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The Impact of Sign Language on Visual Attention and the Development of the American Sign  
Language Test Battery

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**Abstract**

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This dissertation presents two projects aimed at advancing accessibility in research and education for D/deaf individuals. The first applied a dual task paradigm to American Sign Language (ASL) letter signs to examine whether deafness or ASL experience alters divided attention. Deaf signers, Children of Deaf Adults (CODAs), and Hearing Non-Signers all showed moderate costs when dividing attention between two letters, with no group differences. This divided attention cost, observed equally across all groups, highlights the need to incorporate what is known about attention in D/deaf individuals when designing classrooms and other learning environments to ensure they are accessible. The second project developed the American Sign Language Test Battery (ASLTB), a low-cost, self-administered online screening tool that minimizes reliance on English and does not require ASL-fluent experimenters. Strong correlations with self-reported fluency and validated measures of ASL receptive skills support its effectiveness for inclusive

participant recruitment. By lowering logistical and expertise barriers, the ASLTB enables more representative sampling and supports research that better reflects the diversity of ASL users.

Together, these projects advance understanding of divided attention in a diverse deaf group and provide the beginnings of a practical tool for more inclusive ASL research.

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## CHAPTER 1: INTRODUCTION

The current thesis aims to contribute to accessibility research and consists of two projects related to the role of attention and the assessment of sign language expertise respectively.

Many areas of research that inform the design of technologies and educational environments are developed around individuals with “typical” sensory experiences. Findings from this type of research often fail to consider the needs of individuals with different sensory modalities, such as D/deaf and Hard of Hearing populations. When inclusion efforts are made, they often lack sufficient research on how to implement them effectively, resulting in individuals with access needs having to work harder to be able to participate as intended. For example, providing an interpreter for a coding course for a Deaf student might offer access on the surface, but that alone does not account for the visual and cognitive load imposed on the student who has to split attention between live coding demonstrations and an interpreter relaying spoken information.

The first project in this thesis addresses an important scientific question – are divided attention abilities enhanced by deafness and experience with ASL? Deaf individuals navigate the world primarily through vision, making divided attention a core skill in successfully navigating everyday life. Understanding the limits of divided attention is essential to developing accessible technologies, learning environments, and public spaces. Despite this, pure divided attention capacities have never been studied in deaf individuals. In Chapter 2, I describe the current literature on visual sensory processing and attention in deaf individuals and in Chapter 3, I describe a psychophysical experiment investigating how deaf and hearing signers divide attention in the visual field for signed letters.

The second project in this thesis addresses an important methodological issue that has proved a significant obstacle to ASL and deafness research. Current tools for assessing sign language fluency can be difficult to implement (requiring experimenters who are fluent in ASL) and are lengthy to carry out, creating a real barrier to research on deaf individuals. In Chapter 4, I describe current assessment tools: their strengths and limitations. In Chapter 5, I describe a pilot experiment developing a screening tool for accurately assessing ASL (American Sign Language) fluency.

### **Deaf Representation in Research**

It is worth clarifying a terminology distinction readers may encounter in this dissertation and in the broader literature. The term “deaf” (lowercase d) refers broadly to individuals with little to no functional hearing while “Deaf” (capital D) denotes a cultural identity rooted in the use of sign language. Understanding this distinction is useful for interpreting research findings. Within these broad categories, there is substantial diversity. Deaf individuals vary in a multitude of factors such as causes of deafness, age of first language exposure, age of sign language acquisition, socioeconomic status, and more. This variability makes it difficult to apply a single theoretical framework to the effects of sign language and deafness on visual processing. One of the most important distinctions is between those who learn sign language early in life as a native speaker, and those who learn sign language in later childhood, after the critical window for language acquisition has closed.

Despite the diversity of the deaf population, many studies investigating vision in deaf individuals recruit from a subpopulation of deaf individuals: Deaf native signers. These individuals are typically born deaf or became deaf early in life and are raised by Deaf families who provide them with sign language exposure early in life. This group represents only about 5-

10% of the total deaf population in the US (Bavelier et al., 2006; Zorzi et al., 2022), while the vast majority of deaf individuals are born to hearing parents (M. W. G. Dye & Bavelier, 2010, 2013). Focusing on Deaf native signers offers clear a methodological advantage, providing a participant pool that is relatively homogenous with respect to duration of deafness and sign language experience. However, while this approach increases internal validity, it also limits the generalizability of findings to the broader deaf population. Despite native deaf signers being relatively atypical of the general deaf population, the results from these studies dominate the literature and are often used to inform applications of accessible technologies and spaces that will be used by the general deaf population. This is a concern because these technologies may not be fully appropriate for deaf individuals who use assistive hearing devices such as hearing aids or cochlear implants, deaf people who do not identify as part of the Deaf community but still need visual access and so on.

This trade-off between experimental control and representativeness is a common challenge in the field. One strength of the studies presented in this dissertation is its effort to broaden inclusion while maintaining methodological rigor. In the divided attention study (Chapter 3), I chose a participant pool that included a diverse range of Deaf individuals, with no additional restrictions beyond ASL fluency and being normally sighted. This recruitment criteria provides a more ecologically valid picture of visual attention across the broader Deaf community. Similarly, the ASL recruitment tool study (Chapter 5) was open to all normally sighted participants regardless of hearing status or language background, supporting inclusive recruitment and greater accessibility in future research. By sampling from a more inclusive sample that better reflects the diversity of the deaf population, these studies aim to offer findings

that accurately capture the realities of everyday experiences for a wider range of deaf individuals and signers.

### **Disentangling the Effects of Language and Deafness**

In addition to considering who is typically included in studies, it is also important to consider what drives observed differences between deaf and hearing individuals. Because deafness and sign language experience often co-occur, it can be difficult to determine whether differences observed in vision between deaf and hearing people are a result of auditory deprivation or sign language. To disentangle these two potential influences, many studies include hearing control groups with extensive experience with sign language, such as interpreters or Children of Deaf Adults (CODAs). These groups fulfill an essential role as secondary control groups alongside hearing non-signing individuals. Including these groups allows researchers to better isolate the role visual language exposure may have on vision from effects deafness might have.

When signing groups (regardless of hearing status) perform differently from non-signing controls, group differences can be attributed to sign language experience. Conversely, if Deaf native signers perform differently from both hearing groups (signing and non-signing), results suggest effects are more likely driven by differences in auditory experiences. This comparison has proved critical for understanding the unique influences of language and deafness on visual processing, as described in more detail below. The divided attention study presented in this thesis adopts this three-group design to examine how signing and deafness shape attentional performance.

Accessibility research requires careful attention not only to methodological design but also to who is recruited and how group differences are interpreted. The experiments in this thesis

are grounded in the recognition that the deaf population is diverse, and that both language experience and auditory status can meaningfully shape visual processing. By embracing this broader perspective, research can move toward findings that are both scientifically rigorous and practically applicable to real-world needs of Deaf individuals in the community.

## **CHAPTER 2: A Review of Visual Processing in Deaf Individuals**

Humans rely heavily on vision to navigate through our environments and localize the objects around us, but this process is generally automatic – barely reaching our consciousness. We only notice how heavily we rely on visual information when carrying out particularly challenging tasks, such as searching for our keys when they go missing, deciding what to wear to work, or determining if the banana that has been sitting in the kitchen for a questionable amount of time should be thrown out.

Sometimes the world we navigate demands that we perform multiple visual tasks at the same time. For instance, when driving, we look at the road to ensure we are traveling in the right direction while simultaneously paying attention to our surroundings for important signals or to avoid accidents. Most normally sighted people can do this seemingly without effort - but there are interesting limitations on this visual multi-tasking. We cannot, for example, text and drive at the same time without putting ourselves and others at risk. We cannot read two research papers at the same time, though that would have made researching my thesis much quicker.

Deaf people rely even more heavily on visual information, as they use their visual system to do tasks that other individuals would use their hearing for. When driving, my father relies more heavily on his peripheral vision to detect lights from emergency vehicles because he cannot hear the sirens. My mother was able to keep an eye, almost literally, on me and my sisters while chatting with her friends in sign language at the park, as she couldn't hear us if we fell off the slide. My Deaf friends in university classrooms had to attend to both the whiteboard and their interpreters during lectures. This experience with managing heightened demands on the visual system results in enhanced performance in many visual tasks, described in more detail below.

While it is well established that deaf individuals excel in certain aspects of visual processing, more research is needed to understand the limitations of this enhanced performance. Some capacity limits for attention may be fixed, while others may be expanded in deaf individuals as a result of their extensive experience with visual multitasking.

Simply converting auditory to visual information without an understanding of the underlying ‘hard limits’ to how attention can be allocated will often fail to provide true accessibility. Approaches that are not truly user-centered place a burden on deaf individuals to continually adapt to a hearing-centered world. A better understanding of how attention operates in different visual contexts can help develop environments and systems for the deaf that support rather than overwhelm.

The following sections examine how deafness influences vision across four domains: simple detection, attentional orienting, selective attention among competing stimuli, and divided attention. While not all studies agree on the extent or consistency of these enhancements, this body of work offers important insight into how visual attention operates in the absence of auditory input.

The literature described below focusses heavily on profoundly deaf individuals who became deaf early in life or are congenitally deaf. As described above, this subgroup represents only a small proportion of the deaf population; as a result, generalizing these findings to the broader deaf population remains challenging.

Another area that deserves additional research is how the effects of deafness on sensory processing and visual attention are influenced by the stimuli that are chosen. In general, the field has used three types of stimuli: 1. Simple shape stimuli chosen to tap into generic form

processing, 2. Motion stimuli such as moving dots that are chosen because sign language is highly dynamic but these stimuli do not require any kind of specialized knowledge, and 3. Stimuli designed to tap into specialized experience with sign language. Because most studies have compared results across different stimulus configurations but have only used one type of stimulus (e.g., motion or shapes, but not comparing the two), it is often difficult to know whether differences in findings across studies are due to differences in the task or differences in the stimuli. As described in Chapter 3, the type of stimulus that is used can have dramatic effects on how attention operates.

### **Tasks That Do Not Show an Effect of Deafness**

Deaf individuals do not simply 'see better'. Studies examining perceptual thresholds for contrast sensitivity, luminance change detection, & direction and velocity of motion changes have no significant differences between deaf and hearing participants (Bavelier et al., 2006; M. W. G. Dye & Bavelier, 2013; Pavani & Bottari, 2012).

### **Visual Detection in Deaf Individuals**

Although deaf individuals do not show differences in sensitivity to low level tasks, they do demonstrate faster reactivity to visual stimuli across the visual field as shown in simple detection tasks (Bottari et al., 2011; Heimler & Pavani, 2014). Notably, they do not exhibit the increased reaction time costs for peripheral stimuli that hearing controls do. This advantage extends even into the far periphery, with deaf individuals showing the fastest responses compared to their signing and non-signing hearing counterparts (Codina et al., 2017; Pavani & Bottari, 2012).

This peripheral advantage may reflect compensatory adaptations to auditory deprivation. While hearing individuals often use auditory cues to monitor environments at the boundaries and beyond the visual field, deaf individuals rely on visual input. Research suggests that deaf people show enhanced visual processing outside the foveal region, especially for tasks that require rapid processing (Bottari et al., 2010; M. W. G. Dye & Bavelier, 2013; Parasnis & Samar, 1985).

### **Visual Spatial Attention in Deaf Individuals**

Because deaf individuals must often rapidly shift their attention across visual space to monitor their environment, the rapid orienting of visual spatial attention has been a major research focus, including measuring the efficiency of orienting cued attention across space. That said, findings from studies observing orientation of attention have mixed results. Some research suggests more efficient attentional orienting in deaf participants than controls, as evidenced by smaller cueing benefits or reduced costs from invalid cueing (Bosworth & Dobkins, 2002a; Colmenero et al., 2004). Other studies report no differences between deaf and non-deaf individuals. One study showed no group differences in the benefit of valid cues (M. W. G. Dye et al., 2007), while another reported faster detection but no differences in discrimination performance, suggesting enhanced reactivity rather than differences in attentional allocation over space (Bottari et al., 2010).

### **Deafness Influences on Allocation of Visual Attention Among Multiple Stimuli**

Real-world environments often require attending to a stimulus in the presence of distractors. Selective visual spatial attention allows distracting stimuli outside the spatial region of attention are excluded from processing (and consciousness). In deaf individuals, the allocation of spatial selective attention seems to be different – it is believed that this results from the strong ecological reasons for retaining peripheral information in the absence of auditory cues that can

alert deaf individuals to peripheral events (M. W. Dye et al., 2008). This notion is supported by an fMRI study conducted on congenitally deaf individuals and hearing controls.

### *Selective attention among competing stimuli*

In one of the earliest studies examining selective spatial attention, it was found that deaf individuals outperformed hearing controls when discriminating direction of motion in the periphery while ignoring central distractors. This effect of enhanced motion discrimination only appeared under conditions of attentional competition (Neville & Lawson, 1987a), consistent with the notion that enhanced visual processing in deaf individuals is not due to increased sensory activity, but differences in how attention is allocated. A follow-up study including Children of Deaf Adults (CODAs) clarified that the source of these effects was deafness rather than experience with sign language: task performance for CODAs resembled hearing non-signers. In the same study, researchers also examined Event Related Potential (ERP) activity. Deaf participants showed attention-related responses over the occipital regions of both hemispheres were several times larger than either control or CODA groups. Both the behavioral and the ERP results suggest that differences in how attention is allocated is driven by deafness and not sign language (Neville & Lawson, 1987b).

In a similar study, performance was compared across two conditions: a “no load” condition in which no information was present in the foveal region when a spatially cued parafoveal target stimulus was presented and a “foveal load” condition in which five black crosses were present in the foveal region when the perifoveal target stimulus appeared. In the “no load” condition, both groups were better at detecting stimuli in expected locations and worse at unexpected locations, demonstrating that there is no difference between groups in the use of spatial cues to orient attention. In the “foveal load” condition foveal distractors interfered with

both groups in stimulus detection in the parafoveal region. However, there was a small but significant interaction between cue type (valid vs invalid), condition (“no load” vs. “load”), and hearing status: Deaf individuals outperformed hearing individuals in the foveal load condition when invalid cues were present. This finding implies that deaf individuals are better at redirecting their attention from one region of the peripheral visual field to another in the presence of distracting foveal visual stimuli (Parasnis & Samar, 1985).

This study can either be interpreted as a measure of attentional orienting in the presence of distractors or as a measure of selective attention in the presence of competing stimuli. The second interpretation is supported by a later study in which participants reported the location of a peripheral target while ignoring centrally presented distractors. Deaf individuals were better at selectively attending to peripheral stimuli while ignoring centrally presented distractors than their hearing counterparts (Reynolds, 1993).

Additional evidence for differences in central versus peripheral attention comes from two fMRI studies in which participants (native Deaf signers and hearing controls) were asked to selectively attend to changes occurring centrally or peripherally while viewing full-field dot displays. In the first study, participants monitored static and moving dot fields for brief luminance changes that occurred in three conditions: foveal, peripheral, or full-field. Participants were asked to keep track of the number blocks that had three or more luminance changes and report them at the end of each experimental run. Congenitally deaf participants showed greater MT/MST (motion selective areas) recruitment than hearing controls when monitoring peripheral motion. The foveal condition did not show differences between groups. Structural equation modeling further revealed stronger effective connectivity between MT/MST and the posterior

parietal cortex in the deaf in the peripheral condition, suggesting enhanced parietal involvement when monitoring the periphery (Bavelier et al., 2000).

A follow up fMRI study extended this work by comparing deaf signers, hearing controls, and hearing native signers. This study included two tasks: detecting changes in luminance and detecting changes in velocity. Behaviorally, deaf participants performed better in the peripheral field condition than the central field condition, while hearing participants showed the opposite pattern. Planned contrasts between central and peripheral attention (collapsed across luminance and velocity tasks) confirmed a significant group difference: the deaf group showed greater MT/MST recruitment for peripheral attention, while hearing groups showed greater recruitment for foveal attention. This finding reinforces the notion that deaf individuals allocate more attention to the periphery than to central vision (Bavelier et al., 2001).

Building on this evidence of enhanced peripheral allocation, a perceptual load study examined how deaf individuals handle central vs. perifoveal (4.2° from fixation) distractors. The study measured the drop in performance for a perifoveal stimulus caused by adding foveal distractors, and the drop in performance for a foveal stimulus caused by perifoveal distractors. Perifoveal distractors were more distracting to the deaf participants whereas central distractors were more distracting to hearing controls. This supports the notion of a shift in attentional resources from the central portion of the visual field to the perifovea or periphery in deaf individuals. A replication of this study replicated the difference between deaf and non-signing hearing individuals, and further found that signing and non-signing hearing individuals showed similar performance (Proksch & Bavelier, 2002).

Deaf individuals also appear to be better at attending to peripheral stimuli while ignoring peripheral distractors. In one study, participants engaged in two cued conditions: a “single

display” condition in which a target motion stimulus appeared in one of four quadrants with no distractors, and a “multiple display” condition in which the cued target appeared in one of four quadrants with noise distractors in the remaining quadrants. The researchers compared threshold ratios (multiple display: cued/ single display: cued) to assess the impact of distractors on performance. A ratio of 1 indicated no influence of distractors, values above 1 indicate that distractors impaired performance, and values below 1 indicate that distractors improved performance. The mean threshold ratio for deaf participants was 0.59, indicating a 1.7x performance *improvement* in the presence of distractors. This was very different from hearing groups whose ratios were just below 1.0, suggesting no cost or benefit from the presence of distractors. These findings suggest that deaf individuals may benefit from the presence of distractors under conditions of focused attention, unlike their hearing counterparts (Bosworth & Dobkins, 2002a).

Additional support for differences in selective attention in the presence of distractors comes from a study using the Eriksen Flanker Task, in which a central target letter is flanked by distractors at varying distances (0.5°, 1°, and 3° spacing). Distractors were either compatible (matching the target) or incompatible (not matching the target). Deaf adults showed significantly slower responses with incompatible flankers at the 1° spacing. This suggests that deaf adults allocated attention more broadly to the parafoveal region of visual space than the hearing group making them more vulnerable to interference from peripheral distractors (Sladen et al., 2005).

### ***Dividing attention in deaf individuals***

One of the characteristic challenges of being deaf is the need to simultaneously pay attention to multiple visual stimuli. An example that comes to mind is a classroom setting, in which a deaf student might need to attend to both the board and an interpreter. Little is known

about how deaf individuals manage this kind of dual attention, since only a few studies explore how attention is divided between multiple regions of the visual field simultaneously.

The same study (Bosworth & Dobkins, 2002a) that found enhanced performance for deaf individuals under cued conditions with distractors also examined performance when the location was not cued. In this version of the task, participants had to divide their attention across all four quadrants of the visual field, as the target (coherently moving dots) could appear in any location. Two conditions were compared: a “single display” in which the target appeared alone, and a “multiple display” in which the target appeared with noise distractors (non-coherent moving dots) in the remaining quadrants. All groups showed reduced performance in the multiple display condition, with no significant differences in threshold ratios. These results contrast with the findings in previously mentioned cued tasks (testing selective attention), where deaf participants showed enhanced performance in the presence of distractors when location was cued. This suggests that the benefit observed for deaf individuals may depend on knowing *where* to allocate attention, rather than a broad advantage in dividing attention to multiple locations simultaneously.

A different study using the Useful Field of View (UFOV) paradigm suggests that deaf individuals may show enhanced divided attention. Participants were asked to perform two tasks simultaneously: determine whether a central target (a smiley face) had long or short hair, while also identifying the location of a peripheral target (a filled star inside a circle) presented among distractors (squares) based on geometric 2D shape. Deaf participants (both signing and non-signing) needed less time to discriminate hair length in the central target than hearing participants (signing and non-signing) (M. W. G. Dye et al., 2009). This lack of an effect of

signing experience implies that deafness (not sign language experience) may support enhanced performance on tasks requiring attention to multiple spatially distinct regions at once.

Researchers reanalyzed the dataset collected in 2009 along with data collected from 20 additional participants to increase statistical power. Unlike the original 2009 study which emphasized a single combined threshold for doing the central and peripheral tasks together, the reanalysis calculated thresholds separately for each task, making it possible to examine the cost of divided attention for performance in each task separately. While the first study showed overall lower reaction time thresholds for deaf groups in the divided attention task, this re-analysis showed larger costs to performance in the central identification task under concurrent peripheral load for deaf individuals. This was evidenced by their larger reaction time thresholds compared to hearing individuals. Importantly, group differences in the central task emerged only under concurrent perceptual load. When the task was performed alone, there were no group differences. Peripheral localization thresholds were also not found to be different across groups (M. W. G. Dye, 2016). This suggests that while deaf participants could divide their attention between the two tasks, doing so came at the expense of central performance. This is consistent with the idea that attentional resources were allocated to the periphery leaving fewer resources for central processing.

Building on these findings, a follow up UFOV study used Event-Related Optical Signal (EROS) to measure cortical activity while participants engaged in the divided attention task. Like the UFOV tasks discussed above, participants engaged in a central task in which they identified hair length on a cartoon face while simultaneously engaging in a peripheral localization task. In this study, the target was changed from a filled star inside a circle to a diamond target to control for potential luminance effects. During imaging, stimulus duration was fixed at 68 to

accommodate recording requirements. A separate behavioral session used the adaptive staircase procedure to measure reaction time thresholds. Deaf participants showed lower peripheral localization thresholds than hearing controls, with no group differences in the simultaneously presented central discrimination task. EROS revealed greater activity in deaf adults in the primary visual cortex (V1/V2) and in the right posterior Brodman area 22 (BA22), along with reduced responses in left Heschl's gyrus and left posterior parietal cortex. Of these regions, only BA22 activity was correlated with lower peripheral localization thresholds, suggesting it plays a key role in supporting divided attention. As central task performance did not differ between groups, these findings indicate the effect was specific to peripheral demands (Seymour et al., 2017).

Taken together, these studies differ in several meaningful ways that may account for their different findings. In the uncued condition of the Bosworth and Dobkins (2002) study, participants were required to monitor multiple peripheral locations simultaneously for a motion target, with all stimuli appearing at approximately  $11^\circ$  from fixation. In contrast, the Dye et al. (2009 & 2016) studies required participants to divide attention between a central discrimination task and a peripheral localization task, with only one of the two target locations known in advance. Importantly, the 2016 study further measured central and peripheral reaction time thresholds separately, clarifying that any advantage for deaf participants came with central cost.

The nature of the stimuli also differed between the studies: Bosworth and Dobkins used motion stimuli for their study, whereas the Dye et al studies used distinct stimulus types (e.g., hair length for central target and shape for peripheral target). These differences in spatial layout and stimulus features likely influence how attentional resources are deployed, and different

analytic approaches can also shape how divided attention results are interpreted. As discussed in Chapter 3, both task and stimulus characteristics have a large impact on divided attention effects.

## **Visual Processing Effects of Sign Language**

### ***Sign language and the brain***

Although sign and spoken languages use different sensory modalities, they are represented in similar ways in the brain. Signed languages, like American Sign Language (ASL), are full-fledged languages. Their processing engages the same left-hemisphere language areas used by hearing individuals for spoken languages. Neuroimaging research consistently show deaf native signers' superior temporal cortex (STC), inferior frontal gyrus, and Broca's area are activated when perceiving and producing sign language. These regions are known for their roles in processing spoken language (R. Campbell et al., 2007; Cardin et al., 2020; Emmorey et al., 2003; McGuire et al., 1997; Neville et al., 1998).

As sign language is visual and spatial in nature, additional areas are recruited for signers perceiving ASL compared to non-signers listening to verbal language. In typical hearing populations, the Visual Word Form Area (VWFA) is activated when reading (Dehaene & Cohen, 2011). This area has also been found to be activated when deaf signers process fingerspelled words in both ASL and British Sign Language (Emmorey et al., 2015; Waters et al., 2007).

Sign languages often use facial expressions, spatial grammar, and movement to convey linguistic information. Both deaf and hearing signers show activation in right hemisphere areas involved in spatial processing. Signers also engage in occipito-temporal areas related to visual input, while hearing speakers show more activation in the auditory cortex (MacSweeney et al., 2002).

These findings highlight that while sign languages draw on the same core language network as spoken languages, they also use additional visual-spatial resources. This raises an important question: how might extensive sign language use influence visual attention?

### *Sign language on visual processing*

There is also evidence that experience with sign language experience influences visual attention. Sign languages use a large portion of the visual field and require complex processing across a wide region of space, because the language includes multiple cues such as the location of hands in relation to a user's body, palm orientation, facial expressions, and movement of hands. Because of its rich visual complexity, long term usage may shape how individuals attend to visual information.

Early evidence for effects of sign language on attention comes from a study combining behavioral Event Related Potential (ERP) measures with a motion detection task. Neville and Lawson (1987) found that deaf and CODA signers showed a right visual field behavioral advantage while hearing non-signers showed an advantage for the left. ERP results mirrored these behavioral asymmetries, with signing groups exhibiting stronger left-hemisphere activity, in contrast with the stronger right hemisphere activity found in the non-signing hearing group. These findings suggest sign language to be the driver of the differences found between the groups (Neville & Lawson, 1987b). A later psychophysical study reinforced this pattern. In a study observing deaf signers and hearing non-signers engaging in a motion direction discrimination task, results showed comparable overall performance between the groups except in hemifield results. Deaf participants' results demonstrated a significant right visual field advantage, while hearing participants demonstrated a left visual field advantage that was not significantly different from right visual field thresholds. While this study did not directly

compare hearing signers vs. hearing non-signers, a follow up study that included Children of Deaf Adults (CODA) found both signing groups (deaf and hearing) exhibited a right visual field advantage, suggesting that these findings were due to experience with a manual-visual language (Bosworth & Dobkins, 1999, 2002b). As sign language is highly dynamic, this right visual field advantage might reflect enhanced motion processing, as a result of learning to process sign. This idea was further supported by a 2001 neuroimaging study which showed that the motion selective brain area MT-MST was more strongly recruited in the left hemisphere for both deaf and hearing early signers compared to non-signing hearing controls when viewing moving dot stimuli (Bavelier et al., 2000, 2001).

In a study observing the effects of British Sign Language (BSL) and deafness on peripheral vision processing, participants were presented with an LED array of 96 LEDs. One of the LEDs would be illuminated between 30-85° from fixation on one of eight possible meridian locations, and participants were asked to indicate the meridian at the target appeared. While deaf participants yielded the fastest reaction times in the task in all eccentricity conditions, hearing BSL interpreters were also faster than non-signing hearing participants in the task, implying that the use of a visual language speeds up reactivity in the periphery (Codina et al., 2017).

Experience with sign language also alters attentional distribution across the upper and lower visual field. In one study analyzing data from a useful field of view task, signers (regardless of hearing status) showed a reduced tendency to misclassify targets in the superior versus the inferior visual field, suggesting a redistribution of attention toward the inferior visual field (M. W. G. Dye et al., 2016). A visual search study also found that deaf and hearing signers demonstrated a stronger bias toward reporting stimuli in the inferior visual field than signing

controls (Stoll & Dye, 2019). Together these findings suggest that ASL experience drives adaptations in attention that lead to an attentional bias towards the lower half of the visual field.

Evidence from eye-tracking supports this interpretation. When comprehending signed narratives, deaf native signers fixate almost exclusively on the face where grammatical information is conveyed through subtle facial expressions. While doing this, they simultaneously process dynamic manual information in the periphery (Emmorey et al., 2008). This pattern highlights how sign language experience shapes attentional strategies to maximize comprehension of both facial and manual components of ASL.

These studies suggest that sign language experience shapes visual processing, enhancing sensitivity to stimuli in the periphery and biasing sensitivity toward the lower half of the visual field where many signs are produced. Sign language also appears to result in lateralization effects that potentially reflect the left hemisphere's specialization for processing language.

## **Conclusions**

Thus, deaf individuals do not seem to have altered sensory perception, but do show differences in how attention is allocated and divided across space. The effects of extensive experience with sign language seem to primarily occur within sensory rather than spatial and divided attentional processing with increased sensitivity and faster reaction times for stimuli in the periphery or right visual field and no significant differences in signing vs. non-signing groups in the studies reviewed in the selective and divided attention sections mentioned earlier in this paper.

Building on this prior work, the current study adopts a well-established approach to studying divided attention: the dual task paradigm (described further in Chapter 3). Rather than

having participants monitor the far periphery or widely separated regions, the current experiment focuses on divided attention within a constrained region of visual space:  $4^\circ$  from fixation, the parafoveal region. This region was selected because it aligns with the distance used in the classic dual task paradigm but still has relatively good spatial acuity. While many studies examining deafness sensory capacity have focused on simple shape or motion stimuli, we chose a task that was ecologically valid while meeting the rapid timing demands of the dual task paradigm: recognizing single signed ASL letters.

## **CHAPTER 3. Measuring the effects of divided attention on deaf individuals**

### **The Dual Task Paradigm**

The current study focuses on visual divided attention, in which an individual is forced to simultaneously process visual information from more than one location. The ability to divide attention is core to the deaf experience. For example, when observing sign language, users need to attend not only to hands but also to facial expressions as well as convey important grammatical information. Critically, students mainstreamed in hearing classrooms have to attend to both the whiteboard and their interpreters during class.

I chose to measure the ability to divide attention using a dual task paradigm, which compares performance in a “single-task” in which participants are asked to process one visual stimulus to performance in a “dual-task” in which participants process two stimuli simultaneously.

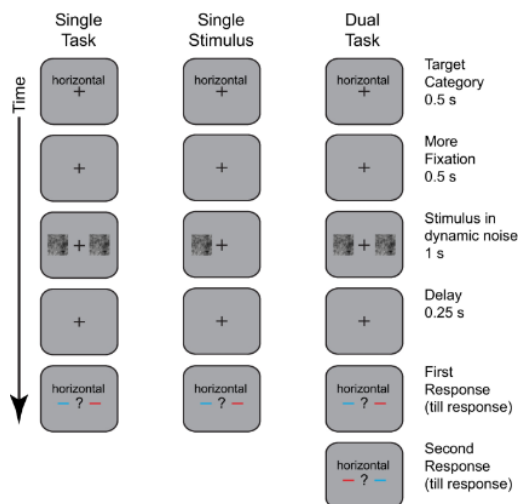
Participants maintain visual fixation in the center of the screen on a fixation cross. Visual cues are provided to the participants to indicate whether to attend to a stimulus on one side of the screen (single-task trials) or both sides of the screen (dual-task trials). The stimuli for single and dual-task trials are identical – and two stimuli are always presented – the only difference between single and dual-task trials is whether participants are cued to either one or both locations. Maintaining identical stimuli across the two conditions ensures that any differences found in performance are due to the attentional demands of the task rather than differences in the

visual stimuli. Presentation times of the stimuli presentation are typically kept below 200 ms, preventing participants from shifting their gaze and minimizing the time available to shift attention from one stimulus to another.

The difference in performance between the dual-task and single-task trials is referred to as the “Dual Task Deficit” (DTD), which is the measure of the cost of dividing attention (Palmer & Moore, 2015). An example of a study utilizing a dual task paradigm to examine divided attention for Gabor stimuli can be seen in Figure 1.

One of the striking findings of the dual task paradigm is that different stimuli elicit very different divided attention effects. A similar finding has been found for search tasks, with some stimuli showing ‘pop-out’ effect where reaction times do not depend on the set size, whereas for other stimuli reaction times grow linearly with set size (Hemström et al., 2019; Treisman & Gelade, 1980).

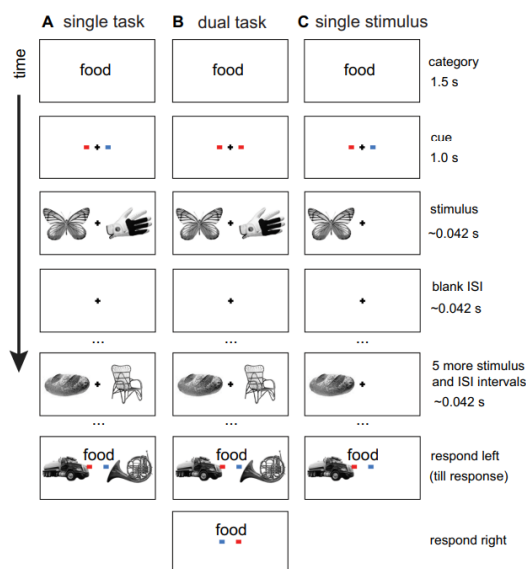
For the dual task paradigm, studies that used luminance and Gabor patches as stimuli found no dual task deficit when comparing dual-task to single-task conditions (Bonnell et al., 1992; Palmer et al., 2025a; White et al., 2017). It seems that simple features can be processed simultaneously with minimal to no cost to divided attention.



