Research report

Motion velocity thresholds in deaf signers: changes in lateralization but not in overall sensitivity

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Abstract

In a series of three experiments, we tested whether deaf native signers process motion velocity information differently from hearing nonsigners. In Experiment 1, participants watched radially moving dots and were asked to detect the quadrant in which the velocity of the dots had changed. Similar 79% thresholds were observed in the two populations. In Experiments 2 and 3, peripheral and central thresholds were assessed separately as previous studies suggest early deafness leads mainly to changes in the processing of visual peripheral information. Neither condition produced an overall population difference. These negative results were not due to a lack of sensitivity in our experiments. Indeed, as has been previously reported, deaf native signers exhibited better thresholds in the right than in the left visual field, whereas the opposite pattern was observed in the hearing. This effect appears triggered by experience with American Sign Language (ASL) rather than deafness per se. Overall, this study confirms that early deafness does not enhance motion processing, and suggests that most of the changes previously described in the literature are instead attributable to changes in attention, and possibly special alterations of attention-to-motion processes.

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1. Introduction

Congenital deafness is believed to lead to changes in visual functions mediated by the dorsal pathway, such as visual attention and motion processing. Support for this hypothesis initially came from Neville and Lawson’s\textsuperscript{[22,23]} finding that attending to peripheral motion leads to larger electrical activity increases over occipital regions for deaf signers than for hearing nonsigners. Bavelier et al.\textsuperscript{[4]} showed further support that deafness leads to modifications of the motion pathway in a more recent neuroimaging study that compared hearing nonsigners and deaf signers as they monitored moving stimuli. Compared to hearing nonsigners, deaf signers had greater activation increases in a brain area specialized for motion processing (MT/MST) when monitoring moving stimuli in the visual periphery. However, motion processing was covaried with attention in these designs, making it difficult to evaluate whether deafness leads to changes in motion sensitivity per se or in the sensitivity of the motion pathway to attention.

There is strong evidence that early deafness benefits processing on attention tasks, particularly those requiring visual selective attention to the peripheral visual field. Compared to hearing individuals, deaf subjects are faster and more accurate at detecting the direction of motion of a peripheral square when selective attention is needed\textsuperscript{[23]}, better at redirecting attention to a peripheral cue when distracted by a central cue\textsuperscript{[26]}, faster at detecting peripherally presented orthographic stimuli\textsuperscript{[19]}, and they exhibit greater attentional resources in the visual periphery as measured by the flanker compatibility effect\textsuperscript{[28]}. Neville and Lawson\textsuperscript{[22–24]} suggested that, in the absence of auditory cues, these peripheral advantages may be mediated by an increased reliance on
Previously, studies have been successful at identifying a role for motion tasks have been plastic changes to the motion pathway, especially when attention is directed peripherally. As most deaf subjects included in these studies were native signers, peripheral attentional enhancements may also stem from the use of American Sign Language (ASL), a visuospatial language requiring the recipient to fixate on the address-see’s face while peripherally monitoring their hand movements. Several studies comparing deaf signers to hearing signers, or adults whose deaf parents taught them ASL in the home environment, have demonstrated that hearing signers do not display peripheral attentional advantages \([7,24,28]\). These results have led to the proposal that congenital deafness, but not signing, leads to an enhancement of peripheral visual attention \([2]\).

More mixed results have been obtained when testing the view that deafness alters motion processing. On the one hand, physiophysical studies testing motion processing without manipulating attention have reported similar thresholds for motion direction in hearing and deaf individuals \([6,8]\), questioning the claim of different motion processing sensitivities between deaf and hearing individuals. On the other hand, there is good evidence from ERPs and fMRI studies that the organization of the motion pathway differs between deaf signers and hearing controls \([1,3,23]\). Could it be that certain aspects of motion processing are more susceptible to plasticity following auditory deprivation than others? To date, deafness induced changes in motion processing have only been psychophysically tested in tasks requiring the discrimination of motion direction \([6,8]\).

