = .15$; visual control vs. early blind subjects: $F(1,27) = 0.08$, $p = .77$]. However, all of the subjects were adults of an age for which the magnitude of VHI has been demonstrated to be equivalent, at least in vision (see, e.g., Hanley & Zerbolio, 1965).

Experimental Design

The sensory substitution device. The PSVA has been described in detail elsewhere (Capelle, Trullemans, Arno, & Veraart, 1998); a demonstration is currently available at the *Perception* Web site (www.perceptionweb.com/perc0899/arno.html). Briefly, black-and-

Table 1
Characteristics of the Blind Volunteers

Gender	Age (Years)	Educational Level	Age at Which They Became Totally Blind	Diagnosis
M	67	College degree	18 months	accident (*)
M	26	College degree	congenitally	genetic (*)
M	29	High school	congenitally	premature birth
M	26	College degree	congenitally	premature birth
M	37	High school	congenitally	premature birth
M	51	College degree	congenitally	bilateral retinoblastoma
M	18	Some college	congenitally	premature birth
F	30	College degree	19 months	bilateral retinoblastoma
F	20	Some college	congenitally	cytomegalovirus

Note—M, male; F, female; (*) no additional details.

white images from a miniature head-mounted video camera (frame rate = 12.5 Hz) are translated in real time into sounds that the subject hears through headphones (see Figures 1A and 1B). The system combines an elementary model of the human retina with an inverse model of the cochlea. The camera image is pixelated according to a dual-resolution model of the human retina (see Figure 1B). This artificial retina consists of a square matrix of 8 × 8 large pixels, with the 4 central ones replaced by 8 × 8 smaller pixels, representing the fovea. The fovea, therefore, has four times the resolution of the periphery. At the distance at which subjects work with the PSVA, a 2-cm line on the computer screen corresponds to 5 pixels of the fovea of the processed image. A single sinusoidal tone is assigned to each pixel of the artificial retina, with frequencies increasing from left to right and from bottom to top; frequencies range between 50 and 12526 Hz. The grayscale level of each pixel modulates the amplitude of its corresponding sine wave. The final auditory output of the PSVA is the real-time weighted sum of all 124 sine waves.

PSVA training. Before performing the experiments, sighted and early blind subjects were trained to use the PSVA in a pattern-recognition task. This training phase (adapted from Arno, Capelle, Wanet-Defalque, Catalan-Ahumada, & Veraart, 1999) consisted of five 1-h sessions preceded and followed by an evaluation session. The sighted subjects worked blindfolded. The subjects were taught to recognize 2-D figures formed with vertical, horizontal, or oblique lines and were provided with tactile feedback; verbal cues were supplied as necessary. A quarter of the stimuli were the same as those used in the VHI experiment. The evaluation procedure was identical to the one used by Arno et al. (1999). After each stimulus exploration, subjects re-created their observations with a set of metal bars. A score ranging from 0 to 100 was then assigned, based on how well the re-creation matched the stimulus pattern. After the training sessions, geometrical figures of equivalent complexity to the VHI figures (Arno et al., 1999) were tested. Early blind subjects obtained a mean score of 80.34% correct responses ($SD = 14.88$) and blindfolded sighted subjects obtained a mean score of 77.21% ($SD = 13.72$) [$F(1,28) < 1$, $p = .5714$]. Performance levels did not differ significantly between the two groups and were considered to be high enough to perform the following experiment.

Experimental setup and stimuli. Six categories of stimuli were used and displayed on a computer screen at a fixed distance from the PSVA camera worn by the subject: five conditions corresponding to five variants of the VHI and one control condition (see Figure 2). Different variants of the VHI were used to assess the bisection illusion: with the horizontal line bisected (Figure 2A), with the vertical line bisected (Figure 2B), with none of the lines bisected (Figures 2C and 2D), or with both lines similarly bisected (Figure 2E). In Conditions A and B, the bisection illusion led to the underestimation of either the vertical or the horizontal line, whereas Conditions C and D were thought to produce a pure VHI effect without the bisection effect. In the five VHI conditions (Figures 2A–2E), the vertical and horizontal lines had exactly the same length (five pixels of the fovea in the PSVA-processed image; see Figure 1B). In the control condition (Figure 2F), the two lines had a length difference of two pixels in the fovea of the processed image. This condition aimed at keeping the subjects concentrated throughout the experiment and avoiding systematic responses (e.g., "the vertical line is always longer"). This was used as a validity index for the whole test. Each condition was composed of 10 trials, with a total of 60 bar-length judgments for the entire test. The presentation order of the stimuli was pseudorandomized.

