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The Ponzo illusion with auditory substitution of vision in sighted and early-blind subjects

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Abstract. We tested the effects of using a prosthesis for substitution of vision with audition (PSVA) on sensitivity to the Ponzo illusion. The effects of visual experience on the susceptibility to this illusion were also assessed. In one experiment, both early-blind and blindfolded sighted volunteers used the PSVA to explore several variants of the Ponzo illusion as well as control stimuli. No effects of the illusion were observed. The results indicate that subjects focused their attention on the two central horizontal bars of the stimuli, without processing the contextual cues that convey perspective in the Ponzo figure. In a second experiment, we required subjects to use the PSVA to consider the two converging oblique lines of the stimuli before comparing the length of the two horizontal bars. Here we were able to observe susceptibility to the Ponzo illusion in the sighted group, but to a lesser extent than in a sighted non-PSVA control group. No clear effect of the ilusion was obtained in early-blind subjects. These results suggest that, at least in sighted subjects, perception obtained with the PSVA shares perceptual processes with vision. Visual experience appears mandatory for a Ponzo illusion to occur with the PSVA.

1 Introduction

Sensory substitution (Bach-y-Rita et al 1969) refers to the use of a sense to receive information that is normally gathered by a different sensory organ (Kaczmarek 1995). Vision sensory-substitution devices convert real-time information from a video camera into either tactile (White et al 1970; Collins et al 1973; Sampaio et al 2001; see Kaczmarek et al 1991 for a review of some of these devices) or auditory (Meijer 1992; Capelle et al 1998) inputs. Although vision is closer to touch than to audition (from a spatial perspective), auditory and tactile vision-substitution devices share functional and perceptual properties. Both allow the user to recognise two-dimensional (2-D) geometrical figures (Bach-y-Rita et al 1998; Arno et al 1999), to locate and identify objects (Bach-y-Rita 1972; Auvray et al 2003), to estimate the distance to an object, and to perceive depth (Bach-y-Rita 1972; Renier et al 2003). A study of pattern recognition with a prosthesis for substitution of vision with audition (PSVA) demonstrated recruitment of the dorsal visual pathway both in early-blind subjects and in blindfolded controls (Capelle et al 1998). The ability of the PSVA to activate visual brain areas known to process spatial information (eg Held 1968) was interpreted as evidence of crossmodal recruitment (Arno et al 2001a). However, despite the growing number of studies on sensory substitution, little is known about the underlying cognitive processes involved.

A number of researchers have presented arguments in favour of the visual nature of perceptions obtained via sensory substitution. Morgan (1977) identified that both vision and its sensory substitutes convey the same kinds of information and lead to similar behavioural responses. Bach-y-Rita (1972) mentioned that subjects using a vision sensory-substitution device usually report visual sensations after a short training in the use of the system. O'Regan and Noë (2001) postulated that sensory-substitution devices based on head-mounted cameras provided visual experience, since the sensorimotor contingencies

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(ie the sensory changes produced by various motor actions) were identical to those for vision. However, these arguments do not take into account the cognitive aspects of sensory substitution, specifically the top–down nature of perception. Cognitive visual illusions refer to perceptual phenomena where sensory information is misinterpreted by the brain. These phenomena are usually considered as models of top–down influences in vision because they result from unconscious influences of cognitive processes (Helmholtz 1867/1962; Gregory 1963; Rock 1975). The Ponzo illusion, in particular, is an optical illusion based on visual perspective and is considered to be heavily dependent on the visual system (eg Gregory 1963).

The purpose of our study was to assess susceptibility to the Ponzo illusion when experienced through a PSVA. We also investigated the role of visual experience on susceptibility to this illusion.

