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Effects of attention and laterality on motion and orientation discrimination in deaf signers

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ABSTRACT

Previous studies have asked whether visual sensitivity and attentional processing in deaf signers are enhanced or altered as a result of their different sensory experiences during development, i.e., auditory deprivation and exposure to a visual language. In particular, deaf and hearing signers have been shown to exhibit a right visual field/left hemisphere advantage for motion processing, while hearing nonsigners do not. To examine whether this finding extends to other aspects of visual processing, we compared deaf signers and hearing nonsigners on motion, form, and brightness discrimination tasks. Secondly, to examine whether hemispheric lateralities are affected by attention, we employed a dual-task paradigm to measure form and motion thresholds under "full" vs. "poor" attention conditions. Deaf signers, but not hearing nonsigners, exhibited a right visual field advantage for motion processing. This effect was also seen for form processing and not for the brightness task. Moreover, no group differences were observed in attentional effects, and the motion and form visual field asymmetries were not modulated by attention, suggesting they occur at early levels of sensory processing. In sum, the results show that processing of motion and form, believed to be mediated by dorsal and ventral visual pathways, respectively, are left-hemisphere dominant in deaf signers.

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1. Introduction

Studies have shown that deaf individuals who use American Sign Language (ASL) have altered or enhanced attentional capacity and visual processing abilities, by virtue of their different auditory and visual sensory experiences during development. Generally, deaf individuals are believed to have enhanced visual detection of targets that move or appear in the parafovea or periphery (Bottari, Nava, Ley, & Pavani, 2010; Chen, Zhang, & Zhou, 2006; Colmenero, Catena, & Fuentes, 2000; Dye, Hauser, & Bavelier, 2009; Loke & Song, 1991; Neville & Lawson, 1987a, 1987b; Reynolds, 1993). This advantage is believed to be stronger under conditions of attentional load, such as when targets in peripheral and central space compete for attention (Dye et al., 2009; Proksch & Bavelier, 2002). In studies using peripheral precues that direct spatial attention towards the location of the upcoming stimulus, deaf signers benefit less with a valid cue, compared to hearing signers and nonsigners (Bosworth & Dobkins, 2002a). When attention is diverted away from the target with an invalid cue, deaf signers' performance was less hindered than hearing nonsigners (Parasnis & Samar, 1985). Together, these results are interpreted to mean that deaf people are able to orient covert attention more efficiently and faster to peripheral events, compared to hearing people (and see Stivalet, Moreno, Richard, Barraud, & Raphel, 1998 for a similar conclusion with a visual search task). These findings are complemented by brain imaging studies showing enhanced neural activity when deaf signers direct attention to peripheral, but not central, targets (*ERP*: Neville & Lawson, 1987a; Neville, Schmidt, & Kutas, 1983; fMRI: Bavelier et al., 2000). Moreover, superior attention to peripheral stimuli is reported in deaf native signers but not in hearing native signers (who have early ASL exposure from their deaf signing parents but normal hearing), indicating the effect is attributed to auditory deprivation and not sign language experience (Dye et al., 2009; Proksch & Bavelier, 2002). In fact, this peripheral attention advantage in deaf individuals may even make peripheral stimuli more distracting, which can hinder performance for irrelevant concurrent tasks (Dye, Hauser, & Bavelier, 2008a). One ecological explanation for these results is that, in the absence of informative auditory cues about changes in one's extrapersonal space, deaf individuals need to rely upon visual cues, and as a result, this experience makes them more efficient at allocating attention to peripheral changes, compared to hearing individuals.

Other visual capacities such as visual shape memory (Cattani, Clibbens, & Perfect, 2007), face processing (Corina, 1989; McCullough & Emmorey, 2009; McCullough, Emmorey, & Sereno, 2005), and mental rotation (Emmorey & Kosslyn, 1996) are altered in deaf

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signers, and these effects are believed to be a result of early exposure to and daily use of a visual sign language. Most relevant to the current study, with respect to motion processing, several studies have reported a consistent right visual field advantage, suggesting a left hemisphere dominance, in deaf signers, while hearing nonsigners show either no asymmetry or a small right hemisphere advantage. This effect for motion processing has been shown using lateralized stimuli for a leftward vs. rightward direction-of-motion discrimination task (Bosworth & Dobkins, 1999, 2002b; Samar & Parasnis, 2005), an apparent motion task (Neville & Lawson, 1987a, 1987b), and a speed discrimination task (Brozinsky & Bavelier, 2004). Hearing native signers also exhibit a similar right visual field advantage for motion processing as do deaf signers suggesting that the asymmetry is attributable to sign language experience, and not to deafness (Bavelier et al., 2001; Bosworth & Dobkins, 2002b; Neville & Lawson, 1987a, 1987b). Supporting these behavioral results, deaf and hearing signers show greater brain activation in the left hemisphere while viewing moving stimuli compared to hearing nonsigners (*ERP*: Neville & Lawson, 1987a; *fMRI*: Bavelier et al., 2001).

The dominant hypothesis in the literature explaining the alteration of lateralization is that it reflects an adaptive developmental reorganization to meet the functional processing demands of sign language. That is, because ASL comprehension is highly dependent on the ability to process moving hands, then perhaps the left, language dominant hemisphere has usurped some visual functions, such as motion processing, needed for language processing (Neville & Bavelier, 2002). In addition to motion cues inherent in hand movements of ASL, other form cues – orientation, position, and configuration of the hands – are also important for sign language comprehension. The purpose of this study is to test this hypothesis by extending previous findings of motion processing asymmetries to other sensory dimensions believed to be relevant to sign language processing, specifically form processing. A critical implication of the hypothesis in the existing literature is that, in addition to motion cues, other sensory cues that are linguistically distinctive for sign language processing (such as form and orientation) should also become left lateralized, whereas sensory dimensions that are not linguistically distinctive for sign language processing (such as brightness) should not.