Task. The experiment consisted of a bar-length comparison task. The subjects were instructed to explore the stimuli and to determine as quickly as possible whether the vertical or the horizontal line seemed to be longer. Both the head movement and the auditory stimulation from the PSVA (intensity and complexity of the sounds) could be used to estimate the length of the lines. The exploration time was recorded and limited to 60 sec for one stimulus. The subjects controlled the beginning and the end of each stimulus exploration by pressing a button. The answers following the length judgments were provided verbally, and were scored on a 0–1 basis. Sighted subjects worked blindfolded. The vision control group performed the experiment in the same way, but without the prosthesis. For this group, the exploration time was about 1 sec (not recorded, for technical reasons). The whole experiment took the form of a between-within design. The three groups were exposed to all six types of stimuli (from A to F).

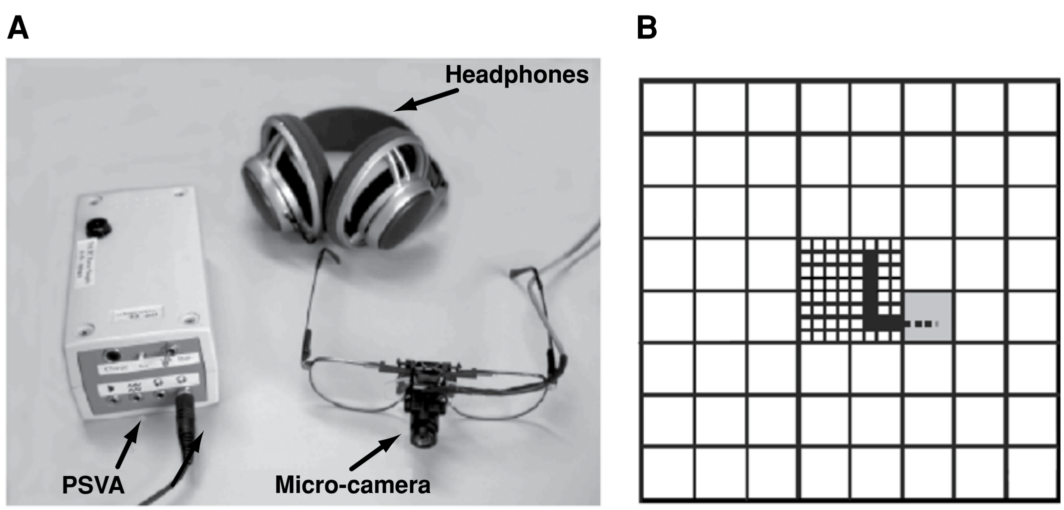

Figure 1. (A) The prosthesis for substitution of vision with audition (PSVA; Capelle et al., 1998) used in the experiments. A head-mounted camera (attached to glasses) allows for real-time translation of visual patterns into sounds that are transmitted to the subject through headphones. (B) The artificial retina of the PSVA when an L-shaped figure is perceived. The image acquired by the camera is divided into pixels, according to a two-resolution artificial retina scheme. A single sinusoidal tone is assigned to each pixel of the multiresolution image (see the Method section).