**Figure 1.**

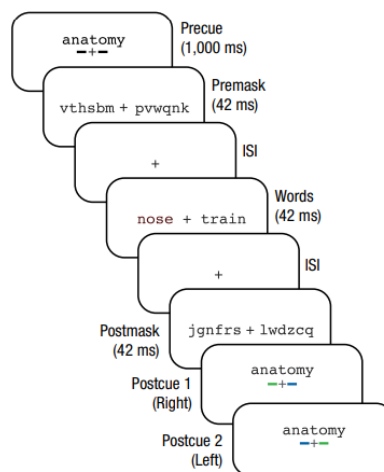
Dual task paradigm from Palmer et al., 2025. Licensed under Creative Commons Attribution 4.0 International License (<http://creativecommons.org/licenses/by/4.0/>). Participants were to report the presence or absence of brief Gabor stimuli. The word horizontal is present to remind participants to look for horizontally oriented Gabor. This was presented in the stimulus, despite the Gabor always being horizontal, as the experiment was run along with another study with semantic words.

As mentioned earlier, set size effects in search tasks differ depending on stimuli. Search tasks requiring only color as the feature for the task elicit a pop-out effect. More complex objects (those made up of a conjunction of features, like faces) have effects that grow linearly with set size (Hemström et al., 2019; Treisman & Gelade, 1980). The Dual Task Paradigm shows similar patterns. In a semantic categorization task, participants were given a category word (e.g., “animal”). They were then presented with two images of nameable objects and were tasked with judging whether the objects matched the cued category, see Figure 2. There was a large dual task deficit, with a divided attention cost of about 8.4% accuracy (Popovkina et al., 2021, 2023). In another study, participants engaged in two different types of judgements using the same physical stimulus (colored and non-colored words). One task was a semantic



**Figure 2.**

Dual task paradigm from Popovkina et al., 2021. Reproduced under the terms of the Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License (<http://creativecommons.org/licenses/by-nc-nd/4.0/>). Participants were to report whether the nameable objects in the cued locations matched the target category pre cue.

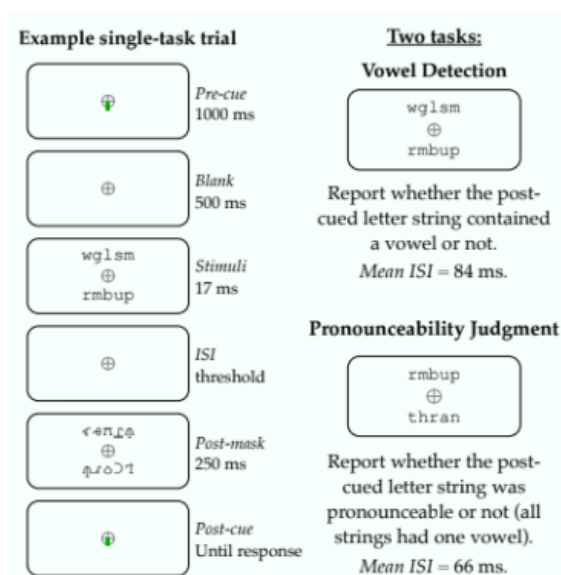


**Figure 3.**

Dual task paradigm from White et al 2018 (Printed with Permissions) in which participants were to report whether the words in the cued locations matched the target category pre cue for the semantic judgement tasks and to report whether color was present in the cued locations for the color judgement tasks.

categorization task, and the other was a color task in which participants judged whether the cued stimulus was colored or gray, see Figure 3. Divided attention costs were minimal for the color judgement (4%) but much larger for semantic judgements using the same stimuli (14%) (White et al., 2018). Together, these findings indicate that both the nature of the stimulus and the level of processing required for the task determine the cost to dividing attention.

Interestingly, the cost of dividing attention for identifying letters is similar to the cost of category judgments for words, see Figure 4. Participants asked to report whether strings of letters contained vowels or not showed a large dual task deficit. The performance cost of dividing attention in this task was approximately 17%. A similar cost to dividing attention was observed when participants were asked to make a judgement on whether the cued word was pronounceable (M. S. Campbell & White, 2022).



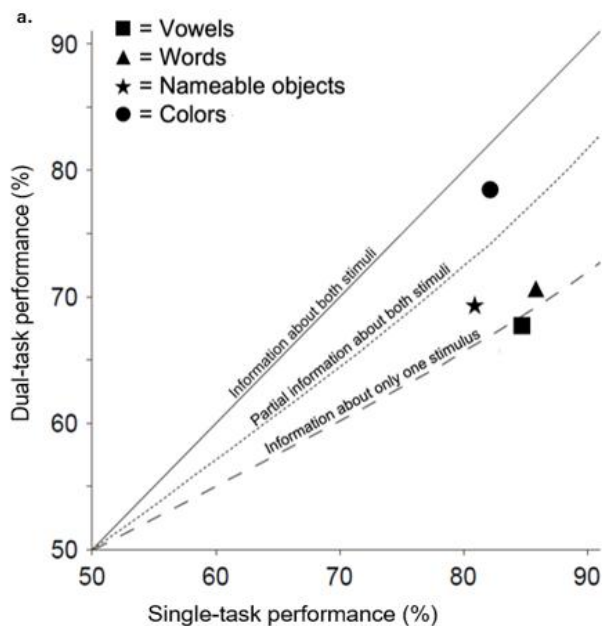
**Figure 4.**

Dual task paradigm from Campbell & White, 2022 (unpublished) in which participants were to report whether the letter strings in the cued locations contained vowels for the semantic judgement tasks and to report whether letter strings were pronounceable in the cued locations for the pronounceability judgement tasks.

Collectively, these studies suggest that for simple visual features such as color, orientation, and luminance there is a minimal cost to dividing attention, Figure 5. Such features can be processed in parallel across the visual field with relatively little cost to dividing attention. In contrast, when judgement requires integrating multiple features or engaging in higher level processes (such as categorizing nameable objects or written words) dual-task deficits become

more prominent. Notably, even seemingly simple linguistic tasks, such as detecting the presence of a vowel among a string of letters yielded a higher dual task deficit than the dual task deficit for color, suggesting an attentional bottleneck may occur once any kind of higher-level processing is needed.

This raises the question of what happens when the stimuli are derived from a visual language such as ASL. Fingerspelled handshapes are ideal for testing this question because they can be presented within the <200 ms window required by the dual task paradigm and can carry linguistic value for fluent signers. One possible outcome is that recognizing these letters engages a bottlenecked, high-level process, similar to categorizing written words or identifying vowels among letter strings. This would result in a very large cost to dividing attention for both Deaf and hearing fluent signers. Alternatively, recognition could be facilitated by extensive practice and overlearning (especially for Deaf individuals who primarily rely on ASL to communicate). This allows for sufficient processing even under conditions of divided attention. Non-signers, lacking both linguistic meaning and familiarity, provide a baseline for comparison. In this way, the choice of fingerspelled letters allows us to test how language experience and sensory experience may shape divided attention.



**Figure 5.**

Summary of divided attention effects from dual task paradigms using a variety of different stimuli and judgments. The X-axis represents performance in single-task trials while the Y-axis represents performance in the dual task trials. The overlaid lines correspond to the predictions of three benchmark models: the solid line represents an ability to process two ASL letters independently, the dotted line represents the ability to process partial information about both stimuli, the dashed line represents a processing bottleneck- only one stimulus can be processed at a time.

### Lateralization in the Dual Task Paradigm for Language Stimuli

When words are used as stimuli in the Dual Task Paradigm participants show a striking right-side bias: they were far more accurate for semantically categorizing words on the right side of the screen than the left (White et al., 2018). This bias was not seen for a color judgement task using the same stimuli. Similarly, no bias was found for a semantic categorization task using pictures of nameable objects (Popovkina et al., 2023). The fact that this bias was selective for making semantic categorizations on visual word stimuli suggests that this right-side bias is specific to reading. Supporting this, brain imaging research conducted the following year found that word recognition is constrained by a bottleneck in the VWFA (White et al., 2019). Because the right visual field directly projects to the left hemisphere, words on the right side of visual space have more efficient access to left VWFA, giving them an advantage when only one word can be processed at a time, as seems to occur for word stimuli under conditions of divided attention.

## Current Study

As mentioned in the literature above, visual attention in deaf individuals is shaped both by the absence of audition (deafness) and the use of visual language (such as sign language), in ways that are different in hearing individuals with no signing experience, and also different from hearing individuals who do have extensive hearing experience; both deafness and sign language experience shape visual attention.

The absence of audition results in a variety of changes in visual processing for deaf individuals. Deaf individuals have enhanced reactivity to stimuli across the visual field, especially in the periphery (Codina et al., 2017; Heimler & Pavani, 2014; Pavani & Bottari, 2012). Deafness also results in the allocation of spatial selective attention towards the periphery (M. W. Dye et al., 2008). This allocation of visual processing resources to the fringes of the visual field results in differences in how distractors impact deaf individuals than hearing, with peripheral distractors interfering with performance in centrally presented tasks for the deaf while the opposite is found for hearing people (Bavelier et al., 2001; Parasnis & Samar, 1985; Proksch & Bavelier, 2002; Reynolds, 1993). These differences found in the literature are most likely driven by the need to monitor at the fringes of the visual field using vision when audition is not available to be used.

Additionally, many deaf individuals use vision to process language. Sign language uses a large portion of the visual field and requires multiple aspects of the visual world to be tracked to be understood (facial expressions, hand shapes, hand movement, etc.). The literature above shows that prolonged use of sign language also has influences in attention. Sign language experience for both deaf and hearing people has also been found to have an enhancing effect in sensitivity to the periphery, though not to the extent seen in deafness (Codina et al., 2017).

People using sign language also exhibit biases towards the lower half of the visual field (Stoll & Dye, 2019), where a lot of signs occur. Biases to the right hemifield were also found with motion stimuli, potentially reflecting the importance of motion in processing sign language (Bosworth & Dobkins, 1999). Taken together, this evidence reveals that attentional strategies are shaped by the use of sign language, or to maximize the processing of visual stimuli critical to sign language, such as central facial expressions and information conveyed by hands in the periphery.

Deaf individuals need to process multiple things in their visual field at once in across a wide though the specific demands can vary depending on the context. In the example given in the introduction of this dissertation, my father relies primarily on visual cues when driving as he is deaf. While processing centrally presented information on the road, he also simultaneously monitors the periphery. He has successfully driven for most of his life with no incident, just as many deaf individuals do every day. This seems to work out because the stimuli on the road that require more visual acuity like reading the names of street signs are processed centrally, while cues that require less acuity like movement changes can be processed peripherally. This is similar to how sign language is processed when watching a narrative told by a single individual - deaf signers are found to maintain fixation near the eyes (where finer grained grammatical differences are picked up better by the fovea), and are still able to process hand information in the periphery (Emmorey et al., 2008). Enhanced processing of peripheral stimuli due to deafness and the ways signed language shapes attentional allocation helps us to understand the enhanced divided attention result found by Dye (2009), in which deaf individuals were much more efficient at simultaneously engaging in a central task while localizing a target stimulus among distractors in the periphery.

There are some instances, however, where deaf individuals experience difficulties when processing multiple things at once. Mainstream classrooms for example, require deaf students to attend to content being presented on the board by the instructor while simultaneously processing language related to the content being taught by an interpreter. This leads to missing crucial information when students try to learn and can contribute to issues such as the gap in academic performance between deaf and hearing students (Mather & Clark, 2012).

One question is – is the challenge of watching an interpreter and a teacher simultaneously simply caused by visual limitations – it is impossible to look at two things at once or do limits in divided attention also play a role?

We know from research in divided attention using the dual task paradigm, that different tasks and stimuli elicit different limitations on attentional capacity, and it seems to be particularly difficult to divide attention across two words at once – possibly because verbal language is highly serial (Popovkina et al., 2021; White et al., 2018). For the deaf, it might be that it is perfectly possible to divide visual attention between the road and objects in the periphery while driving a car. In contrast, processing context rich information being visually presented by signing interpreters while also attending to blackboard might be very difficult indeed.

Until now, most research on accessibility in the classroom has focused on visual rather than attentional limitations. This thesis is intended to address this gap in the literature by furthering our understanding of attentional capacity limitations in deaf individuals under conditions of divided attention.

A second novelty of our study is that existing studies of attention in deaf individuals rarely use ecologically valid stimuli. This was because these studies were focused on general capacities. In our case, the goal was to understand how divided attention limitations might be impacting the classroom. It is possible that differences in attentional capacities in deaf individuals might be specific to sign language, which many deaf signers use as their main form of communication.

Finally, we have chosen to use a paradigm designed to provide a direct measure of divided attention: the dual task paradigm. While previous studies have measured attention, it has sometimes been difficult to determine whether differences in performance are due to differences in capacity limits across groups or differences in how attention is allocated.

The UFOV task (M. W. G. Dye, 2016; M. W. G. Dye et al., 2009) requires participants to perform a central discrimination and peripheral localization simultaneously. In the 2009 version thresholds were titrated by a single staircase and deaf signers showed lower reaction time thresholds than hearing groups, suggesting more efficient simultaneous processing. However, a later reanalysis and replication used separate staircases to measure central and peripheral thresholds independently and found that deaf participants experienced a cost to performance in the central task under concurrent peripheral load. This, although this study shows clear differences in divided attention between groups, it is not clear to what extent these differences reflect differences in how attention is allocated across fovea and periphery rather than differences in overall attentional capacity. The better performance of deaf individuals may have been the result of a more efficient strategy rather than a difference in divided attention capacity limits.

The dual task paradigm addresses holds task-type, stimulus, and stimulus eccentricities from fixation constant. Moreover, performance is normalized based on single-task performance. Thus limits the ability to which differences in sensory processing across the visual field or differences across stimuli can be confounded with measuring the cost to dividing attention. Because performance is measured on both sides of the visual field and is compared to single-task performance it is possible to determine whether performance reflects simultaneous processing of both stimuli without capacity limits, attending to one side or the other, or dividing of attention (either simultaneously or over time) across each side. Results can be evaluated against different theoretical models, allowing for stronger theoretical inferences for the mechanisms underlying attention. For example, previous use of this paradigm has shown that color tasks seem to have no cost to divided attention, whereas semantic judgments have strict capacity limits consistent with only being able to process one stimulus at a time.

The Bosworth & Dobkins (2002) study examined divided attention by comparing performance when an uncued motion target appeared alone versus among three distractors. Stimuli were presented briefly (200 ms), but without masks. This set-size manipulation is analogous to contrasting single and dual-task conditions in the dual task paradigm. Across groups, threshold ratios did not differ, indicating no measurable group differences in dividing attention under these conditions. Further analysis showed that all groups have performances consistent with being able to process all presented stimuli with unlimited capacity. This finding suggests that there is little cost to dividing attention across multiple motion stimuli. This is consistent with previous studies of divided attention (Bonnell et al., 1992; Palmer et al., 2025b; White et al., 2017, 2018) and search (Treisman & Gelade, 1980) which suggests that there is

little to no cost to dividing attention for simple features such as color or orientation. More complex or linguistically relevant stimuli may have a higher cost for dividing attention.

One limitation of the Bosworth & Dobkins task is that participants did not know which location contained the target. As a result, differences between groups could be due to differences in attentional capacity limits – but could also be due to strategy differences in how attention is focused. By contrast, the dual task paradigm uses cues to indicate where the participant needs to attend.

The current study is the first to use the dual task paradigm to examine divided attention in Deaf signers, Children of Deaf Adults (CODAs) exposed to ASL in early childhood, and hearing non-signing individuals. These group comparisons enable us to understand how different experiences in audition and language impact divided attention within the context of a theoretical framework that has been developed through using the dual task in hearing populations for a wide variety of stimuli.

This study also fills a gap in the ASL literature. Although many studies have examined how ASL influences attention, none have studied divided attention using signs as stimuli. Ideally, the most ecologically valid stimulus would be words. However, ASL is highly dynamic language, making word stimuli technically impossible to use in the dual task paradigm as it requires stimuli to be presented for less than 200 ms to control for attentional shifts. In contrast ASL letter signs are static and can be processed in a 200ms window.

ASL letters are expected to have linguistic meaning for signers and not for non-signers. To our knowledge this is the first study to examine how long-term perceptual learning (experience with signed letters) might influence divided attention capacities. There is evidence

that dual task performance tends to be better for highly practiced tasks (Hirst et al., 1980; Logan, 1992) – but the dual task paradigms that have been used to examine this have tended to not be ‘pure’ measures of divided attention. To enable comparisons with the broader dual-task literature, stimuli in this study were centered 4 degrees from fixation, consistent with previous uses of this paradigm. This use of stimuli at 4 degrees is consistent with prior evidence for enhanced peripheral attention in deaf individuals at this region and beyond (Pavani & Bottari, 2012; Reynolds, 1993).

Based on the studies reviewed in Chapters 2 and 3, two competing outcomes were hypothesized:

***Hypothesis 1: An effect of ASL experience on divided attention costs.***

Two outcomes are possible:

1. Signers may show a greater cost to dividing attention if ASL letters engage a bottlenecked high-level linguistic process in signers but are processed as objects in non-signers. This would parallel findings from divided attention studies using linguistic stimuli in the dual task paradigm, where the presence of linguistic associations increases task demands (White et al., 2018).

2. Signers may show a smaller cost to dividing attention if familiarity and overtraining make recognition more efficient (Hirst et al., 1980; Logan, 1992). This might be due to lifetime experience with dividing attention for sign.

In either case, if both Deaf and Hearing signers perform differently from non-signers, this provides evidence that ASL experience influences divided attention. We recognize that this is a ‘two-sided’ hypothesis, but both outcomes are supported by the literature. Fortunately, the two

effects are unlikely to ‘cancel’ each other out. Letter stimuli are highly automatized, but have nonetheless show a strong attentional bottleneck (M. S. Campbell & White, 2022). So, if stimuli are processed as letters we expect strong divided attention effects in signers, despite being highly practiced stimuli.

***Hypothesis 2: An effect of deafness on divided attention costs.***

As mentioned earlier in this dissertation, my mother often had to attend to me and my siblings in the playground while also communicating with friends in ASL, since she could not rely on hearing for either task. Similarly, my father had to attend to the road in front of him when driving while also attending to peripheral cues (flashing lights or behaviors of nearby drivers) that might indicate an emergency vehicle was coming, prompting him to stop the car. If it is the need to monitor multiple visual stimuli that results in enhanced divided attention abilities, then we should expect Deaf individuals to have a lower cost of dividing attention for ASL signs than hearing individuals.

## **METHODS**

This study was approved by the University of Washington’s Institutional Review Board and carried out in accordance with the Code of Ethics of the Declaration of Helsinki. All participants consented to the study and were compensated for their time.

### ***Participants***

A total of 30 participants (14 male, 14 female, 2 gender non-conforming) were recruited from the Greater Seattle and Tacoma communities and placed in one of the three following groups for this study: Hearing Non-Signing, Child of Deaf Adult (CODA), or Deaf group. All participants reported normal or corrected to normal visual acuity. Participants were recruited via

flyers posted in the Greater Seattle Area and online social media posts. Demographic information regarding gender, age, self-reported fluency, and ASLCT scores was collected at screening.

Relevant demographic information and ASLCT scores can be found in Table 1 in the Appendix.

### Deaf

The Deaf group consisted of 10 participants (3 men, 5 women, 2 gender non-conforming). To be placed in this group, participants identified themselves as being deaf and reported communicating in American Sign Language. All Deaf participants included in the study identified as being part of the Deaf community and are referred to as Deaf with the capital letter “D” to align with their identity and hearing status. All participants in this group were able to further demonstrate their sign language knowledge by communicating with the researcher in American Sign Language.

### CODA

The CODA group consisted of 10 participants (4 men, 6 women). CODAs identified themselves as being individuals born to one or more Deaf parent(s) and reported learning American Sign Language during their childhood. All participants in this group were able to further demonstrate their sign language knowledge by communicating with the researcher (who is a CODA and interpreter herself) in American Sign Language.

### Hearing Non-Signing

The Hearing Non-Signing group consisted of 10 participants (7 men, 3 women). Participants identified themselves as hearing individuals with no American Sign Language experience or ability (including the ASL Alphabet).

### *Pre-experimental preparation*

In their first visit, all participants are given consent forms, a demographic survey, and the American Sign Language Comprehension Test.

### American Sign Language Comprehension Test

Participants completed the American Sign Language Comprehension Test (ASLCT), which is a 30-item multiple choice assessment of American Sign Language receptive skills. Scores closely matched previously published values, see Table 1.

**Table 1.** Participant ASLCT scores compared to published scores.

<b>Groups</b>	<b>Deaf</b>	<b>CODA</b>	<b>Hearing Non-Signers</b>
Current Divided Attention Study	21.7 ± 5.21	24.4 ± 1.84	10.2 ± 1.64
Published ASLCT scores (Hauser et al., 2016)	21 ± 5.67 (non-native) 26 ± 2.03 (native)	21.6 ± 4.98	Not published

Some CODAs in this study work as sign language interpreters, which explain their slightly higher scores compared to the published data for hearing native signers. As expected, the Hearing Non-Signers, with no ASL experience, performed poorly with a maximum score of 13/30 questions. Individual ASLCT results are shown in Table 1 in the Appendix.

### Demographic Survey

A survey was provided to all participants with questions about age, gender identity, handedness, level of education, use of assistive listening devices in the past and present, current use of ASL, current use of Signed Exact English, current use of spoken & written English, involvement with signing communities, languages used growing up, and hearing status of

primary care taker(s). Responses were used to assign participants to the appropriate experimental groups prior to training.

### Apparatus and Eyetracking

Stimuli were presented on a linearized CRT monitor (Sony GDM-FW900) with a resolution of 1024 x 640 pixels and a 120 Hz refresh rate. The monitor was viewed from a 60 cm distance and had a peak luminance of 90cd/m<sup>2</sup>. The presentation of stimuli was controlled using MATLAB (MathWorks, Inc., Natick, MA, USA) and the Psychophysics toolbox (Brainard & Vision, 1997). An Eyelink 1000 eye tracker (SR Research, Kanata, ON, Canada) and the Eyelink Toolbox (Cornelissen et al., 2002) were used to monitor and enforce fixation during the experiment. A trial was terminated and removed if the participant blinked or moved their eyes out of a 2° window while stimuli were present on the screen. On average,  $2.17\% \pm .61\%$  of trials were terminated due to blinks or apparent eye movements in this experiment.

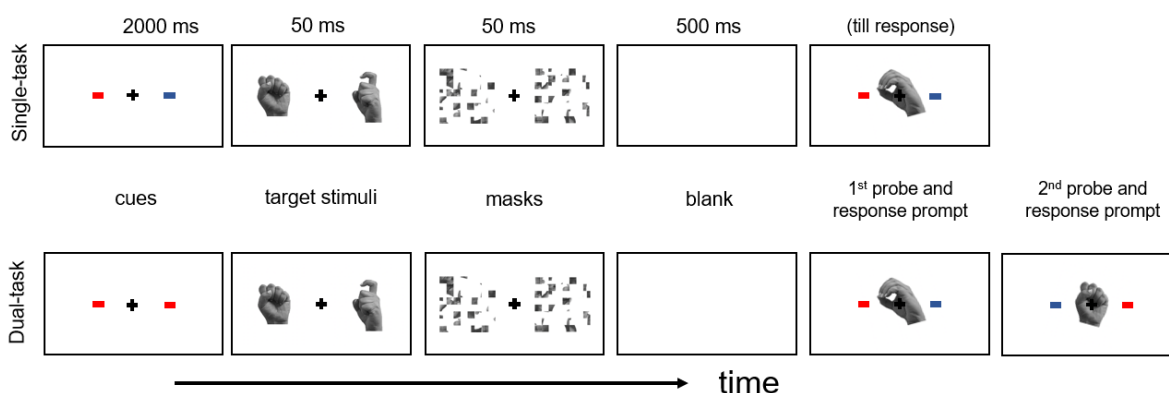
### Training and Setting Contrast

During their first visit, participants were given a handout outlining the task and were guided through the procedure. After ensuring understanding of the handout, they practiced with an unlimited number of trials within each condition, receiving visual feedback. Trial design and tasks are explained in the Procedures portion of this Methods section. Practice ended when participants felt confident in their ability to complete the tasks. During training, target stimuli contrast was set at 100%. After training, participants proceeded to the contrast adjustment phase, where the image contrast was set to achieve approximately 80% accuracy in the single-task condition.

The contrast level was adjusted individually for each participant to ensure consistent task difficulty. This level was maintained for all target stimuli throughout the experiment. The mean contrast for the Deaf and CODA groups was 27% while the Hearing Non-Signing group was 24%. No significant differences in contrast levels were observed between groups. Once contrast level difficulty was obtained, the experiment began.

### ***Procedure***

A schematic of the task is shown in Figure 6. On each trial, participants were presented with a cue indicating the relevant location, followed by briefly presented target ASL letter signs, followed by a mask, followed by the response prompt. The task included two conditions: single-task and dual-task.



**Figure 6.**

Example trial sequence. The participant must attend to the side(s) indicated by a red cue. Stimulus contrast was adjusted for each participant to reach 80% accuracy in the single-task condition.

In the single-task condition, ASL letter signs were presented in both left and right locations, but only one side was relevant. A cue at the beginning of the trial indicated which side to attend to, and participants responded only to the sign on that side.

In the dual-task condition, both locations were relevant. ASL letter signs were again presented on both sides of the fixation cross, but participants were required to make judgements on both sides.

## Cues

Blue and red colored lines were used as cues, with one color assigned as the “relevant cue” for each participant and the other serving as the “irrelevant cue”. To balance cue assignment, approximately half the participants in each group were assigned the red “relevant cue” (4 Deaf, 4 CODAs, 5 Hearing Non-Signers) and the remaining were assigned the blue “relevant cue” (6 Deaf, 6 CODAs, 5 Hearing Non-Signers). In Figure 6, the relevant cue is red while blue serves as the irrelevant cue. The  $0.5^\circ$  cues were presented to the left and right of a  $0.5^\circ$  fixation cross and were centered at  $4^\circ$  away from fixation. Cues were presented for 2000ms.

## Target Stimuli

American Sign Language letters were used as stimuli. 24 Greyscale photographs were taken of the researcher’s hand signing letters of the American sign language alphabet, with each photo capturing a single letter. The letters “J” and “Z” were excluded



**Figure 7.**

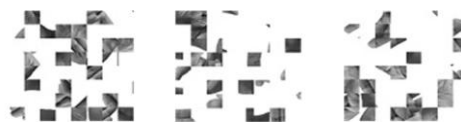
Full set of 24 static American Sign Language letters used in this divided attention study. Letters “J” and “Z” are not included as they are dynamic signs not suitable for this experiment.

from the stimuli set as they are non-stationary signs. The background of each photograph was removed from context. The final product resulted in 24 100 x 100 pixel stimuli, see Figure 7.

On each trial, following the cue, two ASL letter stimuli were presented to the left and right of the  $0.5^\circ$  fixation cross. Each  $4.2^\circ \times 4.2^\circ$  image was centered at  $4^\circ$  away from fixation and appeared for 50 ms.

## Masks

To minimize potential afterimage effects, masks were included immediately after target stimulus presentation. The ASL letter stimuli were sectioned into 8x8 squares and randomly rotated and repositioned to create 100x100 pixel masks, see Figure 8. These 4.2° x 4.2° masks were shown for 50 ms, followed by a 500 ms blank screen, and then the response prompt(s).



**Figure 8.**

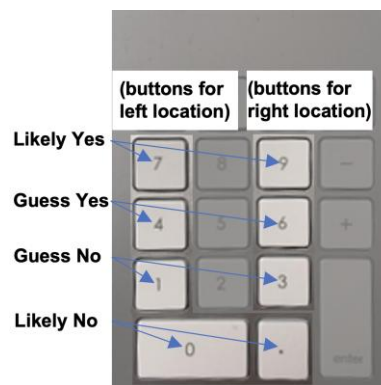
Example of three masks used in the divided-attention experiment to control for after image effects.

## Response Prompt

Following the blank screen, a response prompt appeared: a 4.2° x 4.2° probe ASL letter in the center of the screen flanked by response cues. Here, the participant gives a response to whether this probe sign matched the target sign they saw previously in the cued location.

To minimize the possibility that participants could rely on pixel-by-pixel visual matching strategies, probe ASL letter signs in the response prompt were rotated either slightly clockwise or counterclockwise during presentation. This manipulation ensured correct responses required recognition of the ASL letters rather than simple image matching.

Responses indicated both their answer and their confidence level using one of four buttons on a keypad: “likely yes”, “guess yes”, “guess no”, or “likely no”.



**Figure 9.**

Keypad used to make responses. Keys on the leftmost column corresponded to answers regarding the sign target on the left side of the screen, while keys in the rightmost column corresponded to answers regarding the right side of the screen.

The keyboard layout was vertical, with the leftmost column used for responses on the left and the rightmost for right side responses, see Figure 9. For each location, the chance that the probe matched the previous target was 50%. Participants had unlimited time to respond. In single-task trials, participants saw one response prompt for the cued condition. In the dual-task trials, two prompts were shown to collect responses for both target locations. The order of left and right response prompts was randomized across dual-task trials.

### Sample Size

To determine the sample size, we examined data from a set of previous dual-task experiments (Popovkina et al., 2021; additional in prep). Participants in these experiments ( $n = 10-12$ ) performed judgements of objects with similar methods to this study. We calculated the sample size needed for the dual-task measure. Our calculations assumed alpha and beta errors of 0.05 (power of 95%). The estimated minimum sample size was 10 for the dual task deficit with 300 trials per condition collected.

### Trial and Block Structure

Each experimental run typically consisted of 8 blocks with 16 trials per block. Within each block, conditions were balanced so that participants completed 8 dual-task trials, 4-single-task left cue trials, and 4 single-task right cue trials. The order of these trial types was randomized within each block. Target presence (present vs absent) was independently balanced at each location, and stimuli were drawn without replacement within each block to minimize repetition and ensure left and right letter signs were never presented at the same time in a given trial. Each block took approximately 2 minutes to complete, and each full experimental run took about 16 minutes. Multiple experimental runs were conducted within an experimental session, and participants were encouraged to take breaks between runs. Some experimental runs were cut

to 4 blocks at the participants' request to adjust to their comfort level and to prevent drop out. Participants were invited back to complete additional sessions. Experimental sessions took between 1-2 hours per appointment based on the comfort level and availability of the participant.

Participants were invited back to complete additional sessions until the number of trials needed to complete the experiment was achieved. A completed experiment included a minimum of 300 trials per task condition. Time between visits varied amongst participants due to differences in availability, most participants were able to reach the minimum amount of trials within 4 weeks of the first session. The 300 trial per condition minimum was usually met by the second or third visit to the lab. Because trials were typically completed in full blocks, most participants contributed more than this minimum amount, see Table 2 and Appendix Table 2).

**Table 2.** Average number of trials completed per condition by group

<b>Group</b>	<b>Number of Single-task Trials completed M (SE)</b>	<b>Number of Dual Task Trials completed M (SE)</b>
Deaf	318.1 (16.56)	317.6 (15.54)
CODA	320.4 (16.09)	325.5 (22.56)
Hearing	438.5 (130.22)	455.9 (143.49)

For the main analysis the minimum number of trials completed overall was 605 and the maximum number of total trials was 1216. This main analysis was run with more hearing non-signing trials than CODA and Deaf trials. A reanalysis of the data excluding session files exceeding the minimum of about 300 trials showed no significant difference to the results included in this dissertation and are not included.

### Analysis and Interpretation

Accuracy was measured as the percentage of area under the Receiver Operating Characteristic (ROC) (Sperling & Melchner, 1978). This metric has properties similar to two traditional accuracy measures: like percent correct, it is bounded by 50% (chance accuracy) and 100% (perfect accuracy); and like  $d'$ , it is an unbiased measure of accuracy.

