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Visual Field Asymmetries for Motion Processing in Deaf and Hearing Signers

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Recently, we reported a strong right visual field/left hemisphere advantage for motion processing in deaf signers and a slight reverse asymmetry in hearing nonsigners (Bosworth & Dobkins, 1999). This visual field asymmetry in deaf signers may be due to auditory deprivation or to experience with a visual–manual language, American Sign Language (ASL). In order to separate these two possible sources, in this study we added a third group, hearing native signers, who have normal hearing and have learned ASL from their deaf parents. As in our previous study, subjects performed a direction-of-motion discrimination task at different locations across the visual field. In addition to investigating differences in left vs right visual field asymmetries across subject groups, we also asked whether performance differences exist for superior vs inferior visual fields and peripheral vs central visual fields. Replicating our previous study, a robust right visual field advantage was observed in deaf signers, but not in hearing nonsigners. Like deaf signers, hearing signers also exhibited a strong right visual field advantage, suggesting that this effect is related to *experience with sign language.* These results suggest that perceptual processes required for the acquisition and comprehension of language (motion processing in the case of ASL) are recruited by the left, language-dominant, hemisphere. Deaf subjects also exhibited an inferior visual field advantage that was significantly larger than that observed in either hearing group. In addition, there was a trend for deaf subjects to perform relatively better on peripheral than on central stimuli, while both hearing groups showed the reverse pattern. Because deaf signers differed from hearing signers and nonsigners along these domains, the inferior and peripheral visual field advantages observed in deaf subjects is presumably related to *auditory deprivation.* Finally, these visual field asymmetries were not modulated by attention for any subject group, suggesting they are a result of sensory, and not attentional, factors.

Key Words: deaf; sign language; motion perception; visual field asymmetries.

INTRODUCTION

It has often been speculated, as early as Hartmann (1933), that the altered sensory experiences during development in deaf individuals may lead to changes in their ability to perceive or attend to visual stimuli. Specifically, the absence of sound during development and the daily exposure to a visual sign language has been argued to improve performance for various visual cognitive abilities (see Emmorey, 1998, for a review). Generally, ‘‘higher level’’ visual–spatial abilities have been found to be enhanced in the deaf population, which is thought to be a result of their signing experience (Bettger, Emmorey, McCullough, & Bellugi, 1997; Emmorey, Kosslyn, &

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Bellugi, 1993; McCullough & Emmorey, 1997; Siple, Hatfield, & Caccamise, 1978). For lower level perceptual abilities, however, there is less consensus as to whether abilities in the deaf population are enhanced (see Bosworth & Dobkins, 2001a, for discussion).

Although overall performance on lower level vision tasks does not appear to differ between deaf and hearing subjects, significant differences between subject groups have been observed with respect to *relative* performance in different parts of the visual field. For example, Neville and Lawson (1987) reported that deaf subjects were faster and more accurate than hearing subjects at discriminating the change in position of a small apparent-motion target when it was presented in the periphery (18° eccentric from central fixation), while the two groups performed comparably when the target was presented centrally (i.e., near the fixation spot). Similarly, Loke and Song (1991) reported that deaf subjects were faster than hearing subjects at detecting a luminance increment in the periphery, while the two subject groups' reaction times were equivalent for central stimuli. However, in both of these studies, performance for central stimuli was at ceiling in both hearing and deaf subjects, indicating that the central task was not sensitive enough to reveal potential differences between groups. In addition, since accuracy results were not reported in the Loke and Song study, an accuracy–speed trade-off cannot be ruled out.

More recently, a functional magnetic resonance imaging (fMRI) study has provided a potential neural substrate for the enhanced peripheral performance in deaf subjects (Bavelier, Tomann, Hutton, Mitchell, Corina, Liu, & Neville, 2000). Employing a task that required moving the focus of attention between peripheral and central moving stimuli, these investigators showed that motion processing areas of the brain were more highly activated when deaf subjects attended to peripheral stimuli compared to when they attended to central stimuli, a pattern that was not observed in hearing subjects. These results led the authors to speculate that there may be a greater propensity for visual sensitivity in the periphery to be modified by early auditory deprivation compared to central vision (and see Neville, Schmidt, & Kutas, 1983, for similar results obtained with visually evoked potentials, VEP's).