The first goal of the current study was to investigate left vs. right visual field laterality in deaf signers and hearing nonsigners for three different aspects of visual processing, which differ in the extent to which they provide important cues for sign language comprehension. *First,* we tested *direction-of-motion* discrimination, which allowed us to replicate the finding of left hemisphere dominance for motion processing in deaf signers and not in hearing nonsigners. As opposed to previous studies which used stimuli containing opposite directions of motion (Bosworth & Dobkins, 2002a, 2002b; Fine, Finney, Boynton, & Dobkins, 2005; Finney & Dobkins, 2001), in the current study subjects discriminated between small differences in the directional angle of motion. We reasoned that this might be closer to the types of finer discriminations signers make during sign language comprehension, since the differences across hand movements in sign language are often relatively subtle. *Second*, we tested *orientation* discrimination, with the prediction that because discrimination of finger and hand orientation is important for sign language comprehension, we might also find a left hemisphere dominance for this aspect of visual processing in deaf signers but not hearing nonsigners. We also used these motion and orientation tasks to ask, more generally, whether the deaf signers and hearing nonsigners differ in processing of stimuli/tasks that are thought to be mediated by the dorsal and ventral pathways. It is believed that the dorsal pathway supports spatial and motion processing and visuo-motor integration while the ventral pathway supports form processing and object recognition (see Desimone & Duncan, 1995; Milner & Goodale, 2008; Ungerleider & Pasternak, 2004 for reviews). It has been previously suggested that the dorsal pathway may be more greatly affected by deafness (Bavelier, Dye, & Hauser, 2006; Samar & Parasnis, 2005; Stevens & Neville, 2006). One recent study compared brain activation in hearing nonsigners, deaf signers, and hearing signers while they performed a spatial matching task that activated the dorsal pathway and an object-matching task that activated the ventral pathway (Weisberg, Koo, Crain, & Eden, 2012). They confirmed differential effects of both deafness and sign language on each pathway. *Finally*, as a control, we tested *brightness* discrimination, with the prediction that since brightness is not important for sign language comprehension, our deaf signers and hearing nonsigners should not show differences in laterality.

A second goal of the current study was to investigate effects of *attention* on visual performance, which we addressed by measuring performance under *full* vs. *poor* attention conditions. This attentional manipulation allowed us to ask two main questions. One, we asked whether any observed left vs. right laterality effects were dependent upon the amount of attention devoted to the stimulus/task. Two, we asked whether effects of attention for central vs. peripheral visual fields differed for deaf vs. hearing subjects, motivated by previous reports that attention effects in deaf individuals are greater in the peripheral than in central visual field (Bavelier et al., 2000; Dye et al., 2009; Neville & Lawson, 1987a; Neville et al., 1983; Proksch & Bavelier, 2002). To manipulate attention, we used a dual-task paradigm, i.e., obtaining visual thresholds for the main task (motion, form, or brightness) under conditions of full attention (main task alone) vs. poor attention (main task with a concurrent foveal task). We and others have previously observed elevated thresholds under poor attention conditions using the dual-task paradigm (Bonnel & Miller, 1994; Bonnel, Possamai, & Schmitt, 1987; Bosworth, Petrich, & Dobkins, 2012; Braun, 1994; Braun & Sagi, 1990, 1991; Huang & Dobkins, 2005; Lee, Koch, & Braun, 1997, 1999; Sperling & Melchner, 1978). The intention of the poor attention condition was to require subjects to maintain endogenous spatial attention at fixation, providing less attention for the main task. Here, we reasoned that if deaf subjects have enhanced attention (i.e., better at shifting or distributing attention amongst multiple tasks), then they would be less impaired by the poor attention condition, compared to hearing subjects, and this effect could differ for left vs. right visual fields, and/or for central vs. peripheral visual fields.

2. Methods

2.1. Subjects

Subjects included 15 hearing (6 males, average age = 22.0 ± 1.0 years) and 9 deaf (3 males, average age = 26.0 ± 1.9 years) adults. Deaf subjects had uncorrected hearing loss greater than 80 Decibels in both ears. Based on self-report, all participants were deaf from birth, with the exception of one who lost hearing at 15 months of age due to uncertain etiology. Two indicated the cause was congenital rubella, all others indicated unknown or genetic causes. Only two had deaf parents or older deaf siblings. All deaf participants reported that they began signing between 6 months and 3 years of age and used ASL on a daily basis in their interactions at school, work, or at home. Hearing subjects had normal hearing and no ASL experience. All subjects were right-hand dominant. The difference in age between the two subject groups was not significant ($t(23) = 1.71$; $p = 0.10$). A subset of the hearing individuals participated in an additional study of visual attention (Bosworth et al., 2012). All subjects gave informed consent before participating, which was approved by the University of California, San Diego Institutional Review Board.

2.2. Apparatus

Visual stimuli were generated on a Dell PC laptop with an ATI Radeon graphics card and displayed on a 21-in. SONY monitor (refresh rate = 60 Hz). Stimuli were created using a PC version of Matlab (version 6.5), and calibrated using a Photo Research PR-650 spectrometer. For each subject, eye position was monitored using a closed couple device (CCD) infrared camera with variable focus (12.5–75 mm) lens (Model #Fc62, Image Sensor), which was focused on the left eye of the subject. Each subject's face was lit with an infrared illuminator and an enlarged image of the eye was viewed on a 12″ Ultrak monitor outside the testing room. Before beginning each block of trials, subjects were instructed to fixate a black fixation square (0.9° × 0.9°) in the center of the video display, and the outline of the pupil was drawn on transparency film that covered the monitor. Previous experiments in our laboratory have shown that this set-up allows for the easy detection of saccadic eye movements and eye drift within ±2° of fixation (Dobkins & Bosworth, 2001). Subjects were instructed to maintain fixation throughout the experiment and were informed that the experiment would be temporarily interrupted if eye movements or eye drift were detected. Thus, subjects were highly discouraged from breaking fixation, and the experiment never needed to be interrupted.

2.3. Stimuli

Each subject was tested on three main tasks: (1) *direction-of-motion* discrimination task, (2) *orientation* discrimination task, and (3) *brightness* discrimination task. Stimuli for these tasks are shown in Fig. 1. All stimuli were presented on a gray background (45.7 cd/m^2), within a 5° circular aperture, and for a duration of 100 ms. Stimuli were presented in one of three locations: central visual field (CVF), centered on the fixation spot (0.9° × 0.9° black square); and left visual field (LVF) and right visual field (RVF), both centered 5° from the central fixation spot. We chose this eccentricity for the LVF and RVF stimuli based on pilot studies showing the tasks were too hard to do if presented further out in the periphery.

For the *direction-of-motion* task, a stochastic motion stimulus was employed (modeled after Newsome & Pare, 1988; and see Bosworth & Dobkins, 2002b). This stimulus consisted of a field of 300 white dots (each 0.04° in diameter, 95.8 cd/m^2, 35.4% Michelson contrast compared to the background) wherein 67% of dots were "signal" dots, moving in a coherent direction, while the remaining 34% of dots were "noise" dots that were positioned in a random location from frame to frame. The trajectory for each signal dot lasted for an average duration of 67 ms (4 frames), after which it disappeared and then reappeared in a random location within the circular aperture, moved coherently for another 67 ms, and so on. To obtain direction-of-motion thresholds, direction of motion varied between 0° and 45° to the left or right of downward motion using a staircase procedure across trials.

For the *orientation discrimination* task, the stimulus consisted of a static 0.8 cycle/degree sinusoidal grating stimulus, presented at 1% contrast (mean background luminance = 45.7 cd/m^2). To obtain orientation discrimination thresholds, grating orientation was varied between 0° and ±45° (i.e., tilted left or right of vertical), across trials, using a staircase procedure.