In this paper, we compare velocity thresholds between deaf signers and hearing controls. Stimuli and methods were modeled after those used in Bavelier et al. \([4]\) in which we observed significant differences between deaf signers and hearing controls in the pattern of cortical organization for processing motion velocity. These differences could have reflected attention, but they also may reflect different sensitivities in motion velocity processing across populations. The latter possibility is attractive because changes in motion velocity are believed to attract attention automatically, especially when the stimuli allow a separate perceptual group to emerge \([15,17]\). As reviewed above, deaf individuals may rely on such visual-orienting cues to a greater extent than hearing individuals do, particularly when peripheral. Alternatively, based on previous studies comparing motion direction thresholds between deaf signers and hearing controls, one may rather expect comparable overall motion velocity thresholds.

Whereas the outcome for overall motion thresholds is unclear, previous studies predict a shift in the lateralization of motion processing in deaf signers \([6,8]\). Indeed, studies that have characterized deaf individuals’ performance on motion tasks have been successful at identifying a role for experience in changing the lateralization of motion perception, but these differences stem from ASL usage rather than auditory deprivation. Native users of ASL, deaf or hearing, have lower psychophysical thresholds for discrimination of motion direction in the right visual field than in the left visual field, whereas the opposite trend occurs in hearing nonsigners \([4,6,8,22–24]\). This pattern of results indicates that early sign language exposure is sufficient to change the cerebral dominance of motion processing. Importantly, this lateralization difference has been documented not only behaviorally but also physiologically. Native signers, hearing or deaf, were found to recruit more MT/MST in the left hemisphere than in the right hemisphere, whereas hearing nonsigners showed no such laterality effect \([4]\).

In the present paper, velocity thresholds were assessed in three experiments, each one testing thresholds at a different distance from the fixation point. Subjects were required to detect velocity increases in a ring of radially moving dots. On each trial, dots accelerated in one quadrant, and the subject indicated the location of this velocity change. The duration of the velocity change was initially large to allow subjects to clearly see the location of the change. When the duration of velocity changes in each quadrant in order to determine the duration of increased velocity necessary for the subject to accurately perceive the change 79% of the time. The observed 79% threshold was then used as a landmark to select fixed values; the method of constants was used to recover the subject’s entire psychophysical curve and allow a more precise estimate of the 79% thresholds. Across three experiments, this procedure allowed us to test (1) whether velocity thresholds differ in deaf and hearing individuals, (2) whether deaf subjects’ peripheral visual field advantages apply to velocity discrimination, thus extending beyond the scope of attentional manipulations, and (3) whether the detection of velocity changes is lateralized differently in deaf users of ASL and in hearing nonsigners, as the other studies of motion processing indicate \([4,6,8,24]\).

2. Experiment 1

In Experiment 1, we determined whether deaf and hearing populations have similar velocity thresholds by requiring subjects to detect velocity increases in a ring of radially moving dots. On each trial, dots accelerated in one quadrant, and the subject indicated the location of this velocity change. This spatial four-alternative forced choice (FAFC) paradigm allowed us to investigate overall population differences, as well as those applicable to specific visual fields.

2.1. Materials and methods

2.1.1. Subjects

Informed consent was obtained from 13 hearing nonsigners (nine female; \(M \text{ age} = 20, \text{ S.D.} = 1.3\)) as well as 13
profoundly deaf individuals (seven female; $M$ age = 21, S.D. = 3). Eleven deaf subjects had binaural hearing loss above 90 dB, one had 90 dB loss in his left and 88 dB loss in his right ear, and one subject had about 75 dB binaural hearing loss. All deaf subjects had deaf relatives; 11 acquired ASL from their deaf parents, one natively acquired Russian Sign Language from her deaf parents, and one began using ASL at home and at school at age 3. All subjects had normal or corrected-to-normal vision and no history of central nervous system damage; 10 deaf and 11 hearing subjects were right-handed.

2.1.2. Stimuli

The stimuli were modeled after the ones used in Bavelier et al. [3,4] and concurrently presented across all four quadrants of the display. Stimuli consisted of 500 radially moving dots bound within a ring covering the visual field between 0.5° and 8° around a central fixation point (0.22°) (Fig. 1). The individual dot size was 0.11°, and all were drawn using the Psychophysical Toolbox routines [9,27] written for Matlab (The Math Works, Natick, MA). To avoid motion aftereffects, half of the dots moved outward and the other half moved inward. Dots extending beyond the outer or inner borders were replaced with randomly positioned dots on either the outer or inner border of the ring. The dots moved at a base speed of $3\frac{3}{5}$/s, and on each trial one quadrant accelerated abruptly to $5.5\frac{5}{8}$/s. Previous research suggests that velocity changes of this amount are detectable within approximately 100 ms [20], and are thus ideal stimulus durations to minimize eye movements since approximately 100–200 ms is needed to plan and execute a saccade [14]. The location of the acceleration was randomized and balanced for each experimental block.