In addition to central vs peripheral visual field differences observed between deaf and hearing subjects, other studies have compared deaf and hearing subjects with respect to relative sensitivity for stimuli presented in the left visual field (LVF) vs right visual field (RVF) (e.g., Manning, Goble, Markman, & LaBreche, 1977; Neville & Lawson, 1987; Parasnis & Samar, 1985; Reynolds, 1993). In the previously mentioned perceptual study by Neville and Lawson (1987), deaf signers were found to exhibit a RVF over LVF advantage in discriminating the direction of the apparent-motion target. Conversely, hearing nonsigners exhibited a slight LVF advantage. Based on the contralateral organization of visual system projections, these results imply differential hemispheric advantages in deaf vs hearing subjects, with a left hemisphere specialization for motion processing in the deaf. These investigators suggested that, because ASL comprehension is highly dependent on the ability to process moving hand signals, perhaps the left, language-dominant, hemisphere has usurped some of the motion-processing functions normally mediated by the right hemisphere. In support of the role of sign language in this visual field asymmetry, Neville and Lawson also found a RVF/left hemisphere advantage in hearing signers. Mirroring these perceptual results, Neville and Lawson's concomitant VEP study demonstrated greater left hemisphere activation in both deaf and hearing signers as compared to hearing nonsigners. It should be pointed out, however, that Neville and Lawson's interpretation of their results is somewhat confounded by their choice of stimuli and task. Specifically, their two-frame apparent-motion stimulus allowed for the use of *position*-based, as opposed to *motion*-based, mechanisms for directional discrimination, an issue that has been widely addressed in the motion literature (e.g., see Nakayama & Tyler, 1981). Thus, the observed superior performance in the deaf could be a result of heightened positional *or* motion processing.

Recently, we (Bosworth & Dobkins, 1999) investigated the issue of left vs right visual field asymmetries using stimuli designed to isolate elementary motion processing mechanisms while eliminating the use of position and orientation cues. This stimulus consisted of a moving dot display, in which a proportion of dots moved in a coherent fashion (leftward or rightward) while the remaining dots moved in random directions. Although deaf and hearing subjects were found to discriminate the direction of these motion stimuli equally well in terms of absolute performance (accuracy and reaction times), we found differences between groups in their relative performance for LVF vs RVF stimuli. In agreement with the earlier results of Neville and Lawson, deaf subjects in our study exhibited a strong RVF advantage, whereas hearing subjects exhibited a slight LVF advantage. Such results confirm a left hemisphere advantage for motion processing in deaf signers. A potential neural basis for these perceptual findings has been demonstrated in the previously mentioned fMRI study by Bavelier and colleagues (2000), who also used moving dot stimuli (however, their motion stimuli covered both the RVF and LVF, whereas ours were presented separately to the RVF vs LVF). In their study, they found greater activation in motion areas of the left (as compared to the right) hemisphere in deaf signers, and an opposite trend in hearing nonsigners.

In our previous perceptual study, as well as in the fMRI study of Bavelier et al. (2000), the differences observed between deaf signers and hearing nonsigners could have resulted from sign language experience or auditory deprivation. In order to separate these sources of influence, in the present study we tested three groups; deaf signers, hearing nonsigners, and *hearing signers* who have the same native ASL experience as do the deaf subjects, yet have normal hearing. For each subject, we measured thresholds and reaction times for discriminating direction of a moving dot stimulus appearing in the central visual field, as well as in each of the four peripheral quadrants of visual space (using the same stimuli we have employed previously; Bosworth & Dobkins, 1999). In addition to investigating differences across groups in *left vs right* visual field asymmetries, we asked whether performance differences exist for *peripheral vs central* visual fields as well as *superior vs inferior* visual fields. With regard to this latter comparison, we hypothesized that sensitivity for visual space below fixation (i.e., the *inferior* visual field) may be enhanced in signers. This is because experienced signers, while conversing in ASL, fixate on each other's faces (Siple, 1978), with the result that most signs fall below the level of the face (Bosworth, Wright, Bartlett, Corina, & Dobkins, 2000). Thus, we predicted that repeated sign language exposure may improve perception for moving stimuli in the inferior visual field for signers relative to nonsigners.

Finally, this study addressed whether the allocation of spatial attention varies across visual fields and whether such effects differ across subject groups. One typical way to investigate attentional effects is to employ a spatial precueing paradigm, wherein subjects' performance when a spatial precue alerts them to the location of the to-be-presented stimulus is compared to their performance when no precue is provided. In a recent study by Carrasco, Penpeci-Talgar, and Cameron (2002), which investigated orientation discrimination in hearing subjects, relative performance across visual fields was the same with and without a spatial precue, leading the authors to conclude that attentional effects do not vary across the visual field. In the present study, we similarly employed a spatial precueing paradigm to investigate whether visual field asymmetries exist in the ability to allocate spatial attention and whether this differs across subject groups.