After finding that, on the motion and orientation task, deaf and hearing subjects differed in their visual field asymmetries, we added a control condition to investigate whether this effect could be driven by non-specific group differences in visual field asymmetries. To this end, we added a *brightness discrimination* control task,

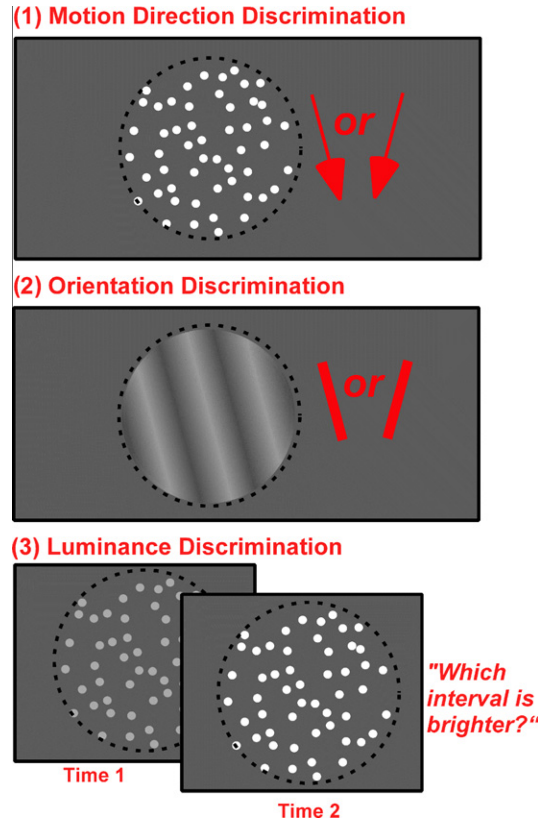

Fig. 1. Stimulus for each task. (1) *Direction-of-motion* discrimination task, for which 67% of the dots moved coherently, and subjects discriminated their direction (leftward vs. rightward of downward motion). (2) *Orientation* (form) discrimination task, for which a static 1% contrast sinusoidal grating was presented and subjects discriminated its orientation (tilted to the left or left or right of vertical). (3) *Brightness* discrimination task, for which two intervals with static dot displays were presented, and subjects reported which interval contained the brighter dots.

because brightness is unrelated to sign language experience. Here, the stimulus was a field of static white dots (same number and size as in motion task) presented in two 100 ms intervals, separated by 100 ms. To obtain brightness discrimination thresholds, in one of the two intervals, the dots were presented at a luminance of 73.1 cd/m^2, and in the other, they were presented at a higher value determined by the staircase procedure, ranging from 89.3 cd/m^2 to 94.6 cd/m^2. We tested brightness discrimination *only* under the full attention condition because of the finding that the difference in the visual field asymmetries for deaf and hearing subjects did not vary between the full and poor attention conditions, as discussed below in Section 3.4.

For the motion and orientation main tasks, a rapid serial visual presentation (RSVP) stimulus was simultaneously presented at fixation (0.9° × 0.9° black square). The purpose of the RSVP stimulus was to modulate the amount of attention paid to the motion or orientation stimulus. As shown in Fig. 2, the RSVP stimulus consisted of a series of 4–7 possible orange-colored shapes (triangle, heart, star, circle and square)[1] presented within the fixation square, and the order of these shapes was randomized across trials. Each shape was presented for 120 ms, separated by a blank period of 120 ms. A total of four to seven shapes were presented (for a total duration

[1] Note that we chose *shapes*, rather than a more conventional stimulus, like letters (see Dye & Bavelier, 2010) because deaf signers may have less English reading experience than hearing subjects do, thus, we thought it fairer to use non-orthographic stimuli, with the notion that both groups would have roughly equal experience with shapes.

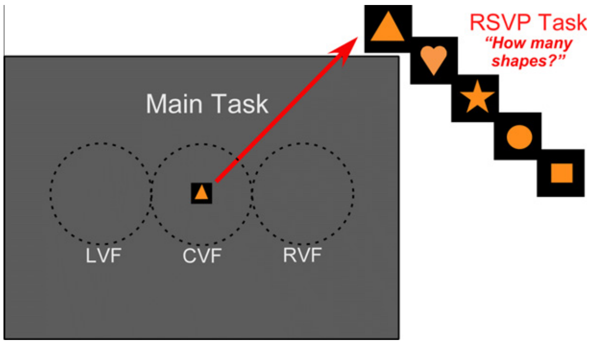

Fig. 2. The main task (motion, orientation, or brightness) was presented in three locations, central (CVF), left (LVF), and right (RVF) visual fields. An RSVP (rapid serial visual presentation) task was presented foveally simultaneously with the main task. The RSVP stimuli consisted of a rapid succession of 4–7 shapes (triangle, heart, star, circle, and square, in random order across trials), each lasting 120 ms, with a 120 ms interstimulus interval between each shape, presented within the black fixation square. Each main task was tested in the CVF, LVF or RVF (within the area shown here as dashed circles), concurrently with the RSVP stimuli. In the poor attention condition, on each trial, participants reported the total number of shapes in the RVSP task, and then reported on the stimulus in the main task. In the full attention condition, the participants ignored the RSVP stimulus and only reported on the stimulus in the main task.

that varied from 840 ms, for four shapes, to 1560 ms, for seven shapes). The main task stimulus was presented simultaneously with the last shape, for a duration of 100 ms. The central RSVP stimulus was presented for the brightness discrimination task as well, but this was conducted under full attention only, and subjects were not required to respond to it.

2.4. 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 (0.9° × 0.9°) black square in the center of the monitor for the duration of each trial. The first trial was initiated by the subject with a key press, which was followed by the RSVP stimulus presented at fixation, and the main stimulus presented simultaneously with the last shape of the RSVP task (described in Section 2.3 above). Upon disappearance of the last RSVP shape/main stimulus, the subject used a keyboard to enter either one (full attention condition) or two (poor attention condition) responses. The next trial automatically started 1500 ms after the subject's response. For the *direction-of-motion* and *orientation* tasks, data were obtained in both the *full* and *poor* attention conditions. For the *brightness discrimination* task, which was added later, data were obtained in the *full* attention condition only (even though the RSVP stimulus was still presented).

In the *full attention* condition, subjects performed only the main task, responding in a 2-alternative forced choice manner using two digits on their left hand (*motion task:* "down-to-the-left" or "down-to-the-right"; *orientation task:* "left-tilt" or "right-tilt"; *brightness discrimination task:* "first interval brighter" or "second interval brighter"). Here, they were told to ignore the irrelevant RSVP at the center of gaze. In the *poor attention* condition, subjects performed a dual task on each trial. They were required to first, report how many shapes appeared in the RSVP stimulus (ranging from four to seven, so that the task was a 4-alternative forced choice), using four digits on their right hand, and second, report on the main task, using their left hand. No feedback was provided in either attention condition.