2.1.3. Apparatus

The stimulus presentation was controlled by a Macintosh G3 computer (Apple Computer, Cupertino, CA) fitted with a Village Tronic MP850 video card (Village Tronic Computer, Sarstedt, Germany). Stimuli were displayed on a ViewSonic P817, 21 in. monitor (ViewSonic, Walnut, CA) running at 160 Hz with a resolution of 1024 × 768.

Fig. 1. (a) Schematic representation of each trial. Subjects fixate, and passively watch dots radially moving at $3\frac{3}{5}$/s. A fixation change from a circle to a cross alerts the subject that the dots in one quadrant have accelerated to $5.5\frac{5}{8}$/s (denoted here by shading). The dots return to their normal speed after a variable time, and the fixation remains a cross until the subject responds. Feedback is given via a color change of the fixation cross. The time necessary to detect a velocity change 79% of the time was computed. (b) Stimulus location. The field of dots extended over the full-field (Experiment 1: 0.5–8° ring), central field (Experiment 2: 0.4–2° ring), or peripheral field (Experiment 3: 12–15° ring).
2.1.4. Procedure
Subjects were given written instructions prior to testing. The instructions were then administered in English to hearing subjects and in ASL to deaf subjects. The experiment began once subjects successfully completed a series of practice trials. Participants’ heads were then comfortably stabilized in a chin rest, the height of which was adjusted to level the participant’s eyes with the fixation point. The monitor was placed 60 cm from the subject’s eyes.

2.1.5. Velocity change task
Figure 1 schematically represents the stimuli and task. Subjects fixated on a central fixation marker throughout the experiment. A shape change of the fixation marker from a blue circle to a blue cross cued the beginning of each trial. When the shape change occurred, the velocity of one quadrant increased beyond that of the other three. The dots returned to their initial velocity after a brief interval, and the fixation cross remained on the screen until the subject made a response. Subjects responded by pressing the keypad number corresponding to the spatial location of the velocity change. Subjects were instructed to use only their right index finger; to reduce intertrial dependencies, subjects were told to place their index finger on the center-key of the keypad at the end of each trial. Key-presses occurring prior to a velocity change were ignored, and trials did not advance until the subject made a response. Feedback was given through a transient color change of the fixation cross from blue to green for correct responses and from blue to red for incorrect responses. To avoid expectations of stimulus onset, the interstimulus interval was randomly set between 1 and 3 s.

2.1.6. Threshold estimation
To obtain a psychometric fit, the temporal duration of the velocity change was varied for each trial in multiples of 6.5 ms (the minimum time for a screen refresh). An adaptive staircase procedure allowed us to estimate the change duration corresponding to each subject’s 79% threshold [18,32]. Change durations increased following one incorrect response, and decreased following three successive correct responses. Six 40-trial sequences were presented within three pairs of randomly interleaved staircases, a procedure used to keep subjects naïve to the adaptive procedure. To recover the entire psychometric function, we used these first data to determine five velocity change durations falling between chance and ceiling performance levels. The method of constants was then used to sample the psychometric function at these fixed durations (80 trials per duration randomly intermixed). Weibull functions were fit to these 400 trials to obtain a more accurate estimation of each subject’s 79% threshold than permitted by the staircase procedure. Separate thresholds were also calculated for each visual field.

2.2. Results
Subjects were excluded from this analysis if their data suggested an inability to do the task; that is, they were removed if their overall threshold extended beyond 2 standard deviations from the mean of their respective population, or if their threshold for any quadrant was beyond 1000 ms. Based on the above restrictions, one deaf and one hearing subject was excluded from the analysis. Twelve deaf and 12 hearing subjects remained.