In sum, this experiment investigated whether visual field asymmetries in motion sensitivity and in the allocation of spatial attention differ across our three subject groups. Results that differ between deaf signers and both hearing groups can be attributed to auditory deprivation, while differences observed between native signers (both deaf and hearing) and hearing nonsigners suggests effects of sign language experience. Note that most of the data for this experiment were obtained during the course of another study, which investigated differences in visual attention among the three subject groups. Much of the methods presented here are also presented in our companion article (see Bosworth & Dobkins, 2001a).

METHODS

Subjects

Sixteen deaf signers (mean age = 31.1 years, *SD* = 9.1; 9 males and 7 females), 15 hearing nonsigners (mean age = 28.1 years, *SD* = 9.3; 6 males and 9 females), and 10 hearing signers (mean age = 31.5 years, *SD* = 12.3 years; 6 males and 4 females) participated in this study. Groups did not differ significantly in age [$F(2, 38) = 0.68$, $p = .51$]. Visual and audiological background was obtained through a questionnaire. All subjects reported a dominant right hand and normal or corrected-to-normal vision.

The deaf subjects had uncorrected bilateral severe or profound hearing loss (≥80 dB). Twelve were born deaf, into families with deaf parents or deaf siblings, and were native signers with exposure to ASL since birth. Of the remaining four subjects, two became deaf due to illness, and two reported an unknown onset and etiology. These four subjects were ‘‘near’’ native in that they acquired ASL approximately at the age of 5 years by attending a school where sign language was used. All deaf subjects used ASL as their primary language.

Hearing native signers reported normal hearing and learned ASL as their first language from their signing parents, one or both of whom where deaf. These subjects used ASL on a weekly or daily basis. The hearing nonsigners had normal hearing, spoke only English, and had no exposure to ASL beyond fingerspelling.

Deaf and hearing signers were recruited from the San Diego deaf community. Hearing nonsigners were recruited from the student population at University of California, San Diego.

Apparatus

Visual stimuli were generated using a SGT Pepper Graphics board (Number Nine Computer Corporation: 640 × 480 pixel resolution, 60-Hz frame rate) residing in a Pentium-based PC and were displayed on a Nanao video monitor with a 21-inch display.

Each subject’s eye position during the experiment was monitored using an infrared camera, which was focused on the left eye of the subject. The subject’s face was lit with an infrared illuminator, and an enlarged image of the eye was viewed on a 12-inch monitor outside the testing room. Subjects were instructed to maintain fixation on a small (0.35°) green square in the center of the video display throughout the experiment and were informed that the experiment would be interrupted if eye movements were detected. Using this set-up, saccadic eye movements and eye drift as little as 2° could easily be detected. Throughout the experiment, subjects had no difficulty in maintaining fixation.

Stimuli

Motion thresholds were obtained using a *stochastic motion stimulus*. This stimulus consists of a field of white dots presented on a black background within a circular aperture, wherein a proportion of ‘‘signal’’ dots moves in a coherent direction (‘‘leftward’’ or ‘‘rightward’’) while the remaining ‘‘noise’’ dots move in a random fashion (see Fig. 1). The trajectory for each moving dot lasted for a duration of 100 ms, after which it disappeared and then reappeared in a random location within the circular aperture, moved coherently for another 100 ms, and so on. Noise dots were positioned in random locations from frame to frame. (See Fig. 1 caption for stimulus parameters.)

The percentage of signal dots in the motion stimulus was varied randomly across trials (from 2 to 30%) in order to obtain a *coherent motion threshold* (i.e., the percentage of moving signal dots required to yield 75% correct directional discrimination). Five different visual field locations were tested, one central and four peripheral locations. The peripheral locations were superior left (SL), superior right

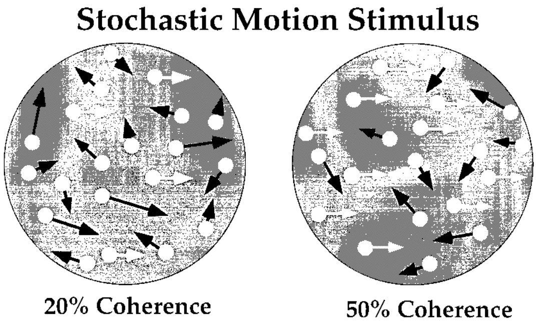

FIG. 1. Two example coherence levels (20% and 50%) are shown. White arrows indicate the motion paths of signal dots, while black arrows indicate the random motion paths of noise dots. Stimulus parameters: dot luminance: 26 cd/m^2; background luminance: 0.3 cd/m^2; dot diameter = 0.12°; dot density = 2.4 dots/degree^2; signal dot displacement = 0.35° per frame; dot speed = 6.9°/s.

