Visual Perception in Hearing Sign Language Users

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Abstract

Deaf signers exhibit superior visual perception compared to hearing controls in several domains, including the perception of faces and peripheral motion. These visual enhancements are thought to compensate for an absence of auditory input. However, it is also possible that they reflect experience using a visual-manual language, where signers must process complex moving hand signs and facial cues simultaneously. Thus, the current study sought to isolate the effects of sign language experience by examining how visual perception is altered as a function of American Sign Language (ASL) proficiency in hearing individuals. Hearing signers completed an online test of ASL proficiency and were compared to hearing non-signers on online behavioural measures of face perception and biological motion perception. No group-level differences in performance were observed, suggesting that the visual enhancements found in Deaf signers result from hearing loss itself rather than sign language. Potential neurodevelopmental mechanisms for these findings are discussed.

Keywords

D/deaf, Sign Language, Hearing Loss, Visual Perception, Face Perception, Motion Perception, Neuroplasticity

Summary for Lay Audience

Deaf sign language users are better at some visual tasks compared to hearing individuals with no sign language experience, especially recognizing faces and detecting motion in the visual periphery. In the absence of auditory input, these enhancements are thought to reflect the increased importance of visual information when D/deaf individuals monitor their surrounding environment. However, compared to spoken language, using a visual-manual language such as American Sign Language (ASL) also provides a drastically different visual experience. Therefore, it remains difficult to determine whether the visual enhancements observed in Deaf signers are the result of sign language experience or a direct consequence of hearing loss.

The aim of the current study was to disentangle the effect of sign language experience from the effect of hearing loss by examining visual abilities in sign language users with typical hearing. Hearing signers and non-signers completed online assessments of their face matching and motion discrimination abilities in the central and peripheral visual fields. Additionally, hearing signers in the current study completed an online ASL proficiency test, which allowed us to examine the relationship between performance on the visual tasks and sign language skill.

Hearing signers and non-signers performed similarly on the visual tasks, suggesting that the visual enhancements previously observed in Deaf signers likely reflect the role of hearing loss itself rather than sign language experience. We propose that differences in auditory experience from a young age can result in distinct developmental paths and outcomes for Deaf and hearing signers and that exploring different aspects of sign language experience is important to understanding how it interacts with hearing loss. Overall, the current study contributes to a growing field of research on deafness and sign language that provides critical insights into the effects of hearing and language experience on the brain unique from the study of typical hearing, spoken-language users.

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List of Abbreviations

ANOVA = analysis of variance

ASL = American Sign Language

ASL-CT = American Sign Language Comprehension Test

BOLD = blood-oxygen-level-dependent

DS = Deaf signer

ERP = event-related potential

fMRI = functional magnetic resonance imaging

HN = hearing non-signer

HS = hearing signer

M = mean

MRI = magnetic resonance imaging

SD = standard deviation

STS = superior temporal sulcus

Chapter 1

1 Introduction

One apparent consequence of hearing loss is that D/deaf[1] individuals show enhanced visual perception compared to hearing controls. The D/deaf rely on visual functions to compensate for the absence of auditory input, resulting not only in visual behavioural advantages for D/deaf individuals, but also reorganized cortical functions. However, understanding the effect of hearing loss on the brain and behaviour is complicated by the possibility that these changes might also arise from sign language experience, which for many Deaf signers, begins at a young age. Thus, the premise of the current study was to isolate the unique effect of sign language proficiency on visual perception while controlling for hearing status. Characterizing the role of sign language experience on visual perception is important for understanding how plastic changes across the brain and related behaviours may vary as a function of environmental input, and critically, the nature of this input.

1.1 Experience-dependent Plasticity

Experience-dependent plasticity refers to the brain's capacity to adapt structurally and functionally in response to sensory input and interaction with the environment. It is the primary means by which humans adapt and learn new behaviours (Feldman, 2009). Experience-dependent plasticity remains active across the lifespan, though the external pressures and mechanisms of control may vary (Oberman & Pascual-Leone, 2013).

During development, experience-dependent plasticity interacts with genetic control to shape the maturing brain (Tierney & Nelson, 2009). Early sensory experiences can alter sensory representations through synaptic pruning. For example, infants, who initially

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[1] In this study, "Deaf" describes individuals who identify with the cultural norms, beliefs, and values of the Deaf Community and "deaf" refers to people who are medically deaf but do not necessarily identify with the Deaf Community. "D/deaf" is used as a collective noun to refer to both "Deaf" and "deaf" people (Canadian Association of the Deaf, 2015).

respond similarly across a variety of sensory stimuli including unfamiliar speech sounds and faces, gain expertise in their native perceptual stimuli once exposed to the native linguistic and social environment through a process called "perceptual narrowing" (Maurer & Werker, 2014). Perceptual narrowing is thought to shape a preference and attention toward the native environment to facilitate future learning. Although the basic structural and functional circuits of the brain are established by early adulthood, experience-dependent plasticity continues to shape connectivity within this framework throughout life.

Neuroplastic changes can result from learning a new ability, practice and training, or environmental input and stressors. Indeed, a variety of experiences such as driving a taxi (e.g., Maguire et al., 2000), playing a musical instrument (e.g., Herholz & Zatorre, 2012), physical exercise (e.g., Erickson et al., 2011), and learning to juggle (e.g., Draganski et al., 2004) have been shown to change the structure and function of the brain. Consistent patterns of synaptic activity produce long-term potentiation, or long-lasting increases in signal strength between pairs of neurons (Malenka & Bear, 2004). The opposite of this is long-term depression, whereby synaptic strength is weakened with disuse or to maintain neural homeostasis. Thus, the brain's history of activity helps shape its current pattern of connectivity.

Evidently, a wide range of experiences and different neuroplastic mechanisms can influence the structure and function of the brain from prenatal development through adulthood. Perhaps one of the clearest illustrations of experience-dependent neuroplasticity can be found in models of sensory loss, such as deafness or blindness.

1.2 Functional Plasticity in the Deaf

Numerous studies have documented how sensory deprivation in one modality affects the development of the remaining sensory modalities. Over 466 million people worldwide, or 6.1% of the world's population, experience hearing loss ranging from mild to profound (World Health Organization, 2021). Some individuals choose to seek medical intervention in the form of hearing aids and/or other prostheses and may use signed and/or spoken language. Conversely, Deaf people typically have unaided profound hearing loss and often use sign language as their primary language. The reduction in sound input and introduction of visual-manual language input provides a highly unique audio-visual experience for Deaf individuals, and several studies have sought to determine how these experiences shape sensory perception.

The effects of hearing loss on visual perception have been conceptualized within two different frameworks: deficit theories suggest that the loss of auditory cues that normally support visual perception would be expected to *impair* visual processing relative to typical hearing controls; on the other hand, compensation theories suggest that the absence of auditory input *enhances* visual abilities through cross-modal plasticity involving the recruitment of brain regions normally involved in audition (Dye & Bavelier, 2013). Indeed, studies comparing visual abilities between D/deaf and hearing groups show mixed results. Depending on the task, D/deaf individuals show visual enhancements, no differences in visual perception, or visual deficits compared to hearing individuals (for reviews, see Alencar et al., 2019; Bavelier et al., 2006; Pavani & Bottari, 2012). Studies investigating the neural substrates behind heightened visual sensitivity in the D/deaf indicate visual enhancements are accompanied by neuroplastic changes within—at a minimum—brain regions typically associated with auditory, visual, and multisensory functions (Alencar et al., 2019). Interestingly, visual advantages in the D/deaf are prevalent for functions that typically benefit most from auditory-visual integration, such as perception of stimuli in the peripheral visual field (where visual acuity is poor relative to central field representations; Bavelier et al., 2006). Previous research also suggests Deaf participants perform better on tasks requiring a global perceptual strategy to process coherent gestalts, such as faces (Parasnis, 1983). Though it is worth noting that most studies have focused on the dorsal or “where” stream of visual processing responsible for motion perception and spatial analysis over the ventral or “what” stream responsible for visual recognition (Mitchell & Maslin, 2007). Furthermore, visual enhancements are primarily found in congenitally Deaf native signers, suggesting the variability in findings may be due to task and demographic differences across studies (Bavelier, 2006). While these studies make a compelling case for visual functional enhancements in the D/deaf, it remains unclear to what extent these changes are driven by hearing loss versus the unique experience of visual language.

1.3 The Role of Sign Language Learning

It is extremely challenging to separate life-long auditory deprivation from life-long sign language use in studies of the congenitally Deaf. While the focus of much of this literature, congenitally Deaf native signers only represent approximately 5% of the total D/deaf population and are usually born to Deaf parents and raised within a signing community (Newport & Meier, 1985; Mitchell & Karchmer, 2004). Congenitally Deaf native signers typically receive their education in sign language and attend bilingual-bicultural schools (Allen & Anderson, 2010). In this population, the effect of auditory deprivation can be evaluated in the context of typical language acquisition (albeit via visual-manual exposure) with minimal confounds from language deprivation or abnormal cognitive development (Bonvillian et al., 1983; Petitto et al., 2001). However, the result is that congenitally Deaf native signers have two different experiences compared to hearing non-signers: hearing loss itself, and sign language acquisition and use. This complicates interpretation because experience with a visual language is also expected to affect visual perception.

Signed languages consist of a complex combination of facial expressions, hand and body movements, and hand shapes that are perceived rapidly and simultaneously by their users (Muir & Richardson, 2005; Bosworth et al., 2019). Fluent signers typically maintain fixation on the face to perceive linguistic facial expressions and use peripheral vision to perceive manual gestures produced near the upper body, typically between 3° and 15° eccentricity (Agrafiotis et al., 2003; Brentari & Crossley, 2002; Emmorey et al., 2009; Muir & Richardson, 2005; Stoll et al., 2018). Accordingly, the Enhanced Exposure Hypothesis put forth by Bosworth and colleagues (2019), suggests that regular sign language use provides a unique experience that may modify general visual abilities, especially those that are important for sign language communication. As such, studies have sought to determine how sign language exposure affects sign-relevant visual functions, including the perception of faces and peripheral motion.

