CONTROL OF LEXICAL INHIBITION IN ASL AND ENGLISH-READING SENTENCE COMPREHENSION IN DEAF AND HEARING ASL USERS

by

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Background: Language experiences of Deaf individuals are variable and impact cognitive-linguistic functioning. Deaf individuals in the U.S. who use American Sign Language (ASL) as their primary communication method must learn to read and write in English; however they typically exhibit difficulty in doing so due to many factors. Cognitive-linguistic functions, such as inhibition and other executive attentional mechanisms, play a key role in literacy acquisition. One task that measures inhibitory functions is the Stroop task. The Stroop effect has been studied in the Deaf ASL population, however results were inconclusive and studies have focused on the single-word level only.

Procedures: This study included 15 hearing non-proficient (HNP), 15 hearing proficient (HP), and 15 Deaf proficient (DP) ASL users. The participants completed an ASL single-word Stroop task, the ASL and English Reading Word Fade versions of the sentence-length Computerized Revised Token Test (CRTT), and the ASL and English Reading Word Fade Stroop versions of the CRTT.

Results: No groups demonstrated a reliable Stroop effect for the single-word ASL task, but 10 participants from the DP group did show a Stroop effect on this task. The DP group was the only group to demonstrate a color word Stroop effect on the CRTT ASL Reading Word Fade Stroop task. All groups demonstrated a significant Stroop effect for the English Reading Word Fade Stroop task. The DP group demonstrated larger interference in English than the hearing groups, and produced lower Mean-CRTT scores across both languages. Language proficiency did not predict a Stroop effect for any group for either language, however, individuals that were more language proficient were faster to respond to the sentence-level stimuli than the less proficient. *Conclusions:* The DP group demonstrated lexical processing in both ASL and English at the sentence level, evidenced by observable Stroop effects, however the magnitude of the effects suggest reduced inhibitory control or slow lexical activation observed in the bilingual (ASL-English) population. At the single-word level, individual participant factors influenced the presence of a Stroop effect. The DP group was slower to read words in all tasks across both languages, suggesting requirement for additional processing time.

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PREFACE

This thesis contains work completed from August 2015 to April 2017. Many individuals volunteered their time to assist the success of this research project and deserve recognition. The supervisors of this project were Dr. Sheila Pratt and Dr. Malcolm McNeil, each of whom provided endless support and guidance throughout the project. Dr. Michael Walsh Dickey, who served as a thesis committee member, dedicated a significant amount of time to conduct the statistical analyses presented in this document. Dr. Claude Mauk served as a member of the thesis committee and provided valuable resources and feedback throughout the process.

The School of Health and Rehabilitation Sciences supported the research project through the School of Health and Rehabilitation Sciences Developmental Fund. Kenneth DeHann continued to serve in the role as signer for the creation of video stimuli, and devoted many hours to be filmed for the construction of the stimuli for this research study. Neil Szuminsky programmed the word fade and Stroop versions of the CRTT-ASL, as well as the ASL single-word Stroop task; thus the study could not have occurred without his significant contributions. Katherine McGovern volunteered as a research assistant and aided in data collection. Angela Ryu and Margot Smith, on behalf of the University of Pittsburgh Television organization, assisted in all video filming and editing. Many thanks for overwhelming support from mentors, advisors, supervisors, professors, family, friends and peers.

1.0 INTRODUCTION

Deaf or hard of hearing (DHH) individuals who consider American Sign Language (ASL) as their primary language constitute a unique group and demonstrate language capabilities unlike hearing speakers. These differences can be attributable largely to variations in language-learning environments and experiences. Language learning typically occurs immediately and rapidly across infancy. However, Deaf and hard-of-hearing infants commonly experience delays in language acquisition due to impoverished or delayed auditory linguistic input (Humphries, et al., 2012). Infants and children with hearing loss who are fitted with hearing aids and cochlear implants frequently do not receive their devices for several months, or in some cases years, after birth. This auditory privation or deprivation has a substantive negative impact on language development.

One option for enhancing exposure to language is to use and teach American Sign Language (ASL). Deaf infants born into Deaf households who are exposed to ASL in its complete form may achieve language developmental milestones and linguistic competence similarly to typically developing hearing peers (Lu, Jones, & Morgan, 2016). However, the majority of deaf infants are born into hearing households where ASL is not a primary mode of communication. If hearing parents choose to use ASL, they typically lack language proficiency and serve as inadequate language models, which contributes to delayed language development and impaired communication abilities (Lu, Jones, & Morgan, 2016).

The language delays common to infants and children with hearing loss can influence linguistic-dependent cognitive and social functions. For example, reading and writing skills are often depressed in children with hearing loss (Hoffmeister & Caldwell-Harris, 2014). Even children with mild and minimal hearing losses are at risk for academic failure. This pattern also is true for children with severe-profound hearing loss regardless of their training models (oral vs. manual). Literacy acquisition is particularly problematic for Deaf children who use ASL. One reason for this disadvantage is that they do not use, and are unable to access the oral language in which they are learning to read and write. The difficulty of this task is increased substantively for those children who enter the formal educational system with impoverished ASL skills.

The lack of access to oral language can interfere with phonological recoding and, consequently, lexical access, which are skills needed for the development and use of literacy (Treiman & Hirsh-Pasek, 1983). Furthermore, development of cognitive and literacy skills are related, and functions of executive control (such as working memory) are recruited during linguistic tasks such as reading (Arfe, Rossi, & Sicoli, 2015; Wagner & Torgesen, 1987). One task that taps into executive function and recruits lexical processing is the Stroop task, where a color word (e.g., “green”) is presented in a different font color and the participant is required to name the color of the font rather than read the word. Because the act of reading is automatic for proficient readers, the word has privileged access to the linguistic system. As a result, the printed color word has to be suppressed so that the font color can be activated and produced. The time taken to name or indicate the incongruent color, relative to reading a neutral form of the word or a congruent color word (the word “blue” printed in blue font), is referred to as the Stroop effect.

In the current study, Stroop tasks were used to assess the impact of first and second language acquisition (ASL vs. English) and language proficiency on executive function in signing populations. Comparisons in English reading and ASL Stroop tasks can contribute to our understanding of Deaf signers' abilities to use and control both languages, which vary in structure and modality.

2.0 BACKGROUND

2.1 AMERICAN SIGN LANGUAGE: A BRIEF OVERVIEW

Children who are Deaf (severe-profound hearing loss and use sign as their first and primary language), often are at a disadvantage when learning to read because they are unable to use awareness and knowledge of the given oral language sound system (Corina, Hafer, & Welch, 2014; Wagner & Torgesen, 1987). American Sign Language is a visual-spatial language that relies on structural sign parameters, including movement, positioning, and orientation of the hands/arms within a sign space that ranges from the torso to the top of the head. There are five parameters that serve as linguistic foundations for the language: (1) non-manual markers, (2) handshape, (3) palm orientation, (4) location, and (5) movement (Stokoe, 1960; Liddell, 2003). American Sign Language also is largely based on Object-Subject-Verb (OSV) grammatical order.

In contrast, English is an oral language that recruits the speech articulators for sound production, and requires audition for acquisition, maintenance and reception. Its phonology depends on rule-based production of phonemes (speech sounds), accurate sequencing of strings of phonemes (such as in syllables and words), and onsets and rimes. There are phonotactic rules in English that govern shape, structures, and stress of syllables, all of which contribute to English phonology. Grammatical word order in English also differs from ASL in that it relies more heavily on Subject-Verb-Object (SVO) sequencing.

However, both languages lateralize to the left-hemisphere and recruit similar neurological structures, including the left perisylvian regions (Campbell, MacSweeney, & Waters, 2007). Although lateralization is similar, neuroimaging studies have shown subtle differences between scans of hearing English speakers and Deaf ASL users. For example, hearing individuals show more dense connections spanning from anterior to auditory regions of the brain than do Deaf ASL users (Emmorey et al., 2003). There is debate as to whether use and understanding of ASL recruits the right hemisphere in addition to the left hemisphere, due to the right hemisphere's role in visuospatial processing (Campbell, MacSweeney, & Waters, 2007). Some of the observed neuroanatomical differences could be attributable to variations in early language-learning environments and histories. These language histories are complex, as the vast majority (90%) of Deaf infants are born to hearing families, and 95% of Deaf infants have at least one hearing parent (Mitchel & Karchmer, 2004). The language used in the homes of these families is typically the oral language of the majority community; in the United States that language tends to be English.

2.1.1 Language Learning Experiences

Language processing capabilities are greatly influenced by language acquisition and exposure. Hearing parents with newborns presenting with severe-profound hearing loss might attempt to teach ASL to their infant in isolation or in conjunction with oral language. However, few parents of infants and young children with severe-profound hearing loss have sign language experience. Of those parents with ASL experience few are proficient, which results in an impoverished language-learning environment (Lu, Jones, & Morgan, 2016). As a result, the potential for language delay and differences in this population is very high for both oral and signed languages. An added issue is that many Deaf children do not learn sign or are exposed to sign in a complete form until they reach school – some not until adolescence or young adulthood. Even when exposed at early ages, Deaf children with hearing parents have been observed to demonstrate reduced vocabularies, and one explanation for this could be that they receive less linguistic input at earlier ages compared to Deaf children with Deaf parents (Lu, Jones, & Morgan, 2016; Moeller, 2000). Deaf children of Deaf parents also have demonstrated more developed phonological systems and more semantic linking capabilities (Lu, Jones, & Morgan, 2016).

