Sign language experience redistributes attentional resources to the inferior visual field

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Abstract

While a substantial body of work has suggested that deafness brings about an increased allocation of visual attention to the periphery there has been much less work on how using a signed language may also influence this attentional allocation. Signed languages are visual-gestural and produced using the body and perceived via the human visual system. Signers fixate upon the face of interlocutors and do not directly look at the hands moving in the inferior visual field. It is therefore reasonable to predict that signed languages require a redistribution of covert visual attention to the inferior visual field. Here we report a prospective and statistically powered assessment of the spatial distribution of attention to inferior and superior visual fields in signers – both deaf and hearing – in a visual search task. Using a Bayesian Hierarchical Drift Diffusion Model, we estimated decision making parameters for the superior and inferior visual field in deaf signers, hearing signers and hearing non-signers. Results indicated a greater attentional redistribution toward the inferior visual field in adult signers (both deaf and hearing) than in hearing sign-naïve adults. The effect was smaller for hearing signers than for deaf signers, suggestive of either a role for extent of exposure or greater plasticity of the visual system in the deaf. The data provide support for a process by which the demands of linguistic processing can influence the human attentional system.

Keywords: deaf, sign language, visual attention, vertical asymmetry, neuroplasticity, lateralization

Word Count: 4,747

1. Introduction

Visual compensation in early deaf individuals has been widely studied and it is now acknowledged that, in the spatial domain, deafness primarily impacts peripheral visual processing. Changes have been observed from low level visual processing characterized by faster detection of peripheral targets (e.g., Bottari, Nava, Ley, & Pavani, 2010; Codina, Pascalis, Baseler, Levine, & Buckley, 2017; Heimler & Pavani, 2014; Loke & Song, 1991) to higher level processing manifest as enhanced attentional resources to the periphery in complex visual displays (e.g., Bavelier et al., 2000; Bosworth & Dobkins, 2002a; Chen, Zhang, & Zhou, 2006; Dye, Hauser, & Bavelier, 2009; Proksch & Bavelier, 2002). It has been argued that attention is redistributed from the central to peripheral visual field (VF) to better compensate for the lack of auditory information and allow deaf individuals to react to unpredictable peripheral events in their spatial environment (Proksch & Bavelier, 2002) or to optimally process sign language (SL) when overt gaze is directed to the interlocutor's face (Dye, 2016).

Eye gaze tracking studies have observed that, during SL communication, signers maintain their gaze on the face of their interlocutor rather that looking at the hands of that individual (Agrafiotis, Canagarajah, Bull, & Dye, 2003; Emmorey, Korpics, & Petronio, 2009; Mastrantuono, Saldaña, & Rodríguez-Ortiz, 2017; Muir & Richardson, 2005). Subtle visual (phonological) distinctions (Siple, 1978) as well as grammatical markings (Brentari & Crossley, 2002; Elliott & Jacobs, 2013; Grossman & Kegl, 2007) that occur on the face of the signer, likely require signers to foveate the face to maintain the high levels of visual acuity required. The movement of the hands and arms, however, takes place mostly in the neutral space in front of the signer's torso (Frishberg, 1975). Therefore, in order to process movement and handshape information produced using the hands and arms, visual processing of SLs requires attention to the inferior part of the VF since this is the spatial location where the manual components of signs are mostly produced. This leads to a specific prediction that whereas deafness should bring about enhanced attention to the entire VF (or at least to regions of that field where unexpected events are most likely to occur in the environment), sign language experience should bring about enhanced attention to the inferior VF. The effect of SL experience on processing in the inferior peripheral VF is not yet clear, with some inconsistencies across published studies. In fact, few studies have explored inferior-superior visual asymmetries in SL users (deaf or hearing). Bosworth and Dobkins (2002b) explored inferior-superior VF asymmetry for motion processing and observed that deaf signers had greater sensitivity in the inferior VF than hearing non-signers and hearing signers. Finney and Dobkins (2001) reported no differences between deaf and hearing participants or between signers and non-signers for contrast sensitivity in both the inferior and superior VF. However, a recent study compared luminance sensitivity between hearing signers of French Sign Language and hearing non-signers and reported interesting differences in the inferior VF (Stoll, Palluel-Germain, Guieriot, Chuiquet, Pascalis, & Aptel, 2018). In this study, participants' luminance sensitivity was measured at different visual eccentricities from the fovea to 27 degrees of visual eccentricity with a Humphrey visual field analyzer. Hearing signers had higher luminance sensitivity than hearing non-signers, specifically between 3 and 15 degrees of eccentricity in the inferior VF — the visual region where most signs are produced (Bosworth, Wright, & Dobkins, submitted).

