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著者	FLAHERTY Mary, MORAN Aidan
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Hemispheric Dominance in Deaf Signers in Perception of a Visual Illusion

Mary FLAHERTY[1]
(School of Psychology and Social Science, Edith Cowan University)
Aidan MORAN
(Department of Psychology, University College Dublin)

Most research on the hemispheric processing of sign language has used linguistic stimuli (such as words or signs) rather than spatial information. The present study attempts to rectify this neglect by investigating possible hemispheric laterality effects in the manner in which deaf signers perform on tasks requiring visuo-spatial processing skills. To achieve this objective, 40 deaf signers and 41 hearing participants were shown the "herringbone" illusion in which a shaded vertical herringbone that is presented inside a square appears to be distorted, thereby giving the impression that it is trapezoidal in shape. Four different stimuli were used ? resulting from a square or a trapezoid figure with two different types of shading in each one (either diagonal or herringbone). These stimuli were presented randomly to the left or right of a central fixation point 80 times on an Apple Macintosh C4 laptop computer. The task in each case was to identify which of two simultaneously presented figures was trapezoidal in shape. Results showed that there was no significant difference between the deaf and hearing Ss in their susceptibility to the illusion. In all participants, the left hemisphere was fooled more readily by the illusion than was the right hemisphere — regardless of whether such participants used oral or gestural language. Following a discussion of the theoretical significance of these findings, suggestions are provided for further research in this field.

Key words: hemispheric laterality, illusion, deaf, sign language

Introduction

Sign language is a language like any other language (Stokoe, 1960). It has all the linguistic levels represented and fulfils the criteria of a language (Lillo-Martin, 1997) as it encompasses phonological, morphological, syntactic, semantic, and pragmatic levels. In neuropsychology, lesion studies have shown that like spoken languages, signed language processing is dominated by left-hemisphere functions (e.g., Hickok, Klima & Bellugi, 1996; Hickok, Love-Geffen & Klima, 2002; Poizner, Klima, & Bellugi, 1990). Structural imaging studies further confirm the lesion data which suggest that classical left-hemisphere areas are engaged in the processing of signed language (e.g., Baverier, Corina, & Neville, 1998). However, new information from functional magnetic resonance imaging (fMRI) studies (Corina & McBurney, 2001; Neville, Bavelier, Corina, Rauschecher, Karni, Lawani, Braun, Clark, Jezzard, & Turner, 1998) and a positron emission (PET) report (Nishimura, Hashikawa, Doi, Iwaki, Watanabe, Kusuoka, Nishimura, & Kubo, 1999) reveal the fact that the *right* hemisphere is also involved during signed language processing. Right-hemisphere effects have been documented for the lexical (Nishimura et al., 1999), sentence

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[1] Address for correspondence: School of Psychology and Social Science, Edith Cowan University, joondalup Campus, 100 Joondalup Drive, Western Australia 6027. Email: m.flaherty@ecu.edu.au

(Neville et al, 1998), as well as discourse comprehension levels of signed language [2].

In the previously cited fMRI study by Neville et al. (1998), deaf native signers, hearing native signers, and hearing non-signing subjects participated. It was shown that, as long as early acquisition is accomplished, left-hemisphere cortical areas are activated. Once the brain organization is established for sign language, however, another type of activation is found for sign language users who read English; they read English primarily by activating the right-hemisphere (Neville et al., 1998). Perhaps not surprisingly, early acquisition seems to be crucial in mediating the development of language processing in classical brain areas. The left hemisphere may not be specialized only for spoken language, but rather for all language - irrespective of perceptual and expressive modalities. Thus it may be suspected that timing of learning a second language is important in the fine tuning of the cortical organization for brain systems mediating sign language [3].