The neurological consequences of the language learning experiences among Deaf ASL users have been compared in fMRI studies, specifically looking at Deaf individuals who acquired ASL later in life compared to individuals who learned ASL natively. The scans of Deaf individuals who learned ASL natively demonstrated typical neural activation patterns in the classic language areas of the brain. The participants who learned ASL later in life demonstrated a negative linear effect - as age of acquisition increased, activation patterns in the anterior regions of the brain responsible for high level linguistic processing decreased. This pattern suggests that late language learners are at a neurophysiological disadvantage (Mayberry, Chen, Witcher, & Klein, 2011). It also has been found that individuals born with severe-profound hearing loss who were not exposed to language early in life performed lower on ASL usage tasks in comparison to individuals who were born hearing, became deaf later in life, and learned ASL later in life (Mayberry, Lock, & Kazmi, 2002). These study findings are consistent with the notion that language exposure and experience play key roles in advanced-level linguistic functioning.

2.2 DEAF BILINGUALISM

Deaf individuals who consider their native language to be ASL often are bilingual. Typically they are taught to read English print because there is no written form of ASL (Hoffmeister, Moores, & Ellenberger, 1975). Many Deaf ASL users show preference towards using ASL rather than communicating via written English, and when they do read or write in English they demonstrate frequent errors. Although most Deaf children are taught to read written English with basal readers (texts that are written with the objective of teaching reading skills to children), there is no standardized method for teaching them English literacy skills, resulting in Deaf children across the United States experiencing a variety of methods for learning English as a second language. As expected, learning English as a second language through text is challenging for Deaf children, in part because they have limited exposure to speech sounds upon which the text is based, and limited experience with the phonology, lexicon, and grammar of oral English (Chamberlain & Mayberry, 2000; Hoffmeister & Caldwell-Harris, 2014; Marschark & Harris, 1996).

Hearing children commonly use a print-sound mapping strategy to acquire English literacy and writing skills, and they learn how to read in a language that they have had constant exposure and access to since birth. Deaf children, in contrast, are unable to use this print-sound mapping strategy when learning to read and write. Even children with hearing loss who use hearing aids and cochlear implants and undergo oral educational training, exhibit delays and difficulties in English reading development (Goldin-Meadow & Mayberry, 2001).

Recoding strategies should be considered when examining how Deaf and hard of hearing ASL users read. Recoding is defined by Treiman and Hirsh-Pasek (1983) as the "translation of a printed text into some other form" (p. 41), and they hypothesized three possible strategies used by Deaf children to recode English print when reading. The first strategy was referred to as articulation, where lip reading and speech knowledge skills could be used to recode written English. The second strategy was to convert written English print into fingerspelling. Fingerspelling is a manual coding of the English alphabet with individual hand-shapes, and has been incorporated into modern ASL. The third strategy involves using ASL to recode when reading. Treiman and Hirsh-Pasek were specifically interested in which recoding strategy second generation Deaf children (Deaf children born to Deaf parents) used when reading. In order to investigate these strategies, four conditions with written English sentences were used. When investigating presence or absence of the articulation recoding strategy, stimuli in the articulation condition contained similar articulation targets (i.e., Sally the snake sits by the sun). The sentences within the fingerspelling condition contained words that would use similar handshapes if they were to be produced using ASL fingerspelling. In the ASL condition, words within the sentences contained words where phonological components (such as handshape or location) occurred repeatedly. A control condition also was included in the study.

They asked 14 Deaf adults who were native ASL users and 14 hearing participants who used oral English to verify sentence accuracy across the 4 conditions. The participants responded with “yes,” “no,” or “rest,” using a button-press system, and recoding was measured by response time and response accuracy. Treiman and Hirsh-Pasek (1983) argued that if the Deaf participants demonstrated difficulty (longer time responding and/or inaccurate responses) recoding English sentences in a given condition, they were using that strategy to recode. The Deaf native participants exhibited significant difficulty in reading and judging accuracy for sentences in the similar articulation and fingerspelling conditions. Deaf native signers also showed prolonged time on the similar sign condition, which approached significance. The results suggested that the Deaf native signers recoded written English using knowledge of articulation and fingerspelling skills, with the potential to recode using signs. When compared to hearing individuals the Deaf participants were less accurate in all conditions except for the homophone condition, suggesting that the recoding strategies used by the participants were insufficient to support high-level reading (Treiman & Hirsh-Pasek, 1983).

While Treiman and Hirsh-Pasek did not find significant evidence suggesting that Deaf native signers recode using ASL, Morford, Wilkinson, and Villwock (2011) presented evidence suggesting that English words with phonologically-related sign characteristics resulted in faster response times in Deaf ASL users, and argued that the Deaf participants recoded using ASL. The variety of findings regarding Deaf reading and recoding strategies is consistent with heterogeneity of the Deaf population and their language experiences. Based on what is known regarding the heterogeneity of the Deaf group and their language skills, it is not surprising that findings regarding recoding and bilingual skills in the Deaf population are variable.

2.3 DEAF LITERACY SKILLS

The advancement and early fitting of sensory aids on infants and young children with hearing loss impacts auditory access to spoken language and has the potential to dramatically impact the English reading skills of Deaf readers. The impact of advances in cochlear implant technology and universal newborn hearing screenings on literacy skill development in Deaf children was recently examined by Harris, Terlektsi, and Kyle (2017). They compared the results of two groups of children with severe-profound hearing loss who had been fitted with cochlear implants and hearing aids. Both cohorts ranged in age from 5 to 7 years. The groups differed historically on nonverbal intelligence, reading ability, English vocabulary, and phonological awareness, with the first group being tested 10 years prior to the second group. Results indicated that the recently tested children had English vocabulary scores that outperformed the earlier group; however, when compared to hearing peers, the recent group performed significantly worse in the area of vocabulary. Although vocabulary and literacy skills are closely related, it is interesting that the study did not find significant improvements in English reading or phonological skills by the recently tested group. The increase in English vocabulary could signify that access to auditory language improved acquisition of words in that language, and the continuous struggle demonstrated on reading and phonological awareness tasks could emphasize the difficulty that Deaf and hard of hearing children experience in learning the written form of a verbal language that they cannot fully access, despite advanced technologies.

2.3.1 Reading Instruction

One factor that can contributes to poor reading and writing skills in Deaf people is the learning process itself. Mounty, Pucci, and Harmon (2014) investigated how Deaf ASL/English bilingual children acquired proficient reading skills, and the strategies that were used to teach English reading. The participants, 11 Deaf bilingual ASL/English-using adults and 1 Child of Deaf Adults (CODA), were interviewed about their experiences with ASL/English acquisition, the relationship between ASL and English, views on the purpose of reading, identification of characteristics of Deaf skilled readers, and belief about strategies that facilitate proficient reading. Four main themes emerged from the interviews. First, exposure to both English and ASL were required in order for children who use ASL as their primary language to acquire proficient English reading skills. The participants of the study indicated that ASL enhances development of English literacy, and that English literacy enhances continued development of ASL – the languages support each other. The second theme was that in order for Deaf children to connect visual signs with written oral language, they should be supplied with a print-rich culture. A third theme was that ASL and English text should be used in school and at home, and children should be encouraged to think critically about both languages in order to develop metalinguistic skills. The final theme was that fingerspelling was seen as a tool to connect ASL with English reading. Mounty et al. also found great variability across Deaf individuals in their educational experiences, hearing loss types, language histories, and social and language-learning environments (2014).

2.3.2 Working Memory

Working memory is another commonly cited factor contributing to literacy performance in children and adults who are Deaf or hard-of-hearing (Alvarado, Puente, & Herrera, 2008). Working memory is considered an executive function, and poor performance on linguistic working memory tasks in written English has been shown to be influenced by hearing status, such as working memory tasks that involve language-based stimuli (Marschark, Sarchet, & Trani, 2016). Working memory has been highly correlated with reading skills, and the Deaf and hard-of-hearing population commonly displays both reduced working memory capacities and English reading skills when compared to the hearing population (Garrison, Long, & Dowaliby, 1997; Marschark, Sarchet, & Trani, 2016). Children who receive cochlear implants at early ages (before or around 5 years of age) still demonstrate working memory capacities that are lower than their hearing peers (Geers, 2003). However children who receive cochlear implants at early ages and are classified as strong readers (within or above average of their grade level) have demonstrated high correlations between reading capabilities and working memory capacities, which highlights the relationship between literacy and working memory (Geers, 2003).

Marschark, Sarchet, and Trani (2016) investigated the performance of Deaf ASL users and hearing participants on three complex working memory span tasks presented in written English, aiming to present data regarding hearing status and its association with working memory tasks. These authors also gathered information on the relationship between age of ASL acquisition and working memory performance, as well as the use of cochlear implants and performance on working memory tasks. Marschark, Sarchet, and Trani found that, regardless of self-reported ASL proficiency and use of cochlear implant technology, Deaf participants performed significantly worse on working memory tasks that elicit verbal coding compared to hearing individuals. Additionally, the study reported that age of acquisition of ASL did not significantly impact performance on these tasks. In summary, the Deaf participants performed poorer than the hearing participants on English written working memory tasks, and the only factor that contributed to these results was hearing status.

Wang and Napier (2013) investigated the linguistic working memory capacity of Deaf and hearing Australian Sign Language (Auslan) users using Auslan based stimuli. The authors were interested in investigating the impact of hearing status and age of acquisition of Auslan on working memory span tasks, and reported two findings of interest: (1) hearing signers (professional interpreters) outperformed Deaf signers on linguistic working memory span tasks presented in sign language, and (2) there was no significant differences on linguistic working memory span tasks between native Auslan users and signers who learned Auslan later in life. These results and those of Marschark, Sarchet, and Trani (2016) supported the argument that

Deaf signers are less skilled at linguistic working memory tasks, and that performance on these tasks is related to hearing status and not age of acquisition of sign language.