To our knowledge, only one study has reported an inferior VF asymmetry attributable to SL experience using a visual *attention* task (Dye, Seymour, & Hauser, 2016). This study analyzed accuracy threshold data from participants who completed two tasks simultaneously: a peripheral target localization task and a central shape discrimination task. By including a number of distractor items, participants could localize the peripheral target only by filtering out the task-irrelevant information. By comparing error distributions across VF locations, the authors observed that signers (deaf and hearing) had enhanced attention to their inferior VF compared to non-signers (deaf and hearing). However, this study was based upon a reanalysis of data collected for another purpose, and estimation of inferior and superior VF thresholds was computed from unequal numbers of trials due to the use of an adaptive staircase procedure that was insensitive to the inferior versus superior location of targets.

The aim of the present study was to prospectively detect inferior-superior VF asymmetry as a function of SL experience. More precisely, we used a visual search task that is likely to reveal such a VF asymmetry (Carlei & Kerzel, 2015; Previc & Blume, 1993; Rezec & Dobkins, 2004), testing early deaf signers, hearing signers and, hearing non-signers. If SL experience redistributes visual attention toward the inferior VF, both deaf and hearing signers should exhibit enhanced inferior VF processing during visual search, compared to hearing non-signer controls. While past research has suggested a "language capture hypothesis" stemming from left versus right VF differences as a result of SL use (Bosworth, Petrich, & Dobkins, 2013; Neville & Bavelier, 2002), here our interest is in the processing demands of language and how these may influence the way in which we attend to the world around us when performing non-linguistic tasks. Furthermore, we model the psychological processes underlying the observed RT distributions using a recent hierarchical Bayesian approach to estimate drift diffusion model parameters. This approach has the advantage of allowing us to separate out decision-related and non-decisional processes, with the goal of distinguishing between sensory/motor effects and those that reflect perceptual and/or attentional processes. Following Smith and Ratcliff (2009), we hypothesized that increased spatial attention to the inferior VF in signers would result in a faster rate of evidence of accumulation and an earlier onset of the evidence accumulation process relative to non-signers.

2. Material and methods

2.1 Participants

Twenty-nine *deaf signers* ($\bar{X}_{age}$=21 years, SD_{age}=2 years, 18 females) from the National Technical Institute for the Deaf (Rochester, NY) participated in the study. All reported severeto-profound bilateral hearing loss (>70 dB) and were native or early signers of ASL (acquired before age 6 years). Five reported daily use of a cochlear implant and 6 reported using a cochlear implant only occasionally or rarely. One additional participant reported having a cochlear implant but did not report the frequency with which they used their device. Of the 29 deaf signers, 6 reported never wearing a hearing aid, 15 wore a hearing aid in the past but had stopped using them, and 6 reported that they still used a hearing aid. No response to the hearing aid question was provided by two participants. More information regarding the individual deaf signing participants is provided in Supplementary Material.

In addition, the study included 18 *hearing signers* born to deaf parents ($\bar{X}_{age}$=21 years, SD_{age}=4 years, 10 females) with ASL as primary language (often referred to as CODAs) and 28 *hearing non-signers* ($\bar{X}_{age}$=21 years, SD_{age}=4 years, 11 females) with no knowledge of any SL. All participants had normal or corrected-to-normal vision and none reported frequent action videogame play. The study was approved by the local Institutional Review Board at RIT/NTID. All participants provided written consent and were paid $10 for their participation.