Fig. 2. Hearing and deaf velocity thresholds over full-field, central field, and peripheral field. Threshold is defined here as the time necessary to detect an abrupt velocity change of 3–5.5°/s with 79% accuracy. In no eccentricity were significant population differences found.
A comparison between overall hearing and deaf velocity thresholds revealed no population differences (Hearing $M = 83.26$ ms; S.D. = 16.63; Deaf $M = 92.34$ ms, S.D. = 22.42; $F_{(1,22)} = 1.271, p > 0.25$) (Fig. 2). This analysis rests on the assumption that processing is equivalent across the entire visual field, and could potentially mask region specific population differences. To clarify whether visual field specific population differences existed, we computed separate thresholds for upper, lower, left, and right visual fields. An ANOVA with population and lower/upper visual field as factors revealed no population differences ($F_{(1,22)} = 0.89, p = 0.355$). However, subjects showed lower thresholds in the upper than lower visual fields (Upper: $M = 85.86$ ms, S.D. = 23.34; Lower: $M = 97.10$ ms, S.D. = 25.80; $F_{(1,22)} = 5.56, p = 0.028$), but this did not interact with population ($F_{(1,22)} = 0.06, ns$). A population by hemifield interaction (Deaf Left: $M = 98.34$ ms, S.D. = 27.62; Deaf Right: $M = 86.19$ ms, S.D. = 19.85; Hearing Left: $M = 79.65$ ms, S.D. = 16.73; Hearing Right: $M = 87.15$ ms, S.D. = 17.83; $F_{(1,22)} = 13.99, p < 0.001$) (Fig. 3) led us to investigate hemi-field effects separately within each population. The deaf group exhibited better performance in the right as opposed to the left hemifield ($F_{(1,11)} = 6.68, p = 0.025$); the opposite effect was found in the hearing group, who had better performance in the left than in the right hemifield ($F_{(1,11)} = 10.2, p = 0.009$).

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Fig. 3. Seventy-nine percent velocity thresholds for the left visual field (right hemisphere) (LVF/RH) and the right visual field (left hemisphere) (RVF/LH) in hearing and deaf individuals. Thresholds were determined by separately fitting Weibull functions to trials with velocity changes in the left and right hemifields. (a) Velocity thresholds for full-field (Experiment 1), (b) velocity thresholds for the central field (Experiment 2), (c) velocity thresholds for the peripheral field ( Experiment 3).
2.3. Discussion

In Experiment 1, deaf native signers and hearing nonsigners displayed comparable velocity thresholds when asked to monitor the full visual field for velocity changes. This result indicates that deafness does not alter the sensitivity of the motion system to velocity changes. Unexpectedly, we found lower threshold in the upper than the lower visual field for both populations tested. This finding is surprising as it is opposite to those previously found for inward and outward radial motion [12, centripetal motion [29], and chromatic motion perception [5]. Because this finding was not an a priori prediction and did not interact with population, it is beyond the scope of this paper and will not be discussed further. More importantly, hemifield specific differences were observed whereby deaf native signers displayed lower thresholds in the right than left hemifield and the hearing subjects displayed the opposite pattern. A change in the lateralization of motion processing has been described previously in the literature, and attributed to signing experience as it is has been observed in deaf signers and in hearing signers but not in hearing controls in several studies using motion stimuli [2,8,24]. Thus, the greater reliance of ASL on motion processing may lead to a greater sensitivity of motion processing in the left, language dominant hemisphere. The observation of the expected lateralization difference between deaf signers and hearing controls confirms that the lack of overall population difference in Experiment 1 cannot easily be attributed to a lack of sensitivity of our paradigm.

3. Experiment 2

Several studies suggest that early deafness leads mainly to changes in the processing of visual peripheral information. Compared to centrally presented stimuli, population effects have been found at eccentricities of 25° [19], 18° [22,23], and as small as 5° [28]. Could the absence of an overall population effect in Experiment 1 reflect the use of stimuli encompassing the central visual field? Using the same velocity change task, we address this issue by assessing central (0.4–2°) thresholds in Experiment 2, and peripheral (12–15°) thresholds in Experiment 3. These visual angles were chosen to minimize the visual field overlap between central and peripheral conditions.

3.1. Materials and methods

3.1.1. Subjects

Eleven deaf individuals (seven female, M age = 21, S.D. = 3.1) who participated in Experiment 1 and 17 hearing nonsigners (13 female, M age = 20, S.D. = 1.2) provided informed consent and participated in this experiment. The hearing subjects had prior experience with the experiment, either by participating in Experiment 1 (five subjects) or a similar pilot study (12 subjects). Experience did not influence the hearing groups’ performance in Experiment 2 (all p’s > 0.14), so their data were combined to constitute a single hearing group. We were unable to increase the number of subjects in the deaf group due to the difficulty in recruiting deaf subjects meeting our criteria for hearing loss and early ASL exposure. All subjects had normal or corrected vision, and 10 deaf and 15 hearing subjects were right-handed.