The phonological loop, which in the context of reading is used when linguistic information is sent to a short-term memory store, is considered a critical component of verbal working memory and there is mounting evidence for the existence of a sign language phonological loop and ASL-based memory codes (Wagner & Torgesen, 1987). Wilson and Emmorey (1997) investigated performance of Deaf signers on serial recall tasks, and the presence of the phonological similarity effect by asking signers to open and close their fists during an ASL sign recall task, and comparing those results to a control condition where participants did not open and close their fists. The phonological similarity effect occurs when a list of words with phonological similarities (i.e. pan, pat, mad, man) is more difficult to recall than a list of words that are not similar phonologically. A phonological similarity effect was detected in the Deaf participants, meaning participants exhibited poorer recall abilities when signs with similar phonological qualities were used in a series. Participants also experienced difficulty in recalling words when opening and closing their fists, which suggests that the signers may use rehearsing strategies during memory tasks (Wilson & Emmorey, 1987). The authors also investigated a sign-length effect in Deaf ASL users, and as expected, found longer signs resulted in decreased word recall, indicating potential time-sensitive verbal memory, reduced memory span, or inadequate rehearsal strategies in order to retain information in the short term memory store in the Deaf participants.

The existence of an ASL-based phonological loop is considered important for Deaf literacy acquisition and performance. Corina, Hafer, and Welch (2014) investigated the relationship between age of exposure to language, phonological awareness capabilities, and

English reading by examining the relationship in performance between phonological awareness tasks in both ASL and English reading. Deaf native participants performed most accurately on phonological awareness tasks in ASL. Early and late ASL learners performed similarly in this study but poorer than the Deaf native signers. Although native signers performed better on ASL phonology assessments, it was found that late ASL learners, who probably depended on English until the age at which they learned ASL, performed better than early ASL learners on English phonological awareness tasks. It is important to highlight that the late ASL users had less severe hearing losses. Their hearing status and language-learning environments likely contributed to these findings.

Working memory often is subsumed under cognitive skills referred to as executive function, which not only includes working memory but other automatic processes such as inhibition and attention. Executive functions appear to be dissociable, meaning that an individual can perform well in one aspect of executive function and not another. Some functions are more language-dependent than others, which impacts performance when considering the Deaf and hard of hearing population. Figueras, Edwards, and Langdon (2008) investigated the relationship between language and executive function performance on a battery of executive function tasks in hearing children, children fitted with cochlear implants, and children fitted with hearing aids. Executive function tasks measured in the study included the Tower Test, visual attention, design fluency, Day-Night and One-Two tasks (which test inhibition), and a card-sorting test. The two groups of children with hearing loss did not differ, but they were slower and less accurate than the hearing children on these inhibition tasks, suggesting that inhibition was more effortful for the children with hearing loss. The Day-Night task, and other tasks included in the study, depended on working memory in addition to inhibition, and the authors were unable to identify if the observed prolonged time required by the child with hearing loss to inhibit interfering pictures and their poor performance generally was due to inhibition or working memory deficits. However executive cognitive control was purported to be involved. These conclusions have important implications for literacy acquisition as they suggest potential executive function deficits being evident as a function of hearing status at a young age.

2.4 THE COMPUTERIZED-REVISED TOKEN TEST

The Revised Token Test (RTT) was developed by McNeil and Prescott (1978) to assess auditory language processing inefficiencies and disorders in people with aphasia, and was later applied to other clinical populations. The test uses 20 tokens, comprised of two shapes (circle and square), two sizes (little and big), and five colors (red, blue, green, black, and white), which patients manipulate in response to a set of commands. The test includes 10 subtests, with 10 commands for each subtest. The subtests vary by difficulty due to command length, complexity, and response demands. For example, the commands can vary by “touch the blue square” (Subtest I) to “Put the big green circle to the left of the little black square,” (Subtest VIII) with the token response selection options changing from 10 to 20 between these two subtests. The redundancy of the stimuli also adds attentional and memorial demands, making the test sensitive to language processing impairments. The RTT is a psychometrically well-established assessment tool (McNeil & Prescott, 1978), however, the stimuli are presented orally and a complex manual scoring system is used. The RTT also does not capture subtle timing distinctions. To address these limitations and expand the use of the test, the RTT recently was computerized (McNeil et al., 2015), which allows for pre-recorded stimuli for consistency, computerized scoring, temporal fidelity and a measure of efficiency.

The CRTT produces two scores that are of interest in the current study. First is the Mean CRTT Score. This score is calculated for each content word within each command, within a subtest and averaged to create a representative mean for each subtest. Like the RTT, scoring is based on a 15-point multidimensional scoring system with points assigned to each element of the command. For example if a command reads "Touch the big blue circle and the little green square" a participant will receive scores for their ability to complete each of the command elements "touch," "big" "blue" "circle" "little" "green" "and" (implied verb) and "little" "green" "square." The CRTT score values and associated descriptions of each potentially assigned value can be found in Table 1. Because timing can be captured using the CRTT, the test also includes an efficiency score (ES), which is derived by multiplying the command performance score by the time it took to complete the command, divided by the amount of time allowed to complete a task. The ES is computed for each command within each subtest and is averaged to provide mean ES at the subtest and overall levels (McNeil et al., 2015).

Table 1. CRTT scoring system.

Score	***Description of Response***
15	Correct
14	Vocal/Subvocal Rehearsal
13	Delay
12	Immediacy
11	Self-correct
10	Reversal
9	Repeat
8	Cue
7	Error
6	Perseveration
5	Intelligible but incorrect response
4	Unintelligible (differentiated)
3	Unintelligible (perseverated)
2	Omission
1	No Response

(McNeil & Prescott, 1978)

Computerizing the RTT also allowed for test expansions, including reading and Stroop versions and more complex commands. The CRTT-Stroop is a sentence-level, self-paced reading Stroop task. In the self-paced reading version, test-takers are presented the commands one word at a time with the previous word disappearing as the next word is added to the screen by clicking a computer mouse. At the end of the command the test-taker responds by manipulating tokens, but uses the font color of the color words rather than the text of the color words to respond. Time spent reading across and within the self-paced reading process is then compared to a control (non-Strooped) self-paced reading version of the test.

A previous study by Goldberg (2015) translated the CRTT into ASL to assess test-retest reliability and compared Deaf and hearing ASL user performance on the ASL and English Reading Word Fade (CRTT-R-$_{WF}$) versions of the CRTT. Whereas the auditory version of the

CRTT uses auditory stimuli, and the CRTT-R-$_{WF}$ depends on the presentation of written English words on the screen, the CRTT-ASL uses filmed stimuli. The signer in the videos is a native and proficient Deaf ASL user, and the original CRTT programmer constructed the CRTT-ASL. It uses the same scoring system as the listening version of the CRTT. In Goldberg's (2015) study, Deaf proficient, hearing proficient, and hearing non-proficient signers were administered the CRTT-ASL and CRTT-R-$_{WF}$. Test-retest reliability was investigated; therefore the participants completed two sessions, with the second session following 7-14 days after the first. The Mean CRTT and Mean Efficiency scores were highly correlated for the Deaf proficient ASL users, but not for the hearing ASL users. This is interpreted to mean that the assessment is reliable for the target population. Although the CRTT has been translated into ASL, an ASL Stroop version of this assessment had not been created prior to the current study. Details on the construction of the Stroop ASL version of the CRTT (CRTT-ASL-$_{STROOP}$) for the current study are provided in the methods section of this document.

2.5 THE STROOP EFFECT

Research on the inhibition and interference in reading dates back to the 19th century, but the widely referenced paper on this paradigm and its effects, commonly called "the Stroop effect" came from John Ridley Stroop in 1935. Stroop's study investigated performance on two conditions related to inhibition and interference. It first aimed to determine if the reading or naming time of a color word (e.g., "blue") was affected by altering the color in which the word was written (i.e., a ***congruent*** condition whereby the word "blue" is printed in "blue" font color versus an ***incongruent*** condition whereby the word "blue" is printed in "red" font color). A second part of the study investigated the time that it took individuals to name the color of a non-linguistic representation (shapes). It took participants longer to produce the name of the incongruent font colors for words as compared to naming colors of squares. The time difference between these conditions was interpreted as interference (Stroop, 1935). Since Stroop's study, calculating the interference effect on a Stroop task requires subtracting the time it takes for participants to read color words written in black (the neutral/control condition), from the time it takes to read color words in the incongruent condition (MacLeod, 1991). Shapes also can be used as a neutral condition. The congruent condition was originally introduced as a control, allowing researchers to determine interference versus facilitation. Although a facilitation effect was observed in the congruent condition, the size of the effect was less than the interference seen in the incongruent condition, and therefore is not frequently used as a neutral condition (MacLeod, 1991).

Since its inception, a large number of Stroop task variations have been developed. One modification of the Stroop task is the embedding of "Strooped" words into sentence-level stimuli. Brega and Healy (1999) investigated whether sentence processing can occur automatically and if a sentence Stroop effect is demonstrated. They looked at responses to sentences with color-related words, non-color related words, non-sentences containing color-related words, non-sentences that used non-color words, and a control condition that used strings of bullets. The examiners told participants to ignore the sentence meanings. They concluded that words were still processed automatically based on the participants' inability to ignore the content of the sentences. They also found that sentences containing related words yielded longer response times and greater error rates compared to non-relevant words were embedded in the sentences.