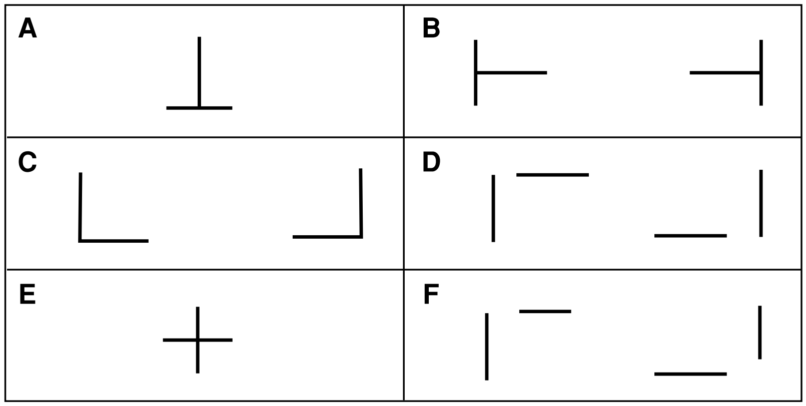

Figure 2. The stimuli corresponding to the different variants of the vertical–horizontal illusion (from A to E) and a control condition (F) used as a validity index. In each condition ($n = 10$), the length of the two lines was identical except in Condition F, in which a length difference of two pixels between the two lines was introduced. For Conditions B, C, D, and F, two different orientations of the configuration were used (five of each).

RESULTS

Validity Index

The proportion of correct responses for Condition F (see Figure 2) was 80% ($SD = 13.76$) in blindfolded sighted subjects, 100% ($SD = 0$) in visual control subjects, and 80% ($SD = 18.52$) in early blind subjects. An ANOVA revealed no significant difference between blindfolded sighted subjects and early blind subjects [$F(1,27) = 0.03$, $p = .85$]. The absence of errors in the visual control group was probably due to the length difference, which was obvious in vision. The validity indices were similar in the two PSVA groups, which indicates accurate understanding and execution of the task by both groups.

VHI Effect

The results of the present experiment are summarized in Table 2, showing the percentages of responses consistent with the VHI effect (i.e., the percentages of answers in which the vertical line was judged to be longer). Results are presented as a function of the groups and of the different conditions (configurations of the stimuli).

Student *t* tests performed on these scores showed a robust effect of the illusion in both sighted groups. The proportion of responses consistent with the illusion effect was significantly higher than the level of chance in each condition in blindfolded sighted subjects [all ts$(19) > 2.9$; ps $<$ .01], whereas Condition B was the only one with a reverse effect in vision control subjects [all ts$(19) > 3$, all ps $<$ .001 in these subjects except for Condition B, $t(19) = -6.52$, $p < .001$]. By contrast, the performance in early blind subjects did not differ from the level of chance in any condition [all ts$(8) < 2$ and > 1.1, all ps $> .3$].

A 3 (group) $\times$ 5 (condition) ANOVA was performed on these scores. The group was a between-subjects factor and the condition was a within-subjects factor. This analysis showed a significant main effect of group [$F(2,46) = 16.17$, $p < .001$], a significant main effect of condition [$F(4,184) = 17.35$, $p < .001$], and a significant interaction effect [$F(8,184) = 71.28$, $p < .001$].

To assess the effect of visual status (early blind vs. sighted) and of the sensory modality (vision vs. audition), post hoc multiple pairwise comparisons of selected means (mean score for the same condition in each group, Table 2) were made at an overall significance level of .05 using a Fisher LSD criterion. The comparisons between blindfolded sighted subjects and vision control subjects revealed a significant difference in Conditions B and D

Table 2
Percentage of Responses (With Standard Deviations) Consistent With the Vertical–Horizontal Illusion as a Function of Group and Condition

	Condition											
	A		B		C		D		E		Overall	
Group	%	*SD*	%	*SD*	%	*SD*	%	*SD*	%	*SD*	%	*SD*
VC	99.5	2.24	18.5	21.59	83.5	16.94	96	9.95	66	21.86	72.7	9.76
BS	87	12.18	73	18.95	69.5	18.49	67	25.96	70.5	18.20	73.4	11.75
EB	38.75	24.75	56.25	22.64	52.5	21.21	51.25	19.59	48.75	16.42	49.5	14.37

Note—VC, vision control; BS, blindfolded sighted; EB, early blind. Groups BS and EB worked with the PSVA.

only (both $ps < .001$), with a trend for Condition C ($p = .087$). By contrast, no significant group difference was observed in Conditions A ($p = .12$) and E ($p = .58$). The comparisons between vision control and early blind subjects revealed a significant difference in each separate condition (all $ps < .002$) except in Condition E, for which only a trend was observed ($p = .079$). The comparisons between blindfolded sighted and early blind subjects revealed a significant difference in Conditions A and E only (respectively, $p < .001$ and $p < .04$), with a trend in Condition C ($p = .061$; all other $ps > .11$). However, the blindfolded sighted subjects demonstrated an effect of the illusion in Conditions B and D, unlike the early blind subjects.