(SR), inferior left (IL), and inferior right (IR) and were centered 15.4° eccentric from fixation (vertical eccentricity = ± 9.0°; horizontal eccentricity = ± 12.5°). These eccentricity values were chosen as they approximate a typical distance in signing space of the hands from fixation (Bosworth et al., 2000).

General Procedures

Subjects were tested in a darkened room and viewed the video display binocularly from a chin rest situated 57 cm away. Subjects were instructed to maintain fixation on a small green square in the center of the monitor for the duration of each trial. After initiating each trial with a key press, the stochastic motion stimulus appeared centered on the fixation square (for central blocks) or randomly in one of the four quadrants of visual space (for peripheral blocks). For both central and peripheral stimuli, subjects reported perceived direction of motion (''leftward'' vs ''rightward'') by pressing one of two appropriate keys. Negative feedback was provided for incorrect trials, which consisted of a white circle (2.3° diameter, 26 cd/m^2) presented for 200 ms near the fixation spot. Although subjects were not instructed to respond in a speeded fashion, as the emphasis in this study was accuracy, reaction times were obtained for all conditions. For all subjects, instructions were provided by the first author (R.G.B.), who is fluent in both ASL and spoken English.

Experimental Design

Central and peripheral locations were tested in separate blocks. For the central location the stimulus duration was 200 ms, and all data were collected within a single block. For peripheral locations, data were obtained for four different conditions: two durations (200 and 600 ms) and two precueing conditions (precue vs no precue). In the *no precue* condition, subjects were uncertain as to where the target would appear. Subjects initiated the trial with a key press, and the stimulus appeared 50 ms later in the IL, IR, SL, or SR location. In the *precue* condition, subjects were alerted to the location of the to-be-presented motion stimulus with a 0.23° square (26 cd/m^2) that appeared beforehand in the center of that location (i.e., centered 15.4° eccentric to fixation in one of the four visual field locations). The significance of the precue was explained to subjects, hence, on trials that contained a precue, subjects knew to focus attention on the appropriate location of visual space before beginning a trial. In order to minimize order and practice effects, half of the total trials were obtained for each condition, before repeating this again. The order of the four precue and duration blocks was randomized and counterbalanced across subjects. The data for these experiments consisted of 1792 total trials (448 trials per condition) after practice on 400 trials across all locations.

Data Analysis

Psychometric curves were fit to the data using Weibull functions and maximum likelihood analysis (Watson, 1979; Weibull, 1951), with threshold defined as the motion coherence level yielding 75% correct performance. Each Weibull function, calculated for the central and each of the four conditions (2 durations × 2 precue conditions) in each peripheral location, was comprised of 112 total trials. Threshold ratios were calculated from these values as follows. To compare peripheral vs central thresholds, a