2.2 Stimuli, Design and Procedure

The visual search paradigm was based on that reported by Carlei and Kerzel (2015). Participants were seated in a dimly-lighted room and positioned in a chin rest such that their eyes were 57cm from an LED screen display (27-inch diagonal, 1920x1080 pixel resolution). On each trial, six red geometric shapes were presented on a grey background. The shapes were evenly spaced on an imaginary circle such that their center was 10° of visual angle from a central fixation point. Three shapes were located in the superior visual field, and three shapes in the inferior visual field (**see Figure 1**). Each trial consisted of five circles (diameter: 3°) and one diamond (diagonal: 3°), or five diamonds and one circle. Within each shape there was either a vertical or a horizontal white line (length: 2°) with 3 vertical and 3 horizontal lines presented on each trial. Singleton shape location and the shape/line orientation association were presented in all 108 combinations and repeated 8 times each for a total of 864 trials per participant.

The participant's task was to report as quickly and as accurately as possible, without moving their eyes from the central fixation point, the orientation of the white line inside the singleton shape. They did so by pressing, with the index and middle finger of one hand, the left or right arrow keys labeled with a horizontal or a vertical line (response keys were counterbalanced across participants, but consistent across trials and blocks within a participant). The visual search display was presented for 1500 msec with a random inter-trial interval between 800 and 1200 msec. Timing was independent of the participant's responses. If a response was not received within 1500 msec, the display was removed and after the ITI a new display was presented. These responses, as well as responses made during the ITI, were recorded as failures to respond (see 3.1 Data Exclusions). After training, (see below), no feedback based upon response accuracy or response latency was provided. Participants performed a total of 864 trials divided across 4 experimental blocks: for two blocks, the visual search display contained 5 diamonds and 1 circle, and for the two other blocks it contained 5 circles and 1 diamond. Order of blocks was randomized.

Before each experimental block, participants performed 20-trial training blocks where they were instructed to maintain fixation on the central cross. During this training, accuracy feedback was provided to the participant with a green or red screen for correct and incorrect responses respectively. The experimenter observed the EEG activity from electrodes positioned at locations Fp1 and Fp2 in order to detect eye movements. If, after 20 trials, the participant could not avoid moving their eyes (any detectable eye movements in the last 15 trials of the block), or if they made too many errors (7 or more incorrect responses in the 20-trial block), then the training block was repeated. If, after three such training blocks (60 training trials), the participant could not meet these conditions, that participant was withdrawn from the study.

Only one participant was withdrawn for this reason (see 3.1 below). The overall experiment lasted about 1 hour for each participant.