Bisection Effect

To assess the condition effect (i.e., the bisection effect) in each separate group, post hoc multiple pairwise comparisons of selected means (mean score for each condition in the same group, Table 2) were made at an overall significance level of .05 using a Fisher LSD criterion. In the vision control group, there was a significant difference between each condition and each of the other ones, except between A and D (all $ps < .02$ except between A and D ($p = .49$). This means that there was no difference between the inverted T and the _I stimuli. In blindfolded sighted subjects, significant differences were found only between Condition A and each of the other ones (all $ps < .01$; all other comparisons with p values $> .24$). In early blind subjects, there was no significant difference between any conditions except between A and B (p value $< .05$; all other $ps > .18$), due to the very low scores in Condition A. This means that there was no significant difference between the inverted T and the L-shape stimuli, for instance. The low scores observed for the inverted T condition did not reflect a reversed illusion because these scores did not differ from the level of chance (as mentioned in the VHI Effect section).

Exploration Times

Figure 3 shows the median exploration times of the blindfolded sighted subjects and the early blind subjects as a function of the different conditions. According to a 2 (group) × 5 (condition) ANOVA, with group as a between-subjects factor and condition as a within-subjects factor, there was only a trend for a group effect [$F(1,27) = 3.90$, $p = .058$], with faster processing times in early blind than in blindfolded subjects, with no significant effect of the condition [$F(4,108) = 0.39$, $p = .82$], and no interaction effect [$F(4,108) = 0.46$, $p = .77$].

DISCUSSION

In the present study, a sensitivity to the vertical–horizontal illusion was obtained using the sensory substitution device in the sighted group. With the device, the illusion was of moderate strength, when compared with vision, and did not occur in early blind subjects. In contrast, a clear bisection effect was observed only in the visual modality.

Binary responses were made in the present study, and no metric measure of the illusion amount was recorded. The consistency of the illusion was used as the dependent measure to judge the strength of the effects (VHI and bisection illusion). The comparison of the exploration times between the two PSVA groups (blindfolded sighted vs. early blind subjects) revealed faster exploration times in early blind subjects using the PSVA (but equivalent overall performance in terms of percentage of correct responses in the control tasks). This was in accordance with previous studies that showed a superiority of congenitally blind subjects in perceptual tasks, such as pattern recognition, with the PSVA (Arno, Vanlierde, et al., 2001) or

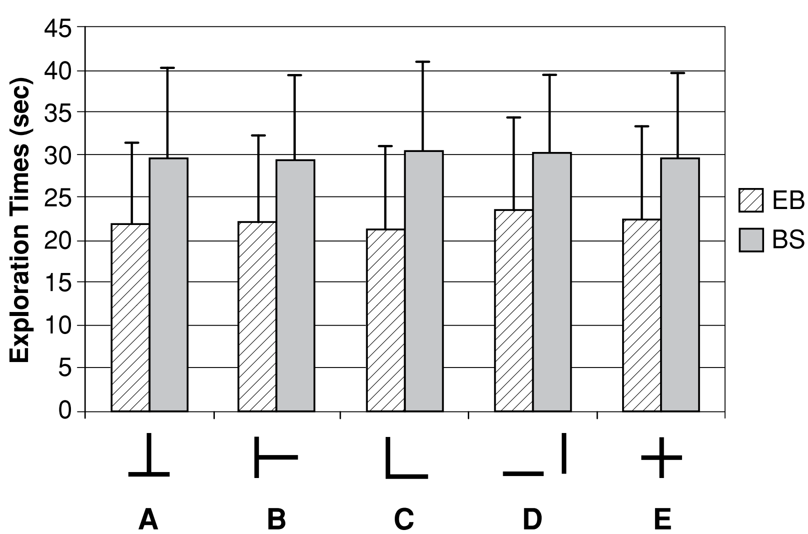

Figure 3. Median exploration times as a function of the condition (from A to E) and of the group (early blind [EB] subjects and blindfolded sighted [BS] subjects).