One of the earliest studies on the topic of face perception in sign language users showed that Deaf signers outperformed hearing signers, who outperformed hearing non-signers on a face matching task (Arnold & Murray, 1998). However, this effect was not limited to faces as Deaf and hearing signers also outperformed non-signers when matching non-face objects (Arnold & Mills, 2001). Other studies have found that Deaf and hearing signers perform equally well, and outperform non-signers on face recognition tasks, but only by taking longer to respond or in very difficult conditions (Bettger et al., 1997; Stoll et al., 2017). Interestingly, Deaf signers who learned sign language later in life performed similarly to Deaf native signers, suggesting sign language effects may not be limited to a “critical period” (Bettger et al., 1997).

In a series of functional magnetic resonance imaging (fMRI) studies on the neural substrates of facial recognition in sign language users, Deaf and hearing signers showed similar blood-oxygen-level-dependent (BOLD) response profiles to emotional facial expressions; however, only Deaf signers showed a left-hemisphere—or language dominant—bias for processing linguistic facial expressions (Emmorey & McCullough, 2009; McCullough et al., 2005). Overall, advantages in face perception resulting from sign language experience remain poorly understood.

Studies of motion processing and target detection in the visual periphery show advantages for sign language users as well, but with some differences between Deaf and hearing signers. These studies have used multiple different outcome measures, experimental tasks, and visual field locations, and are summarized in Table 1. Early work in this area found that Deaf and hearing signers had superior motion detection abilities in the right visual field while hearing non-signers showed superior motion detection in the left visual field (Neville & Lawson, 1987). Bosworth & Dobkins (2002) also observed a motion detection advantage for Deaf and hearing signers in the right visual field; however, Deaf signers also showed an advantage for motion processing bilaterally in the periphery. These results are consistent with studies that find peripheral advantages for Deaf signers versus central processing advantages for hearing signers and non-signers (Bavelier et al., 2001; Proksch & Bavelier, 2002). Deaf signers also showed faster response times to far peripheral stimuli compared to hearing signers, who were faster than hearing non-signers, but accuracy was the same across groups (Codina et al., 2017). In fMRI studies, hearing signers do not show cross-modal activation of the auditory cortex to visual stimuli like Deaf signers (Benetti et al., 2021; Fine et al., 2005). However, hearing signers do show enhanced sensitivity in the inferior visual field compared to hearing non-signers, but only for eccentricities where sign language occurs (Stoll et al., 2018). These studies suggest sign language experience and auditory deprivation may have separable effects on brain reorganization and visual perception. That said, the effect of sign language experience on visual behaviour is challenging to isolate due to the difficulty of including an appropriate control group (i.e., deaf non-signers).

Table 1: Summary of Studies Investigating Motion Perception in Deaf Signers (DS), Hearing Signers (HS), and Hearing Non-signers (HN)

Author(s)	Measure/Task	Visual Field Location	Results
Bavelier et al. (2001) Bavelier & Neville (2002)	BOLD signal in motion selective brain regions to visual motion	6.66 - 8°	DS > HS = HN
Benetti et al. (2021)	BOLD signal in auditory brain regions to visual motion	5.3 - 8.1°	DS > HS = HN
Bosworth & Dobkins (2002)	Direction-of-motion discrimination	15.4° (right)	DS = HS > HN
Codina et al. (2017)	Response time to far peripheral stimuli	30 - 85°	DS > HS > HN
Fine et al. (2005)	BOLD signal in right-hemisphere auditory brain regions to visual motion	5 - 20°	DS > HS = HN
Neville & Lawson (1987)	ERPs and direction-of-motion discrimination	18° (right)	DS = HS > HN
Proksch & Bavelier (2002)	Allocation of attentional resources during visual search	4.2°	DS > HS = HN
Stoll et al. (2018)	Luminance sensitivity	3 - 15° (inferior)	HS > HN

Only findings of functional enhancements in Deaf/hearing signers are reported. BOLD = blood-oxygen-level-dependent, ERP = event-related potential.

1.4 Disentangling Sign Language from Hearing Loss

Studies of deaf non-signers yield insights into the unique effects of sign language experience and deafness on visual perception. In a comparison of visual spatial skills between deaf and hearing non-signers, Parasnis and colleagues (1996) found no difference between these groups and concluded that sign language, but not deafness, drives visual enhancements observed in Deaf signers. Alternatively, Dye and colleagues (2009) found D/deaf participants outperformed hearing participants on the Useful Field of View Task even after controlling for sign language experience, suggesting deafness itself drives differences in visual perception between these groups. To resolve this discrepancy, Cardin and colleagues (2013) measured fMRI BOLD response to sign stimuli in Deaf signers and deaf and hearing non-signers and found separable effects for deafness and sign language. While the effect of auditory deprivation was limited to the right superior temporal cortex, the effect of sign language experience was apparent in both the left and right superior temporal cortices. Studying deaf non-signers allows researchers to explore the effect of language modality while controlling for sensory experience; however, several limitations impede the interpretation of these results.

Deaf non-signers often have hearing parents, receive intensive speech therapy, and communicate via speech and lipreading (Dye & Bavelier, 2013). While studies of deaf non-signers can examine the separable effects of sign language experience and hearing loss directly, they are influenced by increased prevalence of neurological comorbidities, such as neonatal meningitis, and language delay (Dye & Bavelier, 2013). Aside from this, greater awareness and promotion of sign language in recent decades means that the majority of schools for D/deaf children now use sign language, significantly decreasing the number of deaf non-signers (Parasnis et al., 1996). As such, the few studies that have investigated visual perception in this rare group have done so with very small samples. Because it is difficult to study deaf non-signers meaningfully, the current study takes the opposite approach by investigating the unique effects of sign language proficiency on visual perceptual abilities in participants with typical hearing.

1.5 Current Study

How is visual perception altered as a function of American Sign Language (ASL) proficiency in the presence of typical auditory development? To answer this question, the current study measured face perception and biological motion perception in the central and peripheral visual fields of hearing signers and non-signers. Hearing signers in this study also completed a test of ASL proficiency which was treated as a covariate of interest to determine the extent to which visual behavioural skills were related to sign language ability.

Previous attempts to disentangle the effects of sign language experience and hearing loss on visual perception have not included a detailed measure of sign language proficiency. While some have classified groups as signers versus non-signers or split signers into low-proficiency versus high-proficiency groups based on self-reported measures or age of sign language acquisition, these methods can oversimplify the complexity of language experience and underpower previous studies. Thus, the current study expanded on previous research by including an online measure of ASL proficiency, the ASL Comprehension Test (ASL-CT; Hauser et al., 2016), which allowed ASL proficiency to be considered as a continuous variable for the first time in a study of this nature. The current study also addressed several limitations involving the behavioural tasks employed in previous research.

Visual perception includes a wide range of abilities, with those directly involved in sign language communication being the most likely to show enhancements resulting from sign language exposure. Thus, not all visual tasks employed by previous research may be ideal to show an effect of sign language experience. Apart from analyses conducted by Bosworth and colleagues (2006; 2019), few attempts have been made to fully document the visual properties of sign language; however, the current study is designed to assess face perception and biological motion perception, which both draw on global processing abilities shown to be enhanced in Deaf signers (Freire et al., 2000; Neri et al., 1998;

Parasnis, 1983). These measures are designed to assess face processing expertise and probe visual motion abilities in the context of human action, both of which appear to be specifically critical to sign language communication.

The sensitivity of these tasks must also be taken into consideration. In some previous studies, participants showed close to ceiling performance on face recognition tasks, obscuring potential differences between signers and non-signers (Bettger et al., 1997; Stoll et al., 2017). In some cases, response times were used as a proxy for accuracy, but they may be affected by task difficulty or bias and are not well-suited to online studies such as the current one, where computer hardware and software limitations may result in inconsistent timing (Garaizar & Vadillo, 2014; Neath et al., 2011; Ratcliff & Hacker, 1981). Thus, the current study includes a large number of trials across a broad range of difficulties in the assessment of face perception and biological motion perception, which reduces ceiling effects and captures a wider range of abilities. Additionally, all tasks were delivered online, reducing geographic limitations, and thus testing a larger number of hearing signers compared to previous studies.

With the above limitations in mind, the current study was designed to provide the most detailed investigation on the impact of ASL learning on these distinct visual abilities to date. Specifically, this study aims to disentangle the impacts of hearing loss and visual-manual language experience on visual perception. If the perceptual advantages described in Deaf signers are the result of ASL experience, hearing signers would also be expected to demonstrate better face recognition and biological motion perception compared to hearing non-signers. Additionally, ASL proficiency should be positively correlated with performance on these tasks. Alternatively, if visual perceptual advantages in the Deaf are a direct consequence of auditory deprivation, we would expect to see no group differences in these measures, and no relationship between visual perception and ASL proficiency in typically hearing participants. A detailed methodology, results, and interpretation of the current study are described below.

Chapter 2

2 Method

The current study comprised two experiments designed to assess the impact of sign language experience on visual perception. This included assessments of both face perception and biological motion perception, each designed to further examine stimulus inversion effects and perceptual differences between the central and peripheral visual fields. Participants provided informed consent (Appendix A) and completed a screening and demographics questionnaire in Qualtrics which collected information about their hearing, vision, and language experience (Appendix B). Finally, signers completed the American Sign Language Comprehension Test (ASL-CT), an online measure of ASL proficiency where signers were presented with 30 prompts consisting of either a line-drawing, event video, or signed description and chose the most relevant answer from a selection of four possible responses (Hauser et al. [2016] Appendix C).