The ROC plots hit rates (HR) as a function of false alarm rates (FR). To compute these hit and false alarm rates from the subjects' response ratings, we varied an index  $i$  from 0-4. At each index level, responses greater than  $i$  as "yes" responses. For each value of  $i$ ,  $HR(i)$  is the proportion of "yes" responses when the target was present in the cued location and  $FR(i)$  is the proportion of "yes" responses when the target was not present in the cued location. For example, when  $i = 3$  only response ratings of 4 (indicating highest confidence) on target-present trials are considered hits, and only response ratings of 4 on target-absent trials are considered false alarms. The five pairs of  $HR(i)$  and  $FR(i)$  trace out the ROC curve (White et al., 2020). For significance testing, all alpha levels were set to 0.05 and all t-tests were two-tailed (Palmer et al., 2025b).

For the Dual Task Paradigm, processing capacity limits are estimated based on the dual task deficit (DTD) - the difference between accuracy in the single-task and dual-task conditions. The area under the ROC was converted to  $d'$  to be able to run a one-way between subjects analysis of variance (ANOVA) to test for group differences. The conversion to  $d'$  serves to minimize ceiling effects and compression that may occur in higher levels of accuracy (Green & Swets, 1966).

To test whether the DTD for each of the groups in this experiment were statistically different from one another, a one-way between-subjects analysis of variance (ANOVA) was conducted.

## RESULTS

### *Dual Task Deficit*

The dual task deficit (DTD) is the difference in performance in single and dual-task conditions. In the dual-task condition, participants provided two responses per trial. To control for potential memory effects, only the first response in the dual-task was compared to single-task responses.

### Deaf Signers

Accuracy in the task for our Deaf group was worse for judging two ASL letters (dual-task accuracy:  $77.93\% \pm 2.16\%$ ) compared with judging one (single-task accuracy:  $85.54\% \pm 1.38\%$ ). The difference is the DTD:  $7.61\% \pm 1.38\%$  (significantly different from zero,  $t(9) = 5.53$ ,  $p < 0.005$ ).

### CODA Signers

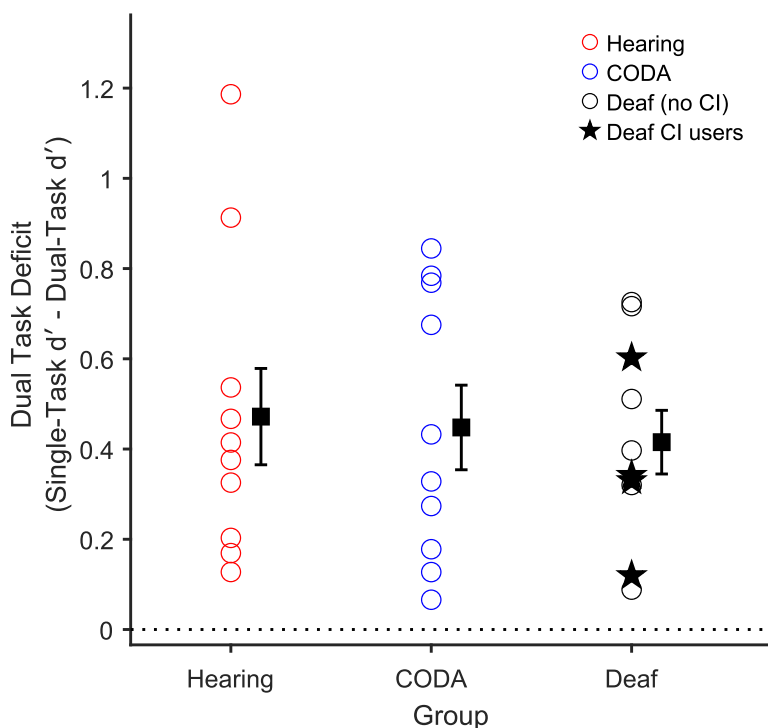
Accuracy in the task for CODAs was worse for judging two ASL letters (dual-task accuracy:  $74.33\% \pm 2.50\%$ ) compared with judging one (single-task accuracy:  $83.17\% \pm 2.05\%$ ). The dual task deficit for this group was  $8.84\% \pm 1.98\%$  (significantly different from zero,  $t(9) = 4.47$ ,  $p < .005$ ).

### Hearing Non-Signers

Accuracy in the task for our Hearing non-signing group was worse for judging two ASL letters (dual-task accuracy:  $69.72\% \pm 1.99\%$ ) compared with judging one (single-task accuracy:  $79.74\% \pm 1.96\%$ ). The difference is the dual task deficit:  $10.01\% \pm 2.00\%$  (significantly different from zero,  $t(9) = 5$ ,  $p < 0.005$ ).

### Comparison of the three groups

Area under the ROC was converted to  $d'$  to test for group differences. Group differences were examined using a one-way between-subjects ANOVA. No significant difference was found across the three groups ( $F(2,27) = 0.96, p = 0.909$ ). A scatterplot of the dual task deficit for the three groups can be seen in Figure 10.



**Figure 10.**

Plot displaying individual dual task deficit (DTD) scores, calculated from  $d'$  values converted from the area under the ROC (y-axis) for Hearing, CODA, and Deaf (x-axis). Group means and standard error bars are positioned to the right of each group. Data points for Hearing individuals are shown in red, CODAs in blue, and Deaf in black. Within the Deaf group, participants with current use of cochlear implants are represented as stars.

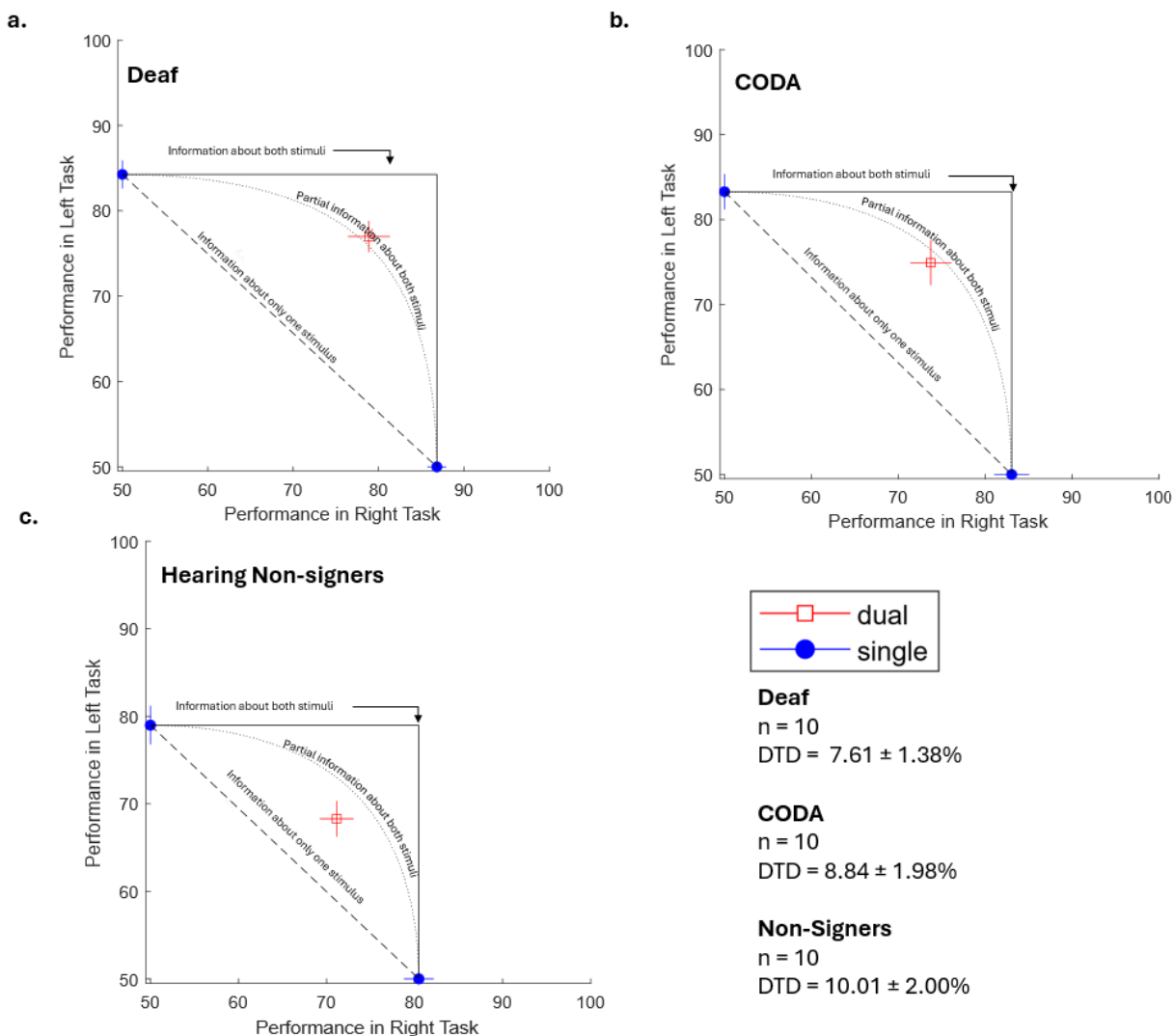
### *Attention Operating Characteristics*

To compare DTDs to model predictions, data was plotted on attention operating characteristics (AOCs) (Sperling & Melchner, 1978). Accuracy for ASL letters to the left are plotted (y-axis) against ASL letters to the right (x-axis). Single-task conditions are pinned to their respective axes while accuracy for the dual-task conditions are represented as a single point within the graph space. This point is compared to three specific models of capacity limits represented by lines overlaid on the AOC (Bonnell et al., 1992; Scharff et al., 2011; Shaw, 2014; Sperling & Melchner, 1978; White et al., 2018).

The solid line represents predictions of the independent parallel model: an ability to process two ASL letters independently (with unlimited capacity). This would be the case if there is no divided attention effect, as accuracy in judging two signs would be the same as one. This would result in virtually no dual task deficit.

The dotted line represents predictions of the fixed-capacity parallel model: an ability to process partial information about both stimuli. It assumes that the perceptual system extracts a fixed-amount of information from the display at a time. This results in shared processing resources among the two ASL letters in the dual-task condition, which lowers sensitivity. As the proportion of resources given to the ASL letter on the right increases, the model traces out a dotted curve in the AOC plot.

The dashed line represents predictions for the all-or-none serial model: a processing bottle neck where only one stimulus can be processed at a time. There would not be enough time to process any information from a second ASL letter, resulting in the largest DTDs.



**Figure 11.**

AOC for three groups: Deaf (a), CODA (b), and Hearing Non-Signers (c). Observed behavioral accuracy, measured as percent area under the ROC, in single (blue) and dual (red) tasks. Error bars in this visualization of the data represent the standard error of the mean. The dual task deficit (DTD) is the difference in performance between the single-task and dual-task conditions. Accuracy for the task on the left side of the fixation cross (y-axis) is plotted against accuracy for the task on the right side of the fixation cross (x-axis). The blue circles on the axes indicate the single-task accuracy for the respective sides and the red square indicates accuracy for each of the side (right and left) in the dual-task condition. The overlaid lines correspond to the predictions of three benchmark models: the solid line represents the independent parallel model, the dotted line represents the fixed-capacity parallel model, the dashed line represents the all-or-none serial model.

### Deaf

The AOC for the Deaf group shows that dual-task performance was lower than single-task performance, indicating a DTD. This pattern does not align with the unlimited capacity

model, which predicts no deficit. The pattern also does not align with predictions from the serial processing model, which assumes only one sign can be processed at a time. Instead, the data falls between these extremes, closest to the model representing the ability to process partial information about both stimuli, see Figure 11a. While this suggests a fixed-capacity parallel processing strategy, there are many other models that can be represented in the intermediate space, and the AOC alone cannot determine the exact mechanism.

### CODA

Similarly, the AOC for the CODA group shows dual task performance between the unlimited and serial models, closest to the fixed-capacity parallel predictions, see Figure 11b. This implies participants may be processing both stimuli at once to some degree, but the exact allocation of attentional resources remains unclear based on AOC alone.

### Hearing Non-Signers

The AOC for the Hearing non-signing group follows the same general pattern as the other two groups: dual-task performance was worse than single-task but does not reflect complete serial processing.

### Comparison of the three groups

Across all groups, the unlimited-capacity model can be rejected, as all groups showed a DTD. The serial model can also be rejected, as performance under dual-task conditions did not drop to the level expected if only one item could be processed at a time. The only benchmark model consistent with the data across the groups is the fixed-capacity parallel model, where participants extract partial information from both stimuli, see Figure 3.11. However, the AOC analysis only shows one model among many possible models that fall within the space between

the unlimited capacity and serial models- the AOC does not pinpoint the exact nature of the process participants may be engaging in when participating in the experiment. Further investigation is needed to determine how resources are being shared.

### *Lateralization*

To test for potential lateralization effects, a one-sample t-test was conducted on bias scores (difference between right and left side performance). Once again, only the first response made in the dual-task trials was used. Means and standard errors for the single-task, dual-task, and aggregate right and left sides for the three groups can be seen in Table 3. In the single-task condition, none of the participant groups had a lateralization bias (Deaf:  $t(9) = 1.386$ ,  $p > .05$ ; Coda:  $t(9) = -0.090$ ,  $p > .05$ ; Hearing:  $t(9) = 1.093$ ).

**Table 3.** Means and standard errors for the single-task, dual-task, and aggregate right and left sides for participants in the Deaf, CODA, and Hearing non-signing groups.

Group	Condition	Right	Left	t(df)	p-value
		Performance M (SE)	Performance M (SE)		
Deaf	Single-task	86.83 (1.17)	84.26 (1.74)	$t(9) = 1.386$	0.19924
CODA	Single-task	83.05 (2.12)	83.29 (2.20)	$t(9) = -0.090$	0.93041
Hearing	Single-task	80.48 (1.79)	78.99 (2.34)	$t(9) = 1.093$	0.30282
Deaf	Dual-task	78.88 (2.60)	76.98 (1.94)	$t(9) = 0.568$	0.58406
CODA	Dual-task	73.74 (2.50)	74.92 (2.78)	$t(9) = -0.330$	0.74891
Hearing	Dual-task	71.15 (2.02)	68.29 (2.17)	$t(9) = 1.127$	0.28901
Deaf	Aggregate	82.85 (1.73)	80.62 (1.60)	$t(9) = 0.963$	0.36076

CODA	Aggregate	78.40 (2.01)	79.11 (2.27)	$t(9) = -0.238$	0.81685
Hearing	Aggregate	75.82 (1.35)	73.64 (1.84)	$t(9) = 2.067$	0.06871

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### Dual Task Lateralization Effects

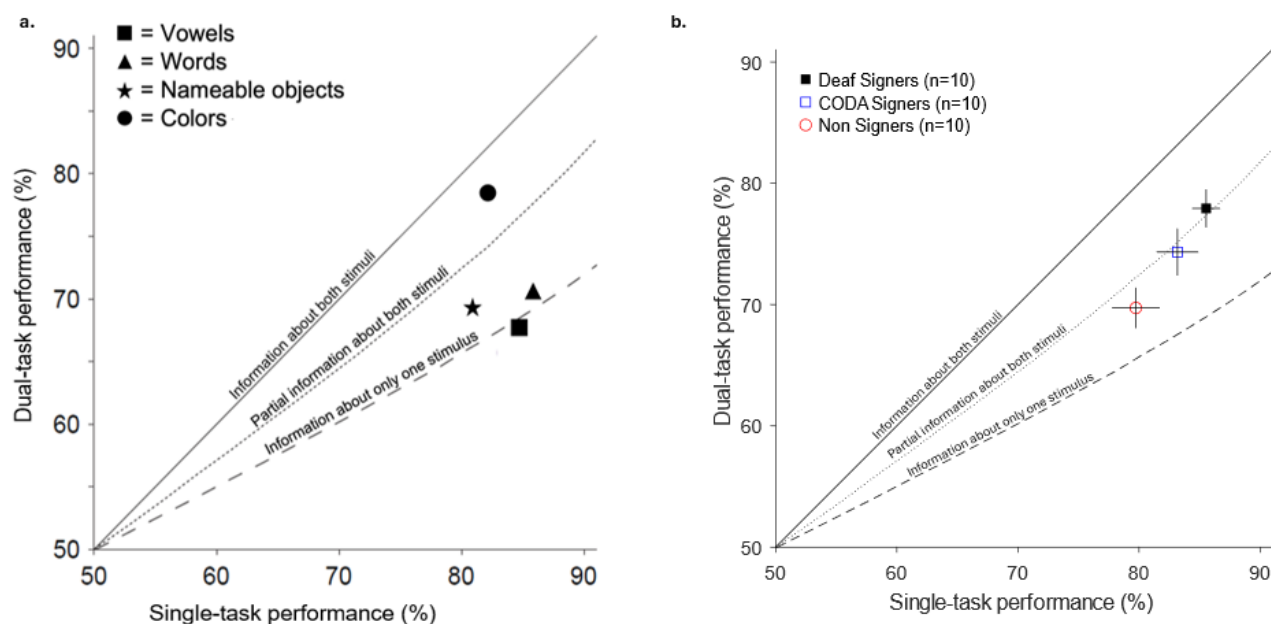
There was also no lateralization bias observed in the dual-task (Deaf:  $t(9) = 0.568$ ,  $p >.05$ ; Coda:  $t(9) = -0.330$ ,  $p >.05$ ; Hearing:  $t(9) = 1.127$ ,  $p >.05$ ) or when data from the single and dual-task were combined (Deaf:  $t(9) = 0.963$ ,  $p >.05$ ; Coda:  $t(9) = -0.238$ ,  $p >.05$ ; Hearing:  $t(9) = 2.067$ ,  $p >.05$ ).

## **DISCUSSION**

This study examined divided attention for ASL letter signs across three groups: Deaf signers, CODAs, and Hearing Non-Signers. All groups exhibited a cost to dividing attention, with lower performance when participants were asked to process two signs compared to one. Contrary to Hypothesis 1, signers did not appear to differ from non-signers. This suggests that ASL experience did not alter divided attention costs in this task. Contrary to Hypothesis 2, Deaf participants did not appear to differ from hearing groups, providing no evidence for an effect on deafness on dividing attention. The results suggest that all participants approached recognizing ASL letters as non-linguistic visual stimuli. The lack of differences appears to align with findings reported by Bosworth and Dobkins (2002), who reported no group differences in dividing attention when participants observed moving dots stimuli in the periphery. While the present study found no evidence for ASL experience or deafness effects, smaller or more subtle group differences may have been missed. This limitation is discussed further below.

When placed in the context of prior dual-task studies, our findings fall between those using low-level tasks such as color detection in letter strings, and those requiring deeper

linguistic processing like the semantic categorization of words(White et al., 2018) or vowel identification in letter strings (M. S. Campbell & White, 2022). Performance more closely aligned with tasks involving the semantic categorization of images of nameable objects, with all three groups clustering near the benchmark model for fixed-capacity parallel processing, see Figure 12. This suggests participants may have relied on visual form recognition of ASL letters rather than accessing their linguistic meanings.

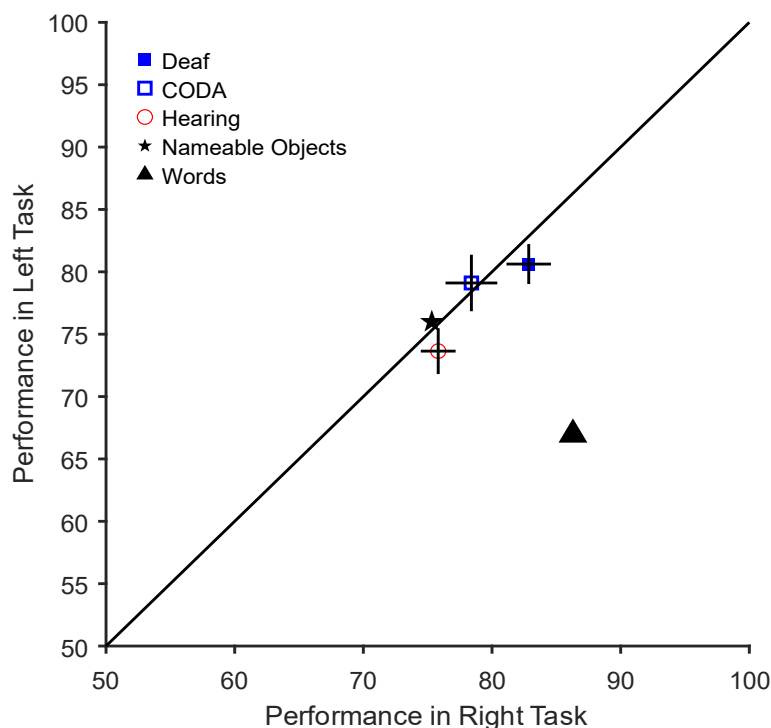


**Figure 12.**

Summary of divided attention effects from previous experiments (a) and summary of divided attention effects of ASL Letter stimuli for Deaf (black), CODA (blue), and Hearing (red) participants (b). Dual-task performance for each study or group (y-axis) is plotted against Single-task performance (x-axis). The overlaid lines correspond to the predictions of three benchmark models: the solid line represents the independent parallel model, the dotted line represents the fixed-capacity parallel model, the dashed line represents the all-or-none serial model.

Further evidence for this interpretation comes from the lack of lateralization effects. In prior work, semantic processing of written words was found to favor the right visual field(White et al., 2018, 2019), while categorizing images of nameable objects did not (Popovkina et al., 2023). Performance for ASL letters was balanced across visual fields for all groups, matching lack of lateralization found in the nameable object study, see Figure 13. This reinforces the idea

that, in this task, participants processed ASL letters as complex visual forms rather than as linguistic symbols.



**Figure 13.**

Lateralization effects of ASL Letter stimuli for Deaf (blue filled box), CODA (blue hollow box), and Hearing (red circle) participants compared to lateralization effects found in dual task paradigm studies using nameable objects (black star) and words (black triangle). Left side performance for each study or group (y-axis) is plotted against Right side performance (x-axis) for single and dual-task conditions. The unity line represents a model where there is no bias on performance based on location.

Taken together, these findings suggest that ASL letters presented in isolation, outside fingerspelling or sentence contexts, may not elicit deep linguistic processing in fluent signers. While all groups clearly understood the task, they may have approached it using visual form recognition strategies rather than engaging in language-specific processing.

### ***Limitations and Future Directions***

While the current findings offer insight into how ASL letters are processed under divided attention, there are several ways future work can build on this study to better understand group differences and attentional strategies. The following limitations and future directions outline promising areas for further investigation.

### More Trials for Conditional Accuracy analysis

Although all three groups in this study showed similar dual task deficits (DTD) when processing ASL letters, this does not necessarily mean they divided their attention in the same way. Different underlying strategies can produce similar DTD outcomes. A more sensitive measure, such as the conditional accuracy analysis (Popovkina et al., 2021, 2023; White et al., 2018), could provide clearer insight on how attention is allocated between two simultaneously presented stimuli. Based on our power analysis, at least 600 trials per condition would be needed to use this measure. Our study was limited to 300 trials due to time constraints, but future work could build on the current study by increasing the trial amount to examine group level differences in attentional strategies.

### Limitations of Power and Sample Size

The power analysis for this study was based on prior dual-task work showing 10-12 participants with a minimum of 300 trials per condition were sufficient to detect single versus dual-task differences within a single group. Follow up calculations in MATLAB (`sampsizepwr`) based on individual variability in this previous study estimated sensitivity to between-group differences. With 10 subjects per group,  $\alpha = 0.05$ , and power = .8, we should be able to detect a DTD difference of 8% between groups. At 95% power, an 11% difference could be detected with 9 subjects per group. Thus, with the current sample (N=30), only relatively large group effects are detectable. While group comparisons made in this dissertation must be interpreted with caution, this study provides one of the first direct examinations of divided attention across Deaf signers, CODAs, and hearing non-signers and offers a foundation for future large-scale research.

### Limitations of Task and Stimuli in Engaging Language Processing

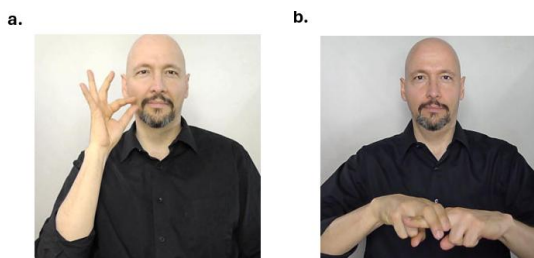
The stimuli used in the current study were ASL letter signs, which are static by nature and well-suited to brief presentation times (e.g., 50 ms) required for dual task paradigms.

However, this design may not have produced the larger DTD observed in vowel detection among letter strings or semantic categorization of written words, likely because ASL letters are rarely used in isolation and the task placed fewer linguistic demands on signing participants.

Future work could extend this paradigm by modifying both the stimulus and/or judgement. For example, participants could judge whether the cued sign is a vowel as participants did in Campell and White’s study (2022). Such a change would increase the linguistic demands of the task and could replicate the larger cost to dividing attention.

Another direction would be to use ASL words as stimuli. Although most ASL vocabulary signs are dynamic, some are visually distinctive enough to be recognized from still images. For example, the signs “CAT” (Figure 14a) and “CHAIR” (Figure 14b) can be conveyed in static form with appropriate training. Using such images would make it possible to design semantic categorization tasks that are more

comparable to those used with written word stimuli. For instance, if the target category was “furniture”, participants could correctly respond with “yes” keys when the static sign for “CHAIR” appeared and “no” keys for non-furniture signs like “CAT” appear in the cued locations.



**Figure 14.**

Examples of stills of dynamic word signs in ASL: cat (a) and chair (b). Images sourced from Lifeprint.com (“cat” American Sign Language (ASL), n.d.; “chair” American Sign Language (ASL), n.d.). Material courtesy of Dr. Bill Vicars and www.lifeprint.com.

### Dividing Attention between Two Signs in the Parafoveal region

The results in the current study, along with findings from Bosworth and Dobkins (2002), may suggest signers do not divide their attention between two stimuli within the same region of space. Instead, attentional strategies in sign language may more commonly involve dividing attention across distinct regions. As mentioned in the introduction, understanding sign language involves processing multiple visual parameters simultaneously, including facial expressions and hand movements. In natural conversation, attention is often divided between the face (facial expression parameter) and the hands (all other parameters). A future study could maybe have a more realistic representation of dividing attention in sign language by simulating this division of attention. For instance, facial expressions could be presented in the foveal region while hand signs appear in the lower visual field.

For instance, the ASL sign for “no” combined with a furrowed brow signals a firm statement. The same sign accompanied with raised eyebrows could indicate a question. This setup could conceptually parallel task demands in Dye et al. (2009), where participants divided their attention between central and peripheral targets. While the study used relatively simple detection targets, the use of linguistically rich ASL signs and facial expression could extend our understanding of visual processing in signers. Exploring how participants coordinate attention across these spatially distinct but integrated elements could offer deeper insight into the attentional demands of fluent sign language comprehension.

### A Fourth Group of Native Signing Profoundly Deaf Individuals

We recruited three groups: Hearing non-signers, CODA signers, and Deaf Signers. Most studies showing enhanced visual performance within signing individuals used profoundly Deaf signers who became Deaf very early in life or were born Deaf and did not use devices that

provided hearing assistance. Would a 4<sup>th</sup> group made up of Deaf individuals that fit these criteria result in different findings?

### *Conclusion*

This study represents an initial step in applying the dual task paradigm into sign language research. By using the simplest unit of ASL, fingerspelled letters, we were able to explore the costs of dividing attention when signers and non-signers process multiple signs simultaneously. To our knowledge, this is the first study to apply the dual task paradigm to signed letters. While the stimuli and judgements were intentionally kept simple, these findings establish a foundation for future work using more complex signs and tasks to further explore divided attention effects in deaf and hearing signers.

Across all groups, we found clear dual-task costs when participants processed two letter signs at once, but no evidence of group differences. This outcome is consistent with Hypothesis 4 and suggests that the use of isolated ASL letters and perhaps the overly simple task of determining the presence of the letter led participants to process the stimuli in their 2D forms rather than linguistic symbols. These results raise important questions about whether group differences might emerge in tasks requiring more language-based judgements, whether isolated ASL letters engage language processing, and whether group differences may be found in different configurations of divided attention such as central vs peripheral stimuli.

These findings also have meaningful implications for Deaf education. While deaf signers are often assumed to have enhanced visual attention skills, the current study shows that processing even simple signs like ASL letters in isolation under divided attention can incur measurable costs. Visually demanding courses like mathematics or live coding courses require

deaf signers to attend to both the instructor/screen/whiteboard and the interpreter. These types of learning environments may overload visual processing and lead to missed crucial information.

This also extends to courses taught by signers as well. Recent research explored ways to address the issue attention split in programming courses and signing instructors by examining different orientations of instructor placement modes in a VR-based lecture in a small user study. Participants reported more visual comfort when they were able to place their signing instructor in a position they preferred (Huffman et al., 2024). This work underscores the need for instructional environments to not only consider the attentional load imposed on deaf students, but also to recognize that enhancements in visual attention may be specific to certain spatial or contextual conditions. Designing learning environments that allow sufficient time for processing signed information and align with known attentional differences (such as heightened peripheral reactivity), may better support comprehension in high-visual-load courses.

This work sets the stage for deeper investigations into how experiences in sign language and deafness shape visual attention, and how that knowledge can be applied to build more accessible environments for deaf signers.

## CHAPTER 4: Current methods for assessing American Sign Language

### INTRODUCTION

To encourage more inclusive research, it is important that tools be available to researchers that make it feasible to study diverse populations. Screening tools that minimize financial and logistical barriers, yield rich data, and can be deployed by labs regardless of their funding situations are important to achieving more inclusive research practices. The American Sign Language Test Battery (ASLTB) was developed to support this goal. It is designed as a stand-alone screening tool to promote the inclusion of American Sign Language (ASL) users in research. While this tool is currently in the beginning stages of development, it represents an important first step toward building more comprehensive and accessible assessments.

#### *Existing Assessment tools*

Multiple assessment tools that have been developed to screen ASL participants for research studies.

The American Sign Language Proficiency Interview (ASLPI) assesses global ASL proficiency through a face-to-face interview between an examinee and interviewer. Interviews are either conducted in American Sign Language Diagnostic and Evaluation Services (ASL-DES), located at Gallaudet University, or on videophone from a neutral site. Interviews take about 20-25 minutes and are recorded to be assessed by a team of trained evaluators. Results are determined through a collaborative rating process and are provided several weeks after the interview (Caccamise & Samar, 2009). The conversational format of this assessment is valuable in that it provides an opportunity to test receptive and expressive ASL skills. Limitations lie in the time it takes to provide scores and the cost for each interview, making it not ideal for

researchers looking to screen large numbers of participants in a timely manner, especially in labs conducting online studies or that have limited funding.

While not specifically designed as a screening tool, the Avant Standards-based Measurement of Proficiency (STAMP) for ASL is an online test that measures both receptive and expressive ASL skills. It is developed primarily for second language learners of ASL and Children of Deaf Adults (CODA) and offers immediate results for the receptive skills portion of the test. The expressive skills responses are scored by a team of raters and results for that portion are typically provided within 20 days (Avant Assessment, n.d). This assessment is beneficial in that it assesses receptive and expressive skills online, giving a quicker more comprehensive review of sign language proficiency but human raters for the expressive response scoring increases assessment cost, making it less ideal for large-scale participant screening. Additionally, the assessment provides instructions for the task in English rather than ASL, which may result in the unintentional exclusion of participants who are fluent in ASL but not in English. Given that the assessment was developed for second language ASL learners and CODAs, this instruction style is understandable- but it does limit the assessment's ability to be an effective screening tool for researchers interested in deaf populations.