2 General method and procedure

2.1 *Subjects*

The study was conducted with forty-nine subjects, including nine early-blind individuals. Twenty sighted subjects (mean age = 26.9 years, SD = 9.3 years; twelve males, eight females) worked blindfolded with a PSVA. The twenty other sighted subjects performed the experiments visually as a separate control group (mean age = 35.2 years, SD = 11.1 years; eight males, twelve females). Early-blind subjects (mean age = 33.8 years, SD = 15.8 years; seven males, two females) were totally blind at 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 as early-blind subjects as they had no history of normal vision or visual experiences. Table 1 provides details about gender, age, educational level, age at which subjects became totally blind, and aetiology of blindness. Subjects underwent an audiometry test to allow the amplitudes of the auditory prosthesis to be optimised for each individual's spectral-sensitivity curve. All participants were without any recorded history of neurological or psychiatric problems. Three early-blind volunteers and one blindfolded sighted subject were involved in previous experiments with the PSVA that took place more than 1 year earlier. Subjects were only told the purpose of the study at its conclusion, and each gave written informed 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 the two groups of sighted subjects ($F_{1,38} = 6.85$, $p < 0.05$; blindfolded sighted subjects versus early-blind subjects: $F_{1,27} = 2.25$, $p = 0.15$; sighted controls versus early-blind subjects: $F_{1,27} < 1$, $p = 0.77$). However, the subjects' ages were within a range over which the magnitude of most visual illusions

Table 1. Characteristics of the blind volunteers, including gender, age, education, age at which they became totally blind, and the aetiology of blindness.

Gender	Age/years	Educational level	Onset of blindness	Diagnosis
male	67	college degree	18 months	accident (no details)
male	26	college degree	congenitally	genetic
male	29	high school	congenitally	premature birth
male	26	college degree	congenitally	premature birth
male	37	high school	congenitally	premature birth
male	51	college degree	congenitally	bilateral retinoblastoma
male	18	some college	congenitally	premature birth
female	30	college degree	19 months	bilateral retinoblastoma
female	20	college degree	congenitally	cytomegalovirus

has been shown to be equivalent (see Robinson 1998 for a review of some of these studies). The Ponzo illusion, for instance, is known to be relatively constant in subjects between 13 and 50 years old, before it starts decreasing (Leibowitz and Judisch 1967).

2.2 *The sensory-substitution device*

The PSVA has been described in detail elsewhere (Capelle et al 1998). Briefly, black-and-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 (see figure 1c) is pixelated according to a dual-resolution model of the human retina (see figure 1d). 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. 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 12 526 Hz. The grey-scale 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.