To account for variability in presentation hardware, participants were asked to measure the height of their computer screen in centimeters and this value was used to ensure that the size of stimuli remained constant across different screens. Participants were also asked to dim their lights and turn up their screen brightness, minimize distractions, place their computer on a tabletop, and sit 50 cm from the screen. This study was approved by the Non-Medical Research Ethics Board at Western University (Appendix D). All participants provided informed consent and were compensated with a $25 gift card of their choice for participating. All experimental methods and analyses across both experiments were pre-registered on the Open Science Framework (https://osf.io/6s5e3).

2.1 Experiment 1: Face Perception

2.1.1 Participants

53 hearing signers (M_{age} = 36.58, SD_{age} = 11.55, 43 female, 5 male, 2 other/non-binary) and 31 hearing non-signers (M_{age} = 33.74, SD_{age} = 12.32, 25 female, 6 male) were recruited to the study via word-of-mouth, targeted emails, and poster and social media

advertisements in ASL community groups across Canada and the United States. Despite reporting significant ASL experience, three signers failed to exceed chance performance on the ASL-CT and were thus excluded from all subsequent analyses. The remaining 50 signers reported an average of 15.49 years of ASL experience (*SD* = 12.51, range: 3 – 52 years) and mostly worked in the Deaf community as ASL interpreters. Age of ASL acquisition ranged from 0 to 54 years of age (*M* = 21.09, *SD* = 9.55). All non-signers self-reported no ASL experience. Furthermore, all participants self-reported normal or corrected-to-normal vision and no known hearing impairments or neurological disorders.

2.1.2 Stimuli

Whole face stimuli were drawn from the Glasgow Unfamiliar Face Database (see Burton et al. [2010] for full details on the construction of these stimuli). Images were cropped so that only the face and top of the hair were visible and were converted to greyscale with a custom Python script. Each trial (48 practice, 160 experimental) consisted of the presentation of a target face, followed by an array of four faces that contained an image of the target individual (taken on a second camera) and three same-sex distractor faces that were previously deemed to be most similar to the target (see Burton et al. [2010] for similarity analyses). Half of the trials contained male faces and half of the trials contained female faces. Each face appeared once as a target and three times as a distractor over 160 trials. To compensate for cortical magnification in visual cortex (i.e., the overrepresentation of the central visual field; Daniel & Whitteridge [1961]), stimuli presented in the periphery (11° off center, in the left or right hemifield) were scaled 1.25x. As a result, faces subtended 5.5° x 7.2° (width x height) of visual angle when presented centrally or 6.9° x 9.0° of visual angle when presented peripherally. Each presentation of a target face was preceded by a black fixation cross at the center of the screen (0.6° square). To disrupt afterimage effects, the target face was followed by a visual mask which consisted of four angled sinusoidal gratings subtending a visual angle of 9° square (central) or 10.3° square (peripheral; Figure 1). All stimuli were presented on a white background.

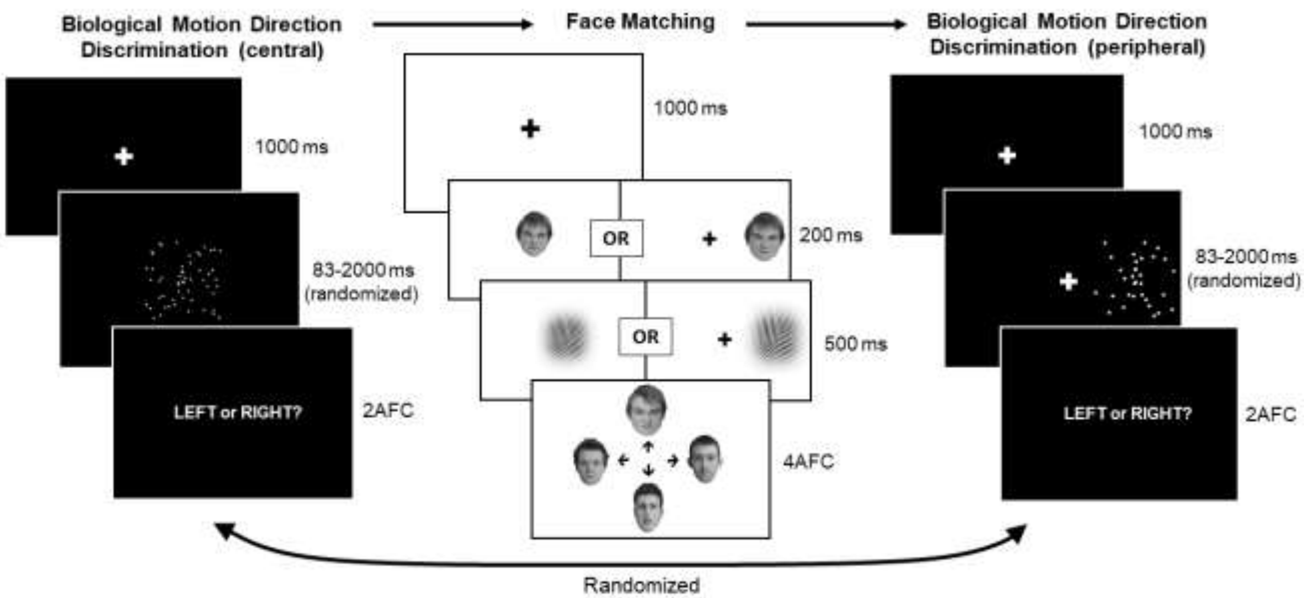

Figure 1: Individual trial progression and overall presentation order of the behavioural tasks in the current study. Stimuli were inverted on 50% of trials (not pictured).

2.1.3 Procedure

For each experimental condition (central x upright, central x inverted, peripheral x upright, peripheral x inverted), participants first received instructions and could repeat those instructions as many times as needed. Instructions were followed by 12 practice trials during which feedback was provided, followed by 40 experimental trials without feedback. During each trial, a fixation cross was presented for 1000 ms, followed by a target face shown for 200 ms, and a visual mask lasting 500 ms. The target face was presented in either upright or inverted orientation, either at the point of fixation (central) or 11° from the center of the screen (peripheral). In the peripheral conditions, the fixation cross remained at the center of the screen, and the target face appeared in the left or right hemifield randomly on an equal number of trials. After viewing the target face and mask, participants were asked to identify the target face from an array of four faces as quickly and accurately as possible using their arrow keys. To prevent image matching, this array included the image of the target face taken on a second camera, as well as three similar distractor faces. Face perception accuracy was measured as the percentage of correct matches. The face matching task was created using PsychoPy and presented online using PsychoJS/Pavlovia (Pierce et al., 2019). The order of each condition block and the order of individual trials within each block was randomized and counterbalanced across participants via the PsychoJS trial handler. Each of the four location x orientation blocks took approximately 5 minutes each to complete (20 minutes total) and participants were free to take breaks between blocks.

2.1.4 Statistical Analyses

2.1.4.1 Group Effects Analysis

To examine face perception, a mixed-model ANOVA was conducted with group (signers/non-signers) treated as a between-subjects factor and target location (central/peripheral) and target orientation (upright/inverted) treated as within-subject factors.

2.1.4.2 Proficiency Effects Analysis

ASL proficiency was calculated as the percentage of correct answers on the ASL-CT. To assess the influence of ASL proficiency on face perception, a separate set of analyses were performed on the subset of participants who identified as signers. This comprised a repeated-measures ANOVA with target location (central/peripheral) and target orientation (upright/inverted) treated as within-subject factors and ASL-CT score treated as a between-subjects covariate.

2.2 Experiment 2: Biological Motion Perception

2.2.1 Participants

Participants in Experiment 2 were the same as Experiment 1 except for two signers who did not complete Experiment 2, and 15 signers and 13 non-signers who were excluded for failing the catch task (described below). Thus, a total of 33 hearing signers (M_{age} =

35.24, SD_{age} = 10.15, 28 female, 4 male, 1 other/non-binary) and 18 hearing non-signers (M_{age} = 28.44, SD_{age} = 7.97, 16 female, 2 male) were included in Experiment 2.

2.2.2 Stimuli

Biological motion stimuli consisted of a single 90° facing point-light walker chosen from a published set of human point-light actions (see Vanrie & Verfaillie [2004] for full details on the construction of these stimuli). The walker comprised 13 white dots positioned at the head and each of the arm and leg joints of the figure, presented against a black background. To increase the difficulty of this task, the walker was occluded by a square mask of randomly moving dots (44 in central conditions, 22 in peripheral conditions) that were the same size and colour as the dots comprising the figure. Masked walkers were presented at 60 fps and completed one walk cycle (2 steps) per second. On each trial, participants were presented with a white fixation cross (0.6° square) at the center of the screen, followed by a walker presented for one of eight possible durations (5, 10, 20, 40, 60, 80, 100, or 120 frames [83-2000 ms]). To compensate for cortical magnification, stimuli in the periphery (11° off center, in the left or right hemifield) were scaled 1.25x. As a result, the masked walker subtended a visual angle of 9.7° square in central conditions and 12° square in peripheral conditions.