Most research on the neural organization of deaf signers focuses on language,stimuli such as words (McKeever, Hoemann, Florian & VanDeventer, 1976) and signs (Grossi Semenza, Corazza & Volterra, 1996). Those studies that have dealt with non-linguistic processing, such as attention to space and perception of motion (Neville, 1991) have focused on the native signer and found sign to impact on the organization of the brain. Although sign language is very dependent on spatial information, data from several studies indicate that spatial comprehension in sign language is different from other visuospatial functions in the brain (Poizner et al., 1990). In addition, most studies on sign lateralization in both the clinical literature (Soderfeldt, Ronnberg, & Risberg, 1994; Hickok et al., 2002) and outside the clinical field (Grossi, et al., 1996) have focused only on native signers. In reality, many deaf people do not learn sign until later in life.

The present study attempts to fill a void in the literature by investigating possible lateralization differences, if any, in the neural organization of deaf signers in extracting spatial relations, explicitly varying age of acquisition of sign language. The paradigm that will be used is the hemispheric dominance in the perception of an illusion. The paradigm was chosen for a number of reasons.

Firstly, there are inconsistencies in the literature as to the laterality of illusions. Some studies have indicated that the right hemisphere is more prone to be deceived by visual illusions than the left (Clem & Pollack, 1975; Rothwell & Zaidel, 1990). Clinical studies of patients with damage to only one hemisphere support these findings. For example, Houlard, Fraisse & Hecaen (1976) employed the Muller-Lyer and the Ponzo distortions and found that patients with left-hemisphere lesions were not cheated by the illusions, whereas those with right-hemisphere lesions were deceived. While superior capacities for dealing with spatial relations are generally attributed to the right hemisphere (Brain, 1941; Kimura, 1970), some studies have found that left visual field

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[2] It should be added that the right-hemisphere involvement in signed language is not a unique linguistic phenomenon. Right?hemisphere activation has been recorded during speech production especially for highly rehearsed speech, like repetition of months of the year (Ryding, Bradvik, & Ingvar, 1996).

[3] Studies of bilinguals in spoken languages indicate that right hemisphere involvement is more pronounced in the second language (Albert & Obler, 1978). It remains to be seen if the right temporal activation of sign language recorded by Soderfeldt, Ronnberg & Risberg (1994) in hearing subjects bilingual in spoken Swedish and Swedish Sign Language was a result of bilingualism or the language form per se.

advantage (LFVA) is not a reliable one when spatial information is processed. Random dot stereograms can give rise to either LVFA or RVFA (Pitblado, 1979). Bertelson and Morais (1983) found the Ponzo-illusion to be of comparable magnitude in the two visual fields. Jackson and Flaherty (in press) report a left hemisphere bias for local feature detection which resulted in a greater left hemisphere susceptibility to the illusory effect in the Fraser Spiral. In essence, geometrical illusions are visual stimuli like any other and need to be studied in the light of particular neuropsychological issues.

Secondly, deaf people show a consistent preference for visual strategies (Bellugi, Lillo-Martin, O'Grady Hynes, Van Koek & Corina, 1990; Flaherty, 2000), and perception of illusions require such strategies. Because visual illusions illustrate the constructive gap between physical reality and perception, as Gregory (1998) points out, their study provides researchers with valuable clues about the mechanisms devoted to everyday visual scene construction (Frisby, 1979).

Thirdly, while illusions have been used as a tool to investigate brain function and laterality (Rasmjou, Hausmann & Gunturkun, 1999) with hearing people, they have not, to our knowledge, as yet, been investigated in the deaf. In summary, the study of visual illusions provide us with a useful tool with which to analyze particular perceptual processes, such as local/global strategies, and may thus prove useful in gaining further insight into the mental architecture of deaf signers.