Stroop tasks are frequently used to measure automaticity. The slowed reading or reaction times in the Stroop task demonstrates how reading a word is largely automatic for most skilled readers. Increased time for labeling font colors in the incongruent presentation conditions is caused by the need to inhibit the more automatic process of word reading. In terms of attentional resources, the large numbers of Stroop studies demonstrating Stroop effects at both single-word and sentence levels supports the conclusion that high levels of attention are not required in these tasks if the individual is proficient in the language (Brown, Joneleit, Robinson, & Brown, 2002; MacLeod, 1991). If a person is a proficient reader, the process of reading words is difficult to inhibit.

The stimuli used for the present study were based on the Stroop version of the CRTT, which has been used to investigate inhibitory function in individuals with aphasia, a language disorder that can occur following acquired brain injury. Individuals with aphasia frequently demonstrate deficits that are similar to those described in the Deaf population, such as decreased working memory function. A study by Pompon, McNeil, Spencer, and Kendall (2015) used a similar measure to the CRTT-R-$_{WF}$ -Stroop task to investigate inhibitory function of people with aphasia (PWA) compared to healthy normal adults in order to better understand the cognitive underpinnings (i.e., attention through measuring inhibitory control) of the presentation of language deficits in PWA. Similarly to the Deaf population, there is a lack of homogeneity within the aphasic population. The Pompon et al. study findings suggested that both healthy adults and adults with aphasia demonstrated interference as measured by the Stroop reading task, with the PWA demonstrating more variable interference effects, and slower responses on the incongruent condition than the healthy normal control participants. The stimuli formulated for the present study were based on the Pompon et al. study.

2.5.1 Developmental Effects

Ligon (1932) demonstrated that groups of children, ranging from grades 1 through 9, demonstrated a positive relationship between age and presence of the Stroop effect for tasks that measured timing of color-naming. This means that older individuals are more proficient readers, and experience larger Stroop effects. Generally, as children increased in literacy skills, reading became a proficient and more automatic skill (MacLeod, 1991).

Deaf children typically perform at reduced levels on reading tasks, possibly due to deficits in the auditory phonological loop, impoverished working memory skills, and overall delayed language. In the Ligon (1932) study, children who were younger demonstrated less interference because English reading was less proficient and not automatic. Because Deaf signers typically demonstrate below age-appropriate reading performance, it is possible that they would not demonstrate a Stroop effect or the Stroop effect would be diminished in comparison to more skilled proficient readers.

Recent developmental studies have produced data suggesting an inverted U-shaped relationship between interference on the Stroop task and age. A study by Ikeda, Okuzmi, Kokubun, and Haishi investigated reaction times on incongruent and control conditions for the Stroop reading task in Japanese across three age groups – 7 to 8 year olds, 9 to 12 year olds, and 21 to 30 year olds. The findings confirmed the presence of an inverted U-shaped relationship between interference and age on the Stroop task, as the 9 to 12 year olds demonstrated more interference between incongruent and control conditions than the 7-8 year old group, as well as the 21-30 year old group. Many believe that older populations show decline in interference on the Stroop task due to maturation of executive function, with executive function control increasing with age. The 7-8 year olds likely demonstrated reduced interference due to lower reading skills.

The evidence and magnitude of a Stroop effect can be influenced by language and literacy history, in that it relates to the level of automaticity or the extent of language and reading proficiency. Because Deaf individuals historically have demonstrated poorer performance compared to hearing individuals in reading, working memory, and other language based tasks, investigating the Stroop effect in written English compared to ASL should provide insight into cognitive control and executive function processes in this unique population, as well as allow for comparison of language processing between written English and ASL.

2.6 THE BILINGUAL ADVANTAGE

Hypotheses related to a bilingual cognitive advantage have surfaced in the literature, and whereas much of this literature focuses on non-linguistic tasks, some studies have included linguistic cognitive tasks such as the Stroop task. Previous studies on differences in bilingual speakers compared to monolingual speakers suggests that bilingual speakers activate both languages simultaneously, recruiting executive control system to direct attention to the language which the speaker wishes to use. The ability of bilingual speakers to divide their attention between two languages, potentially inhibiting one, has prompted some to consider increased executive control function in bilinguals (Bialystok, 2009). Related to the Stroop task, Bialystok investigated whether a bilingual advantage was observable in younger and older bilingual individuals, and found that both groups of bilingual speakers demonstrated less time spent naming incongruent ink colors than monolinguals. With this in mind, Deaf signers are a unique bilingual group for several reasons. One reason is that the language they consider as their primary method of communication (ASL) does not possess written form. A subset of Deaf individuals do not learn to speak or hear English, therefore they learn one modality (written) of English only; whereas some Deaf individuals use auditory technologies (e.g., hearing aids or cochlear implants) to access spoken English in addition to reading in English and using ASL.

Kulshalnagar, Hannay, and Hernandez (2009) investigated the bilingual advantage in Deaf signers. Results reported in the literature historically have suggested that Deaf signers demonstrate low processing skills on linguistic-cognitive tasks; however they are bilingual. Bilingual individuals demonstrate increased cognitive control on tasks such as the Stroop task, evidenced by the ability to respond to interfering stimuli faster compared to monolinguals. This raises the question of whether Deaf ASL users demonstrate a bilingual advantage, or if their diminished performance on executive functioning tasks dictates their performance. Kulshalnagar, Hannay, and Hernandez (2009) attempted to investigate this question and hypothesized that Deaf people who were proficient in both ASL and written English have the potential to demonstrate the cognitive advantages found in bilinguals who are proficient in oral/written languages. They divided Deaf signers into two groups based on subjective language proficiency ratings. The first group was the balanced bilingual group (proficient in both written English and ASL), and the second group was unbalanced (proficient in just one of the languages). The participants completed three attention tasks: central, peripheral, and switching. The results showed that both the balanced bilingual group and unbalanced bilingual groups performed similarly on low-level attention tasks, and both did better on central visual tasks compared to peripheral visual stimuli. The study also showed that balanced Deaf bilingual individuals had a stronger advantage than the unbalanced group on the attention switching tasks.

Emmorey et al. (2008) conducted a similar study, but compared unimodal and bimodal language users. *Unimodal bilinguals* know two languages that depend on the same modality; for example an individual who can speak both Spanish and English. *Bimodal bilinguals* know two languages that depend on two different modalities; for example a Deaf individual who can both write English and sign using ASL. Although unimodal bilinguals are incapable of producing words in the two languages that they know simultaneously, bimodal bilinguals are able to do so. Emmorey et al. hypothesized that there would be a difference in the bilingual advantage between Deaf unimodal and bimodal bilinguals when examined with computerized nonlinguistic flanker tasks. They found that the unimodal bilinguals (exposed to another spoken language at birth and acquired English as a second language during childhood) were faster in responding on these executive control tasks. Bimodal bilinguals (children of Deaf adults who were exposed to both English and ASL during the first 12 months of life) were better at go/no-go tasks, demonstrating superior abilities to inhibit responses in no-go trials. Unimodal bilinguals were faster than monolinguals on congruent and incongruent trials, which is consistent with the bilingual advantage. The authors concluded that bilingual individuals who know two languages that depend on the same modality possess more cognitive control, because they are required to completely suppress one language when using another. Suppressing a language that uses the same output modality required more control and effort than the bimodal bilingual individuals who are able to use both languages simultaneously (Emmorey et al., 2008).

The age of first and second language acquisition in Deaf signers varies, and has the potential to influence performance on executive function tasks such as Stroop. Yow and Li (2015) studied English-Mandarin bilinguals to investigate age of second language acquisition and its effects on four executive functioning tasks: Stroop, Eriksen flanker, number-letter switching, and *n*-back. One of the results of the study was that the interference effect on Stroop tasks was predicted by age of acquisition of the second language, specifically that the earlier an individual was exposed to a second language, the smaller the interference. This suggested that a bilingual advantage is stronger for those who learn a second language at an earlier age. Though it might be expected that more language proficiency results in more language interference, the opposite is true in people who are bilingual. This concept was further demonstrated by the finding that a more balanced use of both English and Mandarin resulted in smaller interference, and that more use of both languages increased inhibition control. These findings all supported the notion of the existence of a bilingual advantage on executive functioning tasks, although it remains unclear how age of acquisition impacts Deaf Stroop performance.

There does appear to be a relationship between level of language proficiency and performance on Stroop tasks. The more proficient a person is in a language, the more interference is observed, and dominant languages produce more interference (MacLeod, 1991). However an interaction between language proficiency and Stroop performance differs in bilingual speakers compared to monolinguals. Suarez et al. (2014) investigated the ability of second language proficiency (i.e., English) speakers to affect performance on a Stroop task in the participants' first language (i.e., Spanish). Suarez and colleagues focused on proficiency and years of education. They showed that there were smaller Stroop effects for participants with higher second language proficiency. The participants who were more proficient in their second language were able to suppress automatic reading in their first language (bilingual advantage explained above). Although there was a relationship between language dominance and number of years of education, a bilingual advantage was not attributable to number of years of education (Suarez et al., 2014). With this in mind, it is difficult to predict whether this pattern of results would be seen with Deaf individuals due to the learning of two languages in two different modes of communication.

2.7 STROOP EFFECT IN DEAF SIGNERS

Stroop studies in Deaf ASL users are limited. Allen (1971) studied Deaf students and found that Deaf students showed less of a Stroop effect than did hearing students on an English reading task. This study was flawed in that it required the Deaf participants to respond using oral language, which was later criticized by Marschark (1988) because the Deaf participants could have had impaired speech or oral language. Levbaert and Alegria (1993) found similar results as Allen for Deaf signing and hearing children when responses were recorded from manual buttons. However, when asked to respond by naming, the Deaf students who were rated as having poor speech intelligibility by their teachers showed decreased Stroop effects. This pattern may relate to response task difficulty, and learning to read a language in which modality interferes with connecting graphemes to phonemes. It likely also relates to access to speech acoustic information, the relationships between audition and speech-sound production and the phonological loop.