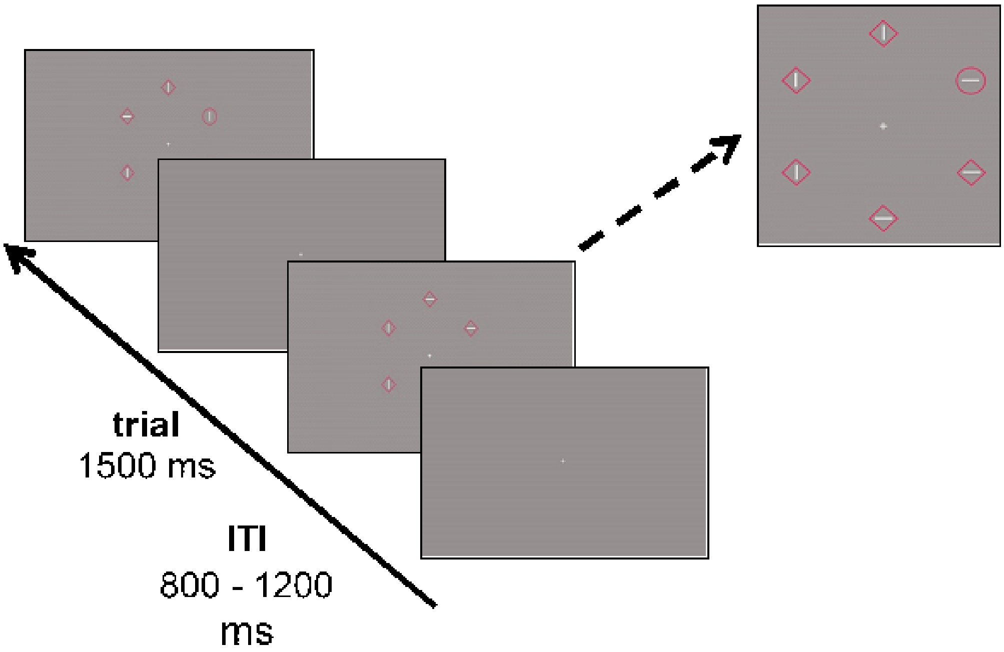

Figure 1: A visual search task was used, with target location determined by a singleton shape. Participants were required to indicate the line direction (horizontal or vertical) within the singleton shape. Performance was analyzed as a function of visual field location – inferior (bottom three locations) versus superior (top three locations).

2.3 Statistical Analysis

Participants' response times (for both accurate and inaccurate trials) were analyzed using a diffusion decision model framework (DDM; Ratcliff & McKoon, 2008). DDM models estimate two decision-related parameters for each participant (a *threshold* and a *drift rate*) and one parameter representing *non-decisional processes*. The threshold (a) corresponds to the amount of information necessary for the individual to make a decision – a high value representing a conservative criterion, and a low value a more liberal criterion. The drift rate (v) corresponds to the rate at which decision-relevant information is extracted from the stimulus array – a high drift rate reflects faster/more efficient extraction. Finally, the non-decisional parameter (t) corresponds to components of the response not related to decision making, for example, sensory encoding, motor planning, or motor execution once a decision has been made.

Parameter estimates were derived from the distributions of correct and incorrect response times across all trials using Bayesian Hierarchical estimation of the Drift-Diffusion Model (HDDM; Python package - Wiecki, Sofer, & Frank, 2013). The resultant parameters were then compared across groups (deaf signer, hearing signer, hearing non-signer) and visual field locations (superior, inferior) with Bayesian ANOVAs as implemented in JASP 0.9.0 with the default prior values (Marsman & Wagenmakers, 2016; Wagenmakers, Love, et al., 2018; Wagenmakers, Marsman, et al., 2018).

3. Results

3.1 Data Exclusions

We initially excluded participants who failed to provide data for all trials due to premature termination of participation. One deaf signer was excluded due to failure to maintain fixation during training blocks, and one hearing non-signer chose to withdraw from the experiment before data collection was complete. Statistical analysis on HDDM-derived parameters was therefore performed on 28 deaf signers, 27 hearing non-signers and 18 hearing signers.

Some participants did not provide data for all trials due to failures to respond within a 1500 millisecond time window, and data was not recorded for some trials due to a technical error. For deaf signers, data was not recorded for 0.19% of trials (n = 46) and no response was given by participants for 2.87% of trials (n = 695). For hearing non-signers, data was recorded for all trials but no response was given by participants for 1.99% of trials (n = 481). For hearing signers, data was recorded for all trials but no response was given by participants for 2.84% of trials (n = 442).

3.2 Hierarchical drift diffusion model (HDDM)

The psychological processes underlying the observed RT and error distributions were modeled using the Hierarchical Drift Diffusion Model (HDDM) developed by Wiecki et al.

(2013). The HDDM uses a Bayesian approach to parameter estimation, and takes advantage of the nested data in hierarchical designs to improve parameter estimation by leveraging information about the groups and conditions to which participants are assigned. The HDDM package was installed under a Python 3.5 environment using Anaconda Navigator 1.9.6 running on a MacBook Pro with macOS version 10.13.6 installed. The Python code used is provided in the Supplemental Materials (S2), and the reader is referred to online documentation concerning the HDDM model at http://ski.clps.brown.edu/hddm_docs/.