Basing the design on that used by Rasmjou et al. (1999), the present study will address the perceptual processes underlying the herringbone illusion. While there is no direct evidence of differences in signers/oral language users' processing in the illusion literature to date, consideration of (i) the stronger preference for visuo-spatial strategies in deaf signers than hearing folks and (ii) the known right hemisphere global bias and left hemisphere local bias, would suggest the possibility of differential lateralized illusory effects across hearing status and gestural/oral communication. In the herringbone illusion, a vertical herringbone shading presented inside a square distorts (slants) the sides, thereby giving the impression of a trapeze. Interestingly, this illusion does not depend on the perception of imaginary contours and is thus robust enough for lateral viewing. Many illusions, such as the Ponzo, Muller-Lyer and the Poggendorff, are not robust enough when viewed laterally (Bertelson & Morais, 1983). Most of these illusions are based on the perception of imaginary contours, an ability which apparently decreases with lateral viewing (Clem & Pollack, 1975).

Method

Subjects

40 deaf subjects (20 males, 20 females) and 41 hearing subjects (19 males, 22 females) participated in the experiment. All subjects were in third level education and were paid for participation in the experiment.

The deaf participants were prelingually and profoundly deaf (loss > 90dB), and had no other limiting conditions. All used sign language on a daily basis. Sixteen of them acquired their sign as a first language and the rest did so after they finished high school.

All of these participants were right handed according to the Edinburgh Handedness

Inventory (Oldfield, 1971). They were screened for corneal irregularities (astigmatism) and were excluded from the study if they reported seeing perceptible deviations from absolute verticality in either eye[3].

Materials

There were four different stimuli, consisting of variations of two shapes: a square and a trapeze, each with either of two different shadings: simple diagonal or herringbone.

Eight pairs of different combinations of these four stimuli, with a fixation cross in between (see Figure 1), were prepared. Only stimuli 7-8 present the illusion. Analysis of the results will be based primarily on people's responses to this latter stimulus pair. The other six pairs were presented to camouflage the experimental intentions, as well as to control the subject's ability to identify a true trapezoid.

The distance from the central cross to the nearest edge of either figure on the right or left subtended 4.0 degrees (at a distance of 50 cm from the computer screen). The height and width of the square, and the lower edge of the trapeze, measured 7.4 degrees; the upper edge of the trapeze measured 6.8 degrees and thus although readily recognizable as a trapeze, it deviated only slightly (7.4 degrees-6.8 degrees = 0.6 degrees) from a square at its upper edge. The figures were

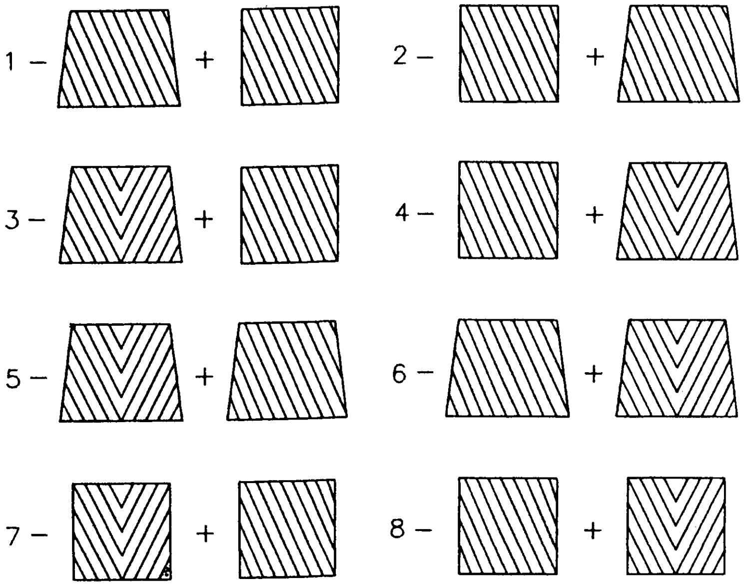

Figure 1. Stimuli pairs used in the experiment, each pair with a fixation cross in between. Figures are either a square or a trapeze, each with one of two different shadings: diagonally-hatched or herringbone. Pairs 1—6 serve as control stimuli and to mask the experimental intentions; only pairs 7—8 bear the herringbone illusion, i.e. stimulus 7-left and stimulus 8-right. Here, the herringbone shading inside the square induces perceptual slanting of the sides, creating the illusion of a trapeze. The stimuli are arranged so that the trapezoids appear grouped in columns, facilitating the comparison and the observation of the trend in the responses made to them (Table 1).

white lines on a black background at an intensity such that after screen blanking any persisting phosphorescence was not noticeable in the darkened room.