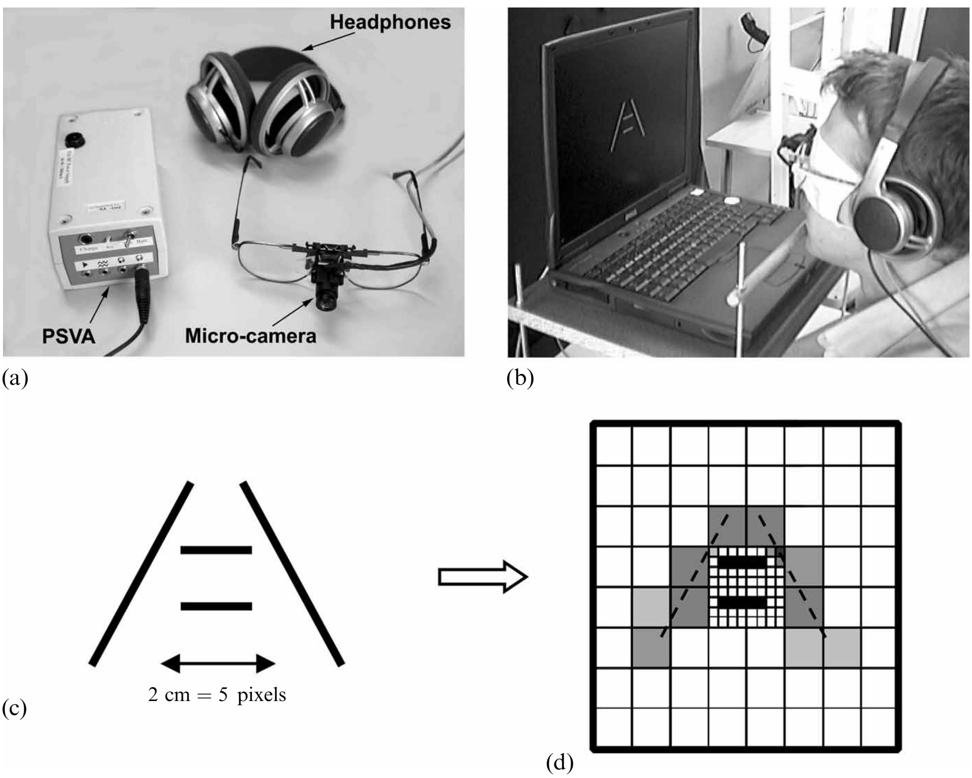


Figure 1. (a) Prosthesis for substitution of vision with audition, or PSVA (Capelle et al 1998), used in the experiments. Head-mounted micro-camera (attached to glasses) allows for real-time translation of visual patterns into sounds that are transmitted to the subject through headphones. (b) Experimental setup used for the presentation of the stimuli. Stimuli were displayed on a computer screen. Subjects explored the stimuli from a constant distance, which was the same for all volunteers. (c) One of the stimuli used in the experiment; (d) its corresponding representation in the artificial retina of the PSVA. 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 multi-resolution image (see text). A 2 cm bar corresponds to 5 pixels in the fovea of the processed image.

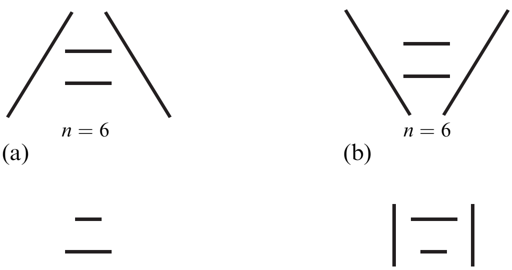
2.3 *PSVA training*

Before performing the experiments, both sighted and early-blind subjects were trained to use the PSVA in a pattern-recognition task. This training phase (adapted from Arno et al 1999) consisted of five 1 h sessions preceded and followed by an evaluation session. Subjects were taught to recognise 2-D figures formed with vertical, horizontal, or oblique lines, and were provided with tactile feedback; verbal cues were supplied as necessary. The sighted subjects worked blindfolded. The evaluation procedure was identical to the one used by Arno et al (1999). After each trial, subjects re-created their observations with a set of metal bars. A score ranging from 0 to 1 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 Ponzo figure (Arno et al 1999) were tested. Early-blind subjects obtained a mean score of 80.34% of correct responses (SD = 14.88%) and blindfolded sighted subjects obtained a mean score of 77.21% (SD = 13.72%) ($F_{1,28} < 1$, $p = 0.5714$). Performance levels did not differ significantly between the two groups and were considered to be high enough to perform the following two experiments.

3 Experiment 1: The Ponzo illusion in early-blind subjects and blindfolded sighted subjects using the PSVA

3.1 *Experimental setup and stimuli*

Three categories of stimuli were displayed on a computer screen at a fixed distance from the PSVA camera worn by the subject (see figure 1b): a Ponzo condition and two control conditions (see figures 2a and 2d). In the Ponzo condition, two horizontal bars of the same length (5 pixels in the fovea or 2 cm on the computer screen; see figure 1d) were surrounded with two converging oblique lines pointing either upwards (figure 2a) or downwards (figure 2b). The stimuli of the first control condition were formed with two horizontal bars with a difference in length of 2 pixels in the fovea of the pixelated image without any surrounding lines (see figure 2c). The stimuli of the second control condition (figure 2d) were formed with two horizontal bars with a difference in length of 2 pixels that were surrounded by two vertical bars (neutral context). In all cases, the two horizontal bars could be perceived either together in the fovea or separately, depending on the subject's head position. The two control conditions were used to evaluate whether the presence of elements around the two horizontal bars affected the bar-length-comparison task. The presentation order of the stimuli was pseudorandomised.