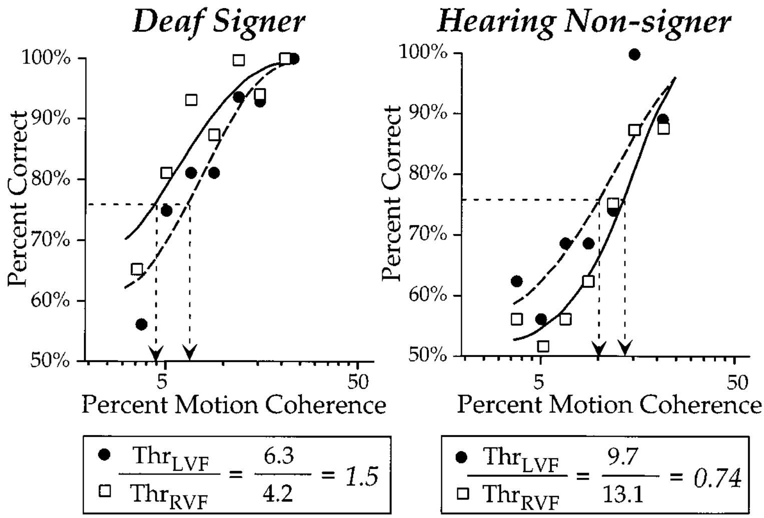

FIG. 2. Data for a deaf signer (left panel) and a hearing nonsigner (right panel) are presented for the cued 200-ms condition. Percentage correct is plotted as a function of percentage motion coherence. Separate functions are plotted for LVF (dashed line, solid circles) and RVF (solid line, open squares). From these functions, thresholds (i.e., the percentage of moving signal dots needed to obtain 75% correct performance) were calculated for each subject and condition. Threshold ratios were calculated to observe relative performance between visual fields. Here, the deaf subject produced a ratio greater than 1.0, indicating better RVF performance, while the hearing subject revealed a ratio less than 1.0, indicating better LVF performance.

mean peripheral threshold value (Thr_P) was calculated for each subject by averaging the thresholds for the four peripheral locations (Thr_{IL}, Thr_{IR}, Thr_{SL}, and Thr_{SR}) obtained for the 200-ms, precued condition and then dividing that value by the central threshold (Thr_C). This produced a Thr_P:Thr_C ratio for each subject.

In order to compare right visual field (RVF) vs left visual field (LVF) thresholds, the mean threshold averaged across SL and IL locations was divided by the mean threshold averaged across SR and IR locations, separately for each subject. This resulted in a Thr_{LVF}:Thr_{RVF} ratio. (See Fig. 2 for example thresholds and ratios.) Likewise, superior visual field (SVF) vs inferior visual field (IVF) thresholds were compared by dividing the mean threshold for IR and IL locations by the mean threshold for SR and SL locations, resulting in a Thr_{IVF}:Thr_{SVF} ratio. In order to observe subject group effects, these visual field ratios were averaged across subjects.

RESULTS

Peripheral vs Central Thresholds

Group mean peripheral vs central threshold ratios (i.e., Thr_P:Thr_C) for each of the three groups (deaf signers, hearing signers, and hearing nonsigners) are plotted in Fig. 3. Peripheral data for the 200-ms precued condition were used for this analysis in order to match the conditions of the central stimulus (see *Methods*). Here, a Thr_p:Thr_C ratio less than 1.0 indicates better peripheral than central performance, while a ratio greater than 1.0 indicates better central performance.

The results of this analysis revealed no significant differences in threshold ratios between the three groups [$F(2, 38) < 1.0$]. There was, however, a trend for hearing subjects to exhibit higher ratios than deaf subjects. Specifically, when data from both hearing groups were combined, their mean ratio was 1.11, while that of deaf signers was 0.89, although neither ratio was significantly different from 1.0 ($p > 0.40$ for both comparisons), nor different from each other [$F(1, 38) = 1.15$, $p > 0.05$]. By contrast, reaction time data did reveal a significant difference in deaf subjects for

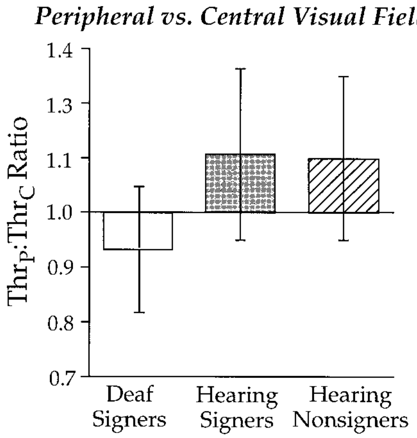

FIG. 3. Only peripheral data for the 200-ms, cued condition were compared to the central data, since central performance was measured under these conditions. These results reveal a tendency for deaf subjects to perform better in the periphery (ratios < 1.0) than in the central visual field, while the reverse pattern (ratios > 1.0) is observed for hearing signers and nonsigners. Error bars denote standard errors of the means.

peripheral vs central stimuli; deaf subjects were significantly faster (by an average of 93 ms) in the peripheral than in the central visual field [$t(15) = -2.14$; $p = 0.04$]. Since deaf subjects were also more accurate in the peripheral, than in the central, visual field, these results cannot be explained by a speed–accuracy trade-off. Because neither hearing signers nor nonsigners showed this peripheral visual field advantage, this effect in the deaf appears to be related to auditory deprivation and not to sign language experience.