3.1.2. Stimuli

Similar to the stimuli described for Experiment 1, a single ring of dots was presented in the center of the screen. Because the ring for this experiment was smaller (0.4° and 2° from fixation), the number of dots was reduced from 500 to 50. A different monitor (Sony 22 in. widescreen, 800 × 600 resolution with a refresh rate of 160 Hz) was used, and stimuli were scaled to preserve the dimensions of Experiment 1’s stimuli. To match Experiment 1’s visual angle, the viewing distance was reduced from 60 to 53 cm.

3.1.3. Design and procedure

The subjects were reminded how to perform the task, and the experiment began once they successfully completed a series of practice trials.

Similar to Experiment 1, an initial adaptive staircase procedure allowed us to estimate six velocity change durations falling between each subject’s chance and ceiling performance levels. The method of constants was then used to sample the psychometric function at these fixed durations (80 trials per duration randomly intermixed). Weibull functions were fit to these 480 trials, and each subject’s final 79% threshold was estimated. Separate thresholds were also calculated for each visual field.

3.2. Results

Two hearing subjects had thresholds extending beyond two standard deviations from their group mean. These subjects, as well as one deaf subject with a threshold over 1000 ms in one quadrant, were excluded from this analysis. Group analyses were performed on the remaining 10 deaf and 15 hearing subjects using a weighted means solution to account for unequal sample sizes in the omnibus ANOVA.

Mean thresholds did not differ between the two populations (F(1,23) = 0.76, p = 0.391) (Fig. 2). Likewise, an ANOVA comparing thresholds in the lower and upper visual fields revealed no population difference (F(1,23) = 0.83, p = 0.373), but subjects had lower thresholds in the upper than in the lower visual field (Upper: M = 113.23 ms, S.D. = 55.75; Lower: M = 138.36 ms, S.D. = 57.95; F(1,23) = 15.65, p = 0.001). A hemifield analysis revealed equivalent thresholds for the two populations (F(1,23) = 0.94, p = 0.342), and, unlike Experiment 1, population did not interact with hemifield (Deaf Left: M = 123.01 ms, S.D. = 42.05; Deaf Right: M = 107.44 ms, S.D. = 49.91; Hearing Left: M = 132.96 ms, S.D. = 41.09; Hearing Right: M = 129.25 ms,
S.D. = 46.35; $F_{(1,23)} = 0.53, p = 0.473$). No other main effects or interactions were found.

3.3. Discussion

In Experiment 2, deaf native signers and hearing controls displayed similar velocity thresholds when tested in the central field. As in Experiment 1, the two populations exhibited a lower threshold in the upper than in the lower visual field, a result difficult to interpret. The population by hemisphere effect reported in Experiment 1 was not replicated for the central stimuli of Experiment 2. Because we did not monitor fixations, it is possible that subtle eye movements disturbed the intended lateralization of our test stimuli. Overall, as in Experiment 1, the lack of a population effect confirms previous research finding equivalent thresholds in deaf and hearing for central vision [6,8].

4. Experiment 3

Experiment 3 compares velocity motion thresholds in the visual periphery. As discussed above, visual periphery has been very loosely defined in previous experiments ranging from about 5° up to 25°. Although our fMRI data [2] indicated a population difference when subjects monitored velocity changes in stimuli extending up to 8°, the lack of any effect in Experiment 1 led us to use an even more eccentric location (12–15°).

4.1. Methods and materials

4.1.1. Subjects

Because we found between-experiment practice effects in hearing individuals in a series of peripheral-field pilot experiments, no subject who performed Experiment 1 or 2 was included in Experiment 3. Ten new deaf individuals (two female, $M$ age = 23, S.D. = 3.2) were recruited from the Rochester community as well as 11 new hearing nonsigners (five female, $M$ age = 20.7, S.D. = 1.9). Three deaf subjects had binaural hearing loss greater than 80 dB, and the remaining seven had binaural hearing loss greater than 90 dB; nine natively acquired ASL from their deaf parents, and one acquired ASL from his hearing parents at age 2. All subjects had normal or corrected vision and no previous history of central nervous system damage; all deaf and hearing subjects were right-handed.