The eight combinations were presented 80 times randomly. Each subject was exposed to 80 presentations of the stimuli (10 exposures of each of the 8 pairs).

The stimuli were presented on a Apple Microsoft G4 laptop computer. The stimuli were randomly generated by a program which recorded the L/R responses made to each stimulus pair.

Procedure

At the beginning of each session, subjects completed the handedness questionnaire.

They were screened for corneal irregularities (astigmatism) by having them monocularly fixate 5 degrees to either side of a perfectly vertical line. The deaf subjects recorded information about their deafness (including level of hearing in each ear, age of onset of deafness, age at which sign language was acquired, and hearing status of parents and siblings). Corneal irregularities were checked.

Subjects were given written instructions for the experimental task. This task was to identify and report, while fixating on a central cross, which of two simultaneously presented figures on the left and right of the central cross was a trapezoid. They were shown a sample trapezoid on the screen prior to testing. The subjects were instructed to fixate on the central cross, and if a trapezoid was identified, to hit the key on the side that it appeared with the corresponding hand (i.e. "/", if they thought the figure on the right was a trapezoid, "Z" if they thought it appeared on the left). The trapezoid was to be identified by its overall impression. Subjects were also shown Fig. 1 stimulus 4 which is clearly a trapeze, and told that other trapezoids would at random have their sides so minutely slanted, that although still a trapeze, the difference to a square would be hard to determine. This misinformation primed the subject for the herringbone illusion when it appeared. The importance of central fixation was stressed, so as to ensure visual attention would not be biased to either side of the screen.

The subject sat before the screen, 50 cm from the monitor with their right index finger on /key and their left index finger resting on z key.

The stimuli were presented as follows. The central cross appeared for one second, followed one second later by the stimulus pair for 180 msec, followed by a blank screen. As soon as the subject responded by hitting the relevant key, which was either / key on the right or z key on the left, the sequence was repeated for the next stimulus presentation. Each stimulus presentation lasted approximately three seconds. The experimental session lasted about 15 minutes for each subject.

Results

Table 1 summarizes the grouped means and standard deviations of responses to the eight pairs of stimuli as shown in Figure 1. As a control, the responses made to stimuli 1-4 illustrate that in every pair, subjects were able to perceive and identify a true trapeze with 85-95% accuracy. The responses of main interest are those made to stimuli 7-8, which bear the illusion. These were

Table 1 Responses to the stimuli shown in Figure 1, the numbers in brackets corresponding to the same numbers for the stimuli. Below each stimulus number is the corresponding grouped mean (maximum number = 10) and SD of responses for hearing and deaf subjects. The responses to the preferred visual field is printed in bold letters.

	L		R		L		R	
		(1)				(2)		
Hearing	8.73	2.14	1.27	2.14	0.98	1.81	9.00	1.80
Deaf	8.70	2.32	1.30	2.32	0.54	1.27	9.46	1.27
		(3)				(4)		
Hearing	8.54	2.83	1.46	2.83	0.95	2.17	9.05	2.17
Deaf	8.52	2.40	1.47	2.40	0.85	1.62	9.15	1.63
		(5)				(6)		
Hearing	7.12	2.25	2.88	2.25	4.12	2.35	5.90	2.34
Deaf	7.35	2.53	2.65	2.53	4.13	2.81	5.88	2.81
		(7)				(8)		
Hearing	4.44	2.62	5.56	2.62	2.07	2.04	7.93	2.04
Deaf	4.35	2.63	5.65	2.63	1.60	1.58	8.40	1.48