The intention of the foveal RSVP task was to require subjects to maintain endogenous spatial attention at fixation, providing less attention for the main task in the poor attention condition.[2] The prediction was that if deaf subjects have enhanced attention (i.e., better at allocating attention amongst multiple tasks), then they would be *less* impaired by the poor attention condition than hearing subjects. Stated another way, this is to say that deaf signers, either by virtue of more efficient allocation of attention or greater attentional resources, show a smaller effect of the attentional load in the dual-task condition, relative to hearing nonsigners.

For the motion and orientation tasks, the two attention conditions (full vs. poor) for each of the three visual fields (CVF, LVF RVF) were presented in separate blocks, all of which were randomized and counterbalanced across subjects. Subjects completed all blocks/conditions for one task before proceeding with another task, and the task order was randomized and counterbalanced across subjects. Before beginning the study, subjects were given practice on the main tasks under full attention, followed by practice on the RSVP task alone, and finally, practice on the main tasks under poor attention. During this practice, subjects' performance on the RSVP task was required to stay above 40% correct (chance performance being 25%).

2.5. Adaptive staircase procedure for obtaining thresholds

In each of the three main tasks, the variable of interest (direction of motion, orientation, or brightness) was varied across trials in an adaptive staircase procedure. Specifically, on the first trial, a highly discriminable stimulus was presented (i.e., *motion* task: dots moving in a direction 45° to the left or right of downward; *orientation* task: grating tilted 45° to the left or right of vertical; *brightness* task: one of the two intervals being 17.3 cd/m^2 more luminous than the other). Then the stimulus signal (i.e., the dependent measure) for subsequent trials varied in a "1-down/2-up" procedure, based on the Parameter Estimation and Sequential Testing (PEST) method (Taylor & Creelman, 1967). This signal value was tilt size for the motion and orientation tasks and luminance value for the brightness task. With this procedure, if the subject responded correctly, the stimulus signal was decreased (made harder) by one step, and if the subject responded incorrectly, the stimulus signal was increased (made easier) by two steps. The maximum step size for the motion task was multiplicative, a 1.59-fold change. For the orientation task, the maximum step size was an absolute amount of 4.0°. For the brightness discrimination task, the maximum step size was 4.6 cd/m^2. The value of the step size was determined by an acceleration factor (AC) of 1.5. The step size was multiplied by AC following either two correct or two incorrect responses, and was multiplied by (1/AC) following a reversal in correctness. The use of a variable step size allowed more precision than a fixed step size. For each participant, for each task, threshold was determined from performance across 125–150 trials. Note that for the poor attention condition, all trials were used, whether or not the subject was correct on the central RSVP task, which follows the analyses of our previous study using the full/poor attention paradigm (Huang & Dobkins, 2005). To obtain thresholds, psychometric functions were fit to the data using Weibull functions (Weibull, 1951) and the maximum likelihood method (Johnson, Kotz, & Balakrishnan, 1995; Watson, 1979). Threshold for each task was defined as the value yielding 75% correct performance. We then took the log of each threshold since logarithmic, but not linear, data conform to normal distributions. To look at relative effects of performance for two conditions within subjects, we took the log of the ratio of linear thresholds, which is identical to subtracting the log of one threshold from the log of another.

[2] An alternative, or additional, explanation for the effect of the dual task paradigm is that performance is impaired because subjects are required to maintain an additional response in memory, and make two responses rather than one. In this case, we have no *a priori* reason to believe deaf signers and hearing nonsigners would differ.

2.6. Data analysis

Data were analyzed in four different ways. First, we analyzed central visual field (CVF) data using a three-factor ANOVA (*tasks:* motion vs. orientation × *attention conditions:* full vs. poor × *subject groups:* deaf vs. hearing). Second, we analyzed lateralized (LVF vs. RVF) data using a four-factor ANOVA (*tasks:* motion vs. orientation × *attention conditions:* full vs. poor × *visual field locations:* LVF vs. RVF × *subject groups:* deaf vs. hearing). We kept the RVF/LVF analyses separate from the CVF analyses because we wanted to contrast LVF vs. RVF performance, which would not be easy to analyze if all three visual fields were analyzed together. Because we observed interactions between subject group and visual field (left vs. right) in these LVF vs. RVF analyses, we explored these effects further with *laterality ratios*: Log ($Threshold_{LVF}/Threshold_{RVF}$). Ratios greater than zero indicate better performance in the RVF (corresponding to a left hemisphere advantage). Based on previous findings of RVF advantages for motion processing in deaf signers (as discussed above in Section 1), we used one-tailed t tests for laterality ratios to test whether ratios were greater than zero. Finally, we analyzed asymmetries in CVF vs. the right and left peripheral visual fields (PVFs) averaged together, to test hypotheses regarding greater effects of attention in the PVF than CVF for deaf subjects, compared to hearing subjects. For this analysis, we calculated *attention ratios*, as Log ($Threshold_{Poor}/Threshold_{Full}$), with log ratio values greater than zero indicating better performance in the full attention condition and conducted a three-factor ANOVA (2 tasks: motion vs. orientation × 2 visual fields: CVF vs. PVF × 2 subject groups: deaf vs. hearing).

3. Results

3.1. Central visual field (CVF) performance

Thresholds for each group are presented in Table 1. A three-factor ANOVA was performed with task (motion vs. orientation) × attention (full vs. poor) × subject group (deaf vs. hearing) as factors. As expected, performance was significantly better for the full than poor attention condition ($F(1,23) = 39.32$; $p < 0.001$). This verifies that the dual-task manipulation succeeded in reducing attentional resources devoted to the main task. There was no main effect of subject group ($F(1,23) = 0.05$; $p = 0.82$) nor an interaction between subject group and attention ($F(1,23) = 0.35$; $p = 0.56$), indicating that deaf and hearing subjects did not differ in overall visual performance or in effects of attention on performance in the central visual field. There was also no interaction between task and attention ($F(1,23) = 0.37$; $p = 0.54$), and no three-way interaction ($F(1,23) = 0.19$; $p = 0.67$). There was a main effect of task ($F(1,23) = 15.72$; $p < 0.001$), with better overall performance on the orientation than motion task. The only meaningful effect was a significant two-way interaction between subject group and task ($F(1,23) = 6.71$; $p = 0.016$), which suggests that motion vs. form processing differs between groups. This interaction was driven by deaf subjects performing worse than hearing subjects on the motion task, while performing better than hearing subjects on the orientation task, although *post hoc* analysis revealed that neither effect was significant on its own (*motion:* $t(23) = 1.71$; $p = 0.10$; *orientation*: $t(23) = 1.35$; $p = 0.19$). This result suggests that for the central visual field, deafness and/or sign language may differentially affect motion and form processing. As motion processing and form processing are mediated within the dorsal and ventral pathways, respectively, we explore further the effect of deafness and/or sign language on these pathways in Section 4.