The three parameters being modelled – decision bound (a), drift rate (v) and non-decision time (t) – were allowed to vary as a function of both group (deaf signer, hearing non signer, hearing signer) and visual hemifield (inferior, superior). The probability of an outlier was set to .01 in order to limit the impact of outliers on the estimates of the posteriors for the HDDM model parameters, a known issue for likelihood-based models (Ratcliff & Tuerlinckx, 2002)[1]. HDDM performs inference using Markov Chain Monte Carlo (MCMC) sampling of the parameter space. The "burn-in" was set to 20 trials and the MCMC chain then went through 2,000 iterations. MCMC chains convergence was assessed by visual inspection of traces, autocorrelations, and marginal posteriors as recommended by Wiecki et al. (2013). Convergence criteria appeared satisfactory for all parameters estimated (see Supplementary Material for convergence statistics) and inspection of posterior predictions of RT distributions suggested a good model fit (see Supplementary Material). The resultant parameters were used to test the hypothesis that lifelong use of a sign language results in enhanced attention (and consequently higher drift-rates) in the inferior visual hemifield.

3.3 HDDM parameter analysis

[1] Failure to model outlier data points can bias parameter estimates. The HDDM procedure does this my employing a mixture model, with an additional uniform distribution model used to model such outliers (which reflect responses that were not based upon decision-related information contained within the stimulus display).

The parameters derived from the HDDM model are shown in Table 1, alongside response times (RTs) and response accuracy in Table 2 to allow comparison with other studies that have not employed a diffusion decision model approach. These parameters were analyzed using Bayesian ANOVAs (as implemented in JASP 0.9.0) with group (hearing non-signer, hearing signer, deaf signer) as a between subjects factor and visual hemifield (inferior, superior) as a within subjects factor. First, the most likely model given the data was determined and the Bayes Factor (BF) associated with that model compared to the null reported (BF_{10}). Secondly, the BFs for alternative models with respect to the most likely model were calculated and reported (BF_{21}).

Threshold (a). A 2x3 Bayesian ANOVA (visual hemifield by group) revealed that the model incorporating both main effects and their interaction was the most likely given the decision threshold data (BF_{10} = 5336.518), outperforming models with group alone (BF_{21}= 0.009), visual hemifield alone (BF_{21}= 0.005), both visual hemifield and group (BF_{21}= 0.0033), and the null model (BF_{21}= 0.002).

As can be seen in Figure 2A, decision bias was similar across the inferior and superior visual fields for deaf signers and hearing non-signers, but for hearing signers the decision bias estimates were larger for the inferior than for the superior visual field.

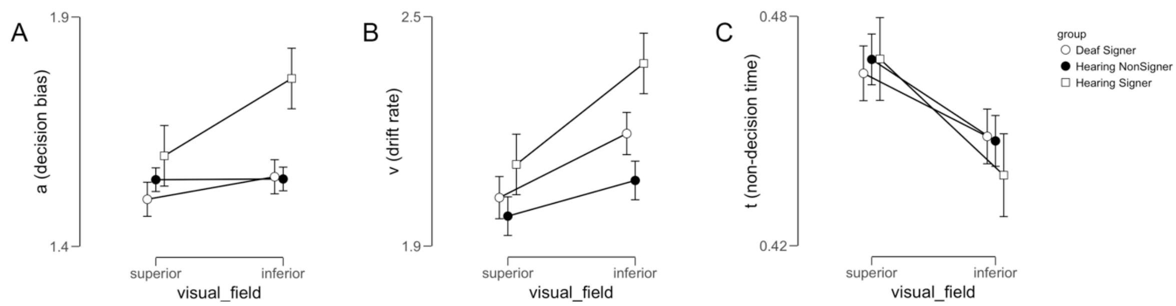

Figure 2: A. Decision bounds varied as a function of hemifield only for hearing signers, where bounds were larger (reflecting a more conservative response criterion) in the inferior hemifield. **B.** As predicted, the drift rate was larger for the inferior than for the superior hemifield (reflecting greater gain and faster accumulation of decision-related information), with this effect more pronounced for signers (both deaf and hearing) than for non-signers. **C.** The non-decision time parameter was smaller in the inferior than in the superior visual field, suggesting either

faster sensory encoding or more rapid motor responses to stimuli appearing below the point of fixation.