2.2.3 Procedure

For each experimental condition (central x upright, central x inverted, peripheral x upright, peripheral x inverted), participants completed a block of 16 practice trials and 256 experimental trials, for a total of 64 practice trials and 1,024 experimental trials. Participants received instructions at the beginning of each block and could repeat these instructions as many times as needed. Instructions were followed by a block of practice trials with feedback. On each trial, the fixation cross was presented for 1000 ms followed by the masked walker (see Figure 1). In the practice blocks for the central conditions, stimuli were presented 8 times for 60 frames (1000 ms) and 8 times for 100 frames (1667 ms). In the practice blocks for the peripheral conditions, stimuli were presented 8 times for 100 frames (1667 ms) and 8 times for 120 frames (2000 ms). Practice trials were followed by 256 experimental trials without feedback, wherein the stimuli were presented

32 times at each of the eight stimulus durations (5-120 frames [83-2000 ms]). The walker was presented in either upright or inverted orientation, at fixation (central) or 11° from center (peripheral). On peripheral trials, stimuli appeared randomly in the left or right hemifield an equal number of times and the fixation cross remained at the center of the screen for the duration of the trial (1083-3000 ms).

The walker appeared to be walking toward the left- or right-hand side of the screen an equal number of times across all trials. After viewing the masked walker, participants were immediately asked to indicate the direction of motion (leftward or rightward) as quickly and accurately as possible. Participants responded using the “right” and “left” arrow keys. Biological motion perception accuracy was measured as the percentage of correct responses at each stimulus duration.

In central conditions, the starting position of the walker was randomly displaced by 0.5° visual angle in any direction from center to prevent participants from recognizing the walker simply from the starting position on the screen. To ensure participants remained fixated at the center of the screen during the peripheral conditions, 24 catch trials were presented randomly throughout peripheral blocks during which the fixation cross changed from white to grey for 300 ms, either 500 ms, 1000 ms, or 1500 ms after stimulus-onset. On these catch trials, participants were instructed to ignore the targets and respond using the “up” arrow key. During peripheral practice blocks, four catch trials were presented with feedback, and participants were reminded to maintain their gaze at the fixation throughout the experiment. Participants who failed to respond correctly to at least 17/24 (70%) catch trials during the experimental blocks were excluded from analyses.

The biological motion direction discrimination task was created using PsychoPy and presented online using PsychoJS/Pavlovia (Pierce et al., 2019). Trials were blocked by stimulus location (central, peripheral), and the order of presentation was randomized and counterbalanced via Qualtrics randomization. All participants completed the face perception task (Experiment 1) between motion task blocks. Within each motion task block, trials were additionally blocked by orientation, with the order of orientation block and individual trial presentation randomized and counterbalanced across participants via the PsychoJS trial handler. Each of the four location x orientation blocks took approximately 15 minutes to complete (1 hour total). Eight break points were provided within each block, and participants could take additional breaks between blocks.

2.2.4 Statistical Analyses

2.2.4.1 Group Effects Analysis

To examine biological motion perception, a mixed-model ANOVA was conducted, with group (signers/non-signers) treated as a between-subjects factor and stimulus location (central/peripheral), stimulus orientation (upright/inverted), and stimulus duration (8 levels ranging 83-2000ms) treated as within-subject factors.

2.2.4.2 Proficiency Effects Analysis

To assess the influence of ASL proficiency on biological motion perception, a separate set of analyses were performed on the subset of participants who identified as signers. A repeated-measures ANOVA with stimulus location (central/peripheral), stimulus orientation (upright/inverted), and stimulus duration (8 levels ranging 83-2000ms) treated as within-subject factors and ASL-CT score treated as a between-subjects covariate.

Chapter 3

3 Results

3.1 Experiment 1: Face Perception

3.1.1 American Sign Language Comprehension Test (ASL-CT)

Performance on the ASL-CT ranged from 43.33 to 90.00 percent correct for the hearing signers ($M = 71.67\%$, $SD = 11.25$). Compared to the normative values provided by Hauser et al. (2016), ASL-CT scores for hearing signers in the current study were well-aligned with hearing native signers (72.00%) and Deaf non-native signers (70.50%).

3.1.2 Group Effects

Figure 2 depicts the average percent correct face identification scores for hearing signers and non-signers at both stimulus locations and orientations. A mixed-model ANOVA revealed performance between hearing signers and non-signers on the face matching task was not significantly different ($F(1, 79) = 5.99$, $p = .44$). The analysis yielded significant main effects of stimulus location ($F(1, 79) = 120.80$, $p < .001$) and orientation ($F(1, 79) = 47.04$, $p < .001$) and a significant location by orientation interaction ($F(1, 79) = 23.96$, $p < .001$). No other interaction was significant (group x orientation: $F(1, 79) = 0.0015$, $p = .96$; group x location: $F(1, 79) = 0.004$, $p = .95$; group x orientation x location: $F(1, 79) = 1.89$, $p = .17$). Follow-up tests of the significant location by orientation interaction revealed that performance was better in the central/upright condition compared to the central/inverted ($t(77) = 9.77$, $p < .001$), peripheral/upright ($t(77) = 13.13$, $p < .001$), and peripheral/inverted ($t(77) = 14.84$, $p < .001$) conditions. Additionally, performance was better in the central/inverted condition compared to the peripheral/inverted ($t(77) = 5.07$, $p < .001$) and peripheral/upright ($t(77) = 3.35$, $p = .005$) conditions.

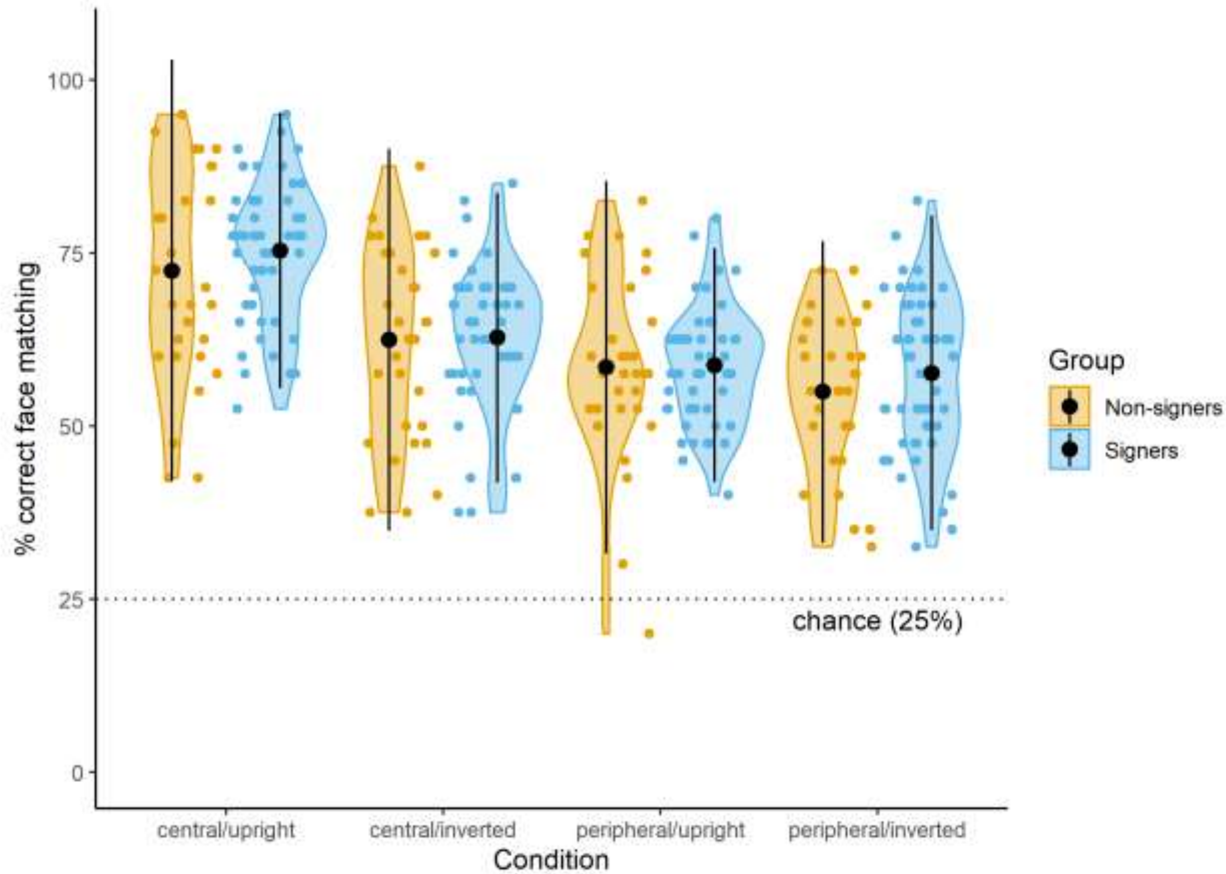

Figure 2: Percent correct on the face matching task for signers and non-signers in each location by orientation presentation condition. Coloured dots represent individual scores while black dots show the average performance for each group and black lines show a ±2SD range. A black dotted line depicts chance performance at 25%.

3.1.3 Proficiency Effects

A repeated-measures ANOVA which included ASL-CT as a between-subjects covariate was conducted on the data from signers only, and revealed ASL-CT score was not a significant predictor of face matching performance in this group ($F(1, 48) = 3.29$, $p = .076$). Additionally, no main effect or interaction reached significance when the analysis was confined to this subset of the data (location: $F(1, 48) = 0.84$, $p = .36$; orientation: $F(1, 48) = 0.01$, $p = 0.92$; location x orientation: $F(1, 48) = 0.77$, $p = .38$).

3.1.4 Exploratory Analyses

3.1.4.1 Age of Acquisition and Years of Experience

To determine whether other properties of language experience such as age of ASL acquisition and years of experience using ASL had any effect on face matching performance, a measure of each was included as a between-subjects covariate in separate repeated-measures ANOVAs confined to the subset of data collected from hearing signers. Neither age of acquisition (F(1, 48) = 0.33, p = .57) nor years of ASL experience (F(1, 48) = 1.01, p = .32) were significant predictors of face matching performance. Additionally, neither age of acquisition (r(48) = -.10, p = .47) nor years of ASL experience (r(48) = .10, p = .48) were significantly correlated with ASL-CT scores.