$n = 6$ (a) $n = 6$ (b)

$n = 6$ 'without context' (c) $n = 6$ 'neutral context' (d)

Figure 2. The stimuli of the three conditions used in experiment 1. Half of the stimuli of the Ponzo condition had their apex oriented upwards (a) and the second half downwards (b). The two horizontal bars always had the same length (5 pixels) in the Ponzo condition whereas in the two control conditions [(c) and (d)] they had a difference in length of 2 pixels in the fovea of the PSVA processed image. In half of the stimuli of each control condition, the upper bar was shorter [3 pixels, see (c)], whereas in the other half, it was longer [5 pixels, see (d)]. n = number of stimulus presentations per subject.

A variant of the control condition without any context (see figure 2c) was pretested in a separate group of eight sighted subjects who were similarly trained to use PSVA to recognise 2-D figures. In this pretest, the larger bar was always 7 pixels long, while the difference in length between the two bars varied between 1 and 5 pixels. Each stimulus was presented ten times, and subjects were told to compare the lengths of the two horizontal bars. This pretest revealed that a difference in length of 1 pixel between bars was correctly detected with a higher level than chance (61.25%, SD = 3.5%; $t_7 = 9$, $p < 0.001$). A difference in length of 2 pixels was correctly perceived in 71.25% of the trials (SD = 19.6%; $t_7 = 3.07$, $p < 0.05$). Performance increased with the differences in length (3 pixels: 77.50%, SD = 12.8%; 4 pixels: 87.50%, SD = 12.8%; 5 pixels: 88.75%, SD = 12.5%). Therefore, the training protocol was sufficient to allow detection of differences in bar length with the PSVA.

3.2 *Task*

The experiment consisted of a bar-length-comparison task. Early-blind and blindfolded sighted subjects were asked to explore the stimuli and to determine as quickly as possible which of the two horizontal bars appeared longer. They were not told that the two horizontal bars were of equal length in the Ponzo condition (figures 2a and 2b). The subjects controlled the beginning and the end of each stimulus exploration by pressing a switch that turned the PSVA on and off. The exploration time of each stimulus was recorded and limited to 60 s for each presentation. After this period, the sound of the PSVA was automatically turned off. Bar-length judgments were scored on a 0 – 1 basis. Vision control subjects performed this experiment visually. For this group, the average exploration time was ~1 s, but this variable is not relevant to the present study. The three groups were exposed to all types of stimuli (figures 2a – 2d). After the experiment, subjects were questioned about their strategies and about the nature of the stimuli.

3.3 *Results*

3.3.1 *Illusion effect.* In the Ponzo condition, the responses were considered as consistent with an illusion effect if subjects overestimated the length of the bar nearest to the vanishing point of the oblique lines. Table 2 shows the proportion of responses consistent with the Ponzo illusion for each experimental group.

A significant illusion effect, with a proportion of consistent responses well above the level of chance, was only observed in the vision control group ($t_{19} = 11.83$, $p < 0.001$; Student t-tests). By contrast, the performance of the two PSVA groups did not differ from the level of chance ($t_{19} = -1.8$, $p = 0.08$ in blindfolded sighted subjects and $t_8 = -0.83$, $p = 0.43$ in early-blind subjects).

Table 2. Percentage of responses consistent with the Ponzo illusion and percentage of correct responses in the two control conditions, and standard deviation (SD), as a function of the group in experiment 1.