Left vs Right Visual Field Asymmetry

Group mean left vs right threshold ratios (i.e., $Thr_{LVF}:Thr_{RVF}$) are plotted in Fig. 4a, separately for 200- and 600-ms-duration conditions. Because threshold ratios did not differ for the cue vs no-cue conditions [$F(2, 38 < 1.0$], data for the two conditions have been combined here. Consistent with previous findings from our laboratory (Bosworth & Dobkins, 1999), deaf signers exhibited threshold ratios significantly greater than 1.0 [$t(15) = 3.58$; $p = .003$], indicating a RVF advantage, while hearing nonsigners exhibited threshold ratios indistinguishable from 1.0 [$t(14) = 0.38$; $p > 0.05$]. However, in this study, the RVF advantage in deaf subjects was significant at the 600-ms duration [$t(15) = 4.01$; $p = 0.001$], but failed to reach significance at the 200-ms duration [$t(15) = 1.66$; $p > 0.05$]. Interestingly, hearing signers also exhibited threshold ratios greater than 1.0, and this effect was also only significant at the 600-ms duration [$t(9) = 3.10$; $p = 0.01$]. At this longer duration, post hoc comparisons revealed that deaf signers did not differ from hearing signers [$p = 0.66$], while they did differ from hearing nonsigners [$p = 0.03$].

In addition, for the 600-ms condition, when data from deaf and hearing signers were combined, their mean $Thr_{LVF}:Thr_{RVF}$ ratio (ratio $= 1.78$) was significantly higher than that of hearing nonsigners (ratio $= 1.02$) [$F(1, 38) = 4.80$, $p = 0.03$]. By contrast, at the 200-ms duration, no differences were observed between signers and nonsigners [$F(2, 38 < 1.0$]. Thus, the similar pattern of RVF advantage observed in deaf and hearing signers suggests that this asymmetry is due to sign language experience rather than auditory deprivation. Consistent with the threshold data, deaf and hearing signers were faster, although not significantly [$F(2, 38) < 1.0$], when the target was

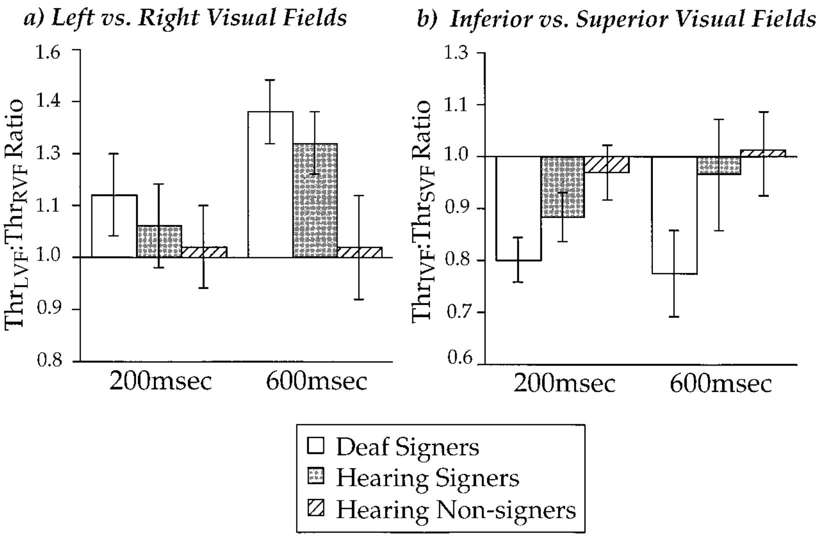

FIG. 4. (a) $\mathrm{Thr_{LVF}:Thr_{RVF}}$ ratios. Data are presented separately for the 200- and 600-ms durations. Both hearing and deaf signers exhibit a RVF advantage, predominantly at the 600-ms duration, while the hearing non signers show near equivalent performance for both visual fields. (b) $\mathrm{Thr_{IVF}:Thr_{SVF}}$ ratios. Deaf subjects exhibit a robust IVF advantage, while no significant asymmetry is observed in either hearing group. Error bars denote standard errors of the means.

in the RVF compared to the LVF, suggesting that their RVF threshold advantage was not due to a speed–accuracy trade-off.

As mentioned above, left vs right visual field ratios did not differ between the precue and no precue conditions for any subject group at either duration ($p > 0.30$ for all six comparisons). As addressed further under Discussion, because the pattern of asymmetry observed in signers vs nonsigners did not vary as a function of spatial attention, these results suggest that the asymmetries are attributable to sensory, rather than attentional, factors.