3.2 Experiment 2: Biological Motion Perception

3.2.1 American Sign Language Comprehension Test (ASL-CT)

For hearing signers included in Experiment 2, performance on the ASL-CT ranged from 43.33 to 90.00 percent correct (M = 73.03%, SD = 10.75).

3.2.2 Group Effects

Figure 3 depicts the average percent correct scores on the biological motion task for hearing signers and non-signers in each location and orientation for all stimulus durations. A mixed-model ANOVA revealed performance of hearing signers and non-signers on the biological motion direction discrimination task was not significantly different ($F(1, 49) = .00001$, $p = .99$). There were significant main effects of stimulus location ($F(1, 49) = 255.26$, $p < .001$), orientation ($F(1, 49) = 48.71$, $p < .001$), and duration (F(1, 343 = 112.91, $p < .001$) as well as significant two-way interactions between location and orientation ($F(1, 49) = 8.59$, $p = .005$), location and duration ($F(7, 343) = 8.46$, $p < .001$), and orientation and duration ($F(7, 343) = 5.01$, $p < .001$). No other two-, three-, or four-way interactions were significant (all $p > .05$). Post-hoc tests of simple effects revealed biological motion task performance was significantly higher in the central visual field compared to the peripheral visual field ($t(49) = 68.17$, $p < .001$) and in upright stimulus presentations compared to inverted ($t(49) = 21.65$, $p < .001$). As expected, performance was higher for longer stimulus durations compared to shorter (e.g. 5 frames M = 58.50% vs. 120 frames M = 80.80%).

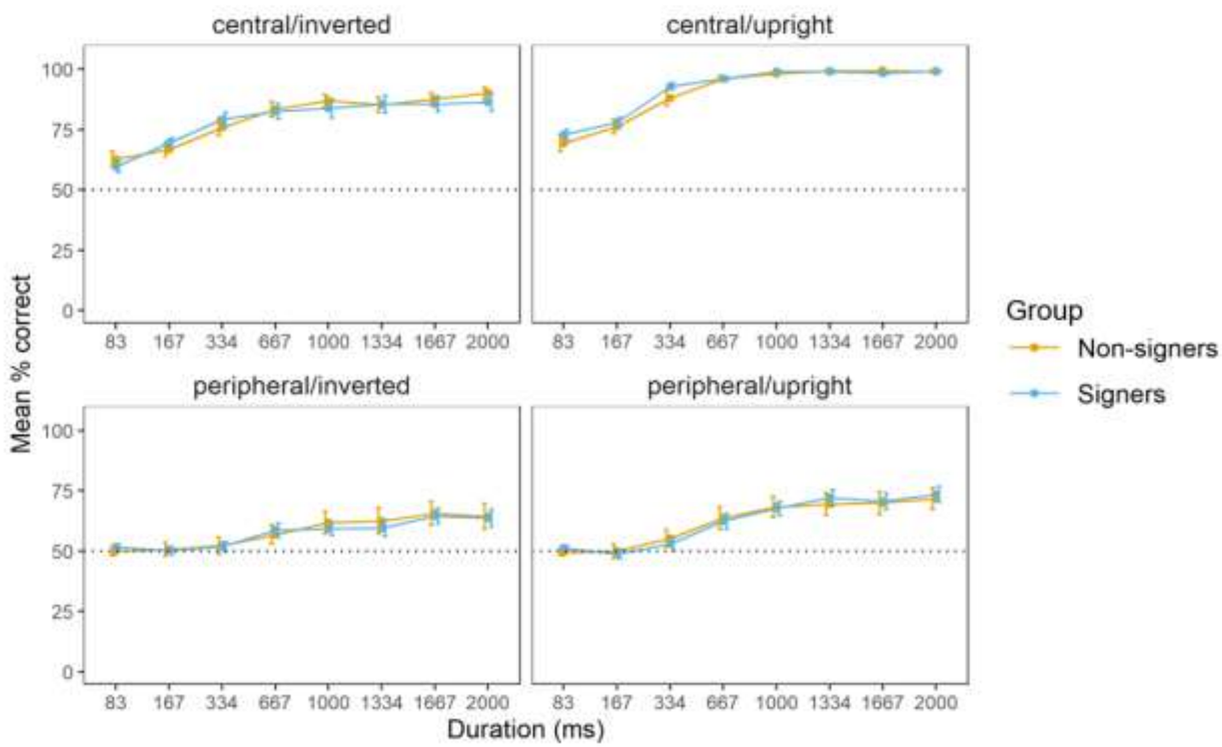

Figure 3: Percent correct on the biological motion direction discrimination task for signers and non-signers in each location by orientation presentation condition across durations. Error bars represent standard error. A black dotted line depicts chance performance at 50%.

3.2.3 Proficiency Effects

A repeated-measures ANOVA which included ASL-CT average as a between-subjects covariate was conducted on the data from signers only. This ANOVA revealed that ASL-CT score was a significant predictor of task performance in our sample of hearing signers (F(1, 31) = 4.42, p = .04). However, this was qualified by interactions between ASL-CT score and location (F(1, 31) = 4.89, p = .03); ASL-CT score, orientation, and duration (F(7, 217) = 4.11, p = .0003); and a significant interaction between all four factors (F(7, 217) = 2.06, p = .04). Post-hoc tests of simple slopes revealed ASL-CT score had a stronger effect on task performance for stimulus presentations in the central visual field compared to the peripheral visual field ($t(29) = 8.90$, $p < .001$). However, the strength of the relationship between sign language proficiency and performance varied considerably as a function of the task parameters (see Figure 4).

3.2.4 Exploratory Analyses

3.2.4.1 Age of Acquisition and Years of Experience

To determine whether other properties of language experience such as age of ASL acquisition and years of ASL experience had any effect on motion perception performance, a measure of each was included as a between-subjects covariate in separate repeated-measures ANOVAs performed on the data obtained from hearing signers. Neither age of acquisition ($F(1, 31) = 0.001$, $p = .97$) nor years of ASL experience ($F(1, 31) = .65$, $p = .42$) were significant predictors of performance on the biological motion task. As in Experiment 1, neither age of acquisition ($r(31) = -.12$, $p = .52$) nor years of ASL experience ($r(31) = .22$, $p = .21$) were significantly correlated with ASL-CT scores (note: these numbers differ slightly across experiments as the participants in Experiment 2 were a subset of those who completed Experiment 1).

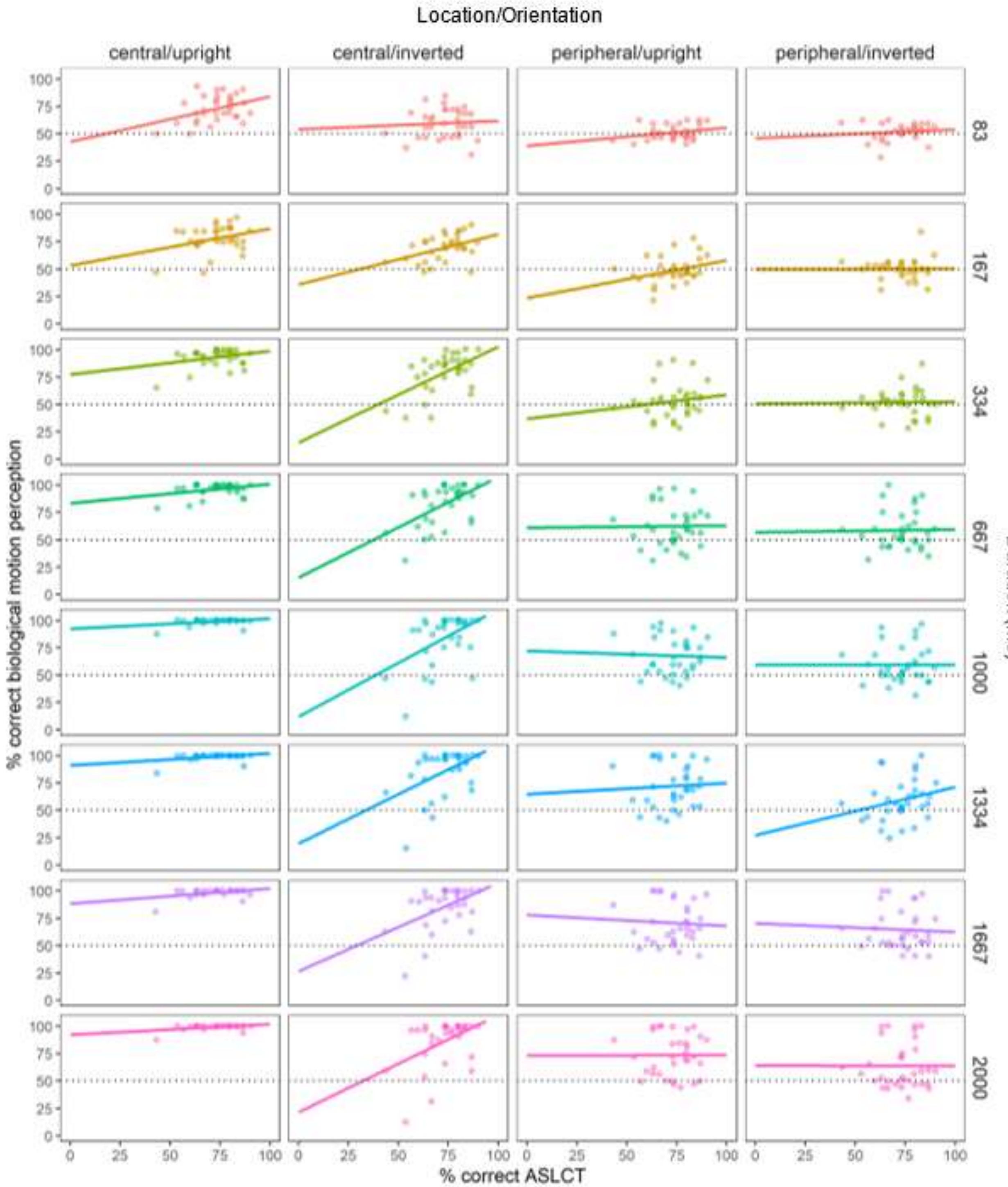

Figure 4: Effect of ASL proficiency on biological motion perception accuracy in each stimulus location and orientation for all levels of stimulus duration. A black dotted line depicts chance performance at 50%.