Groups	Ponzo condition		Control conditions			
	answers consistent with with illusion/%	SD/%	without context		neutral context	
			correct answers/%	SD/%	correct answers/%	SD/%
Vision control	87.5[a]	14.18	100	0	100	0
Blindfolded sighted	42.9	17.6	82.5	16.64	70.8	17.83
Early-blind	45.4	16.2	74.1	26.5	75.9	18.84

[a] $p = 0.001$.

An analysis of variance (ANOVA) performed on the number of responses that were consistent with the Ponzo illusion revealed a group effect ($F_{2,46} = 43.9$, $p < 0.001$). This effect was only significant between the vision control group and each of the two other groups ($F_{1,46} = 76.65$, $p < 0.001$ with blindfolded sighted subjects; and $F_{1,46} = 42.48$, $p < 0.001$ with early-blind subjects). The two PSVA groups did not differ from each other ($F_{1,46} < 1$, $p = 0.70$).

3.3.2 *Effect of the context in control conditions.* The percentage of correct responses obtained in the two control conditions as a function of experimental group is shown in table 2. Given the absence of errors in the control conditions in the vision control group, statistical analyses were only performed on the two PSVA groups. All scores in the PSVA groups were satisfactory (higher than 70%) and were equivalent between groups and conditions. A 2 (group) × 2 (condition) ANOVA revealed no group effect ($F_{1,27} < 1$, $p = 0.79$), no condition effect, ie no significant effect of the context ($F_{1,27} = 1.29$, $p = 0.27$), and no interaction effect ($F_{1,27} = 2.44$, $p = 0.13$).

3.3.3 *Exploration times.* Figure 3 shows the median exploration times in the PSVA groups as a function of condition. Early-blind subjects explored all stimuli faster than blindfolded sighted subjects, but this group difference did not reach a significant level in the Ponzo condition ($F_{1,27} = 1.91$, $p = 0.18$, one-way ANOVA).

To assess whether the presence of vertical bars around the two horizontal bars affected the exploration speed, a 2 (group) × 2 (control conditions) ANOVA was performed on the median exploration times. It revealed a group effect in favour of the early-blind subjects, who were significantly faster than sighted subjects ($F_{1,27} = 4.74$, $p < 0.05$). There was no effect of the condition ($F_{1,27} < 1$, $p = 0.82$), and no interaction effect ($F_{1,27} < 1$, $p = 0.64$).

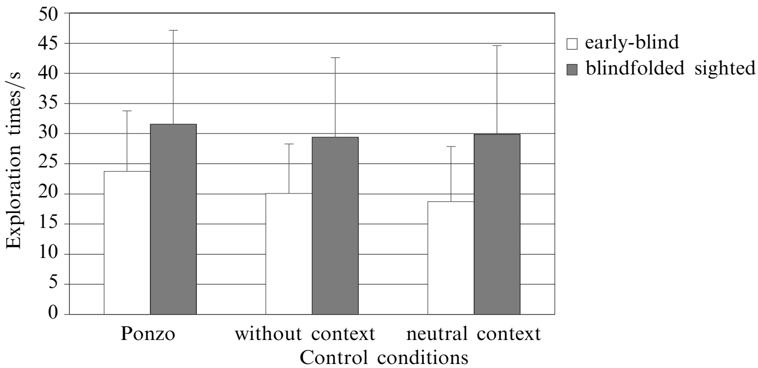


Figure 3. Exploration times in early-blind subjects and blindfolded sighted subjects in the Ponzo condition as well as in the two control conditions: 'without context' and with a 'neutral context'. Although early-blind subjects were faster than blindfolded sighted subjects in all conditions, this difference was only significant for the two control conditions (see text).