3.2. Peripheral (left vs. right) visual field performance

A four-factor ANOVA was performed on log thresholds, with task (motion vs. orientation) × attention (full vs. poor) × visual field (left vs. right) × subject group (deaf vs. hearing) as factors. As was the case for CVF data, there was a trend for deaf subjects to perform worse than hearing subjects on the motion task, yet perform better than hearing subjects on the orientation task, although the interaction between subject group and task did not reach significance ($F(2,46) = 2.72$; $p = 0.11$). With regard to overall effects of attention, as expected, performance was significantly better for the full, than the poor, attention condition ($F(1,23) = 36.3$; $p < 0.001$). This can be noted from thresholds presented in Table 1. There was no main effect of subject group ($F(1,23) = 2.34$; $p = 0.14$), nor an interaction between subject group and attention ($F(1,23) = 2.90$; $p = 0.10$), indicating that deaf and hearing subjects do not differ in overall performance or in effects of attention on performance. There was a main effect of visual field ($F(2,46) = 10.0$; $p = 0.004$), but this should be interpreted in light of a significant subject group × visual field interaction ($F(2,46) = 8.38$; $p = 0.008$). This subject group × visual field interaction indicates that visual asymmetries differ between deaf and hearing subjects, which we explore further in the next section. The lack of three-way and four-way interactions suggests that the subject group × visual field interaction did not depend on attention ($F(1,23)$ = all F values < 1; all p values > 0.34). [There were also no other two-way interactions: $p \geqslant 0.13$. There was a main effect of task ($F(1,23) = 148.1$; $p < 0.001$), which is not surprising, as the two tasks are not expected to yield comparable thresholds.] To further explore the interaction between visual field and subject group, we turn to laterality ratios next.

3.3. Laterality ratios

In order to explore visual field asymmetries, we calculated *laterality ratios,* as Log ($Threshold_{LVF}/Threshold_{RVF}$), with values greater than zero indicating better performance (lower threshold) in the RVF. Mean laterality ratios are presented for each subject group in Fig. 3. Since the visual field × subject group interaction did not did

Table 1
Mean thresholds and standard deviations in parentheses for deaf signers and hearing nonsigners. Note the brightness task was conducted as a control only within the left and right visual fields in the full attention task.

Mean thresholds (SD)		Full attention (single task)			Poor attention (dual task)		
	Task	Left	Center	Right	Left	Center	Right
Deaf signers ($N = 9$)	Motion	1.19 (0.30)	0.98 (0.22)	1.07 (0.24)	1.43 (0.17)	1.13 (0.31)	1.24 (0.25)
	Orientation	0.64 (0.25)	058 (0.23)	0.54 (0.23)	0.87 (0.35)	0.81 (0.31)	0.75 (0.32)
	Brightness	1.43 (0.21)	Na	1.45 (0.220	Na	Na	Na
Hearing nonsigners ($N = 15$)	Motion	0.97 (0.23)	0.82 (0.23)	1.04 (0.27)	1.21 (0.23)	0.97 (0.26)	1.08 (0.25)
	Orientation	0.61 (0.16)	0.74 (0.25)	0.65 (0.15)	0.72 (0.21)	0.91 (0.31)	0.72 (0.19)
	Brightness	1.17 (0.13)	Na	1.24 (0.19)	Na	Na	Na

not differ across attention conditions, we collapsed laterality ratios across full and poor attention conditions in these analyses.

For the *motion* task, deaf subjects' mean laterality ratio was 0.155 and was significantly greater than zero ($t(8) = 2.71$; $p = 0.01$), indicating 1.43-fold better motion performance in the RVF than the LVF. By contrast, for hearing subjects, the mean laterality ratio for motion was 0.029 and was not significantly greater than zero ($t(14) = 1.01$; $p = 0.17$), indicating no visual field asymmetry for motion. In addition, deaf subjects' mean laterality ratios for the motion task was significantly greater than those of hearing subjects ($t(23) = 2.03$; $p = 0.025$).

Likewise, for the *orientation* task, deaf subjects' mean laterality ratio was 0.104 and was significantly greater than zero ($t(8) = 1.94$; $p = 0.04$), indicating a 1.27-fold better discrimination in the RVF than LVF. By contrast, hearing subjects' mean ratio was -0.021, and was not significantly different from zero ($t(14) = 0.43$; $p = 0.34$). Deaf subjects' laterality ratios were marginally significantly greater than those of hearing subjects ($t(23) = 1.66$; $p = 0.055$).

For the *brightness* task, for neither group was the laterality ratio different from zero (*hearing*: mean = -0.069; $t(14) = 1.24$; $p = 0.12$, *deaf*: mean = -0.023; $t(8) = 0.44$; $p = 0.34$), indicating no visual field asymmetry for brightness discrimination.

This pattern of laterality effect across conditions was also observed in the number of subjects with nonzero laterality ratios. For motion, orientation and brightness tasks, respectively, 70%, 80%, and 40% of deaf subjects, compared to only 53%, 53% and 33% of the hearing subjects, had log ratios greater than 0.08 (i.e., 1.2-fold), i.e. a RVF/LH advantage.

In sum, these results suggest that there are group differences between deaf and hearing subjects in hemispheric laterality for both motion and form processing. The fact that we found neither a laterality effect nor group differences for *brightness* discrimination suggests that the group differences observed on the motion and orientation task do not reflect general differences between groups in laterality effects. Moreover, because brightness discrimination has nothing to do with ASL, whereas motion and form clearly do, it is tempting to entertain that this may be related to visual language use. But as we did not test hearing signers in the current study, we cannot definitively determine whether the laterality is linked to auditory deprivation or sign language use.

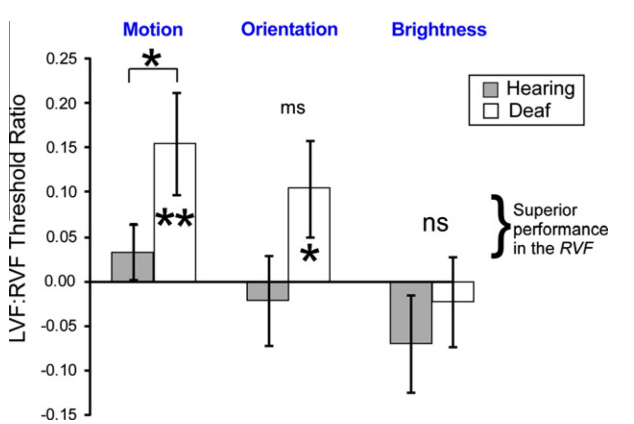

Fig. 3. Laterality ratios. Mean log Threshold_{LVF}:Threshold_{RVF} ratios for hearing and deaf subjects for the motion, orientation, and brightness tasks. Ratios greater than zero indicate better performance in the RVF than the LVF (i.e., a *left* hemisphere advantage). Symbols above each bar indicate significance of group differences, and those within the bars indicate whether a mean ratio is significantly different from zero ($^{**}p < 0.01$; $^{*}p < 0.05$; ms = marginally significant; ns = not significant). Error bars denote standard error of the mean. These data are collapsed for full and poor attentions since there was a not a significant difference between attention conditions.