Marschark (1998) conducted three experiments to investigate automaticity in ASL recognition and printed English words using a Stroop task. The ASL Stroop stimuli were presented live with dyed white gloves, so that when a color word was signed a different colored glove overlaid the signer’s hand. In the first experiment, the participants included nine students aged 15-17 who were attending residential schools for the Deaf, and had learned ASL between 2 and 5 years of age. Baseline data were gathered using a neutral condition naming, and ASL and written English Stroop data were collected. The results showed that ASL and English reading produced Stroop effects, indicating that both languages were processed automatically. The results for the first experiment also found that written English yielded larger Stroop effects than ASL, which was an unexpected finding and has important implications for which language is processed more automatically (Marschark, 1988).

The second experiment used picture slides instead of live signs with colored gloves. Marschark (1988) detected a Stroop effect and response times decreased relative to the live sign task. Except for differences in timing due to stimulus modality, the experiment replicated findings from the first, including the finding that reading English words was more automatic than signs.

The third experiment targeted younger students (aged 11 years) and the task used numbers and not colors. In this task, number words were presented for an incongruent number of times; for example the word “three” may appear only two times on the screen, and the correct response would be the number of times the word appeared on the screen (in that example, the correct response is 2). Larger interference effects were observed for signs than reading of printed words, but did not reach significance. The results agreed with the previous experiments in that both languages are processed relatively automatically, and number words were not an exception. It is possible that response times were overall faster for English words than for ASL, resulting in a misrepresentation of the Deaf participants showing less interference. Across the experiments, magnitude of interference declined as age increased, which is consistent with findings in hearing populations (Ikeda et al., 2011).

Marschark and Shroyer (1993) investigated the effect of language proficiency in ASL and English in Deaf participants on the Stroop interference effect. The participants included Deaf signing adults, oral Deaf adults, hearing certified interpreters, beginning ASL students, intermediate ASL students, and another group of certified interpreters. This study examined the Stroop effect in ASL using photographs of an individual with her hand painted in 6 different colors, and in English using computer-printed words. The study found that the Deaf participants responding with ASL took longer than the hearing participants who responded orally, and that responding to ASL signed pictures took longer than written words for all populations. The Deaf adults and interpreters demonstrated almost identical responses to ASL and English words. The Deaf adults and interpreters responding in ASL demonstrated greater Stroop interference compared to hearing ASL students and ASL interpreters responding orally. Another finding of this study was that differences in language proficiency did not affect the magnitude of the Stroop effect.

Recently the Stroop effect was investigated in Deaf signers using single-word video stimuli. Dupuis and Berent (2015) used Stroop tasks to investigate automaticity and interference in arbitrary (non-iconic) signs because ASL signs for color are not iconic. Three colors were used and there was a control condition where the signer produced the handshape “x.” To create a Stroop effect the signer’s body (from the torso up) was edited so that it appeared in one color. The study was composed of three experiments, two of which required participants to respond via sign and one requiring a button press. The study showed that both response modes were associated with Stroop effects but the sign responses were more inaccurate than when a response button was used.

2.8 EXPERIMENTAL QUESTIONS AND HYPOTHESES

The ASL Stroop studies in the literature were inconsistent, with some Deaf signers showing stronger Stroop effects in written English compared to ASL, and others showing the opposite pattern. The Stroop studies in ASL were first conducted with live presentations. Later pictured stimuli were used to significantly reduce response times relative to the live presentations. The use of computer-controlled recorded stimuli has yet to be tried with Deaf signers and if proven to be valid, has the potential to be used as a standardized assessment for evaluating bilingual language proficiency. Finally, by considering self-rated language proficiency scores and performance on Stroop tasks, the results of the current study held the potential to provide a standardized and computerized language proficiency measure in ASL, which had yet to be developed.

The research questions posed in the current study are listed below:

(1) Do Deaf proficient ASL users demonstrate significant Stroop effects in ASL and written English with sentence-level stimuli as tested with the CRTT?

(2) Do Deaf proficient ASL users differ in their performance on the CRTT Stroop tasks from hearing proficient signers (interpreters) and hearing non-proficient signers (college students in a beginning ASL course)?

(3) Do the three groups differ in performance on an ASL Stroop task when presented at the single-word level as compared to the sentence level?

(4) Do self-rated language proficiency scores correlate to observable Stroop effects in both ASL and written English in Deaf and hearing signers?

It was hypothesized that Deaf proficient ASL users would demonstrate longer reading times for ASL incongruent stimuli compared to control stimuli, relative to reading times for

English incongruent stimuli compared to English control stimuli (demonstrating larger reaction time differences between the two languages), hearing proficient signers would demonstrate a significant difference between incongruent and control conditions for both languages, and hearing non-proficient signers would demonstrate a significant difference between reaction times on incongruent and control conditions for written English but not for ASL. Because the ASL Stroop version of the CRTT (CRTT-ASL-$_{\text{STROOP}}$) was the first assessment of its kind, it also was hypothesized that sentence level videos would elicit a significantly larger Stroop effects for the DP and HP groups in comparison to a control condition (single-word), which also had been shown to elicit the Stroop effect (Dupuis & Berent, 2015). Finally, it was hypothesized that ASL and English self-rated proficiency across all groups would correlate positively with magnitude of interference between incongruent and control conditions – that is, as individuals rated themselves to be more proficient in ASL, they would demonstrate more significant reaction difference between incongruent and control conditions; the same prediction was made for reading English.

3.0 METHODS

3.1 PARTICIPANTS

This study included 45 participants divided into three groups for 15 each: Hearing non-proficient ASL users (HNP), hearing proficient ASL users (HP), and Deaf proficient ASL users (DP). The number of participants was estimated to achieve a power of .80 on the interaction for a two-way Analysis of Variance with repetition on one factor, when the language factor had a high effect size (d = .45) and group had a low effect size (d = .10). An alpha level of .05 was chosen and the effect sizes were estimated from Marschark (1998). Proficiency of ASL was based on descriptive information provided by participants during preliminary procedures. This information included years of experience using ASL, number of hours using ASL per week, and a self-rated sign language proficiency score. The participants ranged in age from 18-45 years. These descriptive data can be found in various tables below.

Participants for the HNP group were recruited from the University of Pittsburgh ASL level 1 classes. Participants for the HP group were recruited predominantly from Bloomsburg University's ASL interpreting academic program, the certified Deaf interpreter community in the greater Pittsburgh, PA area, educators of the Deaf from Gallaudet University, and children of Deaf adults from the Pittsburgh, PA community. Participants in the DP group were selected from the Deaf signing community from the Pittsburgh, PA and Washington D.C. areas. By recruiting Deaf participants from two different geographical areas, the study aimed to target a broader sample of the Deaf community in the United States than would be realized from the Pittsburgh area only. Because native signers (signers who were born into Deaf households) were difficult to recruit, the focus on ASL skill was based on level of language proficiency in the Deaf participants instead of nativity. Participant recruitment was completed through classroom presentations, flyers posted at Deaf associations, social media posts on various ASL-using community web-pages, and a video logs created by a proficient Deaf signer in the Pittsburgh Deaf community.

The median age and the gender distributions of the groups are listed in Table 2. The HNP group consisted of 15 females, the HP group consisted of 14 females and 1 male, and the DP group consisted of 5 females and 10 males. Because of the lack of male students in ASL classes and ASL interpreting programs, and due to the challenge of finding hearing and Deaf proficient ASL users, gender was not balanced. The majority of participants identified as Non-Hispanic White or Euro American. Two participants identified as Black, Afro-Caribbean, or African American (1 within the HNP group and 1 within DP group), four identified as Latino or Hispanic American (1 within the HP group and 3 within the DP group), and four identified as East Asian/Southeast Asian (2 within the HNP group, 1 within the HP group, and 1 within the DP group).

This study was approved by the University of Pittsburgh Internal Review Board and the Gallaudet University Internal Review Board, and all participants provided verbal/signed and written informed consent prior to inclusion in the study. All participants received $20.00 for remuneration at the end of the study.

Table 2. Age and sex of participants.

Group	Median Age	Age Range	% Female	% Male
HNP	20	18 to 22	100%	-
HP	22	20 to 36	93%	7%
DP	28	19 to 45	33%	77%

3.1.1 Inclusion Criteria and Preliminary Procedures

A battery of preliminary tasks was first administered to the participants. Some of the information gathered in the preliminary portion of the study served as criteria, and others provided descriptive data. There were three criterion measures used to determine participant eligibility. The first criterion measure required participants to read a reduced Snellen visual acuity chart with minimum accuracy of 20/40, corrected or uncorrected. This measure was included to minimize the possibility that performance on the computerized assessments was impacted by a visual acuity defect. The second criterion measure examined participant literacy using an English reading subtest of the Clinical Evaluation of Language Fundamentals 5th edition (CELF-5; Wiig, Semel, & Secord, 2003). The reading level of this screening tool was 13 years, or 8th grade level. This measure required participants to read two separate passages and answer content-based questions about the passages and ensured that participants possessed the literacy skills necessary to complete specific English reading tasks in the study. Means and standard deviations of scores for each group on the CELF-5 reading subtest passages are presented in Table 3 and the individual performance data are presented in Appendix 1. The first CELF-5 passage posed 10 questions, and the second passage posed 9.

Table 3. Mean score and standard deviation on reading subtest of the CELF-5.