Inferior vs Superior Visual Field Asymmetries

Group mean inferior vs superior threshold ratios (i.e., $\mathrm{Thr_{IVF}:Thr_{SVF}}$) are plotted in Fig. 4b. As for left vs right visual field ratios, there was no main effect of precue condition [$F(2, 38 < 1.0$], and thus data for the two have been combined. To maintain consistency with Fig. 4a, ratios are plotted separately for 200- and 600-ms-duration conditions, although no significant difference between durations was observed [$F(2, 38 < 1.0$]. For deaf signers, threshold ratios were significantly less than 1.0 [$t(15) = -4.37$; $p = 0.0006$], indicating an IVF advantage. By contrast, threshold ratios were indistinguishable from 1.0 for both hearing signers [$t(9) = -1.0$; $p > 0.05$] and hearing nonsigners [$t(14) = -0.23$; $p > 0.05$]. In addition, when data from hearing signers and nonsigners were combined, their mean $\mathrm{Thr_{IVF}:Thr_{SVF}}$ ratio (ratio = 0.92) was significantly different than those of deaf signers (ratio = 0.78) [$F(2, 38) = 6.89$; $p = 0.01$]. The fact that a significant inferior visual field advantage was observed in deaf signers, but in neither hearing group, suggests that the effect is related to auditory deprivation rather than sign language experience. Note that the inferior visual field advantage in deaf signers cannot be explained by a speed–accuracy trade-off, since they showed no difference in reaction time between inferior and superior visual fields (and this was also true for hearing subjects).

In addition, as was the case for left vs right visual field ratios, $\mathrm{Thr_{IVF}:Thr_{SVF}}$ ratios were not significantly different for precue vs no precue conditions for any subject group at either duration ($p > 0.10$ for all comparisons). For this reason, the deaf subjects' inferior visual field advantage can be attributed to sensory, and not attentional, factors.

DISCUSSION

The main goal of these experiments was to compare visual field asymmetries (peripheral vs central, left vs right, and superior vs inferior) across deaf signers, hearing signers, and hearing nonsigners. With respect to peripheral vs central motion thresholds, we found a tendency for deaf subjects to exhibit better and faster peripheral than central performance. Since hearing signers did not resemble deaf signers along this dimension, we can conclude that the difference between deaf and hearing subjects is related to auditory deprivation in the deaf population. These results are in line with previous reports of faster and more accurate performance in deaf subjects for the detection of peripheral, but not central, targets (Loke & Song, 1991; Neville & Lawson, 1987). A potential neural basis for these perceptual findings has been revealed in VEP (Neville & Lawson, 1987) and fMRI (Bavelier et al., 2000) studies, which have demonstrated selective enhancement of responses to peripheral, but not central, visual field stimuli in deaf signers as compared to hearing controls. We should point out, however, that in the present study we found no overall subject group differences in threshold or reaction time, for either peripheral stimuli [thresholds: $F(2, 38) < 1.0$; reaction time: $F(2, 36) = 1.78$, $p > 0.05$, and see Bosworth & Dobkins, 2001a] or central stimuli [thresholds: $F(2, 38) < 1.0$; reaction time: $F(2, 38) = 2.0$, $p > 0.05$]. This result, which replicates our earlier findings (Bosworth & Dobkins, 1999), suggests that overall motion sensitivity is not enhanced in the deaf population. Rather, *relative* sensitivity to different parts of the visual field appears to be modified in the deaf.

With regard to left vs right visual field asymmetries, both deaf and hearing signers in the present study were found to exhibit a right visual field advantage for motion processing, although this effect was larger (and only significant) for the longer duration (600-ms) condition. Based on the contralateral organization of visual system projections, this right visual field advantage suggests a left hemisphere specialization for motion processing in deaf and hearing signers. In our hearing nonsigners, we found no consistent left vs right visual field advantage, which is in line with previously reported inconsistencies in the literature (see Christman, 1997, for a review). Since similar results were found for deaf and hearing signers of the present study, we can conclude that the right visual field/left hemisphere advantage is attributable to sign language experience rather than auditory deprivation. Taking into consideration evidence indicating that many aspects of ASL processing are lateralized to the left hemisphere in native ASL users (e.g., Bellugi, Poizner, & Klima, 1989; Corina, Vaid, & Bellugi, 1992; Emmorey & Corina, 1993; Grossi, Semenza, Corazza, & Volterra, 1996; Pettito, Zatoore, Nikelski, Gauna, Dostie, & Evans, 1997), our results suggest that sensory functions required for the acquisition of language, such as motion processing in the case of sign language, may be ''captured'' by the left, language-dominant hemisphere of the brain, an idea originally proposed by Neville & Lawson (1987).