3.4. Attention effects for center vs. periphery

We were motivated to investigate differences between groups in attention effects, specifically for central vs. peripheral visual fields, based on previous studies reporting that attention effects in deaf subjects are bigger in the peripheral than the central visual field, while the opposite asymmetry is seen in hearing subjects (*behavioral data*: Proksch & Bavelier, 2002; *fMRI data*: Bavelier et al., 2001; Fine et al., 2005). In order to explore attention effects, we calculated *attention ratios,* as Log ($\text{Threshold}_{Poor}/\text{Threshold}_{Full}$), with values greater than zero indicating better performance in the full attention condition. For the peripheral (PVF) condition, we averaged data across the LVF and RVF, despite our finding differences between the two visual fields. Our justification for this averaging is based on wanting to compare our results to those of previous studies of peripheral vs. central attention effects in deaf vs. hearing subjects that also combined data across LVF and RVF (e.g., Bavelier et al., 2000; Dye et al., 2009; Neville & Lawson, 1987a; Neville et al., 1983; Proksch & Bavelier, 2002).

Our analysis was a three-factor ANOVA on attention ratios with task (motion vs. orientation) × visual field (central vs. peripheral) × subject group (deaf vs. hearing) as factors. The results of the ANOVA revealed no main effect of task ($F(1,23) = 0.12$; $p = 0.73$), subject group ($F(1,23) = 2.22$; $p = 0.15$) or visual field ($F(1,23) = 0.09$; $p = 0.76$). Likewise, no significant two-way interactions (subject group × visual field: $F(1,23) = 1.04$; $p = 0.32$; task × subject group: $F(1,23) = 0.44$; $p = 0.51$; task × visual field: $F(1,23) = 0.55$; $p = 0.47$) or three-way interactions ($F(1,23) = 0.0$; $p = 0.97$) were found. This result suggests that deaf subjects do not exhibit enhanced attention effects, nor do they show stronger attention effects in peripheral than central vision. Because these findings counter our hypotheses, we checked whether our non-significant subject group main effect ($p = 0.15$) was due to a lack of statistical power, using *post hoc* power analyses with power $(1-\beta)$ set at 0.80 and α set to 0.05, two-tailed. Sample sizes would have to increase to $N = 19{,}594$ and 384 for *central* motion and orientation tasks and to $N = 88$ and 86 for the *peripheral* motion and orientation tasks, respectively, in order for group differences to reach statistical significance at the 0.05 probability level. Thus, the limited statistical power because of the modest sample size in the present study ($N = 24$) may have played a role in limiting the significance of the peripheral attention effects.

3.5. RSVP task performance

Although not a main focus within the current study, the RSVP data might speak to deaf individuals' ability to attend to the center and periphery when two tasks are presented simultaneously. In the current study, the RSVP stimuli were presented at fixation, within foveal vision, while the main task was presented simultaneously outside of foveal vision, and therefore was more peripheral (this is true even when the main task was in the CVF stimulus). Interestingly, we found that overall RSVP performance in hearing nonsigners (82%, SD = 14%) was significantly better than that of deaf signers (67%, SD = 16%; $F(1,23) = 7.88$; $p = 0.01$), which was revealed in a three-factor ANOVA on RVSP performance (tasks × visual fields × subject groups). Importantly, the three-factor ANOVA revealed no interactions, indicating that the amount of attention devoted to the RSVP task was consistent, regardless of whether subjects were concurrently performing the motion or orientation task in the CVF, LVF, or RVF. For this reason, we strongly believe that the significant interactions we observed between subject group and visual field on the motion task (reported above in Section 3.2) cannot be driven by differences between subject groups on RSVP performance. This result for the RSVP data suggests that deaf people may have less attention devoted to foveal stimuli (i.e., the RSVP task at fixation) when there are distracting stimuli in the parafoveal and peripheral fields (i.e., the main task). We return to this possibility in Section 4.

4. Discussion

The primary aim of the current study was to compare visual field asymmetries in deaf signers and hearing nonsigners for motion and form tasks, which are mediated by the dorsal and ventral pathways, respectively. Previous studies have reported a right visual field advantage (i.e., a left hemisphere advantage) for motion processing, which has led to the hypothesis that the left hemisphere "captures" visual processing abilities necessary for language acquisition. Here we tested this language capture hypothesis using motion and form tasks, which are both assumed to be relevant to language processing, and a brightness task, which is clearly not relevant to language processing. The critical implication of the hypothesis is that both motion and form processing may both be left-hemisphere lateralized, whereas sensory dimensions that are not linguistically distinctive for sign language processing (such as brightness) should not be. Results from the current study do support this notion that both motion and form processing are lateralized to the left hemisphere, while brightness performance was not.

Our second primary aim was to determine whether deaf signers and hearing nonsigners differ in the efficiency of attentional allocation, using a dual task paradigm. We reasoned that if the deaf subjects had enhanced ability to shift or distribute attention across multiple tasks, then this would confer an advantage in the poor attention condition. That is, the dual task condition would impair performance *less* for the deaf subjects, compared to hearing subjects. However, in this study, we did not find evidence for enhanced attention in deaf subjects, as the effect of the poor vs. full attention manipulation was nearly identical for deaf and hearing subject groups. For the remainder of Section 4, we address the results in terms of overall visual sensitivity, visual field laterality effects, and attention, in the context of previous literature comparing deaf and hearing subjects.

4.1. Overall sensitivity

The results from the current study allow us to address the longstanding hypothesis that deaf signers might show heightened visual sensitivity due to one of two factors. First, because they cannot hear, they may rely more on their remaining senses, in particular, vision. Sensitivity to visual stimuli might be particularly important for objects entering the visual field from the periphery, as auditory cues that ordinarily help for orienting to such stimuli are absent. Second, visual sensitivity may be heightened in deaf signers because they have lifelong experience with a visual language, which might afford them greater-than-average experience with visual stimuli and/or greater reliance on visual information.

The results of the current study found no overall differences in performance between deaf and hearing subjects using a direction-of-motion discrimination task and an orientation (tilt) discrimination task. These findings corroborate results from many other studies showing no difference between deaf signers and hearing nonsigners in overall sensitivity for low-level visual tasks performed under full attention conditions, including luminance contrast sensitivity (Finney & Dobkins, 2001), leftward vs. rightward direction-of-motion discrimination (Bosworth & Dobkins, 1999, 2002a; Neville & Lawson, 1987a, 1987b), speed discrimination (Brozinsky & Bavelier, 2004), temporal order judgment tasks (Nava, Bottari, Zampini, & Pavani, 2008), flicker fusion (Poizner & Tallal, 1987, see also Bross & Sauerwein, 1980; Mills, 1985), shape identification (Proksch & Bavelier, 2002; Reynolds, 1993), numerosity judgment and visual tracking of multiple moving objects (Hauser, Dye, Boutla, Green, & Bavelier, 2007), visual digit span and line orientation judgment (Parasnis, Samar, Bettger, & Sathe, 1996).