Group	Passage 1		Passage 2	
	Mean	SD	Mean	SD
HNP	9.73	0.59	8.93	0.26
HP	9.53	0.52	9	0
DP	9.40	0.63	8.93	0.26

The third, criterion measure was the pretest of the CRTT presented in the participant's native language. The DP group completed the CRTT-ASL self-paced Stroop Pretest, and the HNP and HP groups completed the CRTT-R-$_{WF}$ (reading) Pretest. Performance on the pre-tests was critical for inclusion in the study, as it indicated a participant's ability to understand the method of delivery of instructions for the assessment, perceive the tokens, and understand the basic response requirements of the CRTT.

The preliminary descriptive measures gathered at the beginning of the study included information about the participants' language experiences, demographic and language background, and self-perception of both English (expressive, receptive, and reading) and ASL (expressive and receptive) skills. First, the participants completed an informal questionnaire regarding hearing status, language background, and educational history. A list of the questions can be found in Table 4 and responses to these questions can be found in Appendix 2, sorted by group. Several members of the HP group were both training to be interpreters/workers for the Deaf and children of Deaf adults (CODAs). All participants in the hearing groups answered questions #6 and #9 identically, indicating that they experienced mainstream educational environments and were able to hear. The Deaf group, however, answered these two questions with more variability, demonstrating a lack of consistency in educational and experiences with hearing technology, which was consistent with the heterogeneity of the Deaf population in the

United States. Answers to those questions, as well as information regarding onset of hearing loss and duration of use of hearing technology by Deaf Proficient ASL using participants can be found in Appendix 3. Seven out of the fifteen (47%) Deaf participants reported not using hearing aids or cochlear implants. Participants who did report using hearing aids or cochlear implants varied in age at which these hearing technologies were introduced, ranging from birth to adulthood.

Table 4. Background questionnaire items.

#	Question
1	What do you consider your primary language to be?
2	What was the primary language you used while growing up?
3	What language did/do your parents use?
4	How long have you been using American Sign Language?
5	When did you start using American Sign Language?
6	What educational environment did you experience?
7	What is the highest level of education you have achieved?
8	Rate your English reading skills
9	If you have a hearing loss, what is the onset of your hearing loss (profound, mild, or able to hear)
10	Do you use a hearing aid or cochlear implant?
10a	10aIf you answered yes, how old were you when you started using the cochlear implant or hearing aid?
11	Approximately how many hours per week do you use American Sign Language?

The participants completed two self-rated language proficiency assessments. First, participants completed the Language Experience and Proficiency Questionnaire (LEAP-Q; Marian, Blumenfeld & Kaushanskaya, 2003). The LEAP-Q was developed to capture linguistic profiles of individuals who are bilingual or multi-lingual, and has well-established reliability and validity (Marian, Blumenfeld, & Kaushanskaya, 2007). This questionnaire provides information on self-perceived proficiency in speaking/signing, understanding, and reading of ASL and

English. Of specific interest was the self-rated level of language proficiency in expression and reception of both languages. Means, medians, and ranges for the self-rated scores (on a scale of 0-10 with 0 being no proficiency and 10 being highly proficient) can be found in Table 5 and individual responses can be found in Appendix 4, sorted by group. The number of years of formal education also was obtained using the LEAP-Q Mean, median, and ranges of years of formal education for each group can be found in Table 6, and individual responses can be found in Appendix 4.

Table 5. Median and range self-rating of proficiency of English and ASL on the LEAP-Q.

Group	Comprehension Language and Modality				
	English Expression	English Comprehension	English Reading	ASL Expression	ASL Comprehension
HNP	Median:10 Mean: 9 Range: (7-10)	Median:10 Mean: 10 Range: (9-10)	Median: 10 Mean: 9 Range: (8-10)	Median: 3 Mean: 4 Range: (2-7)	Median: 4 Mean: 4 Range: (3-7)
HP	Median: 9 Mean: 9 Range: (8-10)	Median:10 Mean: 10 Range: (9-10)	Median:10 Mean: 9 Range: (7-10)	Median:7 Mean: 7 Range: (6-9)	Median: 7 Mean: 8 Range: (6-9)
DP	Median: 4 Mean: 5 Range: (0-10)	Median: 5 Mean: 5 Range: (0-9)	Median: 9 Mean: 8 Range: (3-10)	Median: 9 Mean: 8 Range: (5-10)	Median: 9 Mean: 9 Range: (5-10)

Table 6. Mean, median, and range of years of formal education

Group	Mean	Median	Range
HNP	14	15	7.5 to 18
HP	17	16	13 to 26
DP	17	15	13 to 26

Another self-rated language proficiency measure used in the present study included the Sign Language Proficiency Interview (SLPI). The SLPI has both reliable and valid psychometric properties, and typically requires administration by a trained interviewer and rater, where filmed interviews of the test-taker are analyzed and a level of language proficiency is assigned. The level options that a trained SLPI rater can assign to a given test taker includes: No functional, Novice, Survival, Intermediate, Advanced, and Superior (Caccamise & Samar, 2009; Marschark et al., 2015). The addition of 5 levels was established, which added the options of Novice Plus, Survival Plus, Intermediate Plus, Advanced Plus, and Superior Plus. Although the SLPI requires trained interviewers and raters to administer, it has been demonstrated that self-ratings are moderately reliable (Stauffer, 2011).

In the current study the participants were presented with the 11 SLPI levels and corresponding descriptions. They were asked to read each description and indicate which level they believed characterized their ASL skills and capabilities. Individual responses are summarized in Appendix 5, sorted by group. Because the SLPI was factored into the statistical analyses in order to investigate the correlation between self-rated language proficiency and significance of Stroop effect in ASL, an interval scale was established for each level on the SLPI. The levels of the SLPI and the corresponding value assigned to each level can be found in Table 7. Based on the values seen below, mean, standard deviation, and range of self-rated SLPI scores per group were calculated and are found in Table 8.

Table 7. SLPI level to value translation.

SLPI Level	Assigned Value
No Functional	0
Novice	1
Novice Plus	2
Survival	3
Survival Plus	4
Intermediate	5
Intermediate Plus	6
Advanced	7
Advanced Plus	8
Superior	9
Superior Plus	10

Table 8. Self-rated SLPI median and range scores.

Group	Median	Range
HNP	4 (Survival Plus)	1 to 6 (Novice to Intermediate Plus)
HP	7 (Advanced)	5 to 10 (Intermediate to Superior Plus)
DP	10 (Superior Plus)	6 to 10 (Intermediate Plus to Superior Plus)

3.2 STIMULI

The experimental protocol was administered with a modified version of the CRTT-ASL, which transformed the assessment into a sentence-level Stroop task (Goldberg, 2015). The signer who provided the ASL video samples for the CRTT-ASL provided additional samples for this study. He is Deaf, a proficient in ASL user, and an ASL instructor. New sets of instructions were filmed due to the change in response requirements for the Stroop task. The original signer was provided with a photograph of his appearance during the original filming that occurred in 2014 and adjusted his look to be as similar as possible (i.e., same clothing, hair-cut, and facial hair). These video samples were filmed using a Panasonic Handicam video camera with the signer standing in front of a green screen to allow for additional editing. The video samples were edited using Premiere Pro CC 2015.0.2 software (Adobe, version 2015.0.2). The background color was modified to a neutral color (light blue) and on and offset ramps (fading in and out) of 500 milliseconds were added to avoid flicker.

The original videos used for the CRTT-ASL were then modified to examine the Stroop effect by imposing translucent colored ovals over the signer's hand each time a color-word was signed. The percent opacity was selected by the investigator and thesis project advisors based on subjective perception so that both the sign and oval were detectable: black = 50% opacity, blue = 40% opacity, green = 40% opacity, red = 40% opacity, and white = 27% opacity. Screenshots from the CRTT-ASL-$_{\text{STROOP}}$ are presented in Figure 1. The dimension (which remained consistent across all stimuli) and positioning of the oval shape was determined by ensuring that, for each command, the signer's hand was encompassed by the opaque color throughout the duration of the signed color-word.

A preliminary study was conducted to validate the selection of opacity and hue by asking 46 young adults to respond to the presentation of screen shots of the video stimuli (Figure 1) by indicating the color that they saw. Each color was presented five times in random order. The participants recorded responses on a Qualtrics web-based questionnaire. The 46 adults ranged in age from 22-40 years, with a mean age of 25 years. Of the 46 participants, 9% were male and 91% were female. The results showed 100% accuracy in detecting and correctly labeling the five colors. The University of Pittsburgh IRB approved this preliminary study.

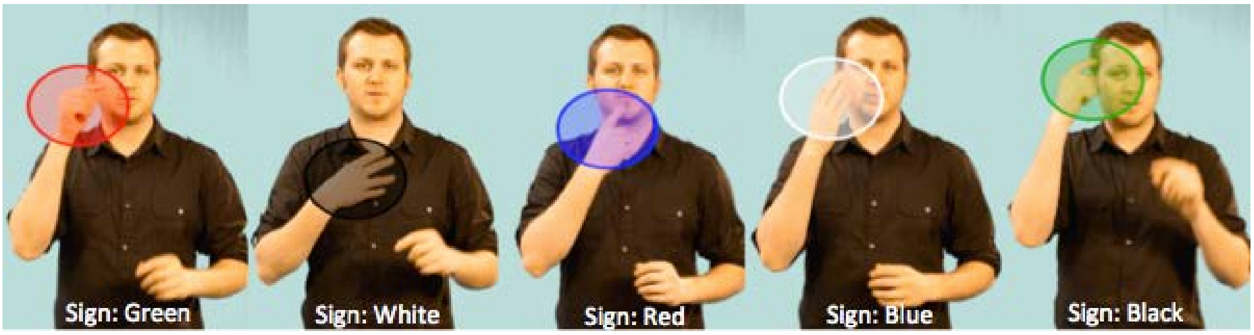

Figure 1. Screenshots of ASL Stroop stimuli.