3.3.4 *Discussion.* In the first experiment, a susceptibility to the Ponzo illusion was only observed in the vision control group. The absence of the illusion effect with the PSVA could be attributed to the fact that subjects did not perceive the two converging oblique lines that induce the illusion effect. After the experiment, subjects using the PSVA specifically reported that they did not explore the elements surrounding the two horizontal bars since it was not necessary for performing the bar-length-comparison task. Furthermore, the instruction was to select the longer horizontal bar as fast as possible, and analysing the oblique lines would have required time and effort. During the interviews following the experiment, only 14% of the subjects mentioned the presence of oblique lines surrounding the horizontal bars. Similar accuracy rates and execution times were observed in the two control conditions with the PSVA. The same 'economising strategy' might explain why the presence of vertical elements around the two horizontal bars did not affect the performance in the control condition with a neutral context. Furthermore, unlike in vision, perception with the PSVA is relatively analytic, sequential, and effortful given the use of an arbitrary code, the small size of the perceptual field of the PSVA (especially the fovea, see figure 1d), and the limited number of sounds that can be transmitted simultaneously without saturating the auditory channel.

Faster exploration times were obtained in early-blind subjects with PSVA. This was in accordance with previous studies that showed the superiority of congenitally blind subjects in perceptual tasks, such as pattern recognition with PSVA (Arno et al 2001b) or sound localisation (Rice 1969; Lessard et al 1998; Röder et al 1999), bringing some support to the existence of compensatory mechanisms subsequent to early visual deprivation (Rauschecker 1995).

A second experiment was carried out with the same subjects to test the hypothesis that no illusion effect was obtained with the PSVA in the first experiment because subjects did not take into account the contextual cues that induce the illusion. In this second experiment, we added a task in order to oblige subjects to process the two converging oblique lines before the bar-length-comparison task. This would promote a mental representation of the entire stimulus in order to increase the power of top–down processes in the perception obtained with PSVA. We therefore expected the context would induce an illusion effect.

4 Experiment 2: The modified Ponzo illusion in early-blind subjects and blindfolded sighted subjects using the PSVA

4.1 *Stimuli*

Two modified Ponzo conditions were used in experiment 2 in addition to the two stimuli of the classic Ponzo condition (see figures 4a–4f). In these modified Ponzo conditions, the two horizontal bars differed in length by between 1 and 5 pixels (the longest bar was always 7 pixels long). In half of the stimuli, the expected illusion effect opposed the actual differences in length between the two horizontal bars (opposition condition, see figures 4c and 4d). In the other stimuli, the expected illusion effect was coincident with the differences in bar length (congruent condition, see figures 4e and 4f). The presentation order of the stimuli was pseudorandomised.

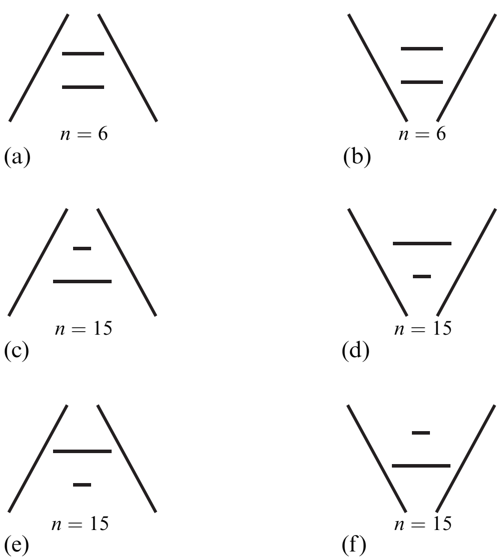


Figure 4. The stimuli of each of the three conditions used in experiment 2. (a) and (b) In the classic Ponzo condition ($n = 12$ trials), the two horizontal bars always had the same length. (c) to (f) A difference in length of 1 to 5 pixels was incorporated into the two modified Ponzo conditions ($n = 6$ trials for each difference in length for each of the two modified Ponzo conditions). In the opposition condition [(c) and (d)], the difference in length was in opposition to the illusion effect. In the congruence condition [(e) and (f)], the length difference was coincident with the illusion effect (n = number of stimulus presentations per subject).