Drift rate (v). A 2x3 Bayesian ANOVA (visual hemifield by group) on the drift rate data revealed that the most likely model was one including both main effects and their interaction (BF_{10}=2.736). This model was better than the models including only a participant group effect (BF_{21}< .001), including only a visual field effect (BF_{21}=0.874), including an effect of both variables without an interaction term (BF_{21}=0.588), and the null model (BF_{21}<.001). Interaction decomposition (see Figure 2B) indicated, as predicted, larger drift rate parameters in the inferior visual field than in the superior visual field for deaf signers (BF_{10}=2.233e+6) and hearing signers (BF_{10}= 161.313), but a much weaker asymmetry (albeit in the same direction) for hearing non-signers (BF_{10}= 3.687).

Non-decision time (t). A 2x3 (visual hemifield by group) Bayesian ANOVA revealed that the most likely model was the one including only a visual hemifield effect (BF_{10}=6.276e+6). This model outperformed the models including only a group effect (BF_{21}= 4.183e-8), including an effect of both visual hemifield and group (BF_{21}=0.322), including both main effects and an interaction term (BF_{21}=0.107), and the null model (BF_{21}=1.593e-7). Non-decision time parameters were smaller in the inferior visual field than in the superior visual field for all participant groups.

Together these results suggest that all groups – regardless of hearing status and SL knowledge – had similar decision thresholds (*a*) across the entire visual field tested, with the exception of hearing signers displaying a more conservative decision criterion for stimuli appearing in the inferior hemifield. In addition, as predicted, signers had a strong inferior visual field advantage with respect to the drift rate parameter (*v*) whether they were deaf or hearing, whereas hearing non-signers exhibited a weaker visual field asymmetry. Finally, all participants were overall faster in non-decisional processes (*t*) for the inferior compared to the superior visual hemifield.

Table 1. Mean estimated parameters derived from the HDDM for each group and for both inferior and superior visual field. Standard deviations of group parameter estimates are reported in parentheses. Lower threshold estimates are indicative of a more liberal response criterion; lower drift rate estimates suggest slower accumulation of decision-relevant information from the stimulus array; and lower non-decision time parameters correspond to faster sensory encoding of the stimulus and/or faster planning and execution of post-decision motor responses.

	Threshold (a)		*Drift rate (v)*		*Non-decision time (t)*	
	Inferior VF	Superior VF	Inferior VF	Superior VF	Inferior VF	Superior VF
Hearing non-signers	1.55 (0.16)	1.55 (0.17)	2.07 (0.42)	1.98 (0.43)	0.45 (0.05)	0.47 (0.04)
Hearing signers	1.77 (0.26)	1.60 (0.15)	2.38 (0.31)	2.11 (0.32)	0.44 (0.04)	0.47 (0.05)
Deaf signers	1.55 (0.20)	1.50 (0.16)	2.19 (0.49)	2.02 (0.46)	0.45 (0.05)	0.47 (0.05)

Table 2. Mean (SD) response times (in milliseconds) and accuracy (percent correct) for the inferior and superior visual hemifields for hearing non-signers, hearing signers, and deaf signers.

	RT (msec)		*Accuracy (%)*	
	Inferior VF	Superior VF	Inferior VF	Superior VF
Hearing non-signers	778 (204)	807 (206)	93.0 (25.5)	92.2 (26.8)
Hearing signers	784 (202)	809 (206)	95.9 (19.7)	94.2 (23.4)
Deaf signers	767 (206)	786 (206)	93.6 (24.5)	92.1(26.9)