The person who helped edit the original video recordings also helped the author edit the new recordings and add the opaque color. The original programmer of the CRTT and CRTT-ASL modified the program to include the CRTT-ASL-$_{\text{STROOP}}$.

Changes to the CRTT program included adding a self-paced (moving window) word/sign by word/sign version of the CRTT-ASL, with and without the added colors. In addition, the scoring had to be changed so that it was consistent with the English reading word-fade version of the test (CRTT-R-$_{\text{WF}}$) and the English Stroop reading word-fade version (CRTT-R-$_{\text{WF-STROOP}}$). The target response in the Stroop version of the CRTT is the font color, not the word. In ASL, this means the target is the color of the oval, and not the sign. When original CRTT-ASL videos were filmed, creation of a Stroop version was not anticipated. Because identical target responses between the CRTT-ASL and CRTT-ASL-$_{\text{STROOP}}$ were required, the same videos from the CRTT-ASL assessment were used and the target colors were changed. In changing the scoring, the programmer and investigator ensured that each color was represented equally. In order to collect the timing information needed for examining a Stroop effect, the durations of each word within each command were recorded, and videos were segmented to allow for self-pacing. In this way, the participant clicked the mouse to advance the next word/sign on the screen with the previous word disappearing with the onset of the next word until the entire sentence in ASL was presented. This method was identical to the presentation method for the CRTT-R-$_{WF}$.

The original creator of the CRTT has investigated the number of commands within each subtest required to represent a participant's mean performance. The motivation for reducing the number of items per subtest was that many populations, such as individuals who have impaired language as a result of stroke (i.e., aphasia), fatigue when completing the CRTT. Arvedson, McNeil and West (1985) demonstrated that administration of 5 commands within one subtest is representative of a participant's performance on all 10 commands. To reduce the risk of fatigue the current study used the first 5 commands of each subtest for all four versions of the CRTT administered in the protocol.

Another task used in the study was a single-word Stroop task. The original signer of the CRTT-ASL was filmed signing five color words (red, blue, green, white, and black) in isolation. The signer's hands began and ended in the same, neutral position for each video; specifically the signer's hands began and ended at the bottom of his torso with his fingers interlaced. The filming and editing procedures for these stimuli were identical to the procedures described above used in the instructions for the CRTT-ASL-$_{STROOP}$. The video samples were edited using Premiere Pro CC 2016 software (Premier Pro, version 2016.1). Editing consisted of modifying the background color to be neutral (light blue, consistent with the CRTT-ASL and CRTT-ASL-$_{STROOP}$), and onset and offset ramps (each lasting 0.5 seconds) were applied. The original programmer of the CRTT designed the ASL single-word task. 50 total trials were presented, with 25 incongruent stimuli and 25 control stimuli.

3.3 PROCEDURES

3.3.1 Location of Testing and Devices

Twenty-five participants completed the testing protocol in a laboratory within Forbes Tower at the University of Pittsburgh. The lab space offered an auditory and visually quiet space for testing within a sound attenuated booth. Participants sat at a desk, squared to a monitor that was connected to a Dell desktop (Dell Precision T3500, Processor: Intel® Xeon ®, RAM: 4.00 GB, System: 32-bit) through a dual monitor configuration, where the researcher was able to operate the CRTT program outside of the sound booth. Data were collected and saved on the password protected desktop computer and cloud space through the Pitt Box system. All identifying hardcopy information was stored in locked filing cabinets in the secured lab space. The investigator and a trained undergraduate student at the University of Pittsburgh administered the study protocol. Both investigators completed all required Institutional Review Board and research lab trainings required by the University of Pittsburgh.

Twenty participants were recruited and tested outside of the lab space at Bloomsburg University and Gallaudet University. The investigator used an HP laptop (HP 17-x061 nr, Processor: Intel i3-6100U, RAM: 8GB, System: 64-bit) with a wired mouse and mouse-pad for all remote testing. While at Bloomsburg University, the investigator gathered data in a quiet and private lounge space in an apartment building where the majority of the recruited participants resided. The laptop's wireless Internet connection was turned off during all testing to eliminate interfering signals and competing resources required for the finite timing required for data collection. Due to a lack of dual-screen capabilities, the participant was positioned so that the investigator was able to observe participant responses. Testing in the lounge space was completed at a table, where participants were seated, similarly to the desk and chair set up in the lab space. Testing at Gallaudet University occurred in 4 spaces on the university's campus. First, several participants completed testing in a secluded section within the campus library building. Other participants completed testing in a private classroom on campus. Others were assessed in the basement area of the student academic center, and one participant was seen in a lounge space within her residence hall. All four settings were non-distractive, visually and acoustically quiet, and well lit. All participants completed testing seated and at a table. Data were secured by the investigator at all times. Immediately upon returning to the University of Pittsburgh, the investigator delivered identifiable documentation to the locked and secured filing cabinets within the previously mentioned lab space in Forbes Tower to avoid risk of compromising confidentiality.

3.3.2 Single-word ASL Stroop Task

Prior to completing the single-word ASL Stroop task, instructions for the task were presented to participants in written English. Participants used a mouse click to initiate onset of single-word videos, and a second mouse click to indicate having processed the sign, which resulted in the video immediately disappearing. Fifty percent of the videos contained incongruent conditions, and 50% of the videos contained control signed conditions. The incongruent and control conditions were presented in blocked forms. Presentation order of the forms was randomized prior to programming the assessment, with incongruent and control conditions intermingled, and all participants were administered this assessment using identical order of video stimuli. When incongruent stimuli were displayed, participants were asked to respond to the color, instead of the sign. Participants were instructed to respond to the sign if they did not see a different color appear.

Response times were measured, representing the time between initial click and second click, which indicated that the sign had been processed. Following second click, five different-colored ovals appeared for the participant to select the color or sign. In this task, the main dependent variable was response time (measured in ms) to the single-word signs in the control presentation and the color of the patch covering the color sign in the incongruent presentation. Additionally, efficiency of responses was considered and these times were later analyzed.

3.3.3 Sentence Level Stroop Tasks

Following the single-word Stroop task, participants completed the CRTT-ASL-$_{WF}$, CRTT-ASL-$_{STROOP}$, CRTT-R-$_{WF}$, and CRTT-R-$_{WF-STROOP}$ tasks. As discussed above, the CRTT-ASL-$_{STROOP}$ contained video stimuli identical to the CRTT-ASL-$_{WF}$, however transparent incongruent colored ovals were imposed over the signer's hand to transform the assessment into a Stroop task. The English CRTT-R-$_{WF-STROOP}$ differed from the CRTT-ASL-$_{STROOP}$ in that rather than using a colored oval the font colors of the color-words were manipulated using incongruent colors. The neutral conditions, referred to as the control conditions, included the CRTT-ASL-$_{WF}$ and the CRTT-R-$_{WF}$ tasks with no color word manipulations. The CRTT-ASL-$_{STROOP}$ and CRTT-R-$_{WF-STROOP}$ conditions served as the incongruent conditions. All language versions and tasks were presented in random order. The primary dependent measure was the difference in time taken to read and comprehend the color word between the control and incongruent conditions. It should be noted that the term "read" in this context was applied to the reception of text as well as the signed stimuli. Additionally, secondary analyses were completed to examine the time spent on the word immediately following the color word, as well as overall sentence reading time. Preliminary work with English reading versions of the CRTT-Stroop has shown that the Stroop effect was evidenced on the noun (shape) following the color word.

Participants were given scheduled breaks in between conditions to control for fatigue; participants were permitted to take a break outside of the scheduled break time if necessary. Upon completing the study, participants completed a post-assessment questionnaire on which they rated the difficulty of the Stroop task in both languages on a 5-point Likert scale, with 1 representing "no difficulty," and 5 representing "maximum difficulty."

The entire protocol lasted between two to three hours and participants were paid $20.00 when they completed the study. Compensation was disbursed using the WePay system through the University of Pittsburgh Medical Center, where preloaded payment cards were distributed.

3.4 ANALYSIS

The primary dependent variable in this study was reading time during word reading (in both ASL and English) in the single-word and sentence tasks. In the sentence stimuli, analyses were performed on reading times for color words and shape words that immediately followed the color words. By analyzing the word immediately following the color word, the investigator hoped to account for a potential "spillover" effect, where participants processing the color word influenced processing of the subsequent word.

The CRTT is constructed so that participants respond to one color and one shape in Subtests I and II. In Subtests III through X, two colors and two shapes are included in the stimuli. Due to potential end of sentence wrap up effects and successive word spillover effects, analyses were completed on the final color and shape words, instead of either treating them independently or averaging color and shape words for commands containing two noun phrases.

Analyses were performed using the software "R." A linear mixed effects model was used to model the contribution of personal variables (e.g., self-reported ASL proficiency) and experimental control variables (e.g., control or incongruent conditions) on reading time performance. By using a linear mixed model, the program determined if personal and/or experimental factors were significant predictors of the dependent variable. With these models, estimates of the reliability of the contribution of each factor and the amount a given factor contributed to the dependent variable were accounted for, treating items and participants as random effects. An alpha level of .05 was set for each comparison.

4.0 RESULTS

The following terms are used in the following sections: A *positive Stroop effect* existed when the reading time for the incongruent condition was longer than the reading time for the control condition. A *negative Stroop effect*, also referred to as a *reverse Stroop effect*, existed when the reading time for the incongruent condition was shorter than the control condition. When considering the Stroop effect, these terms and definitions were consistent with the concept that interference can be calculated by subtracting reading time on the control condition from reading time on the incongruent condition. In the following sections, descriptive and statistical data are presented.