4.2 *Task*
Before the second experiment, subjects received a description of the shape of the stimuli (two horizontal bars surrounded by oblique lines pointing either upwards or downwards). For each stimulus, subjects using the PSVA were required to determine the orientation of the two oblique lines before performing the bar-length-comparison task. Otherwise, the experimental procedure was identical to that of experiment 1. In the vision control group, instructions remained unchanged.

4.3 *Results*
4.3.1 *Illusion effect.* In the two sighted groups, the rate of responses that were consistent with the Ponzo illusion was significantly higher than chance (in blindfolded sighted subjects: 62.5%, SD = 19.96%; $t_{19} = 2.80$, $p < 0.05$; in vision control group: 78.7%, SD = 13.38%; $t_{19} = 9.61$, $p < 0.001$; Student *t*-tests). By contrast, in early-blind subjects, this rate of responses was below the level of chance (28.7%, SD = 24.69%; $t_8 = -2.59$, $p < 0.05$).

An ANOVA performed on the number of responses that were consistent with the Ponzo illusion revealed a significant group effect ($F_{2,46} = 22.57$, $p < 0.001$), with a stronger illusion effect in the vision control group. Each group differed significantly from the other two groups ($F_{1,46} = 7.66$, $p < 0.01$ for vision control versus blindfolded sighted subjects; $F_{1,46} = 20.58$, $p < 0.001$ for blindfolded sighted subjects versus early-blind subjects; $F_{1,46} = 45.13$, $p < 0.001$ for vision control versus early-blind subjects).

4.3.2 *Modified Ponzo conditions.* Given the absence of errors for the modified Ponzo conditions in the vision control group, statistical analyses were only performed on the results obtained in the two PSVA groups. Figure 5 shows the proportion of accurate responses, ie correct identification of the longer bar regardless of the context, as a function of the PSVA group and the condition.

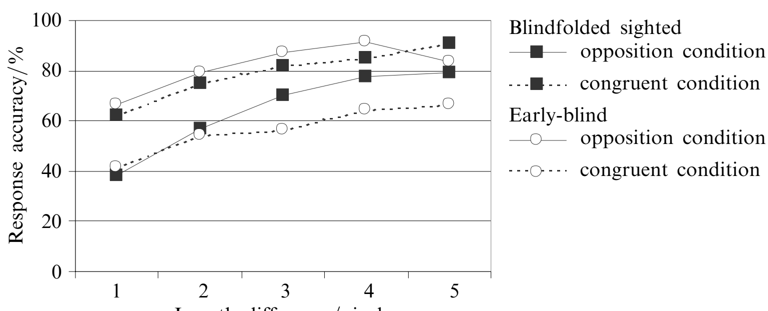


Figure 5. Percentage of accurate responses (ie correct identification of the longest bar) in the two PSVA groups, as a function of the length difference (from 1 to 5 pixels) in the two modified Ponzo conditions of experiment 2.

The results from the modified Ponzo conditions confirmed the susceptibility to an illusion effect in sighted subjects who scored systematically better in the congruent condition than in the opposition condition, especially when the difference in bar length was 1 pixel. A 2 (group) $\times$ 2 (condition: opposition or congruent) $\times$ 5 (length difference: 1 to 5 pixels) ANOVA was performed on the proportion of accurate responses (correct identification of the longer bar) with the group as the between-subjects factor and the condition and length difference as the two within-subjects factors. This analysis showed no significant group effect ($F_{1,27} < 1$, $p = 0.36$), no condition effect ($F_{1,27} = 2.64$, $p = 0.12$), but a significant interaction ($F_{1,27} = 17.86$, $p < 0.001$). There was a significant effect of the length difference ($F_{4,108} = 21.68$, $p < 0.001$), without any significant interaction with group ($F_{4,,108} = 1.91$, $p = 0.11$) or condition ($F_{4,108} < 1$, $p = 0.44$).