With regard to superior vs inferior visual field asymmetries, the deaf subjects in the present study exhibited a robust inferior visual field advantage for motion processing, which was significantly different from both hearing groups. Thus, unlike the pattern of results observed for left vs right visual field asymmetries, this robust inferior visual field advantage in deaf signers appears to be a result of auditory deprivation rather than sign language experience. This result is somewhat surprising, since we had predicted that an inferior visual field advantage in deaf signers, should it exist, would be due to exposure to signs falling predominantly in the inferior visual field (Bosworth et al., 2000). If this were the case, we would have expected to observe an inferior visual field advantage in hearing signers, which we did not. Given that this asymmetry is, in fact, a result of auditory deprivation, it might be explained by the fact that the inferior field contains more ecologically salient information relevant for navigation (see Previc, 1990, for a discussion) and that deaf subjects (devoid of auditory cues) rely more heavily on this region of space. In fact, even in hearing subjects, inferior visual field advantages have been noted (Edwards & Badcock, 1993; Raymond, 1994; Rezec, Bosworth, & Dobkins, 2000), although in some cases these effects are weak (e.g., Smith & Hammond, 1986; and see Christman & Niebauer, 1997 for a review), as was the case for the hearing subjects in the present study. Thus, the inferior visual field advantage may simply be amplified in deaf individuals due to greater reliance on this part of visual space.

While this auditory deprivation explanation is viable, the inferior visual field advantage may still be driven by sign language experience despite the fact that this effect was observed in deaf, but not hearing, signers. Specifically, it is possible that the strength of the inferior visual field advantage is dictated by the degree of daily exposure to sign language. Assuming that deaf signers generally have more exposure than hearing signers over the course of their lives, this might explain why the inferior visual field advantage exists only in the deaf signers. If this explanation is correct, it would further suggest that the inferior field advantage is not set up during the early years of language acquisition, since deaf and hearing signers have comparable exposure to sign language during this time. By contrast, the right visual field/left hemisphere advantage observed in both deaf and hearing signers may be set up during the critical period of language acquisition. That is, motion processing may be lateralized to the left hemisphere at the same time that left hemisphere dominance for language processing is established. This hypothesis predicts that a left hemisphere advantage would not be found in ‘‘nonnative’’ signers who acquired ASL during adolescence or adulthood. In line with this hypothesis, results from five nonnative hearing signers who learned ASL between 16 and 21 years of age [with approximately 17 years (SD = 4.4) of daily signing experience] reveal visual field asymmetries resembling those of hearing nonsigners (Bosworth & Dobkins, unpublished observations). Thus, these preliminary results support the notion that exposure to ASL during the critical period of language acquisition may be required for the hemispheric asymmetry. By contrast, the inferior visual field advantage may be governed more by the amount of exposure to ASL throughout life.

Finally, to address whether the allocation of spatial attention varies across visual fields, and whether such effects differ across subject groups, we compared performance across the visual field with and without a spatial precue. In line with previous results in hearing subjects (Carrasco et al., 2002), we found visual field ratios to be indistinguishable between the two conditions, suggesting that the effects of spatial attention are constant across the visual field. Most importantly, this finding indicates that the right visual field advantage observed in deaf and hearing signers and the inferior visual field advantage observed in deaf signers are sensory, and not attentional, in nature. The conclusion that the ability to allocate attention across the visual field is not altered in the deaf agree with those of Parasnis and Samar (1985), who also found no visual field asymmetries in precueing effects in deaf and hearing subjects.

In sum, the present study demonstrates several visual field asymmetries in deaf signers that are due to sensory, rather than attentional, factors. First, a strong left hemisphere advantage for motion processing was observed in deaf signers, which appears to be related to sign language experience. Deaf signers also exhibited a robust inferior visual field advantage, which appears to be related to auditory deprivation since hearing signers did not exhibit a similar pattern. However, this effect could also reflect the fact that deaf signers have far more sign language exposure than hearing signers over the course of their lives. Finally, a peripheral over central visual field advantage was also observed in the deaf subjects, yet not seen in hearing signers or nonsigners, which is in line with several previous reports.

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