4.1.2. Stimuli and apparatus

The apparatus was the same as in Experiment 2. Stimuli were identical to those used in Experiment 2 except for the following two changes: to create a ring in the peripheral visual field, dots moved radially between 12° and 15° from a central fixation point. The number of dots was increased from 50 to 1055 to match the dot density to that of Experiment 2.

4.1.3. Design and procedure

Except for monitoring fixation with an eye tracker, all other procedures followed those outlined for Experiment 1. Weibull functions were fit to the 480 trials (excluding eye-movement trials), and subjects’ final 79% thresholds were estimated. Separate thresholds were also calculated for each visual field.

4.1.3.1. Eye tracking protocol. Due to the high eccentricity of the stimuli and the general difficulty of the task, we anticipated that subjects might break fixation. This was an important concern because smooth pursuit eye movements can significantly influence motion thresholds [30]. Eye position was recorded at 60 Hz with an Applied Science Laboratories 504-remote pan-tilt camera positioned underneath the monitor’s stand. Eye position was determined by calculating the angular disparity between the center of the recorded pupil and the corneal reflection of an infrared beam projected at that eye. To determine where on the monitor the subject was directing their gaze, eye position was recorded as subjects fixated on each vertex of a nine-point calibration grid, a 15.6° by 15.6° square centered at fixation. Eye movements to any position located within the confines of the calibration grid could then be computed from these initial calibration measurements. To compensate for measurement error caused by slight head movements within the chin-rest, the subject was asked to fixate before each test block to allow for a manual offset correction to be applied to the calibration parameters.

4.1.3.2. Eye tracking analysis. Subjects’ fixations were calculated using the EYENAL software provided by Applied Science Laboratories. Whether due to an actual eye movement or to camera signal loss, we excluded from the analysis any trial in which the subject was not looking within 1.5° of the center of the fixation marker when the velocity change occurred. Although there was a trend for deaf subjects to deviate outside the 1.5° fixation boundary more frequently than hearing subjects (Deaf: $M$ removed = 11.15%, S.D. = 11.79%; Hearing: $M$ removed = 3.17%, S.D. = 4.3%; $F_{(1,17)} = 4.33, p = 0.053$), this did not severely impact any of our statistical comparisons. There were no significant differences between analyses including and excluding trials during which subjects broke fixation. We adopted a stringent criteria of inclusion and will report only the analyses of trials during which subjects held fixation.

4.2. Results

Two deaf subjects were removed from further analysis—eye tracking data were lost for one deaf subject, and another’s threshold extended beyond one standard deviation
from his group mean. For the remaining eight deaf and 11 hearing subjects, trials in which subjects maintained fixation were analyzed as in Experiment 2.

The deaf and hearing groups had equivalent overall performance \( F_{(1,7)} = 0.045 \), ns (Fig. 2). No difference was observed between the upper and lower visual fields \( F_{(1,7)} = 2.35, p = 0.142 \), nor did this factor interact with population \( F_{(1,12)} = 1.51, p > 0.2 \).

A population by hemifield interaction (Deaf Left: \( M = 197.36 \) ms, S.D. = 79.39; Deaf Right: \( M = 142.93 \) ms, S.D. = 68.51; Hearing Left: \( M = 172.78 \) ms, S.D. = 47.86; Hearing Right: \( M = 181.65 \) ms, S.D. = 60.15; \( F_{(1,17)} = 4.46, p = 0.05 \)) confirmed the laterality effects found across the full-field stimulus used in Experiment 1 (Fig. 3). The deaf showed better performance in the right than left visual field \( (F_{(1,7)} = 12.75, p < 0.01 \), but hearing subjects had equivalent thresholds for both hemifields \( (F_{(1,10)} = 0.15, n.s.) \).

### 4.3. Discussion

To summarize Experiment 3, velocity thresholds were equivalent between deaf and hearing individuals, even when using peripheral stimuli. As observed in Experiment 1, deaf signers showed lower thresholds in the right visual field than in the left visual field, but hearing nonsigners showed no hemifield effects. As discussed above, this laterality difference in motion processing has been described previously and attributed to signing.