The American Sign Language Comprehension Test (ASLCT) is a 30-item multiple choice assessment of American Sign Language receptive skills (Hauser et al., 2016). This test was developed and validated using a sample of 80 college students including Deaf native signers, hearing native signers, Deaf non-native signers, and hearing ASL students. An online version of the ASLCT is available upon request, free of charge, through the Science of Learning Center on Visual Language and Visual Learning (VL2) at Gallaudet University. The test offers immediate results upon completion (and was used to assess ASL abilities of participants in the Divided

Attention of the first half of this dissertation). What makes this assessment tool not-ideal for generalizable screening is the sample used to develop the assessment was made up of exclusively college students. This population does not fully represent the broader community of ASL users. The test also requires a researcher to be present during the initial setup of the assessment to provide constructive feedback during practice trials. This proctoring requirement, while important for validity, limits the ability for researchers to use it as a screening tool for large-scale online studies seeking to minimize logistical demands and increase participant reach.

The American Sign Language Discrimination Test (ASLDT) is a 48-item assessment designed to measure participants' ability to discriminate phonological and morphological contrasts in ASL (Bochner et al., 2016). In each item, participants are presented with two short ASL sentences and were instructed to determine whether the second sentence was identical to the first. This test provides an overall measure of ASL proficiency, provides results immediately upon completion, and is free to use making it a potentially valuable tool for large-scale online research. A limitation is that the test instructions are provided in English.

The American Sign Language – Sentence Reproduction Test (ASL-SRT) is a 39 item assessment designed to measure participants' expressive skills in adults and children with the aim to discriminate between native and non-native signers. There was an additional aim to discriminate between those that have “fully mastered” ASL to those who have not within the native signing groups. When taking the assessment, participants are to watch computer displaying video clips of a native signer signing sentences of increasing length & complexity. When the sentence presentation ends, participants are to reproduce the sign viewed- as closely as possible. Recorded responses are scored by raters trained on rating video data (Hauser et al., 2006). This assessment was carefully developed to capture a wide range of signing experiences

by recruiting participants of varying proficiency in ASL, ages, and hearing status. These participants came from summer camps, schools, & colleges for the Deaf who grew up in different regions of the United States. Some of the many strengths of the assessment is in its use of native signers for the prompts, the ability to test sign production, its computer-based administration, and its consideration of diverse signer backgrounds. However, the assessment is less suitable for large-scale online research applications. This is due to its measurement of expressive skills, which requires participants' responses to be recorded and rated. Though the developers sought to minimize rater training, the scoring process still demands considerable time and human resources to evaluate multiple sentences for each participant.

There are also some well-established assessments designed specifically for children and/or teens such as the ASL Assessment Instrument (ASLAI; targeting students aged 8-16), the ASL Receptive Skills Test (ASL-RST; ages 3-13), and the ASL Expressive Skills Test (ASL-EST; ages 4-13). While these assessments are valuable in their ability to evaluate language in younger populations, they are not directly relevant to the present review and will not be discussed here. Critically, these tests were developed and normed on child and adolescent participant data, with no adult data included. The item content and their linguistic complexity are calibrated to developmental benchmarks. As a result, adults with moderate sign knowledge might score highly on these assessments, making these measures unsuitable for screening adult populations. The assessment being developed in the current study is built with the distinct goal of screening adult participants for large-scale online research.

Interestingly, there appears to be another assessment with the same name as the current assessment being developed in this dissertation, listed online as "The American Sign Language Test Battery" ("ASL Test Battery," n.d.), associated with Georgetown University. However, the

page hosting information about the assessment does not provide a clear way to request materials or to determine whether the assessment is currently available for use. To date, there are no peer-reviewed publications describing this assessment. The closest related tool seems to be the Test Battery of ASL Morphology and Syntax, which appears to have been unpublished since 1995. More recent citations to that work cite it as “unpublished” with no links to accessible materials.

Some of the tests listed on this page describing the Morphology and Syntax battery share the same names as those for Georgetown’s ASL Test Battery (<https://www.signlang-assessment.info/test-battery-for-american-sign-language-morphology-and-syntax.html>). A study was conducted adapting many of the assessments in the Test Battery of ASL Morphology and Syntax (five of which are listed on the Georgetown web page for the American Sign Language Test Battery) for Australian Sign Language (also known as Auslan) (Schembri et al., 2002). Three of the adapted tests appear to measure sign language production: the Verb Agreement Production (VAP) test, the Noun Verb Production (NVP) test, and the Verb of Motion Production (VMP) test. The other two tests appear to measure receptive skills of sign language: Sign Order Comprehension (SOC) test and the Noun Verb Comprehension (NVC) test. Taken together these adaptations suggest that the unpublished ASL Test Battery was originally intended to measure both receptive and expressive skills in ASL. However, the reliance on production tasks requiring scoring by raters makes the battery ill-suited for large-scale online studies, where automated scalable scoring is essential.

### ***Considerations for Developing Valid ASL Assessments***

The development of sign language assessments should be guided by a Deaf-first perspective. These assessments should be led by researchers who are highly fluent in sign language & knowledgeable in linguistics. They should also have a working understanding of

Deaf culture, history, and education to maximize cultural and linguistic validity. A Deaf-signer framework is essential not only for cultural reasons but also because of known differences in language profiles and cognition found within the deaf population. This population is highly heterogeneous, with differences in age of first language acquisition, educational background, cause of deafness etc.

Multiple factors should be considered when designing assessments. For example, some fluent D/deaf signers will not be able to respond to assessments relying on written English in instruction and response. Sign Language assessments should also consider differences in cognitive processing found in deaf individuals compared to hearing, and design assessments with their strengths in mind (i.e. designing assessments that use spatial memory rather than serial memory spans since the prior is enhanced and the latter is much shorter for deaf people). Keeping the heterogeneity of the population in mind, sign language assessments that claim to have standardized normative data should be considered alongside participant history to determine whether they accurately reflect language ability rather than artifacts of delayed language exposure, educational background, or other contextual factors (Denmark & Atkinson, 2015).

There is value in using established spoken-language assessments as models to assess sign language, but this should be approached cautiously. Direct translation of these assessments introduces cultural and linguistic biases that may distort scores. Adaptation is preferred over translation, as it retains useful task formats while revising content to measure sign language in a culturally and cognitively appropriate way. Such adaptations should be led by native signers immersed in Deaf culture with expertise in psychological and language assessment as these individuals are better able to recognize potential psychometric conflicts that may arise during the

process. If the lead researcher(s) is/are lacking in expertise in any of the aforementioned qualities, they should collaborate with those having complementary skills to ensure tests are both linguistically and culturally valid (Denmark & Atkinson, 2015).

Beyond design, it is also important to consider how test scores are interpreted and used. As noted in language testing literature, tests can support norm-referenced decisions (ranking individuals across an ability spectrum) or criterion-referenced decision (classifying individuals based on a threshold) (Spolsky & Hult, 2008). Criterion-referenced screening is especially relevant to ASL research, where the goal is often to determine whether a participant is fluent enough in ASL to be included in a study. Such decisions are vulnerable to classification errors, and the consequences of these errors should be considered. In the case of using an assessment with instructions and responses given in written English (not designed with a Deaf-signer focus), a false negative might occur that excludes a fluent Deaf signer with delayed language access or who learned English as a 2nd language. In the case of an assessment using easy to recognize single-signs with high iconography, a false positive may occur which includes individuals who are not able to comprehend natural ASL discourse. Both error types undermine validity, with false negatives excluding segments of the deaf population and false positives distorting datasets.

These risks tie back to concerns raised by Denmark and Atkinson (2015). Without attention to heterogeneity in language experience and community context, assessments risk becoming “gatekeeping” rather than “door opening”. Misclassification not only affects research findings but also has broader consequences. Scientific studies recruiting D/deaf signers can inform technologies, policies, and practices that can directly impact their lives. Criterion-referenced screening designed with linguistic expertise, community input and awareness of

classification costs offer a pathway toward more inclusive, accurate, and ethically responsible research practices (Denmark & Atkinson, 2015; Spolsky & Hult, 2008).

These principles highlight the importance of a Deaf-first, culturally valid, and practically scalable assessment. Though the assessment designed in this dissertation is still in the early stages of development, it was created with these priorities in mind. Chapter 5 details its design and initial validation.

## **Chapter 5: Developing an enhanced online ASL assessment tool**

### **Current Study**

The ASLTB was developed as a stand-alone, self-administered screening tool intended to increase the inclusion of D/deaf and signing individuals in research. The ASLTB includes three task types: Story Comprehension (Story Task), fingerspelling in context (Fingerspelling Task), event sequencing (Maze Task), and a match task (Match Task). The first three were designed to provide insight into participants' ASL comprehension skills and language processing strategies while minimizing reliance on English proficiency. The Match Task was included to offer additional context about participants' likely age of first language (L1) exposure, assuming ASL was their L1, based on patterns previously associated with early vs late L1 acquisition.

The Story Task was modeled after reading comprehension questions commonly found in standardized tests, such as the Scholastic Aptitude Test (SAT), adapted for the visual nature of ASL. Because ASL lacks a standardized writing system, video-based story tasks serve as an appropriate equivalent for assessing discourse level comprehension. The use of comprehension questions following videos of stories told in ASL reflects approaches used in assessments like the Avant STAMP, which evaluates skills through video stimuli followed by multiple choice comprehension items. The image-based multiple-choice options used in the Story Task was modeled after the ASL Receptive Skills Test (Enns et al., 2013), which uses visual answer options to reduce dependence on English to accurately assess ASL comprehension in children.

The Fingerspelling Task extends the story task by embedding a fingerspelled word within each signed phrase. This task was expected to be harder for new signers and to be easier for fluent signers who are generally more experienced at visually decoding rapid fingerspelling. Like

the story task, this task uses image-based multiple choice responses to minimize the influence of English fluency. Because only one word in each signed phrase is fingerspelled, with the rest of the words being signed, the task remains accessible to ASL fluent participants regardless of their English proficiency. Fingerspelling is frequently taught in college-level ASL courses and is widely regarded as an important component of ASL fluency. For example, Lifeprint, a widely used ASL curriculum developed by Deaf educator Dr. Bill Vicars, highlights fingerspelling as one of the characteristics of ASL fluency (Vicars, 1997). Embedding the fingerspelled word within a signed sentence mirrors how fingerspelling typically appears in natural signed conversations, enhancing the task's external validity. Including this task reflects not only linguistic relevance but also standards commonly emphasized in ASL instruction use in signing communities.

The Maze Task, originally intended to assess spatial reasoning, was redesigned to examine participants' understanding of the temporal sequence of events in short ASL stories. The original concept involved tracking participants' navigational decisions after viewing a set of directions given in ASL on a map-like interface, but due to limitations in the online testing platform (e.g., The inability to record mouse paths on Pavlovia at the time), this approach was not feasible. Instead, the task was adapted into a story sequencing format. Unlike the Story and Fingerspelling Tasks, which emphasize discourse and lexical processing respectively, the Maze task was intended to focus on how signers interpret timing, causality, and progression of events conveyed through ASL.

The Match Task was adapted from Qi and Mayberry, and was included to provide additional context about the likely age of participants' first exposure to ASL as their L1, rather than to assess fluency. Late L1 individuals rely on event plausibility more than grammatical

word order when interpreting simple sentences in ASL. A shortened version of this sentence-to-picture paradigm was added to the ASLTB to help distinguish between early and late language signers. This task was excluded from the ASLTB raw score and factor analysis to avoid conflating language access history with overall proficiency. Although the present sample did not include confirmed later L1 ASL signers for comparison, the task remains a valuable addition for providing contextual information about participants' language backgrounds (Cheng & Mayberry, 2021).

Together, these tasks were designed to capture a range of ASL skills while minimizing reliance on ASL fluency. While each task emphasizes different aspects of comprehension, they all reflect features of ASL emphasized in instruction and daily use. The Match Task, while not included in the main ASLTB score, adds value by offering contextual information about participants' background, particularly in the timing of ASL exposure as an L1.

Beyond task-level considerations, the ASLTB was developed to address broader accessibility barriers in research. As a free stand-alone self-administered screening tool, it enables researchers to include D/deaf and signing participants in studies without the need to be fluent in ASL themselves or to be reliant on live interpreters. This makes the tool especially valuable for labs with limited funding, staffing, or ASL expertise. Hosted on Pavlovia, this tool can be distributed online with minimal cost and logistical burdens, allowing researchers to streamline their screening process and allocate more time and resources on research and analysis. This tool would be freely available for adaptation and use by other researchers in the future who may want to improve the ASLTB. Recruiting participants online rather than relying solely on university populations allows for broader inclusion of ASL users with diverse language backgrounds. This approach helps to ensure that the resulting assessment tool is more

representative of the wider signing community. As higher education in the United States is conducted primarily in English, exclusively recruiting from college settings risks overrepresenting bilingual ASL-English users in screening tool validation.

Overall, if successfully developed and validated, this assessment has the potential to increase enhance efficiency and inclusivity of research efforts involving D/deaf and Hard of Hearing populations. Given these goals, the current study focused on evaluating the preliminary validity of the ASLTB in its' current form.

To examine whether the ASLTB is sensitive to differences in ASL proficiency, we first asked whether participants' scores on the battery reflected their self-reported fluency. If the ASLTB functions as intended, participants who report higher fluency should show stronger performance.

We also examined whether the different tasks within the battery capture distinct dimensions of ASL comprehension or reflect a different underlying structure. To test this, we first used a Confirmatory Factor Analysis to evaluate a task-based model in which items were grouped according to their respective task. If tasks measure distinct aspects of comprehension, we would expect this model to show good fit. We then conducted an Exploratory Factor Analysis (EFA) to examine how items cluster based on participant performance, to examine whether a different pattern emerged beyond the predefined task divisions.

Finally, we conducted a follow-up analysis comparing ASLTB scores to the American Sign Language Comprehension Test (ASLCT), a previously evaluated ASL screening measure (Hauser et al., 2016). Although the ASLTB and ASLCT differ in structure and format, a positive

correlation between the two assessments would suggest the ASLTB is functioning as intended: assessing ASL receptive skills in a manner consistent with an established screening tool.

## **METHODS**

This study was approved by the University of Washington's Institutional Review Board and carried out in accordance with the Code of Ethics of the Declaration of Helsinki.

### ***Participants***

Participants were recruited via flyers posted in the Greater Seattle Area and online social media posts. Informed consent was obtained from all participants. All participants were compensated for their time.

A total of 75 participants ( $M=30.89$ ,  $SD = 8.00$ ) of varying self-reported ASL fluency were recruited for this study. Group assignment relied on participant response to the following question: "How fluent are you in ASL?"

### **Fluent**

A total of 22 participants in this study self-reported being fluent in ASL. Of these fluent signers, seven identified as Deaf, four as Hard of Hearing (HH), ten as Children of Deaf Adults (CODA), three as having other family members that are Deaf aside from parents, eight as interpreters, and six as hearing. These identities were not mutually exclusive, as participants were able to select from multiple options given in the demographic survey. In terms of educational background: two participants reported completing some high school or graduating from high school, three reported having some college experience, 11 reported having a bachelor's degree, and six reported having graduate-level education (e.g. a Master's or PhD).

### Somewhat Fluent

A total of 11 participants in this study self-reported being somewhat fluent in ASL. Of these somewhat fluent signers, two identified as Deaf, two as HH, five as CODA, and five as hearing. These identities were not mutually exclusive, as participants were able to select from multiple options given in the demographic survey. In terms of educational background: four reported having some college experience, five reported having a bachelor's degree, and two reported having graduate-level education (e.g. a Master's or PhD).

### Can Communicate with Difficulty

A total of 18 participants in this study self-reported being able to communicate in ASL with difficulty. Of these participants 16 identified as hearing, and 2 reported their identity as not being listed. In terms of educational background: five reported having some college experience, nine reported having a bachelor's degree, and four reported having graduate-level education (e.g. a Master's or PhD).

### Cannot Communicate

A total of 24 participants in this study self-reported not being able to communicate in ASL. Of these participants, 23 identified as hearing and one did not respond with their identity. In terms of educational background: one reported having some college experience, 11 reported having a bachelor's degree, and 12 reported having graduate-level education (e.g. a Master's or PhD). Non-signers were included as a baseline to document how individuals without ASL knowledge perform, helping to demonstrate that the assessment could distinguish signers from non-signers.

## *Procedure*

All participants were emailed a link to complete the demographic survey, HIPAA authorization, and consent forms via REDCap. Upon completion of these forms, participants were sent an email in which they were given a participant identifier and links for the ASLTB, which was hosted on Pavlovia. The email also emphasized the importance of entering the provided participant identifier when accessing each link and instructed to use Google Chrome on a laptop when engaging in the assessment, as the videos in the ASLTB were not compatible with other browsers or devices. Participants were paid upon completion of both the survey and the two-part assessment.

## Materials

### *Demographic Survey*

A survey was provided to all participants with questions about age, gender identity, handedness, educational background, current use of ASL, current use of Signed Exact English (SEE), current use of spoken & written English, involvement with signing communities, languages used during childhood, hearing status of primary and secondary caregivers, and the languages those caregivers used. Two versions of the survey were used: The original and a slightly updated version that included new questions regarding participants' past and present use of assistive listening devices, what type of signing they tend to use daily (full SEE to full ASL), and how much they rely on facial expressions and lip movements when watching ASL. The original is the same demographic survey administered in the divided attention experiment described in Chapter 1, with the updated version used for later participants. A copy of the full survey, original and updated, is available in the supplemental materials of this dissertation.

### *American Sign Language Test Battery*

The ASLTB is a battery of tests meant to assess a participant's knowledge of ASL. This assessment contains four tasks, with the intention of measuring different aspects of ASL: Story task, Maze Task, Fingerspelling Task, and Match Task. The ASLTB was split into two "experiments" on Pavlovia to allow participants to take a break and return to their computers for the second half if needed. Part 1 contained the Story Task and Maze Task while Part 2 contained the Fingerspelling Task and Match Task. All tasks in the ASLTB were built using Psychopy.

When opening the links for Part 1 and Part 2, participants were asked to provide their participant identifier. This identifier was provided to them in the email in which they received the links. Once the content for the tasks were loaded participants can click "OK" to start the ASLTB tasks. The first provided link contained the Story and Maze Tasks, while the second contained the Fingerspelling and Match Tasks.

#### Story Task

The purpose of the Story Task is to test the understanding of content in a conversation or story in ASL.

#### Story Paradigm

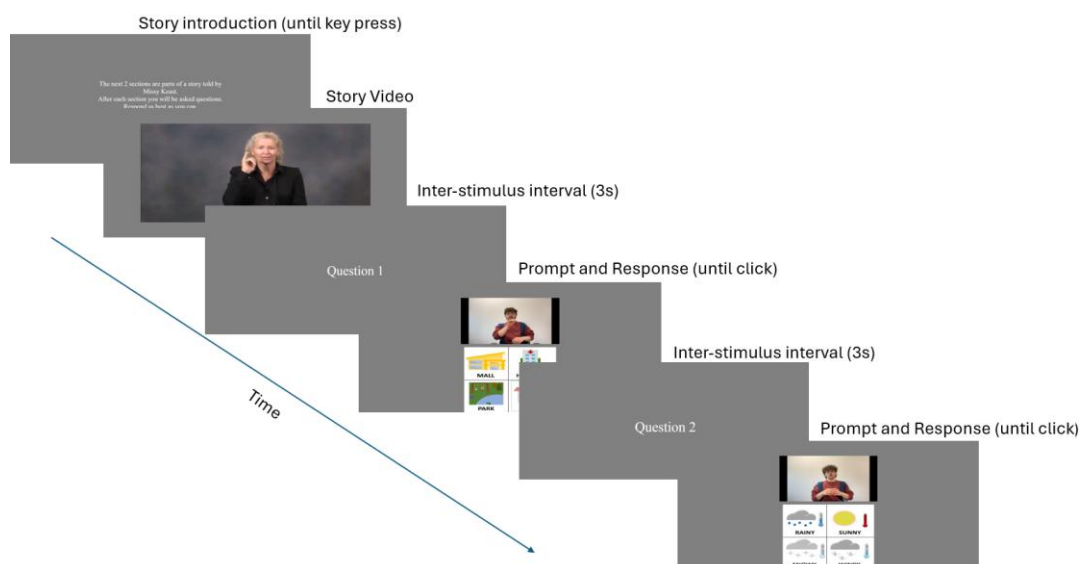
Participants are presented with an instruction video in ASL. Text captions for the sentences signed were provided in the video. The instructions were as follows: "You will be observing a series of videos in sign. Once each video finishes, you will be asked a question about the story. You will respond by clicking 1 out of 4 options. Please click the image that best matches the correct answer to the question. Please ensure you are in a space with minimal distractions before beginning this experiment. You will not be able to pause, rewind, or fast forward while the video is playing. The videos presented here are stories, interviews, & opinions

that do not necessarily reflect the views or experiences of our research group. Thank you for your participation. If you are ready, click the spacebar to start.” Beneath the instruction video a text message appeared which stated the following: “Video will repeat- Press space bar to continue”. Participants were able to view the instructions as many times as they desired.

Once the space bar was clicked, participants were then presented with the example screen. The top of the screen presented the following text: “EXAMPLE OF TASK”. Beneath this text an example video explained how to do the task. The example video starts with someone signing “We will now show you an example” in ASL, followed by a screen recording of a researcher engaging in the task. Text explanations are overlaid to help participants keep track of what is happening in each step of the process. Toward the end of the first playthrough of the example video, a text message appeared at the bottom of the screen stating the following: “Video will repeat- Press space bar to continue”. This example video repeated until the participant indicated that they were ready to start the task through pressing the spacebar on their keyboard.

The task began with a text introduction of the video they would watch, this text introduction told participants whether they would be watching a story or interview, and the names of the people in the videos they would be watching. This information was followed by the following message: “After each section you will be asked questions. Respond as best you can. Press the space bar to continue”. Once the space bar was clicked, the page refreshed and a video appeared of a person or people telling a story or having a conversation in ASL. The video played only once, and the screen refreshed to the prompt and response screen. On this screen, a video with a comprehension question in ASL was presented above four images of options a participant could use to answer the question. The prompt video did not have captions in English text and repeated until an answer was selected via mouse click. Once a selection was made a second

prompt and response screen appeared with a new question about the story video participants saw. Upon selecting an answer for the second question, a new text introduction appeared, providing information for the next story video and the process repeated again. Each story video had two questions to answer. Examples of set of trials for a single video can be seen in Figure 15.



**Figure 15.**

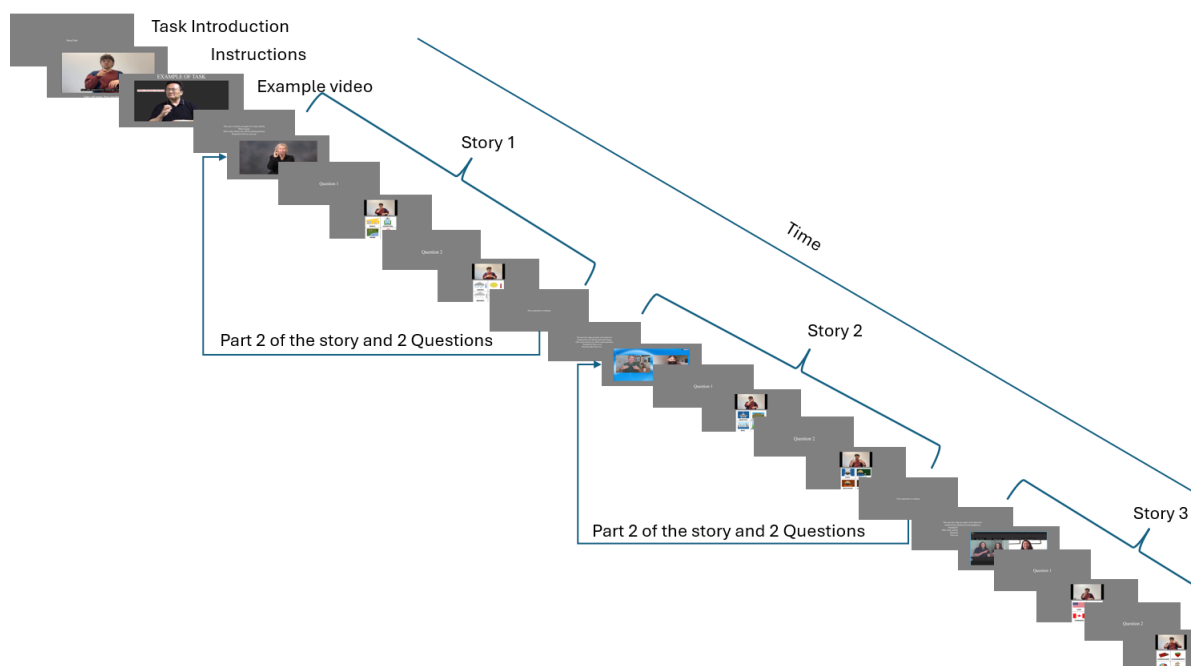
Example of a set of trials for a video presented in the Story Task. Participants were instructed to view a portion of a story once and then asked two comprehension questions regarding the story. Participants responded to the question by clicking on one of the multiple choice images provided on the screen.

In total there were three “stories” provided to participants. Two of the stories were split in half to reduce memory effects a longer story may have on participant responses. The first story video was told in ASL by a single person. This story was split into two parts. Participants answered four questions about this story in total. The second story video was an interview between two people in ASL. This interview was also split into two parts with four questions to be answered by participants. The final video was an interview between three people in ASL, with just two questions to be answered by participants. Participants answered 10 questions in total, with each question being worth one point in the ASLTB raw score. The order in which the

videos were presented remained consistent across all participants to preserve the structure of the story. Consistent order ensures two-part stories are viewed in the intended sequence. The full Story Task paradigm can be seen in Figure 16. Questions asked, multiple choice options, response labels generated (items used in the Confirmatory and Exploratory Factor Analysis), and information on the videos presented to the participants can be seen in Table 3 of the Appendix.

All story videos used in the Story Task were sourced from YouTube and were available under the Creative Commons Attribution license, which allows for the reuse and editing of the original content. More information about this license can be found here:

<https://support.google.com/youtube/answer/2797468>. All instruction and prompt videos were original videos made by ASLTB researchers fluent in ASL.



**Figure 16.**

Story Task paradigm. Participants were presented with three “stories”, with a set of questions to answer related to the videos presented. Two of the stories were split into two parts, while the final story was a single part. There were a total of 10 questions asked in the Story Task.

### Maze Task:

The purpose of the Maze Task is to test the comprehension of event sequences in a story in ASL.

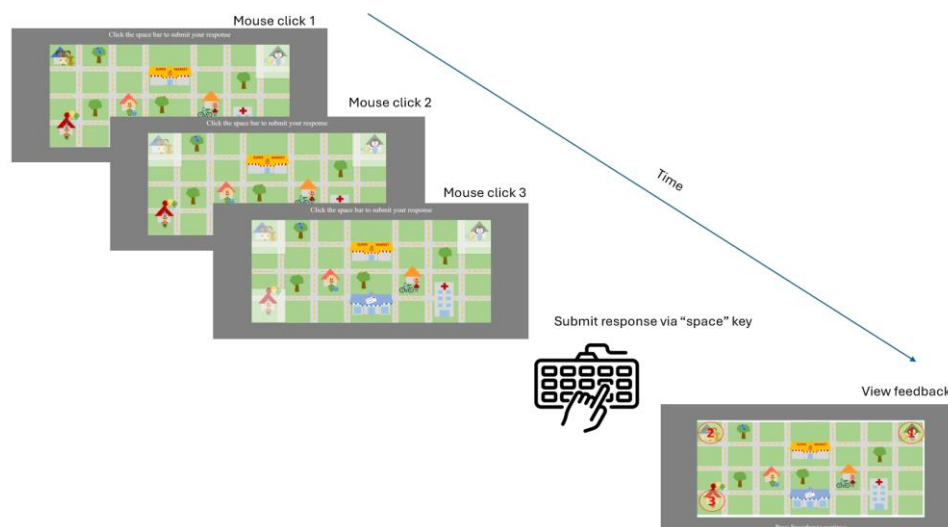
### Maze Paradigm

Participants are presented with an instruction video in ASL. Text captions for the sentences signed were provided in the video. The instructions were as follows: “You will be observing a series of videos in sign. These videos will have stories within them. After the video, a picture of a town will appear. For this task, you will select events as they occurred. First, select who the story is about. Second, select the first location visited. Third, select the last location visited. When you’ve made your 3 selections you can submit your response by clicking the spacebar. You cannot erase mistakes but try your best. If you feel ready, press the space bar to start the task. If you need to see this again, the video will loop.” Text then appears in the video stating the following: “Press Space Bar Or Video Will Repeat”. Beneath the instruction video a text message appeared which stated the following: “Video will repeat- Press space bar to continue”. Participants were able to view the instructions as many times as they desired.

Once the space bar was clicked, participants were then presented with the example screen. The top of the screen presented the following text: “EXAMPLE OF TASK”. Beneath this text an example video explained how to do the task. The example video starts with someone signing “We will now show you an example” in ASL, followed by a screen recording of a researcher engaging in the task. Text explanations are overlaid to help participants keep track of what is happening in each step of the process. After the example response is shown, the researcher explains their response process in ASL. This is followed by text on the video that states the following: “Video will repeat OR If ready, press the space bar”. Toward the end of the

first playthrough of the example video, a text message appeared at the bottom of the screen stating the following: “Video will repeat- Press space bar to continue”. This example video repeated until the participant indicated that they were ready to start the task through pressing the spacebar on their keyboard.

The task began with a prompt to begin the trial. This screen contained text stating the following: “Click space button to begin”. Once the space bar was clicked, the page refreshed and a video appeared of a person telling a short story in ASL. The video played only once, and the screen refreshed to the response screen. An image of a town with eight clickable objects was centered on the screen. Above this image was the following message presented in text: “Click the spacebar to submit your response”. While participants were instructed to select only three objects in a specific order to represent the sequence of events that occurred in the story, they were able to select anywhere from zero to eight objects before submitting. As participants clicked an object, it became highlighted to let the participant know this option had been selected and recorded. If a participant selected an object by mistake, they were unable to undo the selection which was the justification to allow for more than three clicks per response submission. Once participants were satisfied with their selected sequence of events, they submitted their response for the trial by pressing the spacebar. This triggered a feedback screen displaying the same town map, now overlaid with number markers indicating the correct objects and their order. Below this image of the town was text that stated the following: “Press Spacebar to continue”. This feedback was included to support participants, as this task required more complex responses compared to other tasks within the ASLTB. When the spacebar was pressed during the feedback presentation, a new screen with a prompt to begin the next trial appeared. A visual schematic of how to respond to a single trial in the Maze Task can be seen in Figure 17.

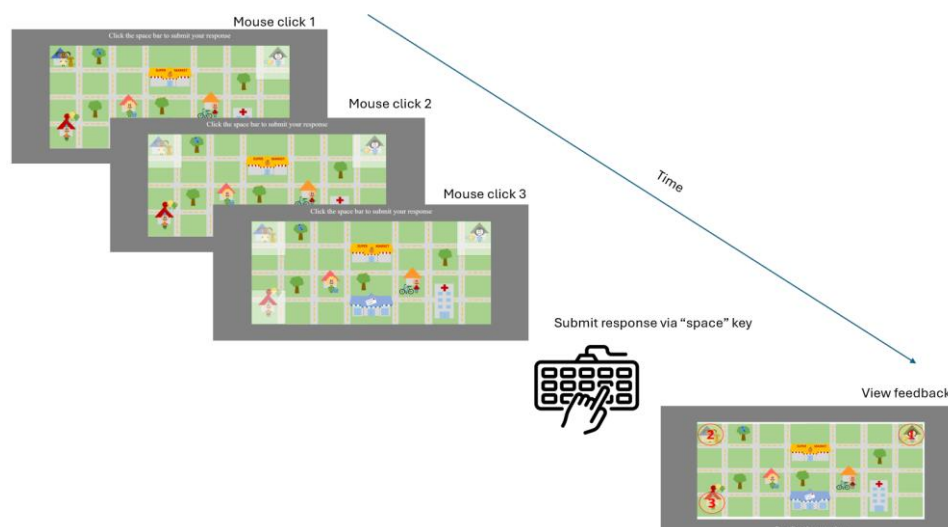


**Figure 17.**

Visual of response to a trial in the Maze Task. Participants begin by selecting the first, second, and third events using mouse clicks. After three objects are selected, responses are submitted by pressing the spacebar. A feedback screen then appears, displaying the correct sequence of events.