sound localization (Lessard, Paré, Lepore, & Lassonde, 1998; Rice, 1969; Röder et al., 1999), bringing support to the idea that compensatory mechanisms exist as a result of early visual deprivation (Rauschecker, 1995). In the present study, the line lengths were physically equal in the majority of conditions, which could have led to biases, although presumably they would tend to decrease the sought-after effects. Despite these limitations, the present study shows for the first time that the VHI can be experienced through sensory substitution.

Optical illusions are visual phenomena (see, e.g., Fick, 1852). Demonstrating the possibility of perceiving a visual illusion through a vision sensory substitution device constitutes a strong argument in favor of a visual perception obtained by sensory substitution. Interestingly, a susceptibility to the Ponzo illusion was previously observed using the same device (Renier, Laloyaux, et al., 2005). In addition, neuroimaging studies have shown a recruitment of visual brain areas during the use of the PSVA, which also highlights the visual nature of perceptions obtained by this sensory substitution device (Arno, De Volder, et al., 2001; Renier, Collignon, et al., 2005). From a more general perspective, these observations suggest that the nature of perception is not predominantly determined by the sensory modality. According to the sensorimotor contingencies theory (O'Regan & Noë, 2001), it would be possible to have visual experiences through a nonvisual modality such as audition if the sensorimotor contingencies of vision (i.e., the sensory variations related to the head movements) are applied to this modality. This theory therefore predicts that the use of a sensory substitution device with a head-mounted camera could provide visual experiences. The observed sensitivity to the VHI could be considered to be a confirmation of this prediction. It may be hypothesized that the application of the sensorimotor contingencies of vision to the auditory channel (when using the PSVA) would have promoted a visual-like perception. This, in turn, would have favored the illusion effect, regardless of the causal mechanisms of the illusion. The existence of visual illusions in the haptic mode brought researchers to postulate that touch shares perceptual mechanisms with vision (see, e.g., Millar & Al-Attar, 2002). This hypothesis finds some confirmation in brain imaging studies that demonstrate that visual and haptic object recognition involve common brain areas (see, e.g., Amedi, Malach, Hendler, Peled, & Zohary, 2001).

According to the theory of Künnapas (1955a), a disappearance—or at least a significant attenuation—of the VHI effect was expected with the PSVA, when compared with vision. In the present study, only an attenuation of the VHI was observed in the sighted subjects who used the PSVA. Although the scores in the vision control group seemed to have reached a ceiling, the scores were significantly worse with the PSVA than with vision in most conditions, especially in Condition D, which represented a "pure" VHI effect (i.e., without bisection effect). However, the VHI did not disappear when the PSVA was used. Previous studies supporting Künnapas's theory showed, similarly, that the VHI was weaker with the monocular than with the binocular view (Prinzmetal & Gettleman, 1993) and was affected by the shape of the surrounding frame (Künnapas, 1959). In addition, results in the present study revealed a discrepancy between early blind and blindfolded sighted subjects using the PSVA. These data lead us to conclude that, although the shape of the perceptual field seems to play a role in the VHI, it cannot be the only causal mechanism underlying this illusion.