Chapter 4

4 Discussion

To disentangle the unique effects of hearing loss and sign language proficiency on visual perceptual enhancements previously observed in Deaf signers, the current study examined visual abilities in sign language users with typical hearing. Performance on online measures of face perception and motion perception was compared between hearing signers and individuals with typical hearing who had no visual-manual language experience (i.e., hearing non-signers). Hearing signers also completed an online test of ASL proficiency. If the visual perceptual advantages described in Deaf signers are driven by ASL experience, hearing signers in the current study would be predicted to outperform non-signers on the visual behavioural tasks and ASL proficiency should be positively correlated with task performance. However, if the groups performed similarly on these tasks and performance was not correlated with ASL proficiency, this would instead suggest that the visual perceptual enhancements found in Deaf signers are not driven by sign language experience, but the absence of auditory input itself.

The current study observed no significant differences in face matching accuracy between hearing signers and hearing non-signers, and there was no evidence that signers' ASL proficiency was related to face matching performance. These findings are inconsistent with previous studies that observed enhanced face perception in hearing signers (Arnold & Murray, 1998; Bettger et al., 1997; Stoll et al., 2017) and suggest that the enhanced face perception previously observed in Deaf signers (de Heering et al., 2012; He et al., 2016; Megreya & Bindermann, 2017; but see McCullough and Emmorey, 1997) is related to an absence of auditory input rather than visual-manual language experience.

There are several theoretical and methodological explanations for why the current findings may be inconsistent with previous work. In an early study, Arnold and Murray (1998) found that Deaf signers outperformed hearing signers, who in turn, outperformed hearing non-signers on a memory test for faces. Their paradigm involved showing participants a series of 36 cards of 18 faces arranged in a grid, with participants asked to locate image pairs from memory. This is in stark contrast to the current experiment, which involved a match-to-sample task with a brief (500 ms) interval between the target and matched faces. McCullough and Emmorey (1997) showed no such advantage for Deaf signers compared to hearing non-signers on whole-face processing using an adapted Recognition Memory Test for Faces, in which a series of 50 facial images were viewed, after which participants were asked to rate whether probe faces were familiar or not. However, when modeling the effect of manipulations to discrete facial features on familiarity judgements, the authors determined that changes to the structure of the mouth were particularly salient to sign language users. Conversely, in a follow-up study using the Benton Faces Test—a paradigm more similar to the current study, in which participants are asked to select a face which matches the identity of a target image from an array of six possible images—Bettger and colleagues (1997) showed that sign language users, regardless of hearing status, outperformed hearing non-signers. These results suggest that skills related to perceiving ASL grammatical facial expressions or lipreading, such as discriminating local features, may be enhanced in signers while recognizing individual faces may be relatively unaffected by ASL experience. While both the study by Bettger and colleagues (1997), and more recent work by Stoll and colleagues (2017), suggest that signers are more accurate at recognizing faces than non-signers, the group differences they report are limited to the perception of very difficult "shadow faces" (i.e., photos taken under lighting conditions designed to produce shadowing across portions of the face; Bettger et al., 1997) or were only evident in trials where participants took longer to respond (i.e., the most difficult discriminations; Stoll et al., 2017). These findings suggest that the face matching task in the current study may not have been difficult enough to show differences between signers and non-signers. Due to the hardware and software limitations of online experiments, response times or speed-accuracy trade-offs could not be reported reliably for the current study.

The results of the current study are in better accordance with previous fMRI studies where Deaf signers, but not hearing signers, showed left-lateralized brain activation to facial expressions (Emmorey & McCullough, 2009; McCullough et al., 2005). That said, hearing signers did not show the same pattern of activation as hearing non-signers, implying some effect of sign language use (Emmorey & McCullough, 2009). Without neuroimaging to accompany behavioural measures, the current study was unable to directly measure potential neural differences between hearing signers and non-signers which may arise despite similar behavioural performance between groups.

On the biological motion task, there were no significant differences in accuracy between hearing signers and non-signers. Like the face matching task, this group-level contrast implies that the enhanced motion perception previously observed in Deaf signers (Bavelier et al., 2001; Bosworth & Dobkins, 2002; Codina et al., 2011; Shiell et al., 2014; Simon et al., 2020; Stevens & Neville, 2006) is related to an absence of auditory input rather than visual-manual language experience.

These findings are consistent with previous studies demonstrating similar patterns of brain activation and behavioural responses to visual motion between hearing signers and non-signers (Bavelier et al., 2001; Codina et al., 2017; Proksch & Bavelier, 2002). This is contrasted by studies in Deaf signers, where visual motion has been shown to elicit activity within presumed “auditory” cortical areas that is not evoked in hearing signers (Benetti et al., 2021; Fine et al., 2005). The current study is inconsistent with that of Neville and Lawson (1987), who observed superior motion perception in the right peripheral visual field for Deaf and hearing signers when compared to hearing non-signers. However, in their study, Deaf signers also exhibited stronger event-related potentials (ERPs) in response to peripheral visual motion compared to hearing signers, again suggesting dissociable effects for auditory deprivation and sign language experience (Neville & Lawson, 1987). The online platform used in the current study made the collection of gaze information (e.g., via eye-tracking hardware) impossible. In lieu, catch trials were introduced to ensure central fixation during peripheral presentations and participants who did not meet threshold performance were excluded. However, it remains possible that decreased vigilance related to online study may have obscured potential group differences in motion perception.

While the current study found no evidence of group-level differences in biological motion perception, ASL proficiency was shown to be a significant predictor of task performance for signers, especially under certain stimulus presentation conditions. This pattern of results could be interpreted in a number of ways. Firstly, it is possible that ASL proficiency modulates motion perception, but that the size of this effect was too small to be observed in the current study. Since the observed effect was qualified by significant interactions with stimulus location, orientation, and duration, it is possible that group differences might emerge under a particular set of stimulus parameters, but this effect is obscured by the myriad combinations in which ASL-CT score does not predict task performance. Alternatively, it is possible that our measure of language proficiency (the ASL-CT) is accurately capturing some latent factor (e.g., attention, motivation) that is correlated with performance across the two tasks. Indeed, ASL proficiency was found to influence task performance independently of other, more commonly collected measures of language experience (i.e., age of acquisition and years of experience), with no correlation observed between these measures. This idea will be discussed in more detail below.

4.1 Language Experience

By reporting individual differences in ASL proficiency related to visual perception, the current study follows the general trend in the field toward more detailed assessments of language experience (Daller, 2011). This not only includes standardized measures of language proficiency and fluency, but demographic and socio-cultural measures as well (e.g., age of acquisition, social diversity of language use), which may have unique effects on the brain (Abutalebi et al., 2001). In terms of a “critical period” for sign language acquisition, hearing signers who learned ASL as their native language show more extensive right hemisphere activation compared to those who learned ASL after puberty (Newman et al., 2002). However, it is unclear whether these maturational constraints are necessarily the result of increased plasticity in early development or increased exposure across the lifespan (Newport, 1990). Indeed, Bettger and colleagues (1997) demonstrated that, at least for Deaf individuals, the age of ASL acquisition did not have a measurable effect on face discrimination performance. Hearing signers in the current study were mostly late learners of ASL and more research with hearing native signers would clarify the effect of age of ASL acquisition on visual perception in this group.

Interestingly, ASL proficiency was not correlated with age of acquisition or years of ASL experience in the current study and was more predictive of visual motion perception than either of these measures. This was somewhat surprising and raises critical questions regarding the extent to which experiential factors, cognitive abilities, and motivation are being captured by measures of language “proficiency”, such as the ASL-CT (as opposed to measures serving as a proxy for language use/exposure; e.g., age of acquisition). It is entirely possible that both ASL-CT score and biological motion perception performance vary as a function of underlying individual differences in attention or motivation. Unfortunately, these questions are especially challenging to resolve in Deaf and hearing signers, as not all scales designed to assess potential latent factors of interest can be directly translated to ASL from English (Paludneviciene et al., 2012). Overall, determining the unique effects of hearing loss and sign language on behaviour and neuroplasticity requires a greater understanding of language experience and the social environment, neural correlates, and cognitive abilities that support this experience.