Participants completed a total of six trials for the Maze Task. Trials were presented in random order. Each trial was worth a maximum of six points in the ASLTB raw score: one point was earned for correctly selecting each object, and one point was earned for selecting each object in the correct order. Because participants were unable to undo clicks once they were made, errors in selection (such as choosing an incorrect object by mistake or repeatedly selecting the same object) could affect the sequence points earned. Even if the correct object was selected later in the response, they would only earn a point for the object points as the response sequence for that object no longer matched the correct sequence for the trial. The full Maze Task paradigm can be seen in Figure 18. Stories presented, response options available in the image of the town, and response labels generated (items used in the Confirmatory and Exploratory Factor Analysis) can be seen in Table 3 of the Appendix.

All instruction and story videos in the Maze Task were original videos made by ASLTB researchers fluent in ASL.



**Figure 18.**

Maze Task paradigm. Participants were presented with a story for which the task was to respond with the sequence of events as they occurred in the video. Selection of events were made by selecting objects on a town map displayed during the response screen. Feedback followed each response submission. A total of six trials were completed in the Maze Task.

### Fingerspelling Task

The purpose of the Fingerspelling Task is to assess the ability to correctly identify fingerspelled words embedded in ASL sentences, using contextual cues to support understanding.

### Fingerspelling Paradigm

Participants are presented with an instruction video in ASL. Text captions for the sentences signed were provided in the video. The instructions were as follows: “You will be observing a series of videos in sign. After each video, there will be a question asking what the fingerspelled word was. Please click the image that best matches the correct answer to the

question. Please ensure you are in a space with minimal distractions before beginning this experiment. You will not be able to pause, rewind, or fast forward while the video is playing. The videos presented here are stories, interviews, & opinions that do not necessarily reflect the views or experiences of our research group. Thank you for your participation. If you are ready, click the spacebar to start.” Beneath the instruction video a text message appeared which stated the following: “Video will repeat- Press space bar to continue”. Participants were able to view the instructions as many times as they desired.

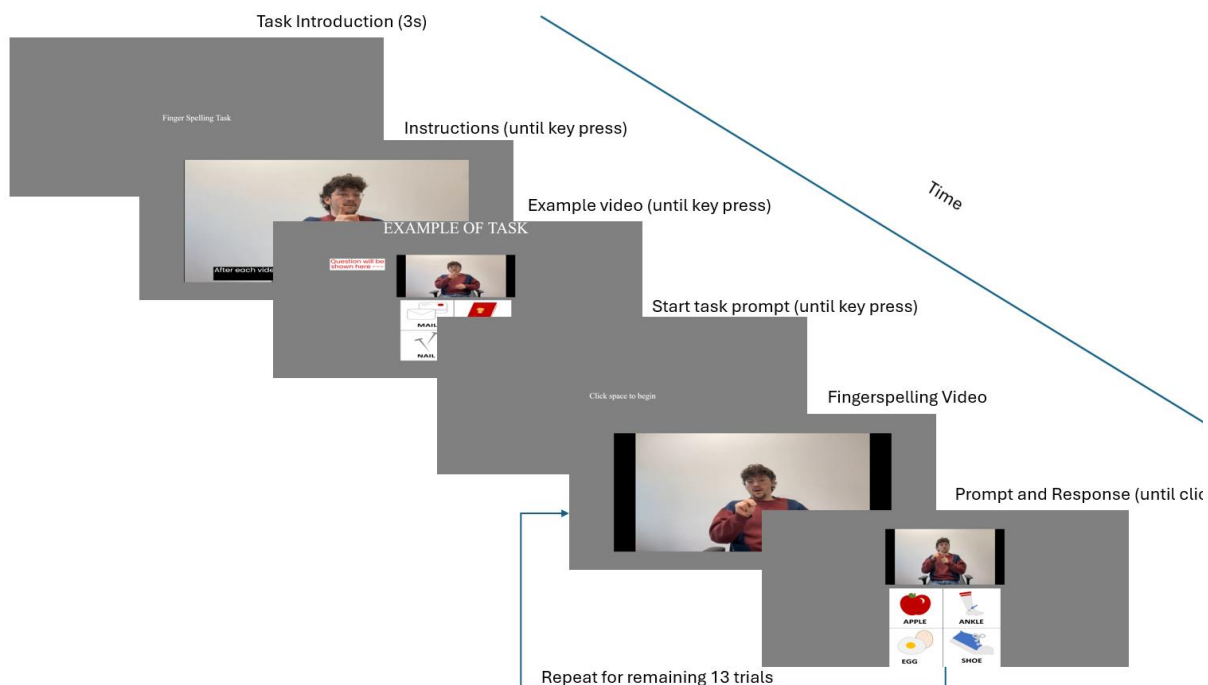
Once the space bar was clicked, participants were then presented with the example screen. The top of the screen presented the following text: “EXAMPLE OF TASK”. Beneath this text an example video explained how to do the task. The example video starts with someone signing “We will now show you an example” in ASL, followed by a screen recording of a researcher engaging in the task. Text explanations are overlaid to help participants keep track of what is happening in each step of the process followed by text on the video that states the following: “Video will repeat OR If ready, press the space bar”. Toward the end of the first playthrough of the example video, a text message appeared at the bottom of the screen stating the following: “Video will repeat- Press space bar to continue”. This example video repeated until the participant indicated that they were ready to start the task through pressing the spacebar on their keyboard.

The task began with a prompt to begin the trial. This screen contained text stating the following: “Click space button to begin”. Once the space bar was clicked, the page refreshed and a video appeared of a person telling a short story in ASL. One of the words in the story was fingerspelled while the rest were in ASL. The video played only once, and the screen refreshed to the response screen. On this screen, a video with a response prompt in ASL was presented

above four images of options a participant could use to answer the question. The video did not have captions in English text, but is translated here: “The video you recently watched had one fingerspelled word. Pick which of the four images best matches that word”. The prompt video repeated until an answer was selected via mouse click. Upon selecting an answer, a new trial began with a prompt screen to start the next video and the process repeated again for the remaining trials.

Participants answered 14 questions in total, with each question being worth one point in the ASLTB raw score. Trials were presented in random order. The full Fingerspelling Task Paradigm can be seen in Figure 19. Video content, multiple choice options, and response labels generated (items used in the Confirmatory and Exploratory Factor Analysis) can be seen in Table 3 of the Appendix.

All instruction and story videos in the Fingerspelling Task were original videos made by ASLTB researchers fluent in ASL.



**Figure 19.**

Fingerspelling Task paradigm. Participants were presented with a story for which the task was to identify the fingerspelled word presented in the video. A total of 14 trials were completed in the Fingerspelling Task.

### Match Task

The purpose of the Match Task is to provide additional information or shed light on whether ASL first Language (L1) participants have early or late exposure to their first language.

This task uses a subset of trials from a study conducted by Qi & Mayberry which used a sentence-to-picture matching paradigm to examine whether early language experience influences syntactic processing. Researchers found late first language (L1) Deaf ASL signers relied more on event plausibility than word order during comprehension, despite having decades of experience in ASL. Early L1 Deaf ASL signers and hearing L2 ASL signers both robustly relied on word

order, despite conflicts with event plausibility (Cheng & Mayberry, 2021). Details of the task are explained below:

In the original study, participants were shown ASL sentences consisting of three signs from the ASL Communicative Developmental Inventory, typically produced by three-year-old native ASL users (Anderson & Reilly, 2002). After viewing the sentence, participants were shown a line drawing that either matched or mismatched the given ASL sentence. For example, a matched trial might pair a video of the signed sentence “DAD-KICK-TABLE” with an image of a man kicking a Table. A mismatched trial would pair that sentence with an image of a Table kicking a man, reversing the semantic roles.

The published study tested four conditions: Implausible (animate – animate), Implausible (inanimate - animate), Plausible (animate - animate), & Plausible (animate - inanimate). Each condition included 12 matched and 12 mismatched trials, for a total of 96 trials. Results showed late L1 ASL signers performed above chance on both plausible conditions and below chance on both implausible conditions, while control groups performed above chance across all conditions.

For the ASLTB, a subset of 20 trials were selected from the original 96 to create the Match Task. This subset included 10 Implausible (inanimate-animate) and 10 Plausible (animate-inanimate) trials. The two (animate animate) conditions were excluded, as performance on those trials did not differ meaningfully from conditions containing inanimate nouns. This allowed for a more concise assessment. Based on published findings, late L1 ASL signers are expected to perform below chance on implausible trials and above chance on plausible trials.

## Match Paradigm

Participants are presented with an instruction video in ASL. Text captions for the sentences signed were provided in the video. The instructions were as follows: “You will be observing a series of videos in sign. These videos will have stories within them. After watching the videos, a picture will appear. After seeing both the video and picture you will indicate whether they match. If the video and picture match, click yes. If the video and picture don’t match, click no. If you feel ready, press the space bar to start the task. If you need to see this again, the video will loop.” Text then appears in the video stating the following: “Press Space Bar Or Video Will Repeat”. Beneath the instruction video a text message appeared which stated the following: “Video will repeat- Press space bar to continue”. Participants were able to view the instructions as many times as they desired.

Once the space bar was clicked, participants were then presented with the example screen. The top of the screen presented the following text: “EXAMPLE OF TASK”. Beneath this text an example video showed participants how to do the task. The example video showed a screen recording of a researcher engaging in the task. Text explanations are overlaid to help participants keep track of what is happening in each step of the process. Toward the end of the first playthrough of the example video, a text message appeared at the bottom of the screen stating the following: “Video will repeat- Press space bar to continue”. This example video repeated until the participant indicated that they were ready to start the task through pressing the spacebar on their keyboard.

The task began with a prompt to begin the trial. This screen contained text stating the following: “Click space button to begin”. Once the space bar was clicked, the page refreshed and a video appeared of a person signing a sentence in ASL. The video played only once, and the

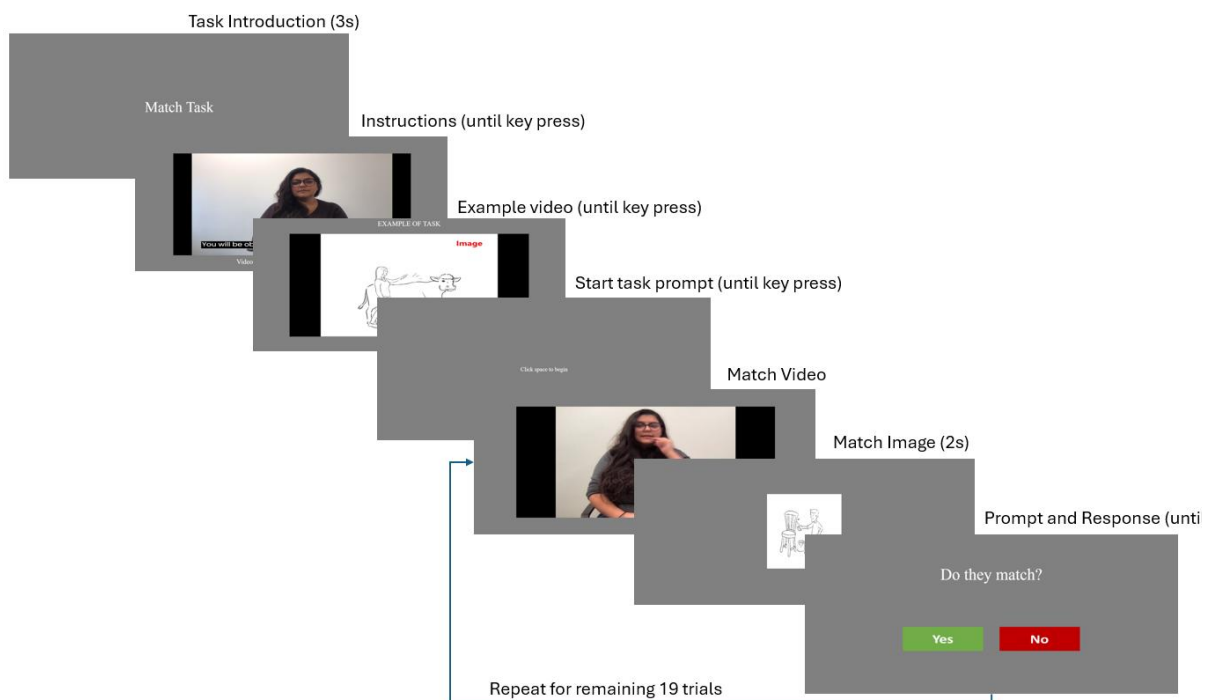
screen refreshed to the image screen. On this screen, a line-drawing of an image, that either matched or mismatched with the intended semantic roles given in the sentence video, was presented for two seconds. After the image was presented, the screen refreshed to the response screen displaying the question: “Do they match?” centered on the screen. Beneath the question were two clickable buttons the participant can use to give their response to the question: a green “Yes” button indicating the video and image matched, and a red “No” button indicating they did not. Upon selecting an answer, a new trial began with a prompt screen to start the next video and the process repeated for the remaining trials.

There were two conditions in this task, as mentioned earlier: 10 Implausible (inanimate-animate) and 10 Plausible (animate-inanimate) trials. Each condition included five matched and five mismatched trials. In the Implausible (inanimate-animate) condition, matched trials presented ASL sentences in which the inanimate object performs an action paired with an image reflecting the same thing. For example, “COOKIE CARRY DAD” would be paired with an image of a cookie carrying a man. Mismatched trials in this condition paired implausible sentences with images reversing the role of the subject and object. For example, “DOOR KICK COW” would be paired with an image of a cow kicking a door. In the Plausible (animate-inanimate) condition, matched trials presented ASL sentences which are more logical in event structure paired with an image reflecting the same thing. For example, “DAD KICK TABLE” would be paired with an image of a man kicking a Table. Mismatched trials in this condition paired plausible sentences with images reversing the role of the subject and object. For example, “BOY CARRY EGG” would be paired with an image of an egg carrying a boy. Trials were presented in random order. Participants answered 20 questions in total with each question worth one point in the Match Task score separate from the ASLTB Raw score. The full Match Task

paradigm can be seen in Figure 20. Video content, Image content, response choice options, and response labels generated can be seen in Table 3 of the Appendix.

All instruction and story videos in the Maze Task were recreated by ASLTB researchers fluent in ASL. This was done to ensure consistency, as the same two signers were used throughout the entire ASLTB. The line drawings used in the task were taken directly from the original Qi and Mayberry study.

Scores from the Match Task were not included in the ASLTB raw scores or in the Exploratory Factor Analysis. This decision was made to avoid making or reinforcing an assumption that late L1 ASL Deaf individuals, with over 9 years of experience with the language, are not fluent in ASL. This task instead aims to provide additional context to the timing of participants' first exposure to language, assuming that language was ASL. Additionally, the ASL sentences used in the task uses signs typically produced by three-year-old native signers which might not be rigorous enough to test fluency. Taking all of this into consideration, performance on this task is best interpreted as a reflection on processing strategies than fluency, providing additional insight on whether participants had late or early exposure to ASL as their first language.



**Figure 20.**

Match Task paradigm. Participants were presented with a sentence in ASL paired with a drawing of an image. The task was to indicate whether the given ASL sentence matched the image shown. A total of 20 trials were completed in the Fingerspelling Task.

Scores from the Match Task were not included in the ASLTB raw scores or in the Exploratory Factor Analysis. This decision was made to avoid making or reinforcing an assumption that late L1 ASL Deaf individuals, with over 9 years of experience with the language, are not fluent in ASL. This task instead aims to provide additional context to the timing of participants' first exposure to language, assuming that language was ASL. Additionally, the ASL sentences used in the task uses signs typically produced by three-year-old native signers which might not be rigorous enough to test fluency. Taking all of this into consideration, performance on this task is best interpreted as a reflection on processing strategies than fluency, providing additional insight on whether participants had late or early exposure to ASL as their first language.

## RESULTS

### *ASLTB Scores*

A non-parametric test, the Spearman's rank-order correlation, was conducted to assess the strength and direction between participants' self-reported fluency and performance in the ASLTB. Results of the correlations are listed below.

### Story Task

Self-reported fluency was positively correlated with performance in the Story Task. This relationship was statistically significant ( $\rho = 0.84$ ,  $p < .001$ ). As reported fluency increased, performance increased. There were 10 story task questions, each worth a single point. Means and standard deviations each fluency groups' performance in the Story Task can be seen in Table 4. In addition to the average raw and percent scores, sensitivity ( $d'$ ) scores were calculated to assess participants' ability to discriminate the correct answer beyond chance. For each participant and task, we computed the proportion correct ( $P_c = \text{\#correct}/\text{\#trials}$ ). To avoid undefined values at the extremes,  $P_c$  was continuity-corrected using the log-linear rule  $(\text{correct} + 0.5)/(\text{trials} + 1)$ . We then converted  $P_c$  to signal-detection signal detection sensitivity ( $d'$ ) using the standard m-AFC signal detection formula (Green & Dai, 1991) implemented in the psyphy package for R, which yields  $d'=0$  at chance performance ( $P_c = 0.25$ ) and increases monotonically with sensitivity.

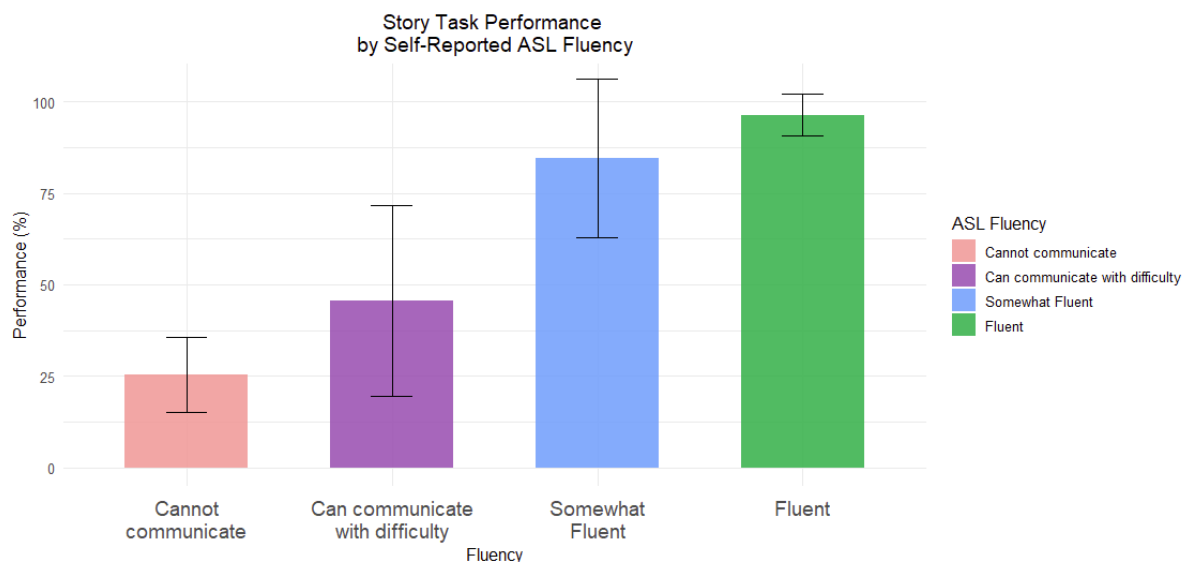
As ASL fluency increased,  $d'$  scores increased, indicating fluent signers were more able to reliably select correct responses well above chance. In contrast, participants with lower self-reported fluency showed reduced discriminability, with  $d'$  scores below 1.

**Table 4.** Story Task performance by Self-Reported Fluency.

ASL Fluency	Story score raw (out of 10 points)	Story performance M $\pm$ SD	Story $d'$ M $\pm$ SD
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**M ± SD**

Fluent	9.64 ± 0.58	96.36% ± 5.81%	2.71 ± 0.40
Somewhat Fluent	8.45 ± 2.16	84.55% ± 21.62%	2.20 ± 0.90
Can communicate with difficulty	4.56 ± 2.59	45.56 % ± 25.95%	0.72 ± 0.95
Cannot communicate	2.54 ± 1.02	25.42% ± 10.21%	0.07 ± 0.36

**Figure 21.**

Performance on the Story Task (y-axis) by self-reported ASL fluency (x-axis). Bars represent the mean percent correct for each fluency group, and error bars indicate the standard deviation. Groups are color coded as follows: Cannot communicate (pink), Can communicate with difficulty (purple), Somewhat fluent (blue), and Fluent (green).

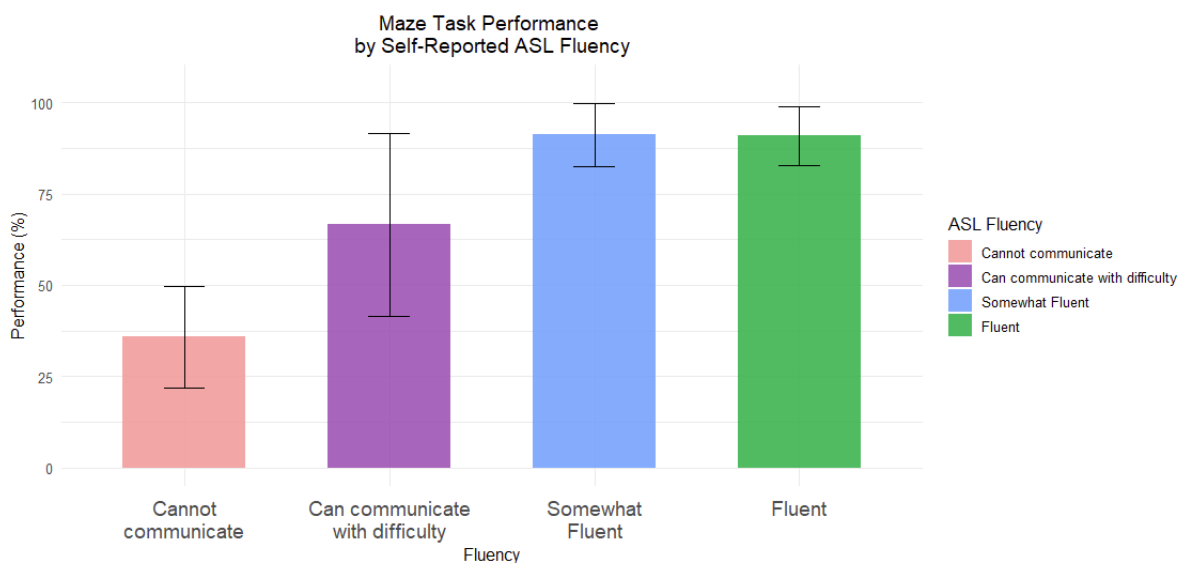
**Maze Task**

Self-reported fluency was positively correlated with performance in the Maze Task. This relationship was statistically significant ( $\rho = 0.80, p < .001$ ). As reported fluency increased, performance increased. There were 6 Maze Task questions, each worth six points. Means and standard deviations each fluency groups' performance in the Maze Task can be seen in Table 5.

Because each question involved a sequence of ordered selections with a changing number of alternatives, signal detection  $d'$  was not applicable.

**Table 5.** Maze Task performance by Self-Reported Fluency.

ASL Fluency	Maze score raw (out of 36 points) M $\pm$ SD	Maze performance M $\pm$ SD
Fluent	32.73 $\pm$ 2.90	90.91% $\pm$ 8.05
Somewhat Fluent	32.82 $\pm$ 3.12	91.16% $\pm$ 8.68
Can communicate with difficulty	23.94 $\pm$ 9.01	66.51% $\pm$ 25.02
Cannot communicate	12.88 $\pm$ 5.02	35.76% $\pm$ 13.93



**Figure 22.**

Performance on the Maze Task (y-axis) by self-reported ASL fluency (x-axis). Bars represent the mean percent correct for each fluency group, and error bars indicate the standard deviation. Groups are color coded as follows: Cannot communicate (pink), Can communicate with difficulty (purple), Somewhat fluent (blue), and Fluent (green).

### Fingerspelling Task

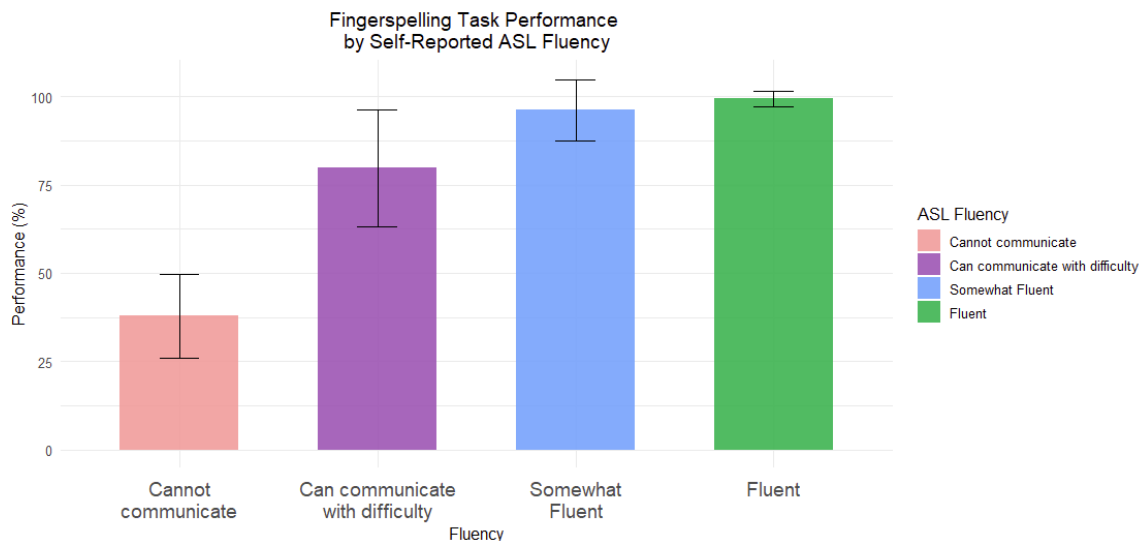
Self-reported fluency was positively correlated with performance in the Fingerspelling Task. This relationship was statistically significant ( $\rho = 0.88$ ,  $p < .001$ ). As reported fluency

increased, performance increased. There were 14 Fingerspelling Task questions, each worth a single point. Means and standard deviations each fluency groups' performance in the Fingerspelling Task can be seen in Table 6.

Sensitivity ( $d'$ ) was calculated in the same way as for the Story Task, using the m-AFC formulation for 4-alternative forced choice trials. The  $d'$  scores for the Fingerspelling task followed the same pattern seen for the Story task scores. Higher fluency groups exhibited greater discriminability compared to lower fluency groups.

**Table 6.** Fingerspelling Task performance by Self-Reported Fluency.

<b>ASL Fluency</b>	<b>Fingerspelling score raw (out of 14 points) M ± SD</b>	<b>Fingerspelling performance M ± SD</b>	<b>Fingerspelling <math>d'</math></b>
Fluent	13.91 ± 0.29	99.35% ± 2.10	3.10 ± 0.21
Somewhat Fluent	13.45 ± 1.21	96.10% ± 8.67	2.88 ± 0.54
Can communicate with difficulty	11.17 ± 2.31	79.76% ± 16.48	1.98 ± 0.80
Cannot communicate	5.29 ± 1.68	37.80% ± 12.00	0.47 ± 0.37



**Figure 23.**

Performance on the Fingerspelling Task (y-axis) by self-reported ASL fluency (x-axis). Bars represent the mean percent correct for each fluency group, and error bars indicate the standard deviation. Groups are color coded as follows: Cannot communicate (pink), Can communicate with difficulty (purple), Somewhat fluent (blue), and Fluent (green).

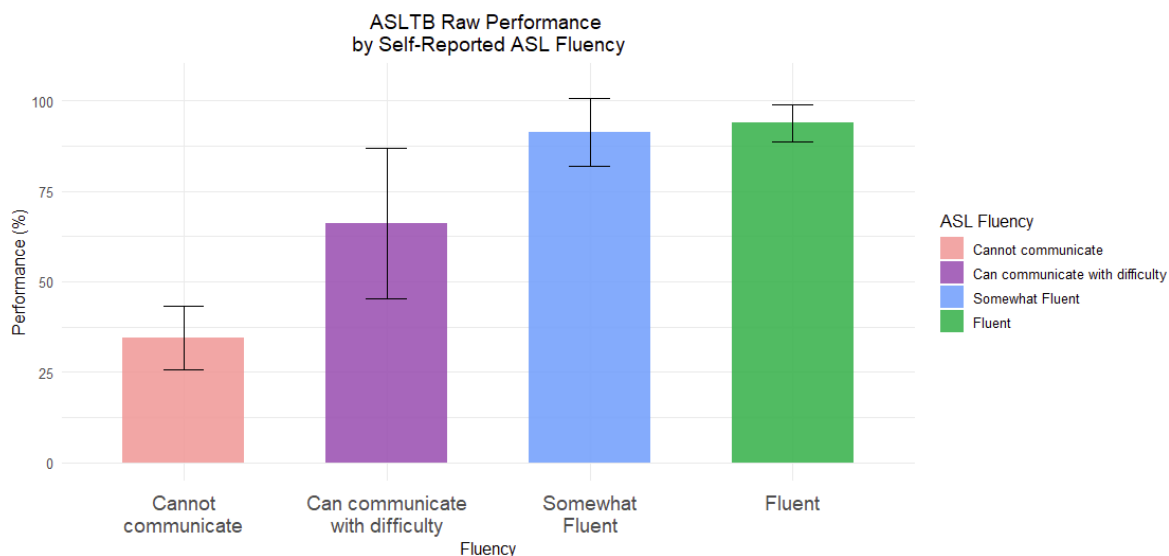
### ASLTB Raw Score

Self-reported fluency was positively correlated with performance in the ASLTB. This relationship was statistically significant ( $\rho = 0.85, p < .001$ ). As reported fluency increased, performance increased. The ASLTB raw score was made up of 10 Story Task Questions, six Maze Task Questions, and 14 Fingerspelling Task Questions. The highest score a person can get in the ASLTB is 60 points. Means and standard deviations each fluency groups' performance can be seen in Table 7. Sensitivity ( $d'$ ) scores were not calculated for the ASLTB as the tasks differed in how many response options were available, making it inappropriate to combine them into a single measure of discriminability.

**Table 7.** ASLTB Raw Score and percent accuracy by Self-Reported Fluency (Combined performance across Story, Maze, and Fingerspelling Tasks).

ASL Fluency	ASLTB raw score	ASLTB performance
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	(out of 60 points) M ± SD	M ± SD
Fluent	56.27 ± 3.10	93.79% ± 5.17
Somewhat Fluent	54.73 ± 5.64	91.21% ± 9.40
Can communicate with difficulty	39.67 ± 12.51	66.11% ± 20.86
Cannot communicate	20.71 ± 5.29	34.51% ± 8.81



**Figure 24.**

Performance on the ASLTB (y-axis) by self-reported ASL fluency (x-axis). Bars represent the mean percent correct for each fluency group, and error bars indicate the standard deviation. Groups are color coded as follows: Cannot communicate (pink), Can communicate with difficulty (purple), Somewhat fluent (blue), and Fluent (green). The ASLTB Raw score is made up of points earned in the Story, Maze, and Fingerspelling Tasks.