analyzed with repeated measures ANOVA (RVF vs. LVF) with hearing status as the between subject variable. In this case, it was the response rate to the illusory figure only, and not the total response rate, that served as dependent variable in these analyses. Results showed that there was no difference between the hearing and deaf subjects in their responses to the illusion (F(1,79) = 0.28, ns). The ANOVA confirmed that visual field was a significant source of variance (F(1, 79) = 121.15, p<.0001), supporting a RVF dominance for the perception of the illusion. No significant interaction was observed (F(1,79) = .67, ns).

A further control was built into stimuli 5-6, where both figures were trapezoid. The herringbone shading may enhance the trapezoid impression so that the figure on the other side may, by comparison, appear to be a square. This speculation was tested with an ANOVA (only on the response rate to left in 5 and right in 6), which again showed no significant difference between the responses of the hearing and deaf subjects (F(1, 79) = .06, n.s.). However, it did reveal visual field to be a significant source of variance, supporting a LVF advantage (F(1, 79) = 11.81, p<.01). The interaction of hearing status and visual field was not significant (F(1, 79) = .10, ns).

Table 2 summarizes the grouped means and standard deviations of the responses of the native and non native deaf signers to the eight pairs of stimuli shown in Figure 1. These responses were analyzed with signing status as the between subject variable (native vs. non-native). Note again that it was the response rate to the illusory figure only, and not the total response rate, that served as dependent variable in these analyses. There was no difference between the responses made to stimuli 7-8, by the native and nonnative signers (F(1, 38) = 1.79, ns).

Table 2 Responses to the stimuli shown in Figure 1, the numbers in brackets corresponding to the same numbers for the stimuli. Below each stimulus number is the corresponding grouped mean (maximum number = 10) and SD of responses for the native and non-native signing deaf subjects. The responses to the preferred visual field is printed in bold letters.

	L		R		L		R	
		(1)					(2)	
Native	9.12	1.63	0.88	1.63	0.53	0.83	9.47	0.83
Non-native	8.42	2.68	1.58	2.68	0.54	1.50	9.46	1.50
		(3)					(4)	
Native	9.19	1.42	0.81	1.42	0.37	1.26	9.63	1.23
Non-native	8.08	2.81	1.92	2.81	1.17	1.79	8.83	1.79
		(5)					(6)	
Native	8.00	2.31	2.00	2.31	3.81	2.29	6.19	2.93
Non-native	6.92	2.62	3.08	2.62	4.33	2.78	5.67	2.78
		(7)					(8)	
Native	4.69	2.52	5.31	2.52	1.19	1.17	8.81	1.17
Non-native	4.12	2.72	5.88	2.72	1.87	1.62	8.13	1.62

Discussion

The findings of this study suggest that there is no difference between deaf and hearing individuals, or between native and non-native signers, in the lateralized perception of an illusion. The left hemisphere perceived the herringbone illusion more efficiently (i.e., was fooled more readily) in *all* subjects, irrespective of whether the subjects relied on a gestural or oral language.

More generally, there is no consensus in the literature as to which hemisphere is more prone to be fooled in the perception of illusions. Rothwell and Zaidel (1990), Clem and Pollack (1975) and Rasmjou et al. (1999) reported a right hemisphere dominance, although the latter was only true of the male subjects. Houlard, Fraisse and Hecaen (1976) found that patients with left hemisphere lesions perceived the Muller-Lyer illusion, while those with right hemisphere damage did not. Meanwhile, Bertelson and Morais (1983) and Rasmjou et al. (1999) found no hemispheric dominance, although the latter was true only of the female subjects who participated in the study. The current study found no difference between deaf and hearing subjects in the hemispheric dominance in the perception of an illusion, all favoring a RVF preference — indicating a left hemisphere dominance. Clem and Pollack (1975) and Jackson and Flaherty (in press) support this left hemisphere dominance (with the Muller-Lyer illusion in the former study and the Fraser Spiral in the latter study, respectively) in the perception of what is generally taken to be simply a visuo-spatial task, i.e., the perception of an illusion.