4.2 Mechanisms of Neuroplasticity

Overall, hearing signers and non-signers showed similar behavioural performance on the visual tasks in the current study. This suggests that the visual perceptual advantages previously observed in Deaf signers are unlikely to reflect the direct results of visual-manual language experience and instead reflect the consequences of hearing loss per se. How then, does hearing status impact the neural systems involved in visual perception when the effect of sign language experience is controlled? To understand this, studies have compared differences in brain activation between groups of Deaf and hearing signers, who both learned sign language as their native language and differ only in auditory experience (for review, see Campbell et al., 2007). Deaf native signers show stronger activation to sign language in auditory and language processing regions compared to hearing native signers. These differences suggest an absence of auditory input from birth may cause some brain processes (i.e., those underlying language processing) to follow a different developmental trajectory (Bavelier et al., 2006; Bavelier & Neville, 2002). That is, experience-dependent neuroplasticity and its behavioural correlates may be contingent on hearing status and the functional role(s) of auditory cortex. In the Deaf, auditory cortex is reorganized for visual functions, which consequently, take on greater importance in the absence of hearing (Benetti et al., 2021; Fine et al., 2005). This reliance on visual information, not only for communication, but for everyday life, leads to several differences in how Deaf versus hearing signers process sign language. For example, bimodal bilinguals (i.e., hearing signers) recruit more posterior regions of the superior temporal sulcus (STS) during sign language comprehension compared to Deaf signers (Emmorey & McCullough, 2009; MacSweeney et al., 2002). This spatial disparity is hypothesized to reflect continued auditory speech processing in the anterior STS of hearing signers which is segregated from sign language processing in the posterior STS (for more information on the cortical correlates of speech and sign, see Capek et al. [2008]). Because the anterior STS does not receive its typical input (i.e., speech sounds) in the Deaf, it can more readily take on alternative functions, especially adjacent functions, like sign language processing in the posterior STS. Similarly, the presence or absence of auditory input may determine whether the introduction of visual-manual language has a behaviourally-relevant effect on visual perception.

Though limited, research on deaf non-signers suggests deafness itself may drive some visual perceptual enhancements (Dye et al., 2009). Indeed, across humans and animal models of hearing loss, the reorganization of auditory cortex has been demonstrated to subserve these functional enhancements (so-called “cross-modal plasticity”; Finney et al., 2001; Lomber et al., 2010). But how does this pattern of reorganization interact with visual-manual language experience? Using fMRI, Cardin and colleagues (2013) compared Deaf signers and deaf non-signers and demonstrated that deafness alone impacted brain activation differently than when it was combined with lifelong sign language experience. Thus, while the availability of auditory cortex may set the stage for cross-modal plasticity, training in a visual-manual language serves to amplify potential neuroplastic changes. Exploring different aspects of sign language experience is therefore crucial to understanding how it interacts with deafness to produce functional enhancements.

4.3 Future Directions

To address the limitations and opportunities outlined above, future studies should be expanded to include participants with different hearing and language backgrounds. Specifically, these tasks should be conducted with Deaf signers to confirm the presence of visual enhancements using the current paradigm and determine whether sign language has different effects in Deaf versus hearing participants. A larger sample of hearing *native* signers should also be examined to determine how age of sign language acquisition might impact visual perception. It would also be compelling to include neuroimaging to directly measure how behavioural differences in visual perception are reflected in brain organization. For example, functional and structural MRI-based connectivity analyses can go beyond measuring brain activation in individual regions of interest—which may not differ between groups—to explore how connectivity between regions throughout the brain may change with experience. Finally, additional measures of intelligence, effort, motivation, and attention should be considered in future studies to disentangle language proficiency from more general cognitive abilities. It is also worth noting that the ASL-CT assesses receptive language skills exclusively and should be supplemented with a measure of productive language skills to assess ASL proficiency more fully as well as compare between these two skillsets. Ultimately, studies of deafness and sign language will provide critical and unique insights into the effects of sensory and language experience on the brain that cannot be deduced from the study of typical hearing, spoken-language users.

4.4 Conclusion

Given considerable evidence of enhanced visual perception in Deaf signers, the current study explored the unique effects of sign language experience on visual perception while controlling for hearing status. Hearing signers and non-signers performed similarly on measures of face and biological motion perception, suggesting that the visual enhancements previously observed in Deaf signers likely reflect the role of hearing loss itself rather than sign language experience. ASL proficiency was a significant predictor of performance on the motion perception task, suggesting that sign language and other visual perceptual tasks are related, but whether this reflects a common relationship with an underlying latent factor remains to be seen. Together, these results suggest deafness, but not sign language, either directly modulates or provides an opportunity for visual-manual language experience to modulate visual perception. As one of the first to relate visual perception to a continuous measure of ASL proficiency, the current findings highlight the need for more detailed measures of language experience, cognition, and brain structure and function to truly understand how hearing and language experience uniquely impact perception.

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Appendices

Appendix A: Letter of Information and Consent

Impact of ASL Learning on Visual Perception

Letter of Information

Project Title: Impact of ASL learning on visual perception
Principal Investigator:
Blake Butler, Ph.D., Department of Psychology | Brain and Mind Institute
The University of Western Ontario, WIRB 5150
[phone number redacted]
[email address redacted]

Introduction: Why you are here?
Dr. Blake Butler and his research team would like to invite you to participate in a study titled: "Impact of ASL learning on visual perception". This study is voluntary, and participation involves completing an online survey, and a series of online tasks, all of which can be completed from the comfort of your home.

Background: What is the purpose of this study?
Dr. Butler and his team want to understand how the brain adapts to the introduction of a visual-manual language (as opposed to oral language experience). Previous findings suggest that deaf individuals present enhanced visual perception, however it is unclear whether these abilities result from deafness per se, or arise from visual language experience. Thus, this study aims to investigate how visual language experience contributes to perceptual advantages in hearing signers.

Participate: If you would like to take part in the study, you will be asked to complete a brief online survey that includes questions about your hearing health history and language experience. Following that, you will complete a series of online visual perceptual tasks and an online assessment of sign language comprehension. Visual tasks will include viewing brief visual stimuli on a computer screen and making judgements concerning direction of motion or facial features. Throughout the session you will have the opportunity to take breaks. The total experiment will take approximately 2 hours to complete.

Voluntary Participation & Withdrawal: Your participation in this study is voluntary. You may elect not to participate at any time, including after the study has begun. You may leave the study at any time without affecting your compensation. If you no longer want to participate, or you do not want your data to be used in this research, you may contact Dr. Butler (see contact information at the first page) to request that your data and personal information be deleted. Withdrawal from the current study is possible until group analyses have been completed. Additionally, you may request that your data be withdrawn from any future project/analysis for a period of up to 7 years.

Risks: There is some risk related to the storage of digital data; while these data are stored on secure servers, there is a chance that these servers could be breached. As participant names are not associated with digital files, the identity of any data subject to a breach would not be obtained.

Benefits: There will be no direct benefit to you by participating in this study.

Confidentiality: Your survey responses, including information about your age and gender, will be collected anonymously through a secure online survey platform called Qualtrics. Qualtrics uses encryption technology and restricted access authorizations to protect all data collected. In addition, Western's Qualtrics server is in Ireland, where privacy standards are maintained under the European Union safe harbour framework. The data will then be exported from Qualtrics and securely stored on Western University's server. Access to these data is restricted to only those on the research team* and will be kept for a minimum of 7 years. De-identified data from this study will be shared on the Open Science Framework, which allows other researchers access to the de-identified data indefinitely. The shared data will not contain any information that could identify you. A master list will be maintained which links your unique subject ID with identifying information; however, this list will be kept securely and separately from any experimental data.
*Representatives of the University of Western Ontario Health Sciences Research Ethics Board may look at your study records at the site where these records are held, for quality assurance (to check that the information collected for the study is correct and follows proper laws and guidelines).

Database for future participation: If you would like to be contacted about future research studies for which you may be eligible, you can choose to have your identifiable information (name, contact information, age, and gender) entered into "OurBrainsCAN: University of Western Ontario's Cognitive Neuroscience Research Registry" by the researchers of this study OR alternatively you can be given the web address of OurBrainsCAN where you are able to enter your information. This is a secure database of potential participants for research at Western University, which aims to enrol 50,000 volunteers over a period of 5 years. The information in this database will be stored indefinitely. The records are used only for the purpose of recruiting research participants and will not be released to any third party. When you are invited to participate future research studies, you will be given a full description of what your involvement would entail. You are, of course, free to turn down any invitation. If, at any time, you decide that you do not want your contact information to be a part of this database, please contact ourbrains@uwo.ca to remove your information.

Costs & Compensation: It is anticipated that completing this survey will take approximately two hours. You are eligible to receive a $25 gift card for participating. At the end of the study, you will be given the option to provide your email address to receive this token of our appreciation.

Questions about the Study:
If you have any questions about the study, please contact:
Blake Butler, Ph.D., Department of Psychology | Brain and Mind Institute
The University of Western Ontario, WIRB 5150
Email: bbutler9@uwo.ca

If you have any questions about your rights as a research participant or the conduct of this study, you may contact The Office of Research Ethics (519) 661-3036,
email: ethics@uwo.ca.

Checking the box below indicates you have read the letter of information, have had the nature of the study explained to you, and agree to take part in the study. You acknowledge that you can leave the study at any time.

○ Yes, I have read the above description and agree to participate

---

I consent to being added to the OurBrainsCAN: University of Western Ontario's Cognitive Neuroscience Research Registry to be contacted about future research studies for which I may be eligible:

○ I have already signed-up.

○ Yes, the researcher can enter my information into the database on my behalf.

○ Yes, please provide me the link to join the database myself.

Thanks for your interest in joining the OurBrainsCAN Neuroscience Research Registry. You can sign up anytime at: https://ourbrainscan.uwo.ca/sign_up.html

Appendix B: Demographics Survey

Please answer the following survey questions to the best of your ability.