### Match Task Scores

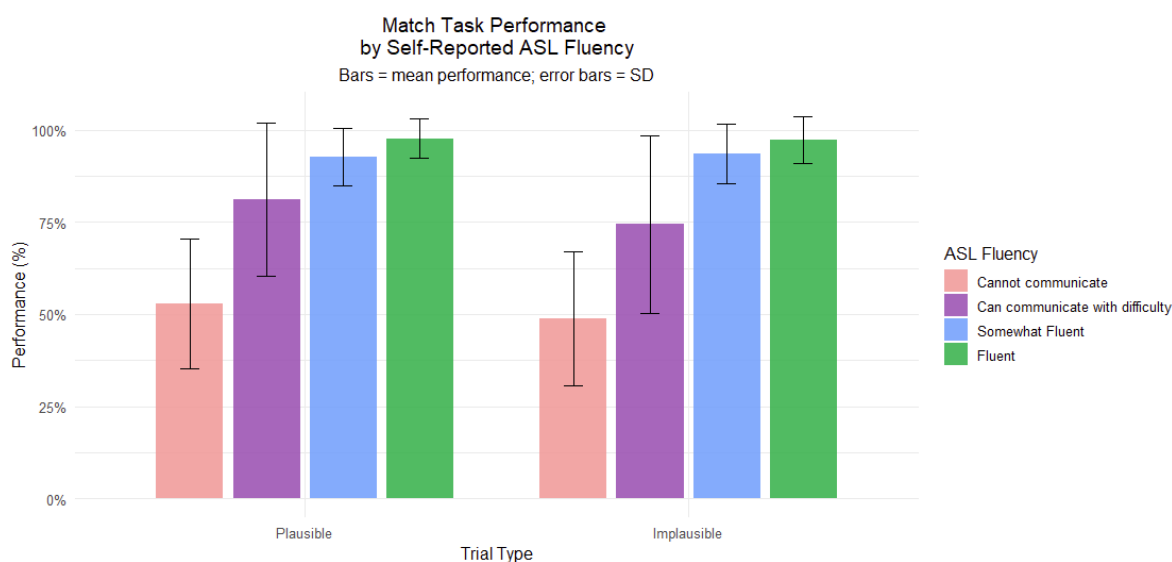
While the Match Task was not included in the ASLTB raw score, it is still informative to examine how performance differed across fluency groups. Self-reported fluency was positively correlated with performance in the Match Task. This relationship was statistically significant ( $\rho = 0.83, p < .001$ ). When examining performance within the task conditions, there were statistically significant positive correlations between fluency and both the plausible trials ( $\rho =$

0.78,  $p < .001$ ) and implausible trials ( $p = 0.78$ ,  $p < .001$ ). There were 20 Match Task questions (10 plausible and 10 implausible), each worth a single point. Means and standard deviations each fluency groups' performance in the Maze Task can be seen in Table 8.

**Table 8.** Mask Task performance by Self-Reported Fluency (Plausible, Implausible, and overall trials).

ASL Fluency	Plausible trials raw score	Implausible trials raw score	Plausible trials performance	Implausible trials performance	Match score raw (out of 20 points)	Match performance
	M ± SD	M ± SD	M ± SD	M ± SD	M ± SD	M ± SD
Fluent	9.77 ± .53	9.73 ± 0.63	97.73% ± 5.28	97.27 ± 6.31	19.50 ± 0.96	97.50 ± 4.82
Somewhat Fluent	9.27 ± .79	9.36 ± 0.81	92.73% ± 7.86	93.64 ± 8.09	18.64 ± 1.50	93.18% ± 7.51
Can communicate with difficulty	8.11 ± 2.08	7.44 ± 2.41	81.11% ± 20.83	74.44 ± 24.06	15.56 ± 4.30	77.78% ± 21.50
Cannot communicate	5.29 ± 1.76	4.88 ± 1.83	52.92 % ± 17.56	48.75 ± 18.25	10.17 ± 3.16	50.83% ± 15.79

Sensitivity ( $d'$ ) scores calculated for overall performance on the Match task in the same way as for the Story and Fingerspelling tasks, except using the m-AFC formulation for 2 alternative forced-choice trials with continuity-corrected proportion correct trials. The scores showed a similar pattern to what was observed for the Story and Fingerspelling tasks included in the ASLTB raw score, with higher fluency groups exhibiting greater discriminability compared to lower fluency groups. To further examine performance,  $d'$  scores were also calculated separately for plausible and implausible trials. Both trial types revealed similar patterns: fluent participants demonstrated high discriminability for both plausible and implausible trials compared to lower fluency groups.  $d'$  scores for overall Match task and the two conditions can be seen in Table 9.



**Figure 25.**

Performance on the Match Task (y-axis) by trial type (x-axis) and self-reported fluency (colors). Bars represent the mean percent correct for each fluency group, and error bars indicate the standard deviation. The left set of bars show performance on Plausible trials, the right set shows performance on Implausible trials. Groups are color coded as follows: Cannot communicate (pink), Can communicate with difficulty (purple), Somewhat fluent (blue), and Fluent (green). The ASLTB Raw score is made up of points earned in the Story, Maze, and Fingerspelling Tasks.

**Table 9.** Match Task sensitivity ( $d'$ ) Scores by Self-Reported Fluency Group.

ASL Fluency	Plausible trials $d'$	Implausible trials $d'$	Overall Match $d'$
Fluent	$2.22 \pm 0.39$	$2.19 \pm 0.44$	$2.51 \pm 0.48$
Somewhat Fluent	$1.84 \pm 0.56$	$1.92 \pm 0.57$	$2.12 \pm 0.70$
Can communicate with difficulty	$1.34 \pm 0.97$	$1.06 \pm 1.08$	$1.31 \pm 1.09$
Cannot communicate	$0.11 \pm 0.62$	$-0.04 \pm 0.65$	$0.04 \pm 0.65$

### *Confirmatory Factor Analysis*

Next, we carried out a Confirmatory Factor Analysis (CFA) grouping items by task. The analysis tested whether the different tasks mapped onto separate latent variables.

The CFA was conducted in R using the lavaan package. Maximum likelihood estimation was used to fit the model, with the 30 ASLTB items grouped according to the task they belonged to. The Match Task was not included in this analysis for reasons mentioned in the EFA section of this dissertation. The Match Task was not included in this analysis to reduce the number of items included in the analysis, since that task was specifically included to provide information on whether a participant had late or early language acquisition. Data wrangling was performed using the tidyverse suite (Wickham et al., 2019). Scree plots were generated using ggplot2.

The Maze Task factor accounted for the largest proportion of model variance with a variance estimate of 2.56. The Fingerspelling Task and Story Task factors accounted for much smaller proportions of variance, with estimates of 0.08 and 0.09, respectively. Standardized correlations among the factors found that the Maze Task and Fingerspelling Task factors were moderately correlated ( $r = .45$ ) and the Maze Task and Story Task factors were moderately correlated ( $r = .44$ ). However, correlation between the Story Task and Fingerspelling Task

factors was low ( $r = .08$ ), suggesting these tasks are relatively independent from one another. The standardized factor correlation matrix is shown in Table 10.

**Table 10.** Standardized factor correlations for Confirmatory Factor Analysis of the ASLTB.

	Story Task	Maze Task	Fingerspelling Task
Story Task	1.00	-	-
Maze Task	0.44	1.00	-
Fingerspelling Task	0.08	0.45	1.00

Multiple model fit indices were used to examine model fit. The Likelihood chi-square value for a three-factor model was significant ( $\chi^2(402) = 968.11, p < .001$ ), but the ratio of  $\chi^2$  to degrees of freedom was 2.41, which is acceptable (ratio  $< 5$ ). RMSEA for this model was .137 (90% CI [.126, .148]) suggesting a weaker model fit (values  $< .08$  are desirable). The Comparative Fit Index (CFI) was .687, suggesting weaker model fit (values  $> .90$  are desirable). The Standardized Root Mean Square Residual (SRMR) was .087 indicating weaker model fit (values  $< .08$  are desirable). Overall, the fit indices for the task-based model suggest poor fit to the data.

The standardized factor loadings for the three factors were moderate to high across most items. Loadings onto the Story Task factor ranged from .50 to .84 and loadings onto the Maze Task ranged from .71 to .92, indicating that these items strongly reflected the factors they loaded onto. Loadings onto the Fingerspelling Task ranged from .30 to .86. Although the majority of the Fingerspelling items showed strong loadings, there were three of the 14 items (FS\_4, FS\_5, and FS\_6) with loadings at or below .40. An additional item, FS\_3, had a relatively weak loading of 0.42. Standardized factor loadings can be seen in Table 11.  $R^2$  values for individual items ranged from .09 to .85, suggesting the factors explained a low to substantial proportion of variance in item performance.  $R^2$  values for the items can be seen in Table 12. Taken together, the

standardized factor loadings and  $R^2$  values suggest the factor scores largely captured individual differences across the three tasks.

**Table 11.** ASLTB Factor Performance by Self-Reported Fluency (Story, Maze, and Fingerspelling Tasks)

<b>Item</b>	<b>Story Task</b>	<b>Maze Task</b>	<b>Fingerspelling Task</b>
story_1_1	<b>0.59</b>	0.00	0.00
story_2_1	<b>0.77</b>	0.00	0.00
story_1_2	<b>0.50</b>	0.00	0.00
story_2_2	<b>0.69</b>	0.00	0.00
story_1_3	<b>0.75</b>	0.00	0.00
story_2_3	<b>0.57</b>	0.00	0.00
story_1_4	<b>0.84</b>	0.00	0.00
story_2_4	<b>0.57</b>	0.00	0.00
story_1_5	<b>0.54</b>	0.00	0.00
story_2_5	<b>0.76</b>	0.00	0.00
maze_1	0.00	<b>0.81</b>	0.00
maze_2	0.00	<b>0.79</b>	0.00
maze_3	0.00	<b>0.92</b>	0.00
maze_4	0.00	<b>0.84</b>	0.00
maze_5	0.00	<b>0.81</b>	0.00
maze_6	0.00	<b>0.71</b>	0.00
FS_1	0.00	0.00	<b>0.68</b>
FS_2	0.00	0.00	<b>0.64</b>
FS_3	0.00	0.00	<b>0.42</b>
FS_4	0.00	0.00	<b>0.30</b>
FS_5	0.00	0.00	<b>0.39</b>
FS_6	0.00	0.00	<b>0.37</b>
FS_7	0.00	0.00	<b>0.83</b>
FS_8	0.00	0.00	<b>0.67</b>
FS_9	0.00	0.00	<b>0.64</b>
FS_10	0.00	0.00	<b>0.64</b>
FS_11	0.00	0.00	<b>0.78</b>
FS_12	0.00	0.00	<b>0.73</b>
FS_13	0.00	0.00	<b>0.86</b>
FS_14	0.00	0.00	<b>0.83</b>

**Table 12.** Variance explained for Each ASLTB Item in Task-Based Model

<b>Item</b>	<b><math>R^2</math></b>
story_1_1	0.34

story_2_1	0.59
story_1_2	0.25
story_2_2	0.48
story_1_3	0.57
story_2_3	0.32
story_1_4	0.70
story_2_4	0.32
story_1_5	0.29
story_2_5	0.58
maze_1	0.65
maze_2	0.62
maze_3	0.85
maze_4	0.70
maze_5	0.65
maze_6	0.51
FS_1	0.46
<i>FS_2</i>	<i>0.41</i>
FS_3	0.18
FS_4	0.09
<i>FS_5</i>	<i>0.15</i>
FS_6	0.13
FS_7	0.70
FS_8	0.44
FS_9	0.40
FS_10	0.40
FS_11	0.61
FS_12	0.53
FS_13	0.74
FS_14	0.68

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### Internal Reliability

Cronbach's alpha ( $\alpha$ ) coefficients were calculated for each of the three task-based factors to evaluate internal consistency. All three factors demonstrated strong internal reliability, with  $\alpha$  values exceeding the recommended threshold of .65. For the Story Task Factor, Cronbach's  $\alpha$  was .91, indicating excellent internal consistency. The average inter-item correlation was moderate ( $r = .54$ ). For the Maze Task Factor, Cronbach's  $\alpha$  was .85, indicating very good internal consistency. The average inter-item correlation was moderate ( $r = .42$ ). For the Fingerspelling Task Factor, Cronbach's  $\alpha$  was .90, also indicating excellent internal consistency. The average inter-item correlation was moderate ( $r = .49$ ). Together, these results indicate the task-based factors showed strong internal consistency. Reliability statistics for each of the factors can be seen in Table 13.

**Table 13.** Internal consistency statistics for task-based factors.

<b>Factor</b>	<b>Cronbach's <math>\alpha</math></b>	<b>Standardized <math>\alpha</math></b>	<b>Average r</b>	<b>Median r</b>	<b>S/N Ratio</b>
Story Task	.91	.90	.54	.59	9.38
Maze Task	.85	.85	.42	.39	5.73
Fingerspelling Task	.90	.93	.49	.47	13.51

### External Reliability

External validity was evaluated by examining Spearman correlations between the task-based factor scores and self-reported ASL fluency collected from the demographic survey. All three factors showed strong positive correlations with fluency. The Fingerspelling Task factor had the strongest correlation with fluency ( $\rho = .89$ ), followed by the Story Task factor ( $\rho = .87$ ),

and the Maze Task factor ( $\rho = .84$ ). These results suggest the task-based factors meaningfully capture variation in ASL fluency levels.

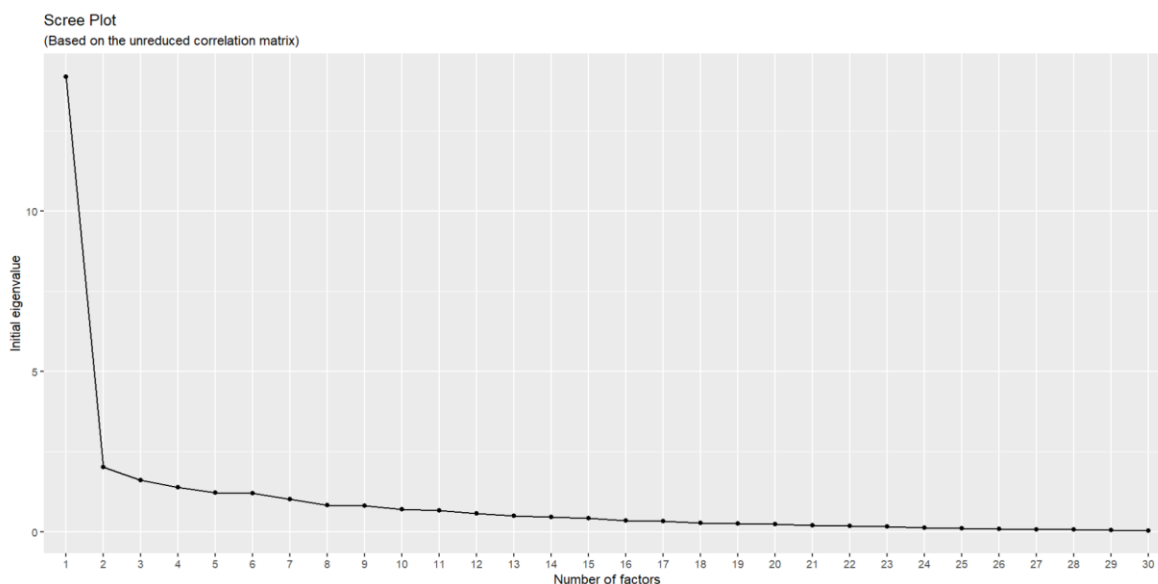
Although the task-based CFA model demonstrated strong internal consistency and meaningful correlations with ASL fluency, the overall model provided a poor fit to the data. This raised the possibility that item performance may not be organized strictly by task type. To further investigate the underlying structure of the ASLTB, we conducted an Exploratory Factor Analysis (EFA).

### ***Exploratory Factor Analysis***

To identify the latent structure of the ASLTB without imposing task-based constraints, we conducted an Exploratory Factor Analysis (EFA). The EFA was conducted in R using the psych package (Revelle, 2024) to examine the underlying structure of participant performance on the ASLTB. A total of 30 items were included in the analysis: 10 story task, 6 maze task, and 14 Fingerspelling Task items. The Match Task was not included in this analysis as it is intended to provide information on whether a participant had late or early language acquisition. Data wrangling was performed using the tidyverse suite (Wickham et al., 2019). Scree plots were generated using ggplot2.

To determine the number of factors to retain, multiple criteria were used. First, factors with eigenvalues greater than one were initially considered. Then, each retained factor was required to have at least three items with substantial loadings. Finally, theoretical clarity was evaluated to ensure each factor reflected a distinct and interpretable construct. A three-factor model was ultimately retained, as it met all of the aforementioned criteria. This decision was further validated by the scree plot shown in Figure 26, which shows an inflection point two to

three factors. A Table of the eigenvalues associated with each number of factors can be found in the supplemental materials of this dissertation.



**Figure 26.**

Scree Plot for Exploratory Factor Analysis of the ASLTB (N = 75)

The EFA was conducted using maximum likelihood extraction with oblimin rotation, which allows for correlated factors and reduces the amount of variance between the models making it orthogonal. The three-factor model explained 55% of the variance found in the ASLTB, with individual contributions of 20% (ML1), 17% (ML2), and 18% (ML3). When examining the proportion of common variance explained, ML1 accounted for 36%, ML2 for 32%, and ML3 for 33%. Variance explained by each factor can be seen in Table 14.

**Table 14.** Variance explained by each factor in the three-factor solution extracted from the ASLTB using maximum likelihood estimation with oblimin rotation.

Factor	SS Loadings	Proportion of Variance	Cumulative Variance	Proportion Explained
ML1	5.85	0.20	0.20	0.36
ML2	5.20	0.17	0.37	0.32

ML3	5.35	0.18	0.55	0.33
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Factor correlations were examined to assess the degree of overlap between dimensions. The three factors showed moderate correlations with one another (ML1& ML2:  $r = .49$ , ML1& ML3:  $r = .63$ , ML2& ML3:  $r = .51$ ). The factor correlation matrix can be seen in Table 15.

**Table 15.** Factor correlations for Exploratory Factor Analysis of the ASLTB (N=75).

	ML1	ML2	ML3
ML1	1.00	-	-
ML2	0.49	1.00	-
ML3	0.63	0.51	1.00

Multiple model fit indices and their criteria were used to examine model fit. The Root Mean Square of the Residuals (RSMR) was .06, indicating good fit (values  $< .08$  are desirable). Root Mean Square Error of Approximation (RMSEA) for this model is .102 (90% CI [.090, .116]) suggesting a weaker model fit (values  $< .08$  are desirable). The Likelihood chi-square value for a three factor model was significant ( $\chi^2(348) = 623.30$ ,  $p < .001$ ), but the ratio of  $\chi^2$  to degrees of freedom was 1.8, which is acceptable (ratio  $< 5$ ). Off-diagonal values are high (.98), indicating this model captured a substantial amount of covariance among the items. Overall, the fit indices suggest adequate but not excellent model fit.

The model's estimated scores closely matched factor structure with regression-based factor scores being highly correlated with the three factors: ML1( $r = .97$ ), ML2( $r = .95$ ), & ML3( $r = .96$ ). Multiple  $R^2$  values further supported this with scores explaining 94% of the variance in ML1, 89% of the variance in ML2, & 92% of the variance in ML3. Even under the most conservative estimates, minimum possible correlations between the estimated scores and the corresponding factors remained strong: ML1 ( $r = .88$ ), ML2 ( $r = .79$ ), & ML3 ( $r = .84$ ). Together

these results indicate the factor scores reliably and accurately estimate how strongly participants scored on each of the three factors.

To interpret the structure of the three factors extracted from the EFA, factor loadings along with each item's communality, uniqueness, and complexity scores are presented in Table 16. Complexity values represent how many factors items meaningfully load onto; higher values reflect cross-loading across multiple factors, while lower values suggest an item primarily loads onto one. Communality values indicate how much variance in each item is accounted for by the model, while uniqueness represents residual variance not explained by the factors. Most items in the analysis strongly loaded onto a single factor.

**Table 16.** EFA Loadings and Item Characteristics

Item	ML1	ML2	ML3	Communality	Uniqueness	Complexity
story_1_1	-0.13	<b>0.60</b>	0.24	0.47	0.53	1.4
story_2_1	0.01	<b>0.57</b>	0.35	0.66	0.34	1.7
story_1_2	0.08	<b>0.55</b>	-0.02	0.34	0.66	1.0
story_2_2	-0.04	0.33	<b>0.55</b>	0.56	0.44	1.7
story_1_3	<b>0.45</b>	0.37	0.09	0.59	0.41	2.0
story_2_3	0.20	0.14	<b>0.33</b>	0.32	0.68	2.1
story_1_4	<b>0.50</b>	0.36	0.16	0.74	0.26	2.1
story_2_4	0.09	0.09	<b>0.49</b>	0.37	0.63	1.1
story_1_5	-0.13	<b>0.47</b>	0.29	0.36	0.64	1.8
story_2_5	0.16	<b>0.65</b>	0.12	0.67	0.33	1.2
maze_1	0.22	<b>0.39</b>	0.37	0.67	0.33	2.6
maze_2	0.07	0.27	<b>0.60</b>	0.67	0.33	1.4
maze_3	0.49	0.02	<b>0.54</b>	0.89	0.11	2.0
maze_4	0.09	0.15	<b>0.71</b>	0.73	0.27	1.1
maze_5	0.12	-0.06	<b>0.81</b>	0.74	0.26	1.1
maze_6	0.30	-0.07	<b>0.54</b>	0.53	0.47	1.6
FS_1	0.36	<b>0.42</b>	0.02	0.47	0.53	2.0
FS_2	0.20	0.13	<b>0.43</b>	0.43	0.57	1.6
FS_3	0.14	<b>0.38</b>	0.01	0.22	0.78	1.3
FS_4	<b>0.50</b>	0.08	-0.26	0.17	0.83	1.6
FS_5	-0.09	0.23	<b>0.39</b>	0.24	0.76	1.8
FS_6	0.07	<b>0.72</b>	-0.26	0.43	0.57	1.3
FS_7	<b>0.80</b>	-0.03	0.16	0.80	0.20	1.1
FS_8	0.41	<b>0.43</b>	-0.04	0.49	0.51	2.0
FS_9	<b>0.44</b>	0.34	-0.03	0.42	0.58	1.9

FS_10	0.03	<b>0.62</b>	0.23	0.60	0.40	1.3
FS_11	<b>0.89</b>	-0.04	-0.01	0.74	0.26	1.0
FS_12	<b>0.61</b>	-0.11	0.29	0.60	0.40	1.5
FS_13	<b>0.51</b>	0.21	0.28	0.73	0.27	1.9
FS_14	<b>0.83</b>	0.09	-0.02	0.75	0.25	1.0

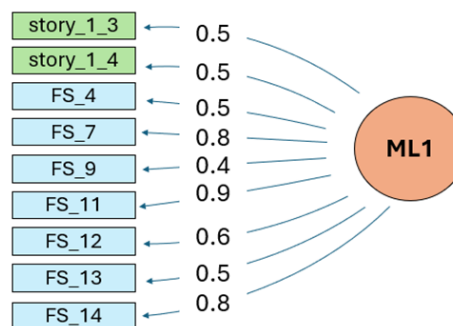
*Notes.* Factor loadings from the three-factor EFA solution using maximum likelihood with oblimin rotation (N=75). Table also includes communality, uniqueness, and complexity. All strongest loadings are bolded.

Rather than grouping items strictly by task type, the factor structure appears to organize items based on shared cognitive and memory processing demands. The following section describes each factor in greater detail, focusing on the types of items that loaded most strongly onto them and the demands those items are likely to place on the participants. It is important to note when examining these factors, that this study was somewhat underpowered. The factor solution should be interpreted with caution, as limited sample size may affect the stability of item loadings.

### ML1

The first factor appears to represent the easiest items in the ASLTB, characterized by lower memory demands. Nine items loaded onto this factor with loadings from .44-.89: story\_1\_3, story\_1\_4, FS\_4, FS\_7, FS\_9, FS\_11, FS\_12, FS\_13, & FS\_14, see Figure 27.

The Fingerspelling Task items that loaded onto this factor had the target fingerspelled word embedded at the very beginning or toward the end of the prompt. This placement of the target word may have minimized memory demands by allowing participants to focus on the target letters without



**Figure 27.**

Visualization of items loading onto factor ML1. Green boxes represent items from the Story Task, blue boxes represent items from the Fingerspelling Task.

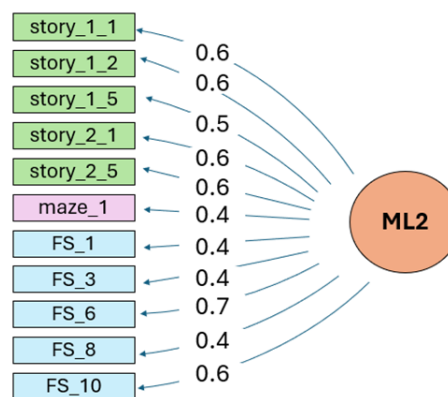
needing to retain or process surrounding signs. When the fingerspelled word appeared at the beginning, participants could attend to it immediately while disregarding the rest of the sentence. When the fingerspelled word appeared toward the end, they could respond right away without needing to hold any earlier signs in memory or attend to additional visual information.

The Story Task items that loaded onto this factor were short straightforward questions asking where the interviewee in the video lives and where he was born. The signing in the prompts were brief and the answers were discussed at length in the associated videos, potentially making them easier to remember. The Story Task items loading onto this factor were also the first questions within their respective trials. The proximity of the response prompt relative to the relevant content also likely reduced memory demands. Both Story Task items in this factor also had high complexity scores (2.0 for story\_1\_3, and 2.1 for story\_1\_4), suggesting these items do not exclusively load onto ML1. The items also showed weaker secondary loadings onto ML2, which contained more complex Story Task items.

## ML2

The second factor appears to represent items in the ASLTB that require recalling brief, easily overlooked details embedded in signed stories or phrases. These details are often not central to the broader context, making them more susceptible to being missed. Rather than relying on memory for sequences, these items

challenge participants to attend and recall isolated brief details. ML2 had 11 items with loadings from .38-.72: story\_1\_1, story\_2\_1, story\_1\_2, story\_1\_5, story\_2\_5, maze\_1, FS\_1, FS\_3, FS\_6, FS\_8, & FS\_10, see Figure 28.



**Figure 28.**

Visualization of items loading onto factor ML2. Green boxes represent items from the Story Task, the purple box represents the item from the Maze Task, blue boxes represent items from the Fingerspelling Task.

The Fingerspelling Task items loading onto ML2 shared characteristics that made the target word easier to miss. In many cases, the target fingerspelled word typically appeared in the middle of the signed phrase, requiring participants to process visual information before and after the target word. When the target word appeared toward the end of the phrase, it was often less predictable from context, requiring more careful identification. For example, in FS\_1 (“Get into the building how? You have to have a b-a-d-g-e”), the correct response is not strongly cued by the question making it hard to anticipate the fingerspelled word. Additionally, response options for Fingerspelling Task Items loading onto ML2 often included words that shared multiple letters with the target word, increasing visual similarity and potential for confusion (e.g., Badge vs Bridge and Baggage in FS\_1; Dell vs Doll and Dill in FS\_6). These structural features align with the broader ML2 theme of brief, easily overlooked details. It is important to

note that the Fingerspelling Task item loadings onto ML2 were moderate compared to the Story Task items loading onto ML2. This may reflect shared variance between the Fingerspelling items across multiple factors, diluting their loadings.

The Story Task items that loaded onto ML2 generally contained wordier questions and required participants to recall information mentioned briefly in the videos associated with the items. For example, story\_1\_5 asked where the interviewer in the story lived- a question similar to story\_1\_3, which asked where an interviewee lived and loaded onto ML1. However, story\_1\_5 included more signed content in the question, which may have increased processing demands. In addition, the video presented before story\_1\_5 was two minutes and 20 seconds long and featured three signers, whereas story\_1\_3 followed a much shorter video (one minute and nine seconds) featuring only two signers. Participants responding to story\_1\_5 may have needed to retrieve a brief detail after a longer delay and from a more complex context, increasing the likelihood it would be overlooked. Other items loading onto this factor, such as story\_1\_1, story\_2\_1, and story\_1\_2, were associated with single-signer videos but the information relevant to the question was mentioned only briefly or less prominently. These features made details easier to miss despite being contextually appropriate, reinforcing the interpretation of ML2 as involving easy to miss details.

Interestingly, one Maze Task item, maze\_1, loaded onto ML2. This was unexpected given the other five Maze Task items loaded onto ML3. We do not have a clear interpretation for why this item loaded onto ML2.

### ML3

The third factor appears to represent items with the greatest overall memory and sequencing demands. ML3 had 10 items with loadings from .39-.81: story\_2\_2, story\_2\_3, story\_2\_4, maze\_2, maze\_3, maze\_4, maze\_5, maze\_6, FS\_2, & FS\_5, see Figure 29.

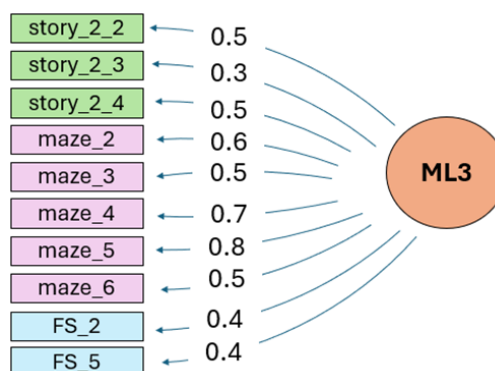
Two fingerspelling task items loaded onto this factor. Unlike most ML3 items, these did not involve increased memory or sequencing. It is unclear why they loaded onto ML3. Given the relatively small sample size for this EFA, these loadings may reflect instability in the factor solution.

All but one of the Maze Task items

loaded onto ML3. This was the most complex

task in the ASLTB as it requires participants to watch a short story and remember the sequence of key events. Once the video was finished, participants needed to select three objects representing events they remembered from the story in the correct chronological order to receive the maximum credit for the trial. These items require participants to not only retain multiple details from a story, but also to track the temporal order of events and accurately reconstruct that sequence. This reinforces the interpretation of ML3 as the factor with the highest memory demands.

Three Story Task Items loaded onto ML3. Notably, all three were the second questions asked within their respective trials, meaning they were presented after a longer delay from the associated video compared to the first questions- likely increasing memory demands. For



**Figure 29.**

Visualization of items loading onto factor ML3. Green boxes represent items from the Story Task, purple boxes represent the items from the Maze Task, blue boxes represent items from the Fingerspelling Task.

example, story\_2\_2 stated ““Missy sat and used the restroom and felt better. She finished, got up, and left the stall to wash her hands. Her sister in law, Linda (to her left) told her "hey you sound like- \_\_\_\_" what was that word?” The options provided were (Leaky faucet, Ocean, Waterfall, Watering can), with “waterfall” being the correct answer. The relevant content was mentioned only briefly in the one minute and four second video, and the similarity in the response options may have additionally increased the chance of misremembering. Story\_2\_3 stated “The man with a beard, Jamil, has what kind of job?”. This item had the lowest loading of the three Story Task items on ML3, possibly due to its structural similarity to the simpler first question items loading onto ML1. It had a complexity score of 2.1 and showed loadings on both ML3 (.33) and ML1(.20). While the question itself was simple, the difficulty may have come from a combination of the delay associated with second question items as well as the visual similarity across the multiple choice images (all of which showed the same character in different occupational uniforms). Story\_2\_4 asked how many different signs the interviewee demonstrated for the word “Bangladesh”. The relevant segment in the video was brief and potentially easy to forget. Combined with the delay that comes with being a second question, may explain why it loaded onto ML3. Notably, the Story Task items showed slightly lower loadings onto ML3 compared to the Maze Task items, suggesting they share the memory demand aspect of this factor, but to a lesser extent than the sequencing demands characteristic of the Maze Task.

### Factor Summary

ML1 represents items with the lowest memory demands. ML2 represents items that that require recalling brief, easily overlooked details that are typically not central to the broader context. ML3 represents items with the greatest overall memory and sequencing demands. Performance patterns across fluency groups reflect these distinctions, see Table 17. ML1 showed

the highest accuracy across most groups, consistent with lower memory demands. ML2 performance dropped sharply for those who can communicate in ASL with difficulty, suggesting that retrieving briefly presented information not central to broader context or embedded in rich language was challenging for this group. ML3 performance remained high for Somewhat Fluent and Fluent groups, in some cases exceeding ML2 item performance. This may be due to the story-based context of many ML3 items, which likely supported recall despite greater memory and sequencing demands. These interpretations are exploratory and based on item characteristics observed in a relatively small sample. While the patterns identified provide a useful starting point for understanding the ASLTB item structure, further research with larger samples are needed to refine these factor definitions.