The current study did, however, find an interesting trend for an interaction between subject group and task (motion vs. orientation), which was significant for central visual field stimuli and a marginally significant trend for peripheral visual field stimuli. This interaction was driven by deaf signers performing *worse* than hearing nonsigners on the *motion* task, while performing *better* than hearing nonsigners on the *orientation* (form) task. This is partly in line with other studies showing that for some visual-cognitive tasks that involve form processing, deaf signers do outperform hearing nonsigners, and this effect is thought to result from sign language experience, since the same elevated performance is seen in hearing signers. For example, mental imagery and rotation (Emmorey & Kosslyn, 1996) and face discrimination (Bettger, Emmorey, McCullough, & Bellugi, 1997; McCullough & Emmorey, 1997, and see Emmorey & McCullough, 2009; McCullough et al., 2005 for relevant fMRI studies) are enhanced in deaf and hearing signers, all of which are believed to be required for the understanding and use of spatial layout and facial expressions in ASL. As further support that this effect is a result of sign language experience, face discrimination is better in deaf signers than in deaf nonsigners (Bettger et al., 1997; Parasnis et al., 1996). The trend for better form processing in the deaf signers than hearing nonsigners observed in the current study could be related to sign language use, but this cannot be ascertained unless we test hearing signers as well. Perhaps if we had used more complex stimuli such as handshapes, that involve a higher level form discrimination than simply tilt discrimination, a significant group difference would have been seen.

4.2. Left vs. right visual field asymmetries

The results of the current study replicated a right visual field, suggesting a left hemisphere, advantage for motion processing in deaf signers. This effect has previously been shown using a leftward vs. rightward direction-of-motion discrimination task (Bosworth & Dobkins, 1999, 2002b), an apparent motion task (Neville & Lawson, 1987a, 1987b), and a speed discrimination task (Brozinsky & Bavelier, 2004). The current study extends this line of evidence to include discrimination between small differences in the directional angle of motion. Although we did not test hearing signers in the current study, several previous studies found that the right visual field/left hemisphere advantage for motion processing also appeared in native hearing signers, suggesting that the effect is likely to be driven by sign language experience (Bosworth & Dobkins, 2002b; Brozinsky & Bavelier, 2004; Neville & Lawson, 1987a, 1987b).

The unique contribution of the current study was to determine whether laterality is atypical in deaf signers for *other* aspects of visual processing that vary in the extent to which they provide important cues for sign language comprehension. We tested *orientation* discrimination, mediated within the ventral pathway, because discerning orientation of the fingers, hands and arms is important for sign language comprehension, especially for classifier constructions (e.g., showing a person or vehicle facing different directions, lying down, or positioned upright). Here, we found that, like motion discrimination, deaf signers also showed a right visual field/left hemisphere advantage for orientation discrimination. To ensure that this asymmetry for both motion and orientation was not due to other general laterality effects, the current study showed no laterality effects for *brightness* discrimination, and no differences between deaf signers and hearing nonsigners in performance for this task. This null effect was predicted since brightness discrimination is not important for sign language comprehension nor is it altered by deafness.

The current study also showed that attention, i.e., whether the task was performed under full or poor attention, did not modulate this laterality finding. This result is in line with results from our previous experiments showing no effect of attention on laterality of motion processing, using a different paradigm, i.e., spatial precuing (Bosworth & Dobkins, 2002a). That study, which measured leftward vs. right direction-of-motion thresholds, found laterality effects in deaf and hearing subjects did not differ when the location of the motion stimulus was known in advance (with a precue) vs. when its location was not known in advance (uncued) under two stimulus duration conditions (200 and 600 ms durations). Similarly, Parasnis and Samar (1985) also reported similar visual field asymmetries in deaf and hearing subjects that did not depend on spatial precuing. In sum, the results from the current study and previous studies suggest that laterality effects exist at an early sensory level, not influenced by attention.

The prevailing explanation for the perceptual asymmetry for motion processing, and possibly for form processing as well, is that it is driven by the linguistic significance of hand movements and handshapes in sign language. The requirement to encode these linguistic contrasts in the visual modality is believed to place developmental pressure on the brain to recruit perceptual processing mechanisms in the same hemisphere as other language functions (Bosworth & Dobkins, 1999, 2002b; Neville & Bavelier, 2002). If motion and form processing is indeed lateralized to the left hemisphere at the same time that left hemisphere dominance for language processing is established, then a left hemisphere advantage would not be found in "nonnative" signers who acquired ASL late. In line with this hypothesis, the asymmetry appears in individuals who were exposed to sign language before the age of 5 years (Bosworth & Dobkins, 1999, 2002b; Brozinsky & Bavelier, 2004; Neville & Lawson, 1987a, 1987b; Samar & Parasnis, 2005), while results from five nonnative hearing signers who learned ASL between 16 and 21 years of age (with approximately 17 years of daily signing experience) reveal symmetrical performance on a motion task, resembling hearing nonsigners (Bosworth & Dobkins, 2002b).

The potential implication of current finding is that perceptual asymmetry may be tied to age of language exposure and language fluency. Delay in early language input past the first 3 years of life is correlated with weaker left-hemisphere language dominance (Ashton & Beasley, 1982; Gibson & Bryden, 1984 Marcotte & LaBarba, 1985, 1987) while deaf children with deaf parents, on the other hand, who have early language exposure, showed greater maturation of the left temporo-frontal cortex than did late-exposed deaf children with hearing parents, based on electrophysiological activity (Wolff & Thatcher, 1990; and reviewed in Mayberry, 2002). It would be intriguing if language dominance and perceptual asymmetries were correlated. Samar and Parasnis (2007) is the only study we know of that sheds some light on the cognitive implications of this perceptual asymmetry. They report that non-verbal IQ correlated substantially with visual field asymmetries such that lower IQ's were associated with larger LVF advantages and higher IQ's were associated with larger RVF advantages in coherent motion thresholds. Thus, non-verbal IQ may reflect some underlying influence on individual differences in lateralization development for motion processing, such as variation in etiology of deafness or age of acquisition. To date, direct measurement of both language and perceptual performance while controlling for age of acquisition of ASL within the same study has not been done, so confirmation that perceptual and language asymmetries are correlated, and both linked to early language exposure, is not currently available.