1. Please enter your age in years. (e.g. 22)

   ____

2. Have you ever been diagnosed with hearing loss?
   a) Yes
   b) No

3. Do you have normal or corrected to normal vision (e.g. prescription eye glasses or contact lenses)?
   a) Yes - Normal vision
   b) Yes - Corrected vision (prescription eyeglasses/contact lenses)
   c) No

4. Are you able to converse in American Sign Language?
   a) Yes
   b) No

5. Have you ever been diagnosed with any neurological or psychological abnormalities (e.g. Schizophrenia, epilepsy, dementia, etc.)?
   a) Yes
   b) No

6. What is your eyeglass prescription? (Please ensure you wear your glasses/contact lenses for the duration of the study)

   ____

7. For how many years have you engaged in formal ASL instruction and/or routine conversation (e.g. 5)?

____

8. What gender do you identify with?
   a) Male
   b) Female
   c) Transgender
   d) Non-binary
   e) Other ____

9. What is your current occupation?

____

10. What is the highest level of education you have obtained?
    a) Elementary School
    b) High School
    c) College Diploma/Undergraduate University Degree
    d) Graduate/Professional Degree (e.g. MA, PhD, MD, LLB)

11. Are you left or right handed?
    a) Left
    b) Right

12. Do you play video games?
    a) Yes
    b) No

13. What kind of video games do you play?

____

____

____

____

____

14. On average, how many hours a week do you play video games? (e.g. 3)

____

15. What size is the screen on which you play video games (measured diagonally in inches)?

____

16. Approximately how far do you typically sit from your screen? (e.g. 24 inches)

____

17. Do you play sports?

a) Yes

b) No

18. Which sport(s) do you play?

____

19. On average, how many hours a week do you play sports? (e.g. 3)

____

20. Is anyone in your immediate family (parents/siblings) deaf?

a) Yes

b) No

21. Please list any deaf family members and the cause of their deafness (if known)?

____

____

____

____

____

22. On average, how many hours per week do you converse in ASL (e.g. 20)?

____

23. Where did you learn ASL primarily (e.g. home, school, community)?

____

24. For how many years have you known English?

____

25. On average, how many hours per week do you speak English?

____

26. Where did you learn English primarily (e.g. home, school, community)?

____

27. Do you have any other difficulties communicating (e.g. speech, spelling, reading)?

a) Yes, please describe the difficulty:

____

b) No

28. Please list up to 3 languages that you speak other than English/ASL (skip to next question if you speak no additional language).

a) Language 1 ____

b) Language 2 ____

c) Language 3 ____

29. Rate your ability in each of your languages using the following scale:

	1 Beginner	2	3 Intermediate	4	5 Advanced	6	7 Native
English	○	○	○	○	○	○	○
ASL	○	○	○	○	○	○	○
Language 1	○	○	○	○	○	○	○
Language 2	○	○	○	○	○	○	○
Language 3	○	○	○	○	○	○	○

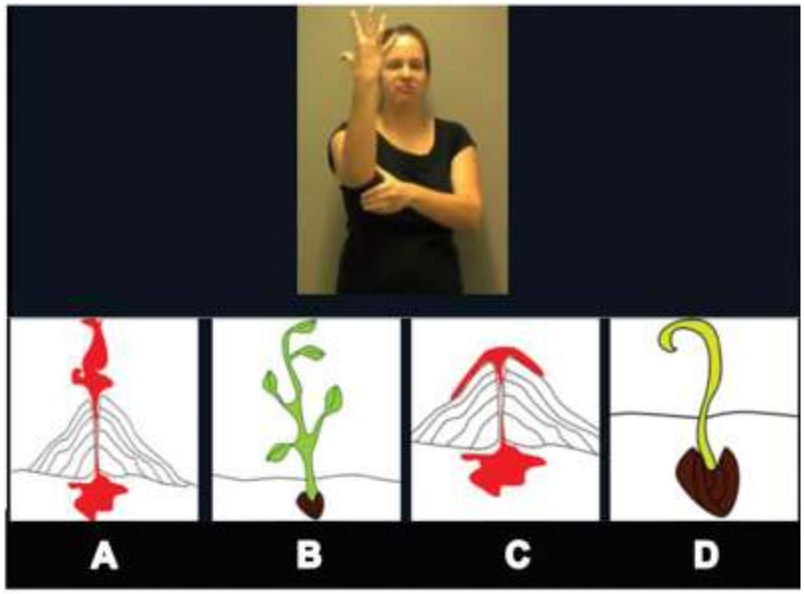
30. What percentage of time are you currently **exposed to** each language on average? (should add up to 100 e.g. English 50%, ASL 50%)

	0 10 20 30 40 50 60 70 80 90 100
English	
ASL	
Language 1	
Language 2	
Language 3	

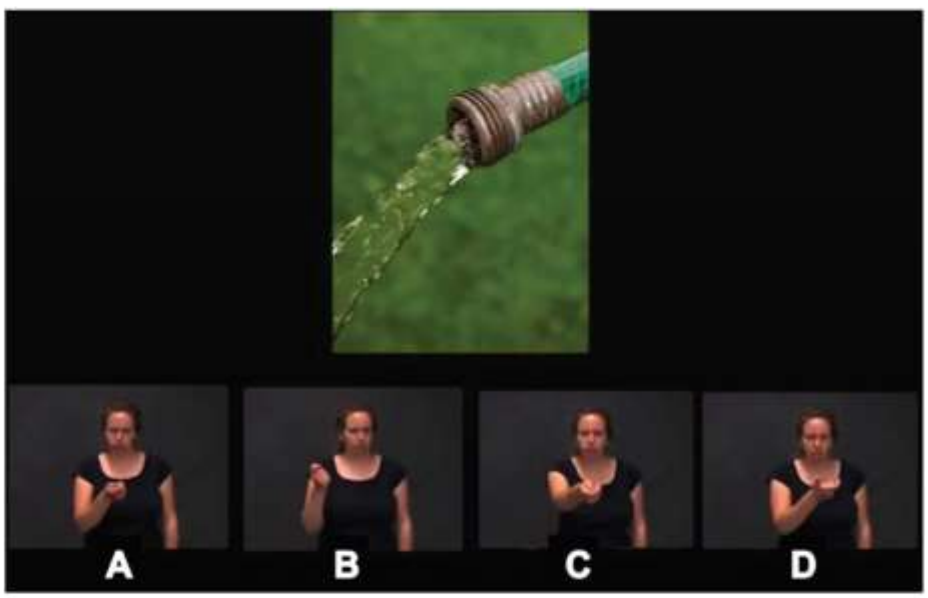
31. What percentage of time do you **use** each language on average? (should add up to 100 i.e. English 50%, ASL 50%)

	0 10 20 30 40 50 60 70 80 90 100
English	
ASL	
Language 1	
Language 2	
Language 3	

Appendix C: American Sign Language Comprehension Test (ASL-CT) Example Questions (not included in the actual test, see Hauser et al. [2016] for full details)



Example Item 1



Example Item 2

Appendix D: Ethics Approval Letter

Western Research

Date: 6 August 2020

To: Dr. Blake Butler

Project ID: 116053

Study Title: Impact of ASL learning on visual perception

Short Title: Visual Perception in Hearing Signers

Application Type: NMREB Initial Application

Review Type: Delegated

Full Board Reporting Date: September 4 2020

Date Approval Issued: 06/Aug/2020

REB Approval Expiry Date: 06/Aug/2021

Dear Dr. Blake Butler

The Western University Non-Medical Research Ethics Board (NMREB) has reviewed and approved the WREM application form for the above mentioned study, as of the date noted above. NMREB approval for this study remains valid until the expiry date noted above, conditional to timely submission and acceptance of NMREB Continuing Ethics Review.

This research study is to be conducted by the investigator noted above. All other required institutional approvals must also be obtained prior to the conduct of the study.

Documents Approved:

Document Name	Document Type	Document Date	Document Version
Poster_Signers	Recruitment Materials	29/May/2020	1.0
Poster_Controls	Recruitment Materials	29/May/2020	1.0
ASLCTexample	Other Data Collection Instruments	01/Jun/2020	1
debrief	Debriefing document	04/Jun/2020	1.0
ResearchProtocol	Protocol	04/Jun/2020	1.0
Recruitment_Email	Recruitment Materials	04/Jun/2020	1.0
QualtricsSurvey_Revised	Online Survey	27/Jul/2020	2.0
Poster_Controls	Recruitment Materials	04/Jun/2020	1.0
Poster_Signers	Recruitment Materials	04/Jun/2020	1.0
LOIconsent_Revised	Implied Consent/Assent	27/Jul/2020	2.0

No deviations from, or changes to the protocol should be initiated without prior written approval from the NMREB, except when necessary to eliminate immediate hazard(s) to study participants or when the change(s) involves only administrative or logistical aspects of the trial.

The Western University NMREB operates in compliance with the Tri-Council Policy Statement Ethical Conduct for Research Involving Humans (TCPS2), the Ontario Personal Health Information Protection Act (PHIPA, 2004), and the applicable laws and regulations of Ontario. Members of the NMREB who are named as Investigators in research studies do not participate in discussions related to, nor vote on such studies when they are presented to the REB. The NMREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000941.

Please do not hesitate to contact us if you have any questions.

Sincerely,

Kelly Patterson, Research Ethics Officer on behalf of Dr. Randal Graham, NMREB Chair

Note: This correspondence includes an electronic signature (validation and approval via an online system that is compliant with all regulations).

Curriculum Vitae

Name:	Jessica Lammert
Post-secondary Education and Degrees:	Western University London, Ontario, Canada 2014-2018 B.A.
	Western University London, Ontario, Canada 2019-present M.Sc.
Honours and Awards:	Ontario Graduate Scholarship 2019-2020
	Mitacs Research Training Award 2020
	Natural Sciences and Engineering Research Council (NSERC) Canada Graduate Scholarship – Master's 2020-2021
Related Work Experience	Research Assistant Western University 2017-2021
	Teaching Assistant Western University 2019-2021

Publications:

Lammert, J. M. (2018). Is Language Unique to Humans? Evaluating the "Narrow Language Faculty" Hypothesis. *Western Undergraduate Psychology Journal*, *6*, 1-9.