**Table 17.** ASLTB Factor Performance by Self-Reported Fluency (ML1, ML2, ML3).

ASL Fluency	ML1	ML2	ML3	MI1 performance M ± SD	MI2 performance M ± SD	MI3 performance M ± SD
	raw score M ± SD	raw score M ± SD	raw score M ± SD			
Fluent	8.00 ± 0.00	7.73 ± 0.46	40.55 ± 3.00	100% ± 0.00	96.59% ± 5.70	92.15% ± 6.83
Somewhat Fluent	7.73 ± 0.90	6.82 ± 1.54	40.18 ± 3.82	96.59% ± 11.31	85.23% ± 19.22	91.32% ± 8.67
Can communicate with difficulty	7.00 ± 1.89	4.33 ± 2.22	28.33 ± 10.63	87.50% ± 14.85	54.17% ± 27.79	64.39% ± 24.17
Cannot communicate	2.38 ± 1.58	2.63 ± 1.66	15.72 ± 5.48	29.69% ± 19.79	32.81% ± 20.79	35.70% ± 12.46

To assess internal consistency and external validity, the EFA model was reconstructed using confirmatory SEM procedures in R using the lavaan package (Rosseel, 2021). This model was based on the original item loadings identified in the EFA.

### Internal Reliability

Cronbach's alpha ( $\alpha$ ) coefficients were calculated for each of the three EFA derived factors to evaluate internal consistency. All three factors demonstrated strong internal reliability, with  $\alpha$  values exceeding the recommended threshold of .65. For ML1, Cronbach's  $\alpha$  was .91, indicating excellent internal consistency. The average inter-item correlation was high ( $r = .54$ ). For ML2, Cronbach's  $\alpha$  was .85, indicating very good internal consistency. The average inter-item correlation was moderate ( $r = .42$ ). For ML3, Cronbach's  $\alpha$  was .90, also indicating excellent internal consistency. The average inter-item correlation was moderate ( $r = .49$ ). Together, these results indicate the factors derived from the EFA solution showed strong internal consistency. Reliability statistics for each of the factors can be seen in Table 18.

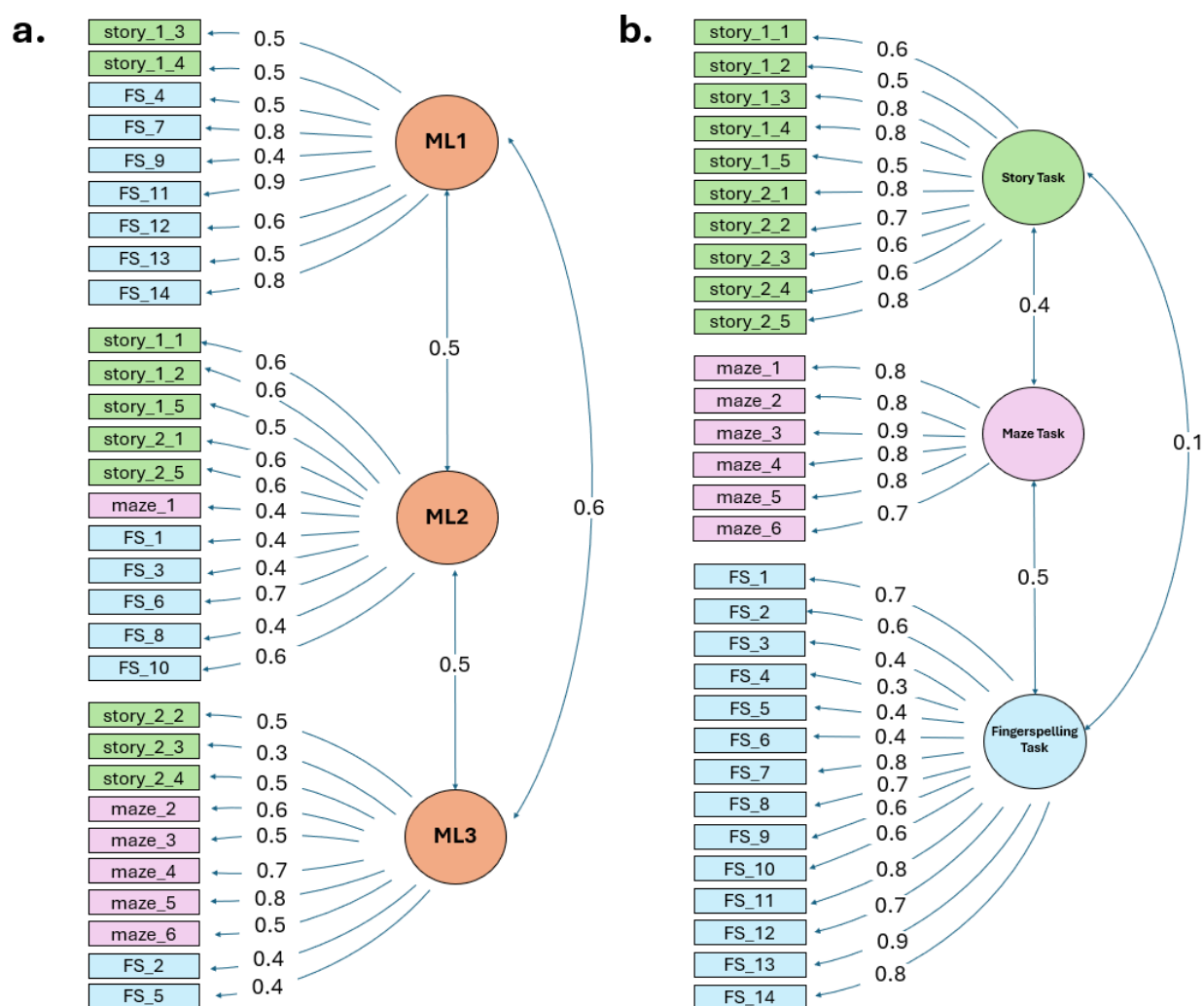
**Table 18.** Internal consistency statistics for EFA derived factors.

<b>Factor</b>	<b>Cronbach's <math>\alpha</math></b>	<b>Standardized <math>\alpha</math></b>	<b>Average r</b>	<b>Median r</b>	<b>S/N Ratio</b>
ML1	.91	.90	.54	.59	9.38
ML2	.85	.85	.42	.39	5.73
ML3	.90	.93	.49	.47	13.51

### External Reliability

External validity was evaluated by examining Spearman correlations between the EFA derived factor scores and self-reported ASL fluency collected from the demographic survey. All three factors showed strong positive correlations with fluency. ML1 had the strongest correlation with fluency ( $\rho = .87$ ), followed closely by ML2 ( $\rho = .85$ ) and ML3 ( $\rho = .85$ ). These results suggest the factors generated from the EFA meaningfully capture variation in ASL fluency levels.

## Summary



**Figure 30.**

Visual representation of the three-factor solutions from the data-driven model (derived from the EFA; a) and the task-based model (derived from the CFA; b). Standardized factor loadings and inter-factor correlations are shown on each model.

Although the CFA factors show strong internal consistency and meaningful correlations with self-reported ASL fluency, overall model fit was poor. The EFA revealed a three-factor solution primarily organized by memory and/or processing demands rather than by task type.

### ***Correlation with Validated Sign Language Assessment tool***

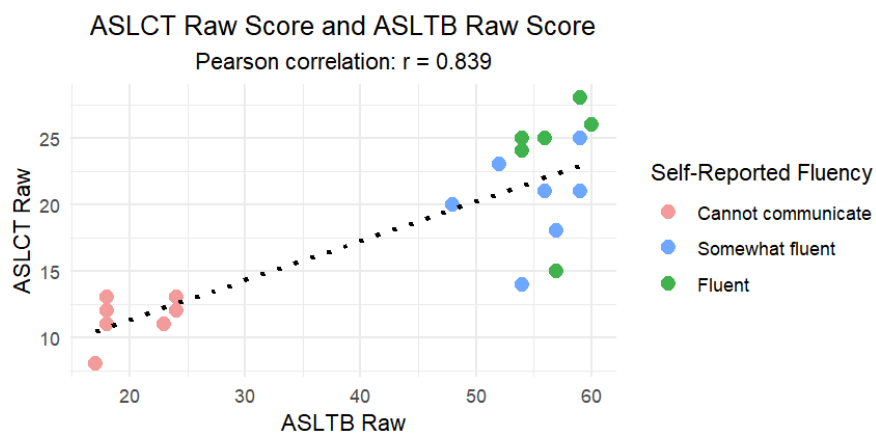
Following data collection, we examined how ASLTB performance compared with the ASL Comprehension Test (ASLCT), a validated and widely used measure of ASL receptive skills. Due to the ASLCT's requirement for proctoring during practice trials, it was not feasible to administer it to all 75 ASLTB participants. However, several participants from the divided attention study in Chapter 3 completed the ASLCT as part of their screening and participated in the current ASLTB study.

The divided attention study sample consistent entirely of signers. To broaden the range of fluency levels, we additionally recruited non-signing volunteers. The final sample included 6 participants who self-identified as "Fluent" in ASL ( $M = 30.67$ , 2 women, 3 men, 1 gender non-conforming), 6 as "Somewhat Fluent" ( $M = 29.29$ , 4 women, 2 men, 1 gender non-conforming), and 7 as "Cannot Communicate" in ASL ( $M = 27.29$ , 5 women, 2 men). All ASLCT practice trials were proctored by the researcher, while the ASLTB was completed entirely as a self-administered online assessment. Means and standard deviations by fluency group for both scores can be seen in Table 19.

**Table 19.** ASLCT and ASLTB performance by Self-Reported Fluency.

<b>ASL Fluency</b>	<b>ASLCT raw score (out of 30 points) M ± SD</b>	<b>ASLTB raw score (out of 60 points) M ± SD</b>
Fluent	23.83 ± 4.54	56.67 ± 2.50
Somewhat Fluent	20.29 ± 3.55	55 ± 4
Cannot communicate	11.43 ± 1.72	20.29 ± 3.2

A Pearson correlation revealed a strong positive relationship between ASLTB and ASLCT scores,  $r = .84$ , indicating higher ASLTB scores were associated with higher scores on the established ASLCT measure, see Figure 31.

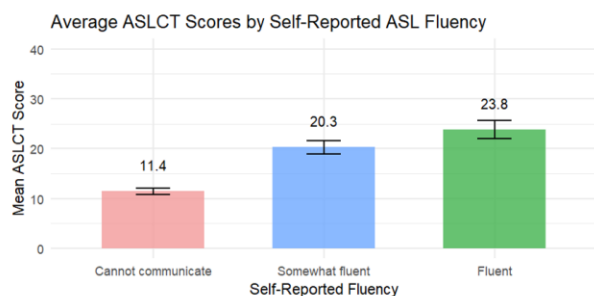


**Figure 31.**

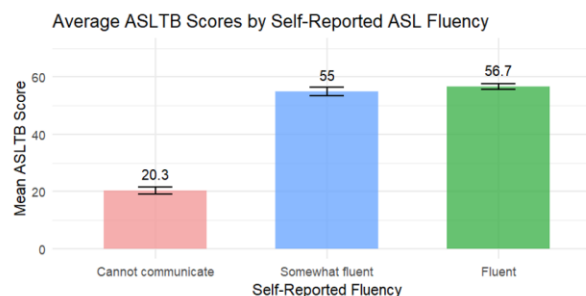
Scatterplot showing relationship between ASLCT raw scores (y-axis) and ASLTB raw scores (x-axis) by self-reported fluency: Cannot communicate (pink), Somewhat fluent (blue), and Fluent (green). ASLCT scores range from 0-30 and ASLTB scores range from 0-60.

Consistent with expectations, both assessments showed gradations in performance by self-reported fluency responses from the demographic survey. Compared to the ASLTB, the ASLCT appears to more effectively distinguish between “Fluent” and “Somewhat Fluent” ASL receptive skills, see Figure 32.

**a.**



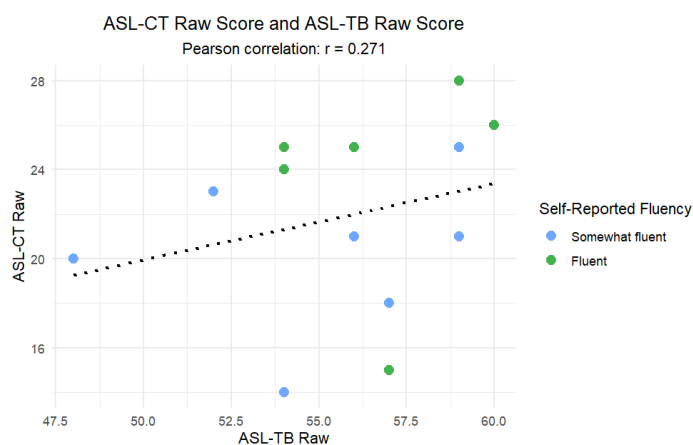
**b.**



**Figure 32.**

ASLCT (a) and ASLTB (b) raw scores (y-axis) by self-reported fluency (x-axis). Bars represent the mean score for each fluency group, and error bars indicate the standard deviation. Groups are color coded as follows: Cannot communicate (pink), Somewhat fluent (blue), and Fluent (green). ASLCT scores range from 0-30 and ASLTB scores range from 0-60.

When individuals who “cannot communicate” were included, the correlation between the ASLTB and ASLCT appeared strong. However, this reflected group separation (signers vs. non-signers) rather than a continuous relationship. Once these participants were excluded, the correlation disappeared, supporting the notion that the ASLTB is more effective at distinguishing signers from non-signers than at differentiating between fluency between “Somewhat Fluent” and “Fluent” signers, see Figure 33. A stratified or mixed-effects analysis might help to address the clustering we see in the correlation analysis including the non-signers, but given the limited sample size and the absence of a “can communicate with difficulty” group, the present data were not sufficient to support such analyses.

**Figure 33.**

Scatterplot showing relationship between ASLCT raw scores (y-axis) and ASLTB raw scores (x-axis) with only Somewhat fluent (blue), and Fluent (green) participants. ASLCT scores range from 0-30 and ASLTB scores range from 0-60.

## DISCUSSION

The ASLTB was created with the long-term goal of becoming a stand-alone assessment tool to support greater diversity in large-scale online research by enabling the inclusion of individuals who use American Sign Language. The current study aimed to address three research questions: 1) Is the ASLTB, in its current form, sensitive to differences in ASL proficiency? 2) Do the different tasks within the ASLTB measure distinct aspects of ASL comprehension? 3) How does the current version of the ASLTB compare to validated measures of ASL receptive skills such as the ASLCT?

### *The ASLTB Reflects Differences in Self-Reported ASL Fluency*

To examine whether the ASLTB reflects differences in participants' self-reported ASL fluency, we examined performance across each of the tasks contributing to the overall ASLTB score. We expected individuals reporting higher fluency to perform better across all tasks than those reporting lower or no level of ASL fluency.

In all three tasks included in the ASLTB raw score (Story, Maze, and Fingerspelling Task), performance had a strong positive correlation with the self-reported fluency levels of the participants. Higher fluency participants generally scored higher on each task within the ASLTB. (This was also true of the Match Task, which was also included as part of the assessment to provide additional context on participants regarding whether they had early or late first language exposure.) Overall, these findings suggest that participant performance on the current version of the ASLTB reflects self-reported ASL fluency levels.

### ***The ASLTB Tasks Do Not Form Fully Distinct Factors***

As mentioned in the introduction and throughout this chapter, the ASLTB raw score includes the Story Task, Maze Task, and Fingerspelling Task. The Match task was excluded from the raw score to avoid conflating language access history with overall ASL proficiency. Each task was designed to target a distinct component of ASL comprehension: The Story Task assessed general ASL comprehension, the Maze Task assessed event sequencing in ASL stories, and the Fingerspelling Task assessed participants' ability to identify and comprehend fingerspelled words. To test whether these tasks reflect distinct underlying constructs, we first evaluated a task-based model using CFA and then examined a data-driven model using EFA.

The CFA grouped items according to their respective tasks. All three factors demonstrated strong internal consistency and were meaningfully correlated with their self-reported fluency, indicating they reliably captured variation in ASL comprehension ability. However, overall model fit was poor which indicates participants did not respond to the items in a way that cleanly separated performance by task type. These results suggest that, while the tasks are individually reliable, they likely draw on overlapping skills rather than measuring fully distinct aspects of comprehension.

The EFA revealed three factors with adequate model fit, strong internal reliability, and meaningful relationships with self-reported fluency. Items did not cluster by task type as originally expected. Instead, factors appeared to group based on potential differences in memory load and/or task demands.

The CFA and EFA results suggest that the ASLTB is not organized purely by task type, but instead by task demands such as memory load. This indicates that performance reflects both

ASL fluency and the cognitive processes needed to meet the demands on each task. Rather than viewing this as a limitation, these findings highlight the interdependence of language and cognition in ASL assessment.

### ***The ASLTB Correlates With the ASLCT***

We also examined how the ASLTB compared to the already validated and widely used ASLCT to assess its potential as a practical alternative. The strong positive correlation between the two measures suggests that, even in its current form, the ASLTB performs well in capturing ASL receptive skills in a way that aligns with an established standard. Closer inspection showed that much of this correlation reflects a clear separation between signers and non-signers. Once participants who “cannot communicate” in ASL were excluded, the correlation became very weak. This suggests that the ASLTB is effective at distinguishing signing and non-signing groups, but at distinguishing between higher fluency groups included in the sample. While the current version of the ASLTB is not as good at differentiating between those identifying as “Somewhat Fluent” and “Fluent” in ASL, the relationship between the scores is strong enough to suggest that the ASLTB has promise as an initial screening tool. A subset of questions did appear to successfully discriminate between “Somewhat Fluent” and “Fluent” and might prove the basis of a test that can successfully discriminate between these individuals.

### ***Limitations***

One limitation of the present study is the relatively modest sample size (N=75) compared to the number of items analyzed (30 items). This sample size may be underpowered for complex factor models, which can lead to instability in model fit indices and factor loadings. Future research with larger, more diverse samples will be important to determine whether the factor pattern revealed in the EFA replicates, and whether the theoretical task-based model shows

improved fit with a larger dataset. It is important to note, however, that the strong internal consistency and relationships with self-reported ASL fluency observed in the CFA suggests that the ASLTB is capturing meaningful variation in ASL comprehension skills, even if those skills do not separate cleanly by task type.

Another limitation concerns the kinds of tasks that were included in the ASLTB. While each task was designed to tap into different aspects of ASL comprehension, the current results suggest that they may reflect overlapping skills. Important areas such as spatial reasoning or sensitivity to fine-grained handshape differences were not directly assessed. Future iterations of this assessment tool could include tasks targeting skills like these, such as the sentence comparison task found in the ASLDT or identifying locations of items based on spatial signs like those found in the ASL-RST. Including tasks that look at specific components that make up ASL fluency could provide a fuller picture of ASL comprehension. This could make the ASLTB even more effective, as it would not only screen for ASL fluency but also pinpoint what skills participants might excel in or struggle with.

The comparison between the ASLCT and ASLTB was based on a smaller subset of participants due to the proctoring required for the ASLCT practice trials. While this subset included a range of fluency levels, the correlation should be interpreted with the limited sample size ( $N=20$ ) in mind. Future validation efforts should include larger samples completing both assessments.

In addition to the task design considerations, the sample lacked confirmed late L1 ASL users. This limits the interpretability of the Match Task, which was intended to offer insight into participants' language backgrounds. Including more participants with this background in future samples would help ensure the ASLTB captures a fuller range of ASL users.

Due to our desire to create an online assessment that is easy to administer, the ASLTB only assesses ASL receptive skills. This simplifies administration as it does not require video recordings or fluent signers to assess participants' ASL expressive skills. Research teams should consider that the ASLTB does not assess participant's ASL production skills when deciding whether the ASLTB meets the needs of their study.

While this assessment was created by two native signers (CODAs), it was not created by Deaf individuals. Future work led by Deaf researchers may offer important insights that could strengthen and refine the ASLTB. This tool was developed to fill a gap where no comparable stand-alone large-scale ASL screening tool currently exists. It is offered as an alternative to be improved upon for research teams who need it, and not to replace existing assessments created by Deaf-led research teams.

### ***Suggestions for Future Implementation of the ASLTB***

To improve feasibility and reduce test-taking time, the next iteration of the ASLTB should streamline the assessment by reducing the number of scored items. Based on current results, we recommend retaining the subset of items that best differentiated performance across self-reported fluency levels, see item level performance in Appendix Figures 1-3. From the Story Task, “Making Noise Part 1” & “Making Noise Part 2” (story\_1\_1, story\_2\_1, story\_1\_2, story\_2\_2) and “Sweets and Drinks” items (story\_1\_5 & 2\_5) should be kept. From the Maze Task, items maze\_1, maze\_3, and maze\_5 should be kept. From the Fingerspelling Task, items FS\_1, FS\_3, FS\_6, FS\_8, FS\_9, FS\_10, FS\_13 could be kept. These items showed clear monotonic relationships between accuracy and self-reported fluency, making them strong candidates for a shorter ASLTB. With 16 questions this test would take around 25 min.

A clear next direction would be to see how well a shorter ASLTB correlates with the ASLCT. As noted earlier in this dissertation, 20 participants completed both assessments. We re-ran the Pearson correlation using only the 16 items mentioned above and found a strong positive correlation ( $r = .85$ ), comparable to the result obtained with the 30-item version of the ASLTB. This provides encouraging preliminary evidence that a shorter ASLTB can perform just as effectively as the longer version.

### ***Conclusion***

This study examined the ASLTB as a self-administered screening tool for ASL comprehension. Results showed ASLTB scores aligning well with participants' self-reported fluency, supporting its use as a meaningful measure of ASL receptive skills. While the tasks within the ASLTB did not reflect distinct linguistic aspects of ASL comprehension, the factor analyses suggested that performance was shaped by both ASL fluency and task demands. These findings highlight the interdependence of language and cognition in the assessment of ASL comprehension.

The ASLTB offers several key strengths. It minimizes English usage, making it accessible to a broader range of signers. It does not require the use of raters or proctors and can be administered online. This enables large scale recruitment for researchers interested in studying participants who use ASL. Additionally, the inclusion of the Match Task, though not scored, provides valuable insight into L1 participants' early language exposure. Altogether, the ASLTB shows strong potential as a practical tool for screening for ASL receptive fluency. While future refinement and validation is needed, the current version offers a promising starting point for more accessible and inclusive ASL research.

## Chapter 6: Closing thoughts

This dissertation presented two projects aimed at advancing accessibility in research and education for D/deaf individuals.

The first study applied an attentional dual task paradigm to ASL letter signs to test whether deafness or ASL experience alters divided attention. All groups (Deaf Signers, CODAs, and Hearing Non-Signers), showed moderate costs to dividing attention between two letters with no group differences. Though the stimuli were potentially processed more as visual forms rather than linguistic symbols. The fact that all groups experienced costs for dividing attention tells us that Deaf people do not develop an improved generalized capacity to manage divided visual attention. Similar or greater costs are likely in more visually complex and language rich environments such as educational settings where signers must attend to multiple visual sources. These findings underscore the importance of designing classrooms and instructional materials in ways that reduce unnecessary visual load and allow adequate processing time.

The second project developed the American Sign Language Test Battery (ASLTB). It is designed to eventually be a low-cost self-administered online screening tool that minimizes reliance on English and does not require ASL Fluent experimenters. Strong correlations with self-reported fluency and the validated American Sign Language Comprehension Tool (ASLCT) support its effectiveness for inclusive participant recruitment. By lowering logistical and expertise barriers, the ASLTB enables more representative sampling and aids research that better reflects the diversity of signing communities that use ASL.

Together, these projects advance scientific understanding of divided attention in Deaf individuals with varying experiences of deafness and provide a practical infrastructure for more

inclusive ASL research studies. Accessibility for D/deaf people does not rely only on inclusive environments, but also on research methods designed to capture the diversity within the population.

# APPENDIX

**Appendix Table 1.** Demographic information for participants.

Group	Participant	Gender	Age	Self-Identified Status	Self-Identified ASL Fluency	ASLCT Score	Reported present usage of ASL	Age learned ASL	Do you use assistive listening devices currently? Which?	Did you use assistive listening devices in the past? Which?
<b>Hearing Non-Signers</b>	H01	Male	27	Hearing	Cannot communicate	9				
	H02	Male	31	Hearing	Cannot communicate	9				
	H03	Male	25	Hearing	Cannot communicate	9				
	H04	Male	18	Hearing	Cannot communicate	11				
	H05	Male	32	Hearing	Cannot communicate	10				
	H06	Male	24	Hearing	Cannot communicate	Missing information				
	H07	Female	25	Hearing	Cannot communicate	13				
	H08	Female	21	Hearing	Cannot communicate	12				
	H09	Male	21	Hearing	Cannot communicate	11				
	H10	Female	34	Hearing	Cannot communicate	8				
<b>CODA Hearing Signers</b>	C01	Female	33	CODA	Fluent	26	Every day	1		
	C02	Male	29	Hearing, CODA, Interpreter	Fluent	25	Every day	2		
	C03	Female	28	Hearing, CODA, Interpreter	Fluent	21	Every day	0		
	C04	Male	20	Hearing, CODA	Fluent	24	Every day	0		
	C05	Male	32	Hearing, CODA, Interpreter	Fluent	24	Every day	0		
	C06	Male	19	CODA	Fluent	24	Every day	2		
	C07	Female	35	CODA	Fluent	23	Every day	0		
	C08	Female	36	CODA	Fluent	24	Every day	1		

Deaf/HH Signers	C09	Female	34	CODA	Fluent	28	Almost every day	0		
	C10	Female	25	Hearing, CODA	Somewhat fluent	25	A few days a month	0		
	D01	Female	29	Deaf, Hard of Hearing	Somewhat fluent	14	A few days a week	19	Cochlear Implant	Cochlear Implant
	D02	Male	34	Deaf	Fluent	29	Every day	0	No	Cochlear Implant
	D03	Female	51	Deaf	Fluent	26	Every day	4	No	Hearing Aid
	D04	Male	50	Deaf	Fluent	20	Every day	1	No	Hearing Aid
	D05	Female	30	Deaf	Fluent	28	Every day	1	No	Cochlear Implant & Hearing Aid
	D06	Female	22	Deaf	Somewhat fluent	18	Every day	14	Cochlear Implant	Cochlear Implant
	D07	Female	34	Deaf, Hard of Hearing	Fluent	15	A few days a week	3	Cochlear Implant	Hearing Aid
	D08	Male	36	Deaf, Hard of Hearing	Somewhat fluent	21	A few days a week	8	Cochlear Implant	Cochlear Implant
	D09	Gender Non-Conforming	27	Deaf	Fluent	25	A few days a week	15	No	Hearing Aid
	D10	Gender Non-Conforming	28	Deaf	Somewhat fluent	21	Every day	1	No	Hearing Aid

Notes. Table includes gender, age, self-identified hearing and signing status, self-identified fluency, ASLCT score, self-reported present day usage of ASL, self-reported age ASL was learned, and current use of assistive listening devices.

**Appendix Table 2. Number of trials completed per condition for all participants**

Participant ID	Status	ST Trials	DT Trials	Total Trials
C01	CODA	304	301	605
C02	CODA	333	333	666
C03	CODA	319	323	642
C04	CODA	358	383	741
C05	CODA	319	320	639
C06	CODA	301	304	605

C07	CODA	310	331	641
C08	CODA	320	320	640
C09	CODA	320	320	640
C10	CODA	320	320	640
H01	NS	316	319	635
H02	NS	522	617	1139
H03	NS	585	631	1216
H04	NS	307	312	619
H05	NS	370	384	754
H06	NS	606	606	1212
H07	NS	605	608	1213
H08	NS	307	315	622
H09	NS	447	447	894
H10	NS	320	320	640
D01	Deaf	311	310	621
D02	Deaf	307	308	615
D03	Deaf	317	315	632
D04	Deaf	362	358	720
D05	Deaf	303	304	607
D06	Deaf	320	319	639
D07	Deaf	320	318	638
D08	Deaf	320	320	640
D09	Deaf	308	304	612
D10	Deaf	313	320	633

**Appendix Table 3.** ASLTB Questions and Responses

Task	Item Name	Video Content English Translation	Response Options	Story Given
Story Task	story_1_1	“That woman’s name was Missy. During the summer	Mall,Hospital, Park, School	“Making Noise” - Part 1 <a href="https://www.youtube.com/watch?v=9ARj6rU-XbU">https://www.youtube.com/watch?v=9ARj6rU-XbU</a>

		Missy, her brother, and his wife (all three) went somewhere. Where?”		first 1 minute and 11 seconds
Story Task	story_2_1	“During the video, missy told a story about going to the mall. During that day outside, was it hot, cold, rainy, snowy... what kind of weather was outside?”	Rainy, Sunny, Snowy, Windy	“Making Noise” - Part 1 <a href="https://www.youtube.com/watch?v=9ARj6rU-XbU">https://www.youtube.com/watch?v=9ARj6rU-XbU</a> first 1 minute and 11 seconds
Story Task	story_1_2	“Missy just told a story about her and her sister-in-law needing to urgently use the bathroom. They went to the restroom together which had multiple stalls. Missy went into a stall. Where did Linda (her sister-in-law) sit? In the stall next to her? A couple of seats down? Where?”	Stall 2 doors down, Stall 4 doors down, Stall 3 doors down, Stall right next to her	“Making Noise” - Part 2 <a href="https://www.youtube.com/watch?v=9ARj6rU-XbU">https://www.youtube.com/watch?v=9ARj6rU-XbU</a> Remaining 1 minute and 4 seconds
Story Task	story_2_2	“Missy sat and used the restroom and felt better. She finished, got up, and left the stall to wash her hands. Her sister in law, Linda (to her left) told her ‘Hey you sound like- ____’ what was that word?”	Leaky faucet, Ocean, Waterfall, Watering can	“Making Noise” - Part 2 <a href="https://www.youtube.com/watch?v=9ARj6rU-XbU">https://www.youtube.com/watch?v=9ARj6rU-XbU</a> Remaining 1 minute and 4 seconds
Story Task	story_1_3	“The man with the beard is named Jamil. This is his name sign. He lives where?”	Seattle, Los Angeles, NYC, Washington DC	“ASL Social Media Revolution”- Part 1 <a href="https://www.youtube.com/watch?v=1V0lDvC207E">https://www.youtube.com/watch?v=1V0lDvC207E</a> First 1 minute and 9 seconds

Story Task	story_2_3	“The man with a beard, Jamil, has what kind of job?”	Chef, Teacher, Mechanic, Lumberjack	“ASL Social Media Revolution”- Part 1 <a href="https://www.youtube.com/watch?v=1V0lDvC207E">https://www.youtube.com/watch?v=1V0lDvC207E</a> First 1 minute and 9 seconds
Story Task	story_1_4	“Where was Jamil born?”	Bangladesh, Turkey, UK, USA	“ASL Social Media Revolution”- Part 2 <a href="https://www.youtube.com/watch?v=1V0lDvC207E">https://www.youtube.com/watch?v=1V0lDvC207E</a> Next 48 seconds
Story Task	story_2_4	“Jamil showed multiple different name signs for a country called ‘Bangladesh’. How many different name signs did he show?”	1,2,3,4	“ASL Social Media Revolution”- Part 2 <a href="https://www.youtube.com/watch?v=1V0lDvC207E">https://www.youtube.com/watch?v=1V0lDvC207E</a> Next 48 seconds
Story Task	story_1_5	“There was a woman who interviewed two guests. She was wearing a black shirt and is named Melissa. She was born where?”	USA, Australia, Canada, UK	“Sweets and Drinks: Did You Know That!” <a href="https://www.youtube.com/watch?v=zkiHNLB2c-Y">https://www.youtube.com/watch?v=zkiHNLB2c-Y</a> First 2 minutes and 20 seconds after intro screen
Story Task	story_2_5	“In the movie Amanda, thin with curly long hair and a blue shirt, said she made a cookie with a swirl in it. What kind of cookie did she make?”	Chocolate, Strawberry, Oatmeal, Date	“Sweets and Drinks: Did You Know That!” <a href="https://www.youtube.com/watch?v=zkiHNLB2c-Y">https://www.youtube.com/watch?v=zkiHNLB2c-Y</a> First 2 minutes and 20 seconds after intro screen
<b>Task</b>	<b>Item Name</b>	<b>Video Content English Translation</b>	<b>Response Options</b>	
Maze Task	maze_1	“The girl in the yellow dress with a dog went to the store to buy cake and things. She then went to the birthday party.”	Yellow dress character with pigtails & dog, Blue dress character with black curly hair & flowers, Green dress character with yellow curly hair & purse, Red shirt character with no hair & bike, Orange shirt character with party hat & balloons, Supermarket, Post office, Hospital	
Maze Task	maze_2	“The girl with the black hair went all the way over to her friends to visit her dog. When they finished,	Yellow dress character with pigtails & dog, Blue dress character with black curly hair & flowers, Green dress character with yellow curly hair & purse, Red shirt character with no hair & bike, Orange shirt character with party hat & balloons, Supermarket, Post office, Hospital	

		both the girl with the yellow dress and pigtails and the girl with the black curly hair went to their friend's birthday party. ”	
Maze Task	maze_3	“The boy with the red shirt biked over to his friend's birthday party. He bumped his head and went to the hospital.”	Yellow dress character with pigtails & dog, Blue dress character with black curly hair & flowers, Green dress character with yellow curly hair & purse, Red shirt character with no hair & bike, Orange shirt character with party hat & balloons, Supermarket, Post office, Hospital
Maze Task	maze_4	“The girl with the curly blond hair and purse went to the hospital, and when she was done she went to the grocery store to gather food.”	Yellow dress character with pigtails & dog, Blue dress character with black curly hair & flowers, Green dress character with yellow curly hair & purse, Red shirt character with no hair & bike, Orange shirt character with party hat & balloons, Supermarket, Post office, Hospital
Maze Task	maze_5	“The girl with the pigtails and dog went to the grocery store to get snacks. She then went to her friend's place for bike riding.”	Yellow dress character with pigtails & dog, Blue dress character with black curly hair & flowers, Green dress character with yellow curly hair & purse, Red shirt character with no hair & bike, Orange shirt character with party hat & balloons, Supermarket, Post office, Hospital
Maze Task	maze_6	“The girl with the curly black hair went to the grocery store for work. When work was finished, she went to the birthday party.”	Yellow dress character with pigtails & dog, Blue dress character with black curly hair & flowers, Green dress character with yellow curly hair & purse, Red shirt character with no hair & bike, Orange shirt character with party hat & balloons, Supermarket, Post office, Hospital
<b>Task</b>	<b>Item Name</b>	<b>Video Content English Translation</b>	<b>Response Options</b>
Fingerspelling Task	FS_1	“Get into the building how? You have to have a b-a-d-g-e.”	Block, Bridge, Badge, Baggage
Fingerspelling Task	FS_2	“My camera's l-e-n-s broke. It is no good.”	Lime, Lens, Lace, Line