4. Discussion

The aim of this study was to explore changes in the spatial allocation of visual attention as a function of SL experience and deafness, and to provide the first robust and prospective test of the hypothesis that attention is redistributed to the inferior VF as a result of SL experience. Utilizing a hierarchical drift-diffusion model (Wiecki, Sofer, & Frank, 2013), we sought to characterize both decisional and non-decisional processes underlying covert visual search performance in deaf signers, hearing signers and hearing non-signers. The results provide support for the hypothesis that signers exhibit greater visual attention toward the inferior VF as compared to the superior VF, with non-signers displaying much weaker lateralization. We interpret the higher drift rate for deaf and hearing signers to mean that they are more efficient at extracting decision-relevant information about a target located in the inferior VF compared to non-signing observers. This increase in efficiency is in line with the hypothesis that allocation of more visual attention resources results in enhanced attentional gain (Dosher & Lu, 2000) and an increase in the rate of accumulation of decision-relevant information (see Smith, Ratcliff, & Wolfgang, 2004, and Smith & Ratcliff, 2009, for further discussion of how attentional mechanisms may result in changes to DDM parameters). This result is similar to that recently reported by Stoll et al. (2018). Using a Humphrey Visual Field Analyzer, they reported great luminance sensitivity for hearing signers than for hearing non-singers but only in the inferior visual field between 3 and 15 degrees of visual angle from fixation (not further out). It is important to note, however, that the Humphrey measure is one of brightness detection in the visual periphery. That is, observers are not required to decide about peripheral visual stimuli other than to indicate whether a stimulus is present. Combined with the data reported here, this suggests visual language exposure in the context of a typically functioning auditory system is sufficient to bring about low-level sensory and higher-level attentional changes that impact the processing of visual information located in the inferior visual field.

However, while hearing signers showed this effect, their inferior-superior laterality effect was intermediate between deaf signers and hearing non-signers. The hearing signers in our study acquired ASL from birth and had more than 20 years of ASL experience, although such individuals, contrary to deaf signers, rarely use ASL every day as their primary means of communication, and are more likely to spend significant time during the day using spoken language with other hearing individuals. This discrepancy in signing frequency between deaf and hearing signers is likely to hold true during development, especially once children reach school age when there is a divergence in the language modality used within school settings for hearing and deaf children from Deaf families. This language use frequency difference during childhood and into adulthood is one candidate for explaining the smaller effect in hearing signers. In addition, for deaf individuals, the absence of typical auditory inputs leads to a cross-modal reorganization of cortical and subcortical structures that enhances the processing of visual inputs (Bavelier et al., 2000, 2001; Bottari et al., 2014; Finney, Fine, & Dobkins, 2001; Hauthal, Thorne, Debener, & Sandmann, 2014; Lyness, Alvarez, Sereno, & MacSweeney, 2014; Scott, Karns, Dow, Stevens, & Neville, 2014; Seymour et al., 2017; Vachon et al., 2013). During this period of neural reorganization in childhood there may be a "window" during which SL experience can better drive redistribution of visual attention toward the inferior VF. Developmental studies on deaf and hearing children acquiring a SL as a first language may be highly informative in this regard. The potential existence of a sensitive period in deaf children during which mechanisms of neuroplasticity are active and able to bring about a redistribution of attentional resources across the VF could have important consequences for delayed exposure to SL in deaf children. For example, a recent study reported that adult deaf non-signers had only horizontal visual asymmetry and not vertical in a direction of motion discrimination task (Almeida, Nunes, Marques, & Amaral, 2018), while another study using a similar paradigm reported a vertical visual field asymmetry in adult deaf signers (Bosworth & Dobkins, 2002b). How early SL experience affects visual and cognitive processes in deaf and hearing *children* is an interesting question that remains to be explored.