5 Discussion

While the first experiment failed to obtain an illusion effect in sighted subjects who used the PSVA, the second experiment succeeded in doing so by forcing subjects to process the two converging oblique lines of the Ponzo figure. No clear effect of the illusion was obtained in early-blind subjects in either of the two experiments.

In early-blind subjects, performance pattern in experiment 2 was compatible with an inverted illusion effect that could be attributed to an uncontrolled bias specific to these subjects. At the end of the study, some of the blind volunteers spontaneously reported that the overall shape of the Ponzo figure was reminiscent of a mental representation of a trestle supporting a table. This representation guided their responses when the differences in bar length were small (1 or 2 pixels) and caused them to consider the bar nearest the vanishing point of the oblique lines to be the shortest. Their responses might therefore result from conscious reasoning rather than by being elicited by perceptual processes. Therefore, early-blind subjects were probably not affected by the actual Ponzo illusion itself. The absence of the illusion effect in early-blind people is consistent both with theories involving apparent distance (Thiéry 1896; Tausch 1954; Gregory 1963; Fisher 1970; Day 1972) and with studies on the haptic Ponzo illusion in congenitally blind subjects (Casla et al 1999). The theories based on apparent distance predict an absence of the illusion effect in subjects who do not have any visual experience. Visual perspective, and the rules of visual depth in general, are often considered to be acquired through visual experience (Gregory and Wallace 1963; Arditi et al 1988; Renier et al 2003), even if the experiences are acquired early in life (Gibson and Walk 1960; Campos et al 1970; Gordon and Yonas 1976; Yonas et al 1978). Furthermore, it has been shown that, although congenitally blind subjects can acquire theoretical and fragmented knowledge about visual depth perception which allows them to understand linear perspective (Kennedy et al 1991), they often have difficulties with the use of this theoretical knowledge (Heller et al 1996).

In sighted subjects using the PSVA, the weakened illusion effect could reflect the poorer quality of the obtained perception, as compared to vision. Nevertheless, the ability to induce a visual illusion by means of a sensory-substitution device indicates that the obtained perception shares perceptual processes with vision. It constitutes an argument in favour of a visual nature of perceptions obtained with a sensory-substitution device. The Ponzo illusion is a cognitive illusion usually considered to be strongly dependent on visual perceptual processes—ie visual perspective and the misapplication of constancy scaling (Gregory 1963). This cognitive process, based on the size-constancy phenomenon, consists of a spontaneous adaptation of the perceived size of an object to its perceived distance from the viewer. In the case of the Ponzo illusion, the two converging oblique lines induce a perspective effect that leads to an overestimation of the horizontal bar that is perceived to be farther (ie closer to the vanishing point). While it is technically possible that the sighted subjects used conscious reasoning to overestimate this horizontal bar, no subject mentioned any such reasoning during the debriefing. Some researchers have hypothesised that illusion effects in blindfolded subjects can be mediated by visualisation processes (Frisby and Davies 1971; Appelle and Gravetter 1985). For instance, some studies have already shown sensitivity to the haptic version of the Ponzo illusion (Révész 1934; Bean 1938; Suzuki and Arashida 1992), although others have failed to obtain such effects (eg Casla et al 1999). In addition, several researchers have reported that blindfolded sighted people recall how things look and then generate visual images when tactually exploring objects (Révész 1950; Heller 2000a, 2000b). A similar intervention of mental imagery could affect perception with a sensory-substitution device, at least in sighted subjects. In this perspective, mental imagery could be the common cognitive process shared with vision, playing a role in the optical illusions with the PSVA.

In conclusion, in the present study we showed it is possible to obtain a visual illusion effect with a sensory-substitution device for vision in sighted subjects, but not in early-blind subjects. This indicates that perception induced by a sensory-substitution device for vision shares perceptual processes with vision. These processes can account for the visual nature of perception by sensory substitution. Additional experiments should further investigate the role of visual experience in the susceptibility to other optical illusions with various sensory-substitution devices.

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