### 5. General discussion

#### 5.1. Deafness does not alter overall velocity thresholds

On a task that varied the duration of velocity changes, thresholds for detecting small changes in velocity (3–5°/s) were equivalent between deaf native signers and hearing nonsigners. This was the case whether stimuli spanned a large visual field (0.5–8°), were limited to the parafoveal region (0.4–2°), or were presented only in the peripheral visual field (12–15°). Taken together with the lack of a population difference in discriminating motion direction \([6,8]\), this study reinforces the view that early deafness does not alter the sensitivity of motion processes, although it remains possible that population differences would emerge at different baseline speeds. More generally, our findings are consistent with the rest of the literature comparing visual thresholds between deaf and hearing, thus providing little evidence that auditory deprivation leads to psychophysical changes in visual functions. For example, in a task measuring contrast sensitivity thresholds across different spatial frequencies, temporal frequencies, and spatial locations, Finney and Dobkins \([13]\) reported no differences between deaf and hearing individuals. An absence of overall population effects has also been found in measures of visual flicker \([11]\), brightness discrimination \([10]\), and temporal discrimination \([21]\).

#### 5.2. Deafness alters motion processing to the extent that it relies on attention

In Bavelier et al.’s \([4]\) study, deaf individuals showed enhanced brain activation as compared to hearing controls when attending to motion velocity changes. The current observation of equivalent thresholds for the detection of motion velocity changes in the two populations weakens an interpretation in terms of different motion processing sensitivities, instead reinforcing the view that early deafness leads to changes in the attentional system. Accordingly, a number of behavioral studies focusing on visual attention and not using moving stimuli have confirmed changes in the attentional system following early auditory deprivation \([19,26,28]\). These studies all converge to indicate an enhancement of peripheral visual attention. The finding that performance in the peripheral visual field is not enhanced in deaf individuals tested on low-level visual tasks (Experiment 3; Ref. \([13]\)) reinforces the view that this enhancement is attention-specific.

Overall, it seems that similarly to other low-level visual tasks, deafness does not lead to a higher sensitivity in motion processing. This is not to say that deafness does not alter processing in the motion pathway. In particular, there is evidence that attentional manipulation during motion processing leads to very robust population differences. In a task requiring deaf and hearing subjects to attend to velocity changes \([4]\), deaf subjects had more activity in the posterior superior temporal sulcus, an area implicated in both motion processing \([31]\) and visual attention \([16,25]\). In contrast, hearing signers and hearing nonsigners had a comparatively low amount of activity in this area, suggesting that auditory deprivation, not ASL exposure, is sufficient to induce plasticity in this polymodal region. Deaf individuals also showed enhanced neural processing when attending to moving stimuli, regardless of whether motion attributes (e.g., direction or velocity) were task relevant. For instance, when attending to brightness changes in moving peripheral stimuli, deaf individuals had a larger effective connectivity between an area specialized for motion processing (MT/MST) and one of the main center for visual attention, the posterior parietal cortex \([3]\). A similar mechanism may also underlie population differences measured with Event-Related Potentials (ERPs). Deaf individuals displayed a larger deflection than hearing individuals in the N100—a posterior ERP component that occurs 170–210 ms poststimulus and reflects in part attentional processes—to the onset of a moving sinusoidal grating. In contrast, deaf and hearing subjects exhibited similar ERP components to the onset of a color change, consistent with the view that deafness alters dorsal functions to a greater extent than ventral ones \([1]\). Overall, the available data suggest that
deafness does not alter the sensitivity of motion processing per se, but rather the coupling between motion and attentional processes.

6. Conclusion

The present study establishes equivalent motion velocity thresholds in deaf signers and hearing nonsigners. The populations did exhibit an opposite laterality of velocity processing in the full-field (Experiment 1) and peripheral field (Experiment 3), but not in the central field (Experiment 2). In particular, as reported previously in the literature, deaf signers displayed better performance in the right visual field/left hemisphere than in the left visual field/right hemisphere, whereas hearing nonsigners displayed either no lateralization or an opposite pattern. This population difference has been previously attributed to fluency in a visual/spatial language rather than auditory deprivation, as hearing individuals who are native in ASL also display a right visual field/left hemisphere advantage during motion processing. In addition, the present results indicate that, unlike what has been reported for visual attention, deafness does not lead to peripheral field advantages for low level motion processing. Indeed, similar population thresholds were observed at all eccentricities tested. Instead, the data presented are consistent with the view that deafness does not directly alter motion processing per se, but rather changes the interactions between attention and motion processing.

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