The absence of a VHI effect in early blind subjects indicates that visual experience plays a crucial role in the VHI with the PSVA. According to the size-constancy scaling theory (Girgus & Coren, 1975; Gregory, 1963), the VHI figure is unconsciously interpreted as a 3-D scene, with the vertical element being foreshortened by a perspective effect. This perception would inappropriately trigger the size-constancy scaling that would lead to correcting the perceived length of the vertical line. Visual perspective is mainly considered to be acquired through visual experience (see, e.g., Gregory & Wallace, 1963) and, although congenitally blind subjects can learn knowledge about visual depth from a theoretical point of view (Kennedy et al., 1991; Kennedy & Juricevic, 2003), they often face difficulties in tasks involving visual depth and perspective (see, e.g., Heller et al., 1996; Renier, Collignon, Tranduy, Vanlierde, & De Volder, 2003). For this reason, the size-constancy scaling predicted an absence of the illusion effect in early blind subjects. Our results are in accordance with this prediction. A susceptibility to the VHI has been obtained in early blind subjects in the haptic mode (see, e.g., Heller et al., 1996). However, the tactual VHI was demonstrated to depend partly on the scanning movements made to explore the stimuli, in addition to the visual determinants in sighted subjects (see, e.g., Gentaz & Hatwell, 2004; Heller et al., 1997). These haptic determinants could be responsible for the tactual illusion in congenitally blind subjects. To explain the VHI, several other experimental data also brought support to the size-constancy scaling theory. For instance, von Collani (1985) showed that the illusion was enhanced when the vertical–horizontal stimulus was embedded in a 3-D drawing. Another implication of the present observations is that visual experience seems to influence the nature of perception with the PSVA. On the one hand, we cannot exclude the possibility that perception with the PSVA was supported by visualization, as it is in touch (Heller, 2000a, 2000b; Prather, Votaw, & Sathian, 2004; Révész, 1950; Sathian, Zangaladze, Hoffman, & Grafton, 1997; Zhang, Weisser, Stilla, Prather, & Sathian, 2004). The implication of mental imagery during the use of the PSVA has already been hypothesized (Renier, Collignon, et al., 2005; Renier, Laloyaux, et al., 2005). On the other hand, since the VHI occurred in sighted subjects only, and not in early blind, the visual nature of this illusion appears to be confirmed. The perception obtained by sensory substitution would be in some sense more "visual" for the sighted subjects than for the early blind subjects. From this perspective, using the PSVA would theoretically provide blind subjects with "visual" experiences that would change the nature of their perception, including depth and perspective effects, after a longer period of utilization in various situations. This "visual" experience using the PSVA would, in turn, allow them to become sensitive to some visual illusions. Various functional imaging studies have indicated that the inputs from auditory and tactile modalities are capable of promoting efficient functional development of extrastriate visual areas in the absence of vision (see, e.g., Amedi, Raz, Pianka, Malach, & Zohary, 2003; Büchel et al., 1998; Sadato et al., 1998; Weeks et al., 2000) and that the activity of extrastriate visual cortex can be modulated by new perceptual experience (Arno, De Volder, et al., 2001).

The bisection illusion occurred clearly only in vision. Its effect appeared mainly in the comparison between the inverted T figure (Condition A) and the same figure rotated to 90º (Condition B). The bisection effects are opposite in these two conditions, shortening the horizontal divided line in the inverted T figure and the vertical divided line in the other condition. Accordingly, results show that the VHI was enhanced in the inverted T figure, whereas it was reversed in Condition B. In contrast with the results obtained in vision, no clear effect of the bisection illusion was observed when the PSVA was used. In sighted subjects, although the inverted T figure was hypothetically the most efficient way to get a VHI illusion with the PSVA (because the bisection illusion adds its effect to the VHI; see Obonai, 1954), this was not significant from a statistical point of view. Interestingly, a bisection illusion has already been obtained for touch in sighted subjects (Millar & Al-Attar, 2000). Further studies should investigate specifically (without the interference of the VHI) the bisection illusion with the PSVA as well as its causal mechanisms, which remain largely unknown.

In conclusion, this study demonstrates that it is possible to experience a visual illusion through sensory substitution of vision. Although the sensory modality seems to influence the VHI, as predicted by the visual field shape theory, the visual experience appears to be a crucial factor in enabling sensitivity to this illusion, as postulated by the size-constancy scaling theory. This contributes to the debates about the perceptual nature of sensory substitution and about the determinants of the VHI. Hypothetically, the "visual" sensorimotor contingencies when using the PSVA would have favored the visual-like nature of the perception and the sensitivity to the VHI. Many questions concerning the underlying mechanisms involved in perception via sensory substitution (e.g., the actual role of the sensorimotor contingencies and the causal mechanisms of the bisection illusion) remain unanswered.

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