4.3. Attention effects

In addition to revealing no group differences in overall visual sensitivity (discussed above in Section 4.1), results from our full vs. poor attention manipulation revealed no group differences in the effect of attention on direction-of-motion and orientation discrimination thresholds. As expected, thresholds were significantly worse in the poor than full attention condition, for both tasks and both subject groups, and this effect did not differ for deaf and hearing groups. This finding is in line with results from our spatial precuing studies in deaf and hearing subjects, where we found equal performance in the two groups under conditions of *spatial certainty* wherein subjects know the location of the upcoming target (Bosworth & Dobkins, 2002a). These results together imply no deaf vs. hearing group differences in *endogenous* attention. A similar conclusion was reached in a recent study investigating selective attentive tracking of moving dots (Hauser et al., 2007). In that study, no differences were found between deaf and hearing subjects, which Hauser et al. interpret to mean that deaf individuals do not have a greater ability to monitor and select several things at once.[3] Although the results of the current and previous studies suggest that selective attention effects may not be enhanced in deaf signers, there is substantial evidence that deaf people may *orient* their attention to the periphery faster than do hearing people, i.e., have enhanced *exogenous* attention (Bosworth & Dobkins, 2002a; Colmenero, Catena, Fuentes, & Ramos, 2004; Colmenero et al., 2000; Parasnis & Samar, 1985, and reviewed by Pavani & Bottari, 2011). Related to this finding, the Bosworth and Dobkins (2002a) study investigated the ability to orient attention by comparing motion thresholds obtained with and without a valid spatial precue, with the notion that *without* a precue, subjects must use exogenous attention to orient to the stimulus after it appears (and this occurs at the expense of processing a limited duration stimulus). If deaf individuals had enhanced exogenous attention (that is, faster to orient attention), then their performance would be less hindered by the absence of the spatial precue. Confirming this hypothesis, results showed that deaf signers benefited less with the spatial precue than hearing (both signing and nonsigning) subjects, with no difference between the hearing signers and hearing nonsigners. These results imply that deafness (and not sign language) confers an advantage on exogenous spatial attention, in line with previous results from Parasnis and Samar (1985).

On a final note, we address the discrepancy between our attention results and those of previous studies with respect to the question of whether deaf subjects exhibit greater attention effects in the *peripheral* (as compared to the *central*) visual field. While the attention ratios of the current study found no evidence for this (on either the motion or form task), other paradigms have reported heightened peripheral attention in deaf people. Specifically, Proksch and Bavelier (2002) reported that while performing a visual search task (for shapes), deaf signers were more distracted by peripheral stimuli, and less distracted by central stimuli, than hearing nonsigners were, suggesting that deaf individuals allocated less attention to central vision and more attention to the periphery

[3] In addition to studies investigating attentional orienting across the visual field, some studies have conceptualized divided attention as the ability to monitor, and process, multiple stimuli in the visual field simultaneously, which is a typical approach in studies employing a visual search paradigm (for examples, see Bergen & Julesz, 1983; Treisman & Gelade, 1980; Wolfe, 1994). The assumption is that performance gets worse with more items one needs to monitor, a phenomenon referred to as "set-size effect". Early theories of visual attention interpreted this result as evidence that visual processing proceeded in a serial fashion, presumably because attentional resources are limited in capacity (reviewed in Pashler, 1998 and Dobkins & Bosworth, 2001). There are alternative views on effects of attention, reviewed in Dobkins and Bosworth (2001) which found no differences in set size effects between deaf signers, hearing signers, and hearing nonsigners.

(and see Dye et al., 2009 which established this effect as due to deafness, not sign language). In a neuroimaging study by Bavelier and colleagues, fMRI responses in motion-sensitive medial-temporal brain areas were measured while deaf signers and hearing non-signers were instructed to pay attention to either the peripheral or central region of a full-field moving stimulus (Bavelier et al., 2000). They reported that whereas hearing subjects displayed more neural activation when attending to central than peripheral stimuli, deaf subjects showed the opposite pattern, which they interpret to mean enhanced peripheral attention in deaf subjects. Also relevant are data from an electrophysiology study by Neville and Lawson (1987a, 1987b). In their study, within a block of trials, apparent motion stimuli were presented in the center and peripheral visual fields, while subjects paid attention, and responded, to stimuli in one of these locations. They found larger attention effects in deaf signers than both hearing signers and nonsigners for peripheral stimuli, but not for central stimuli. Like the Bavelier et al. studies, they concluded that peripheral attention is enhanced by deafness.

To reconcile the results of the current study with those of previous studies, we propose that deaf individuals may devote more attention to the peripheral visual field when central and peripheral stimuli are presented simultaneously (and vice versa for hearing individuals), an idea proposed by Bavelier et al. (2006), Dye, Hauser, and Bavelier (2008b), Dye et al. (2009). More specifically, it may be that deaf people have a hard time attending to central vision when there are distracting stimuli in the periphery (and vice versa for hearing people). We believe this proposal could explain why in the current study, RSVP performance (at fixation) was lower in deaf than hearing subjects. We think it unlikely that deaf are simply overall worse at doing the RSVP task because Dye and Bavelier (2010) found no group differences when the same RSVP task was presented *alone*. Instead we suggest that the deaf subjects in the current study may have had trouble performing the foveal RSVP task because there were stimuli simultaneously presented parafoveally (in the CVF condition) or peripherally (in the RVF or LVF condition). If peripheral stimuli are more attention capturing for deaf individuals, then it logically follows that that peripheral performance is enhanced, which is what others have reported, however, this is not *necessarily* the case – greater attentional capture may mean better or faster detection, but it does not always mean the quality of the attended stimulus is processed more *efficiently*, especially if the stimulus signal strength is already sufficiently high enough. It is also possible that poorer RSVP performance in deaf subjects arose because they allocated relatively more attention to the main task than the RVSP task in the poor attention condition (as compared to hearing subjects). We think this unlikely, because if it were true, we would expect deaf subjects to show superior performance on the main tasks in the poor attention conditions, which was not the case. In sum, the deaf subjects in the current study may have had reduced attention in the central visual field in the presence of parafoveal and peripheral competing stimuli, in line with previous studies.

4.4. Summary

Given that processing of ASL is left-hemisphere dominant in native ASL users (Bellugi, Poizner, & Klima, 1989; Corina, Vaid, & Bellugi, 1992; Emmorey, 2002; Emmorey & Corina, 1993; Grossi, Semenza, Corazza, & Volterra, 1996; Petitto et al., 2000), we propose that aspects of vision that provide important cues for the comprehension of language get captured by the left, language-dominant hemisphere. This is likely to be the case for motion processing, based upon previous findings that the right visual field/left hemisphere dominance for motion processing is also observed in hearing native signers (Bosworth & Dobkins, 2002a; Brozinsky & Bavelier, 2004; Neville & Lawson, 1987b) and not in late deaf signers (Bosworth & Dobkins, 2002a). This may be true for orientation processing, as shown in the current study, however, since hearing signers were not tested, it is uncertain whether this is due to auditory deprivation or from sign language acquisition. However, because we were able to demonstrate that the asymmetry was *not* observed for a brightness task, which is clearly unrelated to language processing, this lends support to the "language capture" hypothesis. More studies are needed in adults who acquired ASL at different ages and children who are acquiring language to better understand the implications of this link between perceptual laterality and language competency.

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