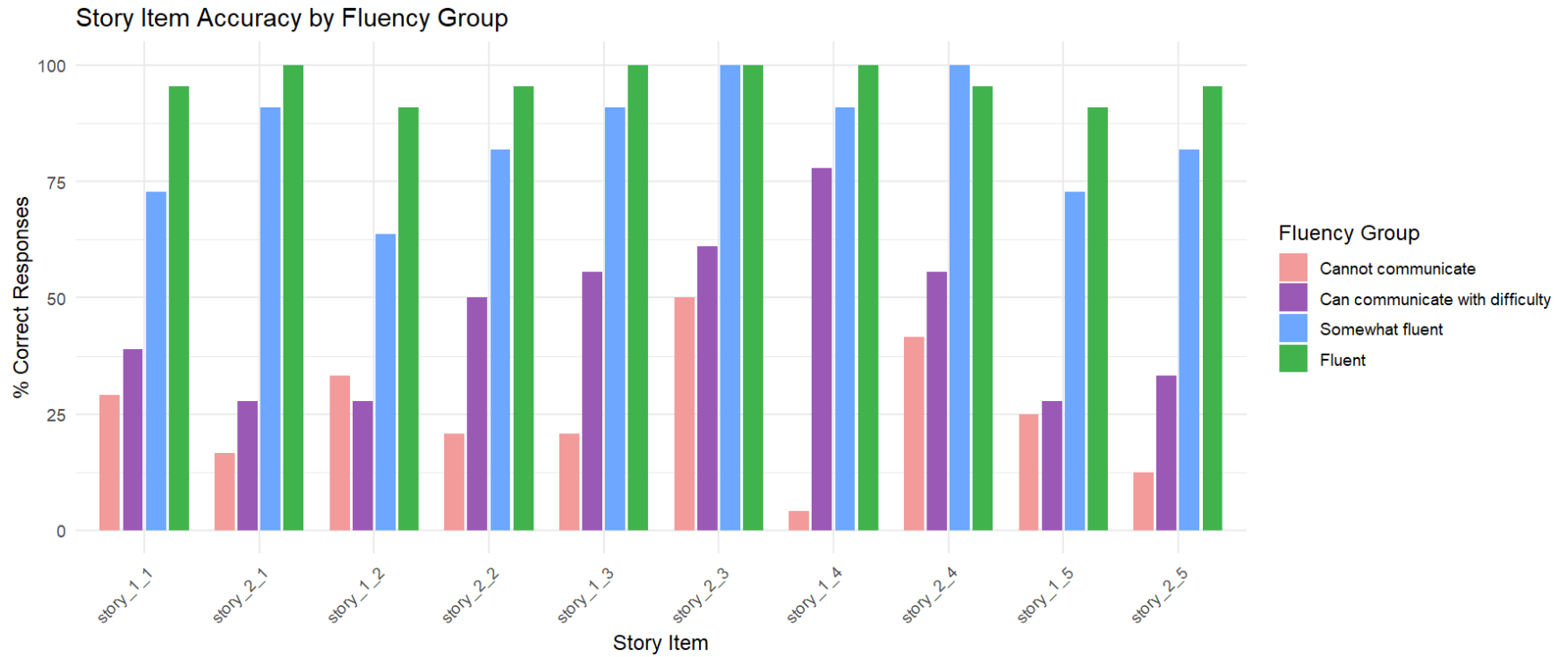
Fingerspelling Task	FS_3	“When I make toast I tend to spread what? I love a-v-o-c-a-d-o spread on toast and it's delicious.”		Egg, Avocado, Apricot, Potato
Fingerspelling Task	FS_4	“Yesterday I ran, mistepped on a curb, and painfully broke my a-n-k-l-e. It really hurt.”		Apple, Ankle, Egg, Shoe
Fingerspelling Task	FS_5	“I arrived to work late, why? I crashed into a t-r-u-c-k.”		Car, Truck, Street, Park
Fingerspelling Task	FS_6	“That computer, the D-e-l-l, is mine.”		Dell, Doll, Dill, Chocolate
Fingerspelling Task	FS_7	“When I grab my favorite drink, what flavor is it? P-e-a-c-h.”		Glass, Peace, Beach, Peach
Fingerspelling Task	FS_8	“I tend to go to the m-a-l-l every weekend.”		Hall, Market, Mail, Mall
Fingerspelling Task	FS_9	“That p-e-n, do you mind giving it to me?”		Book, Kite, Pen, Hammer
Fingerspelling Task	FS_10	“The library has stacks and stacks of b-o-o-k-s.”		Book, Kite, Fork, Berry
Fingerspelling Task	FS_11	“When I go to a restaurant I order a cheese p-i-z-z-a.”		Peas, Pizza, Cheese spray, Pasta
Fingerspelling Task	FS_12	“The best ice cream flavor is what? V-a-n-i-l-l-a.”		Lemon, Strawberry, Vanilla, Apple
Fingerspelling Task	FS_13	“I prefer to i-c-e skate.”		Iron, Car, Street, Ice
Fingerspelling Task	FS_14	“In the summer I grow what? Black b-e-r-r-y.”		Bear, Radish, Berry, Rat
<b>Task</b>	<b>Item Name</b>	<b>Video Content English Translation</b>	<b>Image Content</b>	<b>Response Options</b>

Match Task	Qi_1	“Cookie carry dad”	Cookie carry dad	Yes, No
Match Task	Qi_2	“Boy carry egg”	Egg carry boy	Yes, No
Match Task	Qi_3	“Apple carry clown”	Clown carry apple	Yes, No
Match Task	Qi_4	“Dad kick Table”	Dad kick Table	Yes, No
Match Task	Qi_5	“Chair kick girl”	Chair kick girl	Yes, No
Match Task	Qi_6	“Door kick cow”	Cow kick door	Yes, No
Match Task	Qi_7	“Man push tree”	Tree push man	Yes, No
Match Task	Qi_8	“Chair push girl”	Girl push chair	Yes, No
Match Task	Qi_9	“Clown push TV”	Clown push TV	Yes, No
Match Task	Qi_10	“Table push teacher”	Table push teacher	Yes, No
Match Task	Qi_11	“Chocolate eat boy”	Boy eat chocolate	Yes, No
Match Task	Qi_12	“Dog eat bone”	Dog eat bone	Yes, No
Match Task	Qi_13	“Grass eat rabbit”	Grass eat rabbit	Yes, No
Match Task	Qi_14	“Girl eat candy”	Candy eat girl	Yes, No
Match Task	Qi_15	“Egg draw mom”	Egg draw mom	Yes, No
Match Task	Qi_16	“Chair paint dad”	Dad paint chair	Yes, No

Match Task	Qi_17	“Boy draw TV”	Boy draw TV	Yes, No
Match Task	Qi_18	“Clown eat cookie”	Cookie eat clown	Yes, No
Match Task	Qi_19	“Mom carry orange”	Mom carry orange	Yes, No
Match Task	Qi_20	Sheep kick apple	Apple kick sheep	Yes, No

**Appendix Table 4.** ASLTB Story Task items- percent of participants with correct response (n=75). Each item is worth 1 point.

<b>Item name (EFA Factor)</b>	<b>Fluent (n = 22)</b>	<b>Somewhat Fluent (n = 11)</b>	<b>Can communicate with difficulty (n = 18)</b>	<b>Cannot Communicate (n = 24)</b>
story_1_1 (ML2)	95%	73%	39%	33%
story_2_1 (ML2)	100%	91%	28%	17%
story_1_2 (ML2)	91%	64%	28%	33%
story_2_2 (ML3)	95%	82%	50%	21%
story_1_3 (ML1)	100%	91%	56%	21%
story_2_3 (ML3)	100%	100%	61%	50%
story_1_4 (ML1)	100%	91%	78%	4%
story_2_4 (ML3)	95%	100%	56%	42%
story_1_5 (ML2)	91%	73%	28%	25%
story_2_5 (ML2)	95%	82%	33%	13%



**Appendix Figure 1.** Percentage of participants (y-axis) within each ASL fluency group (colors) who responded correctly (1 vs 0) on each Story Task item (x-axis; story\_1\_1 – story\_2\_5).

**Appendix Table 5.** ASLTB Maze Task items- percent of participants with scores from 0-6 points (n=75).

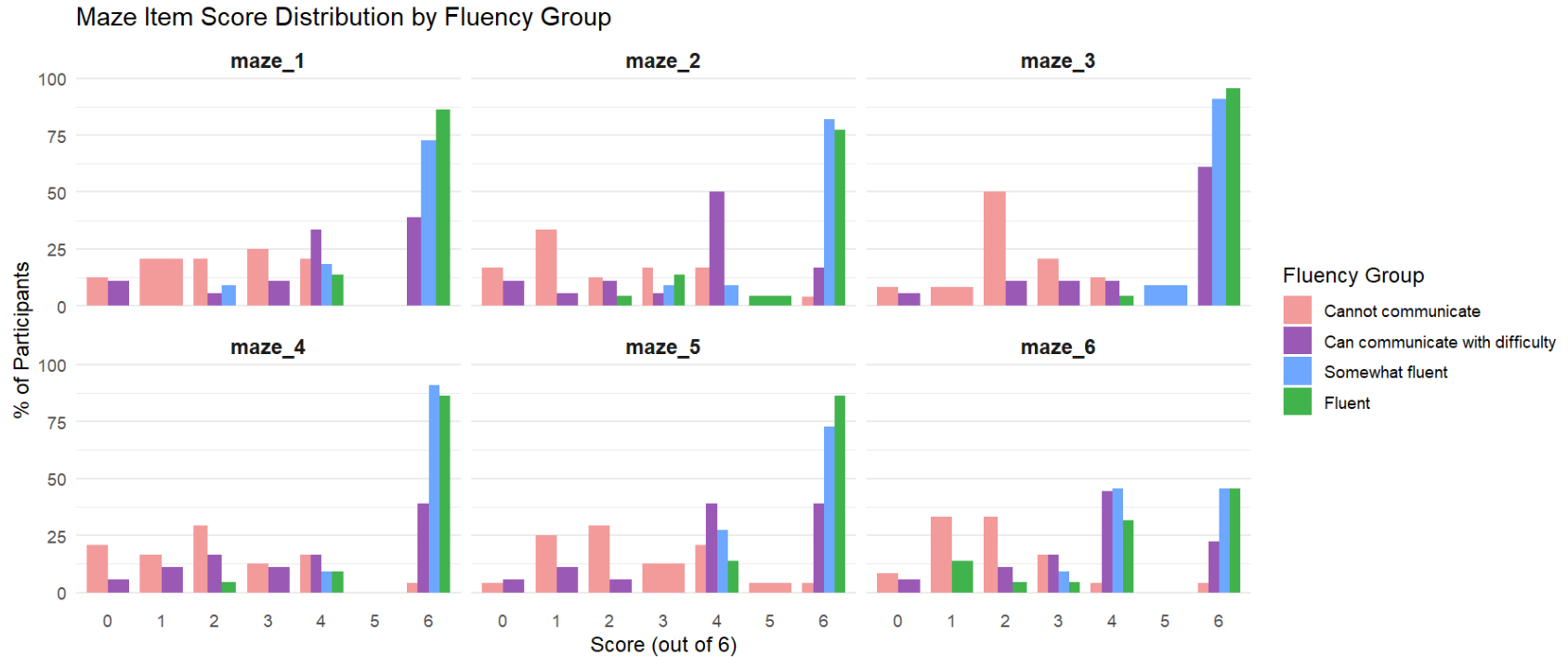
Item name (EFA Factor)	Fluent (n = 22)	Somewhat Fluent (n = 11)	Can communicate with difficulty (n = 18)	Cannot Communicate (n = 24)
maze_1 (ML2)	6 points = 86%	6 points = 73%	6 points = 39%	4 points = 21%
	4 points = 14%	4 points = 18%	4 points = 33%	3 points = 25%
		2 points = 9%	3 points = 11%	2 points = 21%
			2 points = 6%	1 point = 21%

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			0 points = 11%	0 points = 13%
maze_2 (ML3)	6 points = 77% 5 points = 5% 3 points = 14%	6 points = 82% 4 points = 9% 3 points = 9%	6 points = 17% 4 points = 50% 3 points = 6% 2 points = 11% 1 point = 6% 0 points = 11%	6 points = 4% 4 points = 17% 3 points = 17% 2 points = 13% 1 point = 33% 0 points = 2%
maze_3 (ML3)	6 points = 95% 4 points = 5%	6 points = 91% 5 points = 9%	6 points = 61% 4 points = 11% 3 points = 11% 2 points = 11% 0 points = 6%	4 points = 13% 3 points = 21% 2 points = 50% 1 point = 8% 0 points = 8%
maze_4 (ML3)	6 points = 86% 4 points = 9% 2 points = 5%	6 points = 91% 4 points = 9%	6 points = 39% 4 points = 17% 3 points = 11% 2 points = 17% 1 point = 11% 0 points = 6%	6 points = 4% 4 points = 17% 3 points = 13% 2 points = 29% 1 point = 17% 0 points = 21%
maze_5 (ML3)	6 points = 86% 4 points = 14%	6 points = 73% 4 points = 27%	6 points = 39% 4 points = 39% 2 points = 6% 1 point = 11% 0 points = 6%	6 points = 4% 5 points = 4% 4 points = 21% 3 points = 13% 2 points = 29% 1 point = 25% 0 points = 4%
maze_6 (ML3)	6 points = 45% 4 points = 32%	6 points = 45% 4 points = 45%	6 points = 22% 4 points = 44%	6 points = 4% 4 points = 4%

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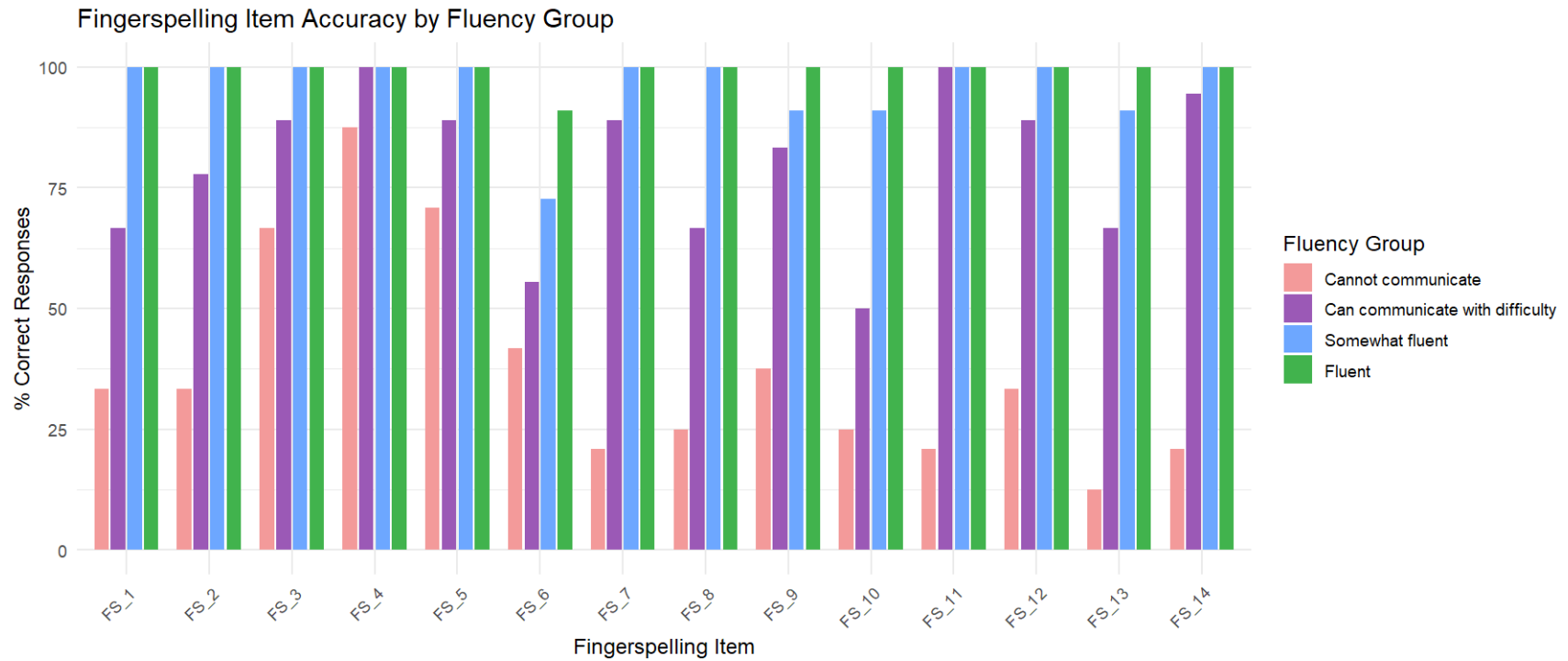
3 points = 5%	3 points = 9%	3 points = 17%	3 points = 17%
2 points = 5%		2 points = 11%	2 points = 33%
1 point = 14%		0 points = 6%	1 point = 33%
			0 points = 8%



**Appendix Figure 2.** Percentage of participants (y-axis) within each ASL fluency group (colors) who earned scores from 1-6 (x-axis) on each maze task item (maze\_1-maze\_6).

**Appendix Table 6.** ASLTB Fingerspelling Task items- percent of participants with correct response (n=75). Each item is worth 1 point.

<b>Item name (EFA Factor)</b>	<b>Fluent (n = 22)</b>	<b>Somewhat Fluent (n = 11)</b>	<b>Can communicate with difficulty (n = 18)</b>	<b>Cannot Communicate (n = 24)</b>
FS_1 (ML2)	100%	100%	67%	33%
FS_2 (ML3)	100%	100%	78%	33%
FS_3 (ML2)	100%	100%	89%	67%
FS_4 (ML1)	100%	100%	100%	88%
FS_5 (ML3)	100%	100%	89%	71%
FS_6 (ML2)	91%	73%	56%	42%
FS_7 (ML1)	100%	100%	89%	21%
FS_8 (ML2)	100%	100%	67%	25%
FS_9 (ML1)	100%	91%	83%	38%
FS_10 (ML2)	100%	91%	50%	25%
FS_11 (ML1)	100%	100%	100%	21%
FS_12 (ML1)	100%	100%	89%	33%
FS_13 (ML1)	100%	91%	67%	13%
FS_14 (ML1)	100%	100%	94%	21%



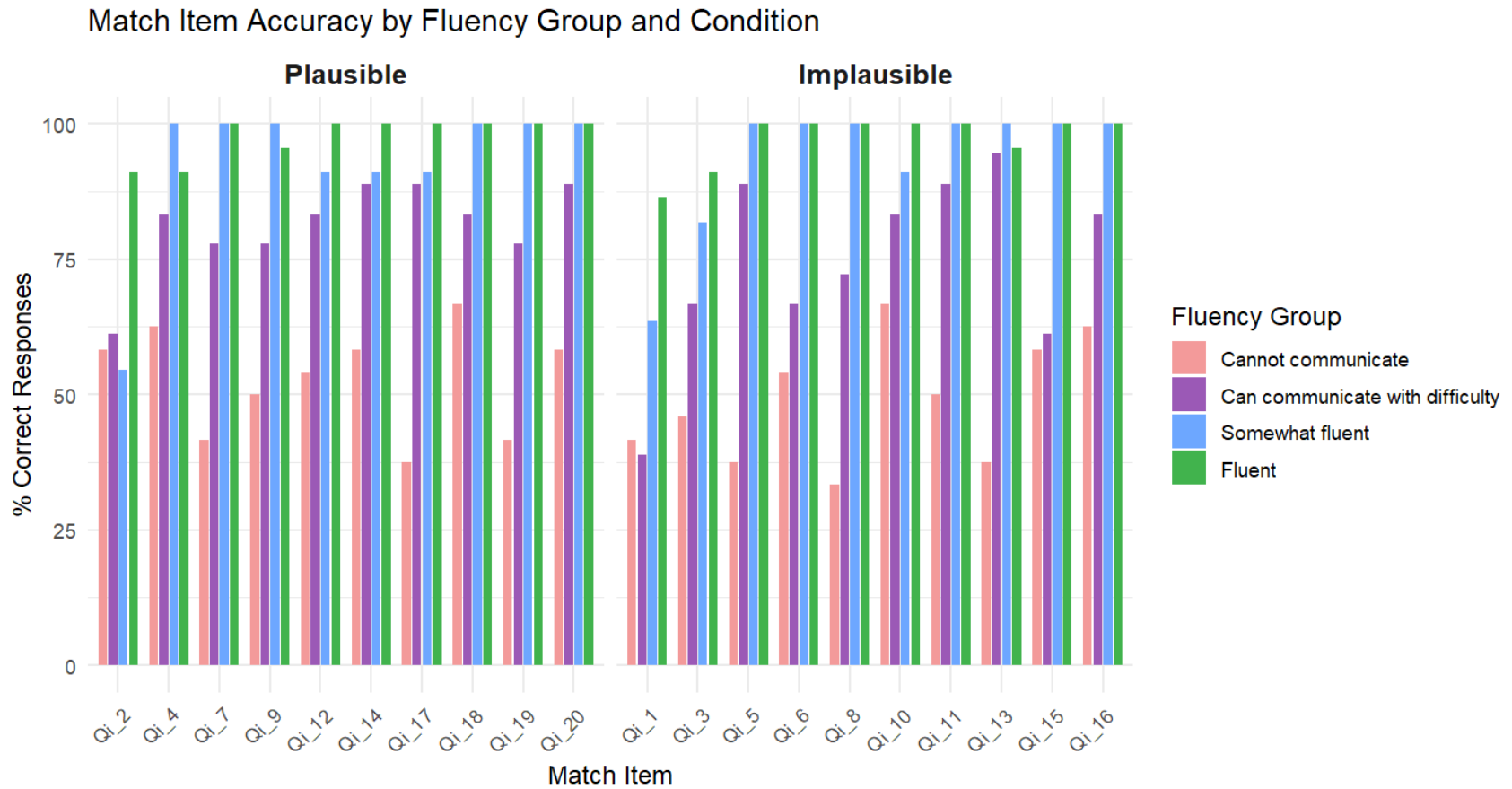
**Appendix Figure 3.** Percentage of participants (y-axis) within each ASL fluency group (colors) who responded correctly (1 vs 0) on each Fingerspelling Task item (x-axis; FS\_1 - FS\_14).

**Appendix Table 7.** ASLTB Maze Task items- percent of participants with correct response (n=75). Each item is worth 1 point.

Item name (Condition)	Fluent (n = 22)	Somewhat Fluent (n = 11)	Can communicate with difficulty (n = 18)	Cannot Communicate (n = 24)
Qi_1 (Implausible)	86%	64%	39%	42%
Qi_2 (Plausible)	91%	55%	61%	58%
Qi_3 (Implausible)	91%	82%	67%	46%
Qi_4 (Plausible)	91%	100%	83%	63%

Qi_5 (Implausible)	100%	100%	89%	38%
Qi_6 (Implausible)	100%	100%	67%	54%
Qi_7 (Plausible)	100%	100%	78%	42%
Qi_8 (Implausible)	100%	100%	72%	33%
Qi_9 (Plausible)	95%	100%	78%	50%
Qi_10 (Implausible)	100%	91%	83%	67%
Qi_11 (Implausible)	100%	100%	89%	50%
Qi_12 (Plausible)	100%	91%	83%	54%
Qi_13 (Implausible)	95%	100%	94%	38%
Qi_14 (Plausible)	100%	91%	89%	58%
Qi_15 (Implausible)	100%	100%	61%	58%
Qi_16 (Implausible)	100%	100%	83%	63%
Qi_17 (Plausible)	100%	91%	89%	38%
Qi_18 (Plausible)	100%	100%	83%	67%
Qi_19 (Plausible)	100%	100%	78%	42%
Qi_20 (Plausible)	100%	100%	89%	58%

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**Appendix Figure 4.** Percentage of participants (y-axis) within each ASL fluency group (colors) who responded correctly (1 vs 0) on each Match Task item (x-axis), separated by trial condition (Plausible vs. Implausible).

**Appendix Survey 1: Information**

First name

\_\_\_\_\_

Last name

\_\_\_\_\_

email address:

\_\_\_\_\_

What is your age in years?

\_\_\_\_\_

Which hand do you use for most tasks?

- 
- 

- I am right handed
- I am left handed (I use my left hand for writing, throwing a ball and prefer left-handed tools)
- I am mostly right handed (I use my right hand for most tasks, but perform some tasks with my left hand)
- I am mostly left handed (I use my left hand for most tasks, but perform some tasks with my right hand)
- I am ambidextrous (I use both hands an equal amount)

What is your level of education?

- 
- 
- 
- 
- 

- Some middle school/ middle school graduate
- Some high school/ high school graduate
- Some college
- Bachelor's degree
- Graduate school (e.g. Masters or PhD)

While gender isn't a primary variant of interest in differences in how men and women are educated in math. With which gender identities did education?

- Female our study, there are
- Male
- Transgender female you identify during your
- Transgender male
- Gender variant/Non-conforming  Not listed
- Prefer not to answer

How do you identify? Select all that apply.

- Hearing  Deaf
- Hard of hearing
- Child Of a Deaf Adult (CODA)

- Another relative of a Deaf/Hard of Hearing person (SODA/GODA/etc)
- Interpreter  Not listed
- Prefer not to answer

Are you okay with our lab sharing your contact information and hearing status with other researchers so that they may reach you for their studies in the future?

Yes  
No

**These questions focus on your current use of ASL (American Sign Language)**

How fluent are you in ASL?

Fluent  
Somewhat fluent  
Can communicate with difficulty  
Cannot communicate

How frequently do you use ASL in your present life?

Every day  
Almost every day  
A few days a week  
A few days a month  
A few days a year  
Never

**These questions focus on your current use of signed English**

Example of Signed English compared to ASL by ASL-Deaf Vlogger [Attachment: "SEEvSASL.mp4"]

How fluent are you in signed English?

Fluent  
Somewhat fluent  
Can communicate with difficulty  
Cannot communicate

How frequently do you use signed English in your present life?

Every day  
Almost every day  
A few days a week  
A few days a month  
A few days a year  
Never

**These questions focus on your use of spoken and written English**

How fluent are you in spoken English?

- Fluent  
 Somewhat fluent  
 Can communicate with difficulty  
 Cannot communicate

How fluent are you at reading text in English?

- 

- Fluent  
 I read text, but not entirely fluently  
 I don't often read text

**These questions focus on your current use of signed languages in the community**

How often have you used ASL or signed English over the past year?

- I+ times a week  
 I+ times a month  
 I+ times a year  
 Rarely  
 Never

How often do you attend Deaf events/expos (including virtual events)?

This includes any social event where the primary language is sign. If participation falls between two categories, choose the closest.

- 

- I+ times a week  
 I+ times a month  
 I+ times a year  
 Rarely  
 Never

How often do you use ASL or signed English for work?

- 

- I+ times a week  
 I+ times a month  
 I+ times a year  
 Rarely  
 Never

**These next questions ask about your use of language when you were growing up. We are interested in the languages you spoke at home between the ages of 4-12.**

Which language(s) did you learn as a child? Select all that apply.

- ASL  
 Signed English

- Spoken English
- A language not listed above

---

At what age did you begin learning ASL (in years)? \_\_\_\_\_

---

How often did you use American Sign Language (ASL) in your household growing up?

- Every day
- Almost every day
- A few days a week
- A few days a month
- A few days a year
- Never

---

At what age did you begin learning signed English (in years)? \_\_\_\_\_

---

How often did you use signed English in your household growing up?

- Every day
- Almost every day
- A few days a week
- A few days a month
- A few days a year
- Never

---

At what age did you begin spoken English (in years)? \_\_\_\_\_

---

How often did you use spoken English in your household growing up?

- Every day
- Almost every day
- A few days a week
- A few days a month
- A few days a year
- Never

---

What were the other languages you learned as a child? \_\_\_\_\_

---

At what age did you begin to learn this other language (in years)? \_\_\_\_\_

---

How often did you use this other language in your household growing up?	<input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/>	Every day Almost every day A few days a week A few days a month A few days a year Never
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Have you ever taken an ASL class in high school or college? If so, for how long?	<input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/>	Never Less than 1 year 1-2 years 2-3 years 4-5 years 5+ years
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Have you ever taken a signed English class in high school or college? If so, for how long?	<input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/>	Never Less than 1 year 1-2 years 2-3 years 4-5 years 5+ years
--	---	--

**Here we ask about the languages spoken by your caregivers (parents/guardians) at that time. If you had more than 2 caregivers please respond based on the two caregivers with which you spent the most time.**

**These first set of questions refers to your PRIMARY caregiver.**

Is your primary caregiver Deaf? Yes No

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What are your primary caregiver's first language(s)? Select all that apply.	<input type="checkbox"/> ASL <input type="checkbox"/> Signed English <input type="checkbox"/> Spoken English <input type="checkbox"/> A language not listed above
--	--

---

Growing up, what language did your primary caregiver mostly speak at home? \_\_\_\_\_

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How fluent is your primary caregiver at ASL?	<input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/>	Fluent Somewhat fluent Can communicate with difficulty Cannot communicate
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How fluent is your primary caregiver at signed English?	<input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/>	Fluent Somewhat fluent Can communicate with difficulty Cannot communicate
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Do you want to report languages for a second caregiver?	<input type="radio"/> <input type="radio"/>	Yes No
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**These next set of questions refer to your SECOND caregiver.**

Is your second caregiver Deaf?	Yes	No
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What are your second caregiver's first language(s)? Select all that apply.	<input type="checkbox"/> ASL <input type="checkbox"/> Signed English <input type="checkbox"/> Spoken English <input type="checkbox"/> A language not listed above
---	--

---

Growing up, what language did your second caregiver mostly speak at home? \_\_\_\_\_

---

How fluent is your second caregiver at ASL?	<input type="radio"/> <input type="radio"/> <input type="radio"/>	Fluent Somewhat fluent Can communicate with difficulty Cannot communicate
---	---	--

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How fluent is your second caregiver at signed English?	<input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/>	Fluent Somewhat fluent Can communicate with difficulty Cannot communicate
--	---	---



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