With such a confusing array of findings, it may be of more interest and use to examine the results in terms of what likely strategies the subjects may have employed in evaluating which of the figures was a trapezoid. The hemispheric specialization would appear to be relative rather than absolute (Fink, Halligan, Marshall, Frith, Frachowiak, & Dolan, 1996) and is greatly influenced by experimental conditions (Lamb & Robertson, 1988). Fink, Marshall, Halligan and Dolan (1999) and Jackson and Flaherty (in press) favor a global/local processing approach to analyzing perceptual responses. In the current study, all subjects perceived the figure in stimuli 5-6 in the LVF to be 'more' of a trapeze than that in the RVF. The herringbone shading may have intensified the trapeze form, when the subjects were observing both trapezes (5 and 6) in a global fashion. However, the multiple "V" forms that induce the illusory slanting of the sides of a true square (stimulus 7-left and 8-right) may have required a finer and more detailed discrimination of local features, which would require a local level of processing. In summary, it seems that subjects adjusted their processing style to suit the task. In the 5-6 pair, they adopted a global approach (manifested in a LVF preference), in 7-8, a more detailed, local approach (manifested in a RVF preference).

That the deaf and hearing, and the native and non-native signers, should perform in a similar fashion in response to the laterality of perception of a visual illusion is an important contribution to research on the cognitive architecture of sign language users. Neuropsychological studies dating back many decades have found it useful to group contrasting perceptual processes into dichotomies. Much work has been carried out on distinguishing and understanding linguistic and visuo-spatial processing in particular. Considering the fact that deaf people have been found to outperform their hearing counterparts in a number of visual memory tests (Bellugi, et al., 1990; Daneman, Nemeth, Stainton & Huelsmann,1995; but see Flaherty, 2000) and appear to use a greater variety of codes, (phonological [4], Hanson & Fowler, 1987; Leybaert, Alegria, & Fonck, 1983; Leybaert & Alegria, 1990; but see Treiman & Hitsh-Pasek, 1983), visual (Fok, van Hoek, Klima & Bellugi, 1991; Flaherty, 1999; Frumkin & Anisfeld, 1977; Locke & Locke, 1971), and sign (Kyle, 1981) when processing words, it is tempting to think of sign language (which is a gestural language heavily dependent on visual cues) as occupying a place in the visuo-spatial processing camp. In general, the current findings reiterate three important facts. First, language is language and is treated as such by the brain, irrespective of whether it is oral or visual/gestural (Stokoe, 1960; Lillo-Martin, 1997). Second, the response mode is crucial to the results of any experiment. We must be wary of the nature of the dependent measure used. Tasks that require pressing a button in response might exert a different influence over participants' lateralized performance than, say, an oral response. Third, neuropsychological studies involving the lateralized perception of illusions have to date based themselves largely on an overgeneralization of right hemisphere visuo-spatial abilities, often ignoring the exact stimulus configurations that give rise to particular geometrical illusions. Indeed, spatial ability itself is a broad and much contested skill, and seems to differ depending on the particular test which claims to test this particular aptitude (Flaherty, 1997).

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[4] Contrary to intuitive expectation, the best deaf readers are not those who have received the most oral training (Hanson & Fowler, 1987).

The working memory components of spoken language are well developed (Baddeley, 2000). The current study was an attempt to add to this knowledge base for sign language. Further studies on hemispheric lateralization with a range of visual stimuli (such as pictures, faces, designs and a range of illusions) may shed light on global and local processing strategies in deaf signers and further enhance our understanding of brain organization and plasticity of cognitive and language processes.

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