Finally, these data also speak to a debate in the literature about impulsivity in deaf populations. Reivich and Rothrock (1972) suggested that problem behavior in deaf students could be explained by impulsivity and an inability to withhold prepotent responses to external stimuli. Subsequent work by Altshuler, Deming, Vollenweider, Rainer, and Tendler (1976) used pencil-and-paper testing, rather than teacher reports, with their data indicative of a lack of task-relevant planning and impulsive decision making. Using a variant of the Gordon Diagnostic continuous performance test, Quittner, Smith, Osberger, Mitchell, and Katz (1994) and Mitchell and Quittner (1996) have reported impulsive responding by deaf children and adolescents. Similarly, Parasnis, Samar, and Berent (2003) reported impulsive response patterns and decreased perceptual sensitivity in deaf college-aged students using another continuous performance test – the Test of Variables of Attention. More recently, using oculomotor data, Heimler, van Zoest, Baruffaldi, Donk, Rinaldi, Caselli, and Pavani (2015) demonstrated that the time course for stimulus-driven and task-driven responding in deaf adults was comparable to that of their hearing peers. Similarly, data from a gaze cueing paradigm also suggested that deaf adults are able to suppress bottom-up stimulus-based responses, thereby attenuating the effect of exogenous cues (Heimler, van Zoest, Baruffaldi, Rinaldi, Caselli, & Pavani, 2015). In line with the findings of Heimler and colleagues, the data here show that young deaf signers demonstrate faster accumulation of decision-relevant sensory information yet have comparable decision bounds to those of hearing non-signers – the deaf adults respond as quickly as (or quicker than) the hearing non-signers, yet are not making their decisions with less information.

5. **Conclusion**

In this study we investigated the impact of sustained and life-long exposure to SL on vertical asymmetries for visual processing in deaf and hearing adults. Analyzing the data with a hierarchical drift diffusion model, we decomposed participant performance into three parameters, observing that early SL exposure induces a lateralization of attention which is biased towards the inferior VF. The effect appeared smaller in hearing early signers than in deaf early signers, which could be related to differences in frequency of SL exposure and usage during infancy and the school years when the brain is extremely sensitive to experience and environment (Knudsen, 2004; Lewis & Maurer, 2005). This visual processing asymmetry should be explored in developmental studies with both deaf and hearing children who use a SL as a primary language. Moreover, it will be interesting to establish if the difference between hearing and deaf signers in how attention is allocated toward the inferior VF is predictive of how they attend to SL inputs. Past work has demonstrated that sign naïve individuals make frequent saccades to re-fixate within the inferior VF when watching videos of SL (Agrafiotis et al., 2003). To date, no one has systematically examined differences in overt gaze during sign language comprehension as a function of age of acquisition or hearing status. Given that SL comprehension requires maintaining eye gaze on the face area, and therefore processing manual gestures located in the inferior VF, hearing signers and late L2 learners of a signed language may need to redirect their eye gaze to the inferior VF more often than do deaf native signers in order to extract linguistic information. The magnitude of this effect may be driven by both age and amount of exposure, making predictions about how the early visual language experience of deaf children affects subsequent visual processing of SLs.

In our prior work, we have used samples of deaf people who do not use a SL to distinguish between effects of deafness and SL exposure (e.g. Dye et al., 2009). A published reanalysis of this work has also suggested that a redistribution of visual attention to the inferior VF is more likely to be driven by SL than by deafness per se (Dye et al., 2016). However, a sample of deaf non-signers was not tested in the current study. SL exposure may therefore be sufficient, but not necessary to induce redistribution of attention to the inferior VF. Future work will need to include participants from deaf non-signing populations to conclusively dissociate effects of auditory and linguistic experience and better characterize the ways in which these experiences may interact to alter visual processing.

6. Acknowledgments

We would like to thank Junpeng (Charles) Lao for assistance in implementing the HDDM, Brennan Terhune-Cotter for help with data collection, and Dick Kerzel for sharing his behavioral experiment code. This research was supported by a Fulbright award to CS and completed as part of her PhD requirements at the University of Grenoble Alpes, and by NSF award BCS1749376 to MWGD. The authors have no competing interests to declare.

7. Supplementary Material

All study materials are available on the Open Science Framework at https://osf.io/beu3s/ (DOI 10.17605/OSF.IO/BEU3S). These materials include original trial level data for all participants; additional demographic and background data for each participant; the experiment files used to present data and collect responses (Paradigm presentation software file); the parameters derived from the HDDM model for each participant; a JASP file containing all information necessary to reproduce the Bayesian ANOVA analyses; the Python code and corresponding data file used to implement the HDDM model; RT distributions for all participants derived from posterior parameter estimates of the HDDM model; and convergence statistics for all HDDM MCMC processes.

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