4.1 ASL SINGLE-WORD STROOP

The means for reading time on control and incongruent words during the ASL single-word Stroop task for each group, and the difference between those means are summarized in Table 9. These descriptive data show that a Stroop effect was not observed for any group during the ASL single-word Stroop task. When comparing groups, the Deaf proficient group spent more time reacting to the stimuli when compared to the two hearing groups.

Table 9. Mean reading times, time differences, and efficiency scores for each group on control and incongruent conditions for the single-word ASL Stroop task.

Group	Average Reading Time on Control Condition	Average Reading Time on Incongruent Condition	Δ (RT Incongruent minus RT Control)	Average Mean ASL Single-word Score Control	Average Mean ASL Single-word Score Incongruent
Hearing Non-Proficient	1824	1816	-8	14.35	14.97
Hearing Proficient	1998	1913	-85	14.45	14.92
Deaf Proficient	2594	2534	-60	13.83	14.86

When mixed effect regression analyses were applied for all participants, not sorted by group, with Stroop condition as a fixed effect, no significant main effect was found. This means that the study population did not collectively demonstrate a significant positive or negative Stroop effect on the ASL single-word task. There was a main effect for group, with hearing groups reacting reliably faster than the Deaf group for both conditions. No significant interaction was observed. Table 10 includes regression estimates, standard errors, and t-values for the main effects of condition on reading time, and group on reading time, and the interaction between these two factors. A t-value of +/-2 or greater indicated a significant effect or interaction.

Table 10. Regression estimates, standard errors, and t-values for main effects of condition and group on color word, and interaction for the single-word ASL Stroop task.

	Regression Estimate	Standard Error	t-value
Condition (Control/Incongruent)	-42.984	121.822	-0.353
Group	-692.501	247.236	**-2.801***
Interaction	8.327	87.928	0.095

Note. Bolded with * = significant t-value

The only significant main effect observed on the ASL single-word Stroop task was for group. The Deaf group demonstrated significantly longer reading times on the single-word task for both control and incongruent words when compared to the hearing groups. No significant positive or reverse Stroop effect was found for any group on this task.

Scores regarding participants' responses were also gathered, and will be referred to as "Average Mean ASL single-word score." As previously described, participants responded to video stimuli by selecting 1 colored circle out of 5 options (red, black, white, blue, and green). Following an incongruent video, participants were asked to select the colored circle that matched the incongruent oval that appeared in the stimulus. Following a control video, participants were asked to respond to the colored circle that was signed. The results regarding the Average Mean ASL single-word score showed a reliable main effect of condition, in that the incongruent condition resulted in higher scores across groups (Table 11). Group differences in token-response performance can be found in Figure 2. This graph displays how each group increased in performance on the incongruent condition for the ASL single-word task. Additionally, the graph exhibits how the DP group produced lower scores than the hearing groups. Due to heterogeneity of the DP group, within group analyses were applied to determine if each DP group member performed as the group. Appendix 6 presents the results to this analysis, and reveals that 5 of the 10 DP participants demonstrated a negative Stroop effect, whereas 10 produced positive effects. This means that a majority of the DP group did experience interference, however, when analyzed as a group their positive effects were masked by the magnitude of the 5 DP individuals who presented with negative effects.

Table 11. Regression estimates, standard errors, and t-values for main effects of condition and group on Average Mean ASL single-word Score, and interaction for the single-word ASL Stroop task.

	Regression Estimate	Standard Error	t-value
Condition (Control/Incongruent)	0.7158	0.3608	**1.98***
Group	0.5685	0.3685	1.54
Interaction	-0.4778	0.3649	-1.31

Note. Bolded with * = significant t-value

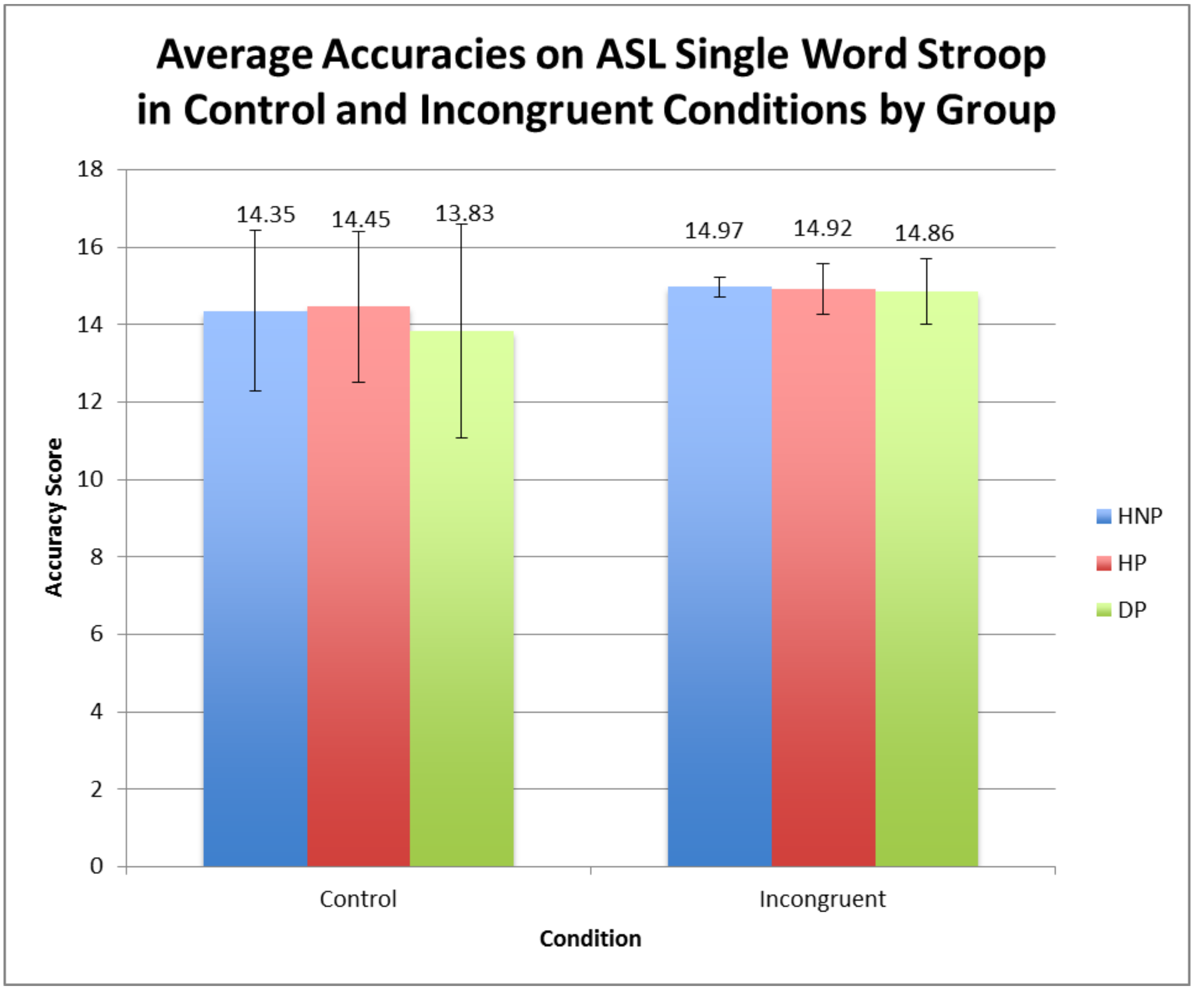

Figure 2. Group average token-response scores on the ASL single-word Stroop task for control and incongruent conditions.

4.2 CRTT-ASL STROOP

The ASL Stroop version of the CRTT provided information regarding individual word reading times extracted from the sentence-level presentation, and there were two time comparisons between each group that were of interest: (1) comparison between time spent on reading words embedded into sentences that contained information regarding color for the regular and Stroop conditions and (2) comparison between time spent reading the noun that immediately followed the color word for the regular and Stroop conditions. Group mean reading times for color word in both conditions and the difference between these times are summarized in Table 12. The same values for the following noun are listed in Table 13. As described previously, the mean reading times for color and shape words are derived from the final color or shape in the sentence.

Bar graphs that demonstrate reading times for each group on the final color word and final shape word can be found in Figures 3, 4 and 5, where reading time is on the Y axis and condition is on the X axis with colored bars representing the color word or shape word. These descriptive data indicate that the Deaf Proficient group demonstrated prolonged reading times during the incongruent condition for both words, compared to the control condition and that the groups demonstrated shorter reading times for the incongruent condition on the color word. The DP group demonstrated longer reading times on color word only. Individual average reading times for the color and shape word and the differences between those reading times on both ASL conditions can be found sorted by group in Appendices 7, 8, and 9.

Table 12. Group mean RTs for the color word in the control and incongruent conditions and difference between conditions for the CRTT-ASL.

Group	Color Word RT Control Condition (ms)	Color Word RT Stroop Condition (ms)	Δ Color Word (RT Incongruent – RT Control)
HNP	1561	1298	-263
HP	1396	1313	-83
DP	1452	1671	219

Table 13. Group mean RTs for the shape word in the control and incongruent conditions and difference between conditions for the CRTT-ASL.

Group	Shape Word RT Control Condition (ms)	Shape Word RT Stroop Condition (ms)	Δ Shape Word (RT Incongruent – RT Control)
HNP	1795	1421	-374
HP	1661	1517	-144
DP	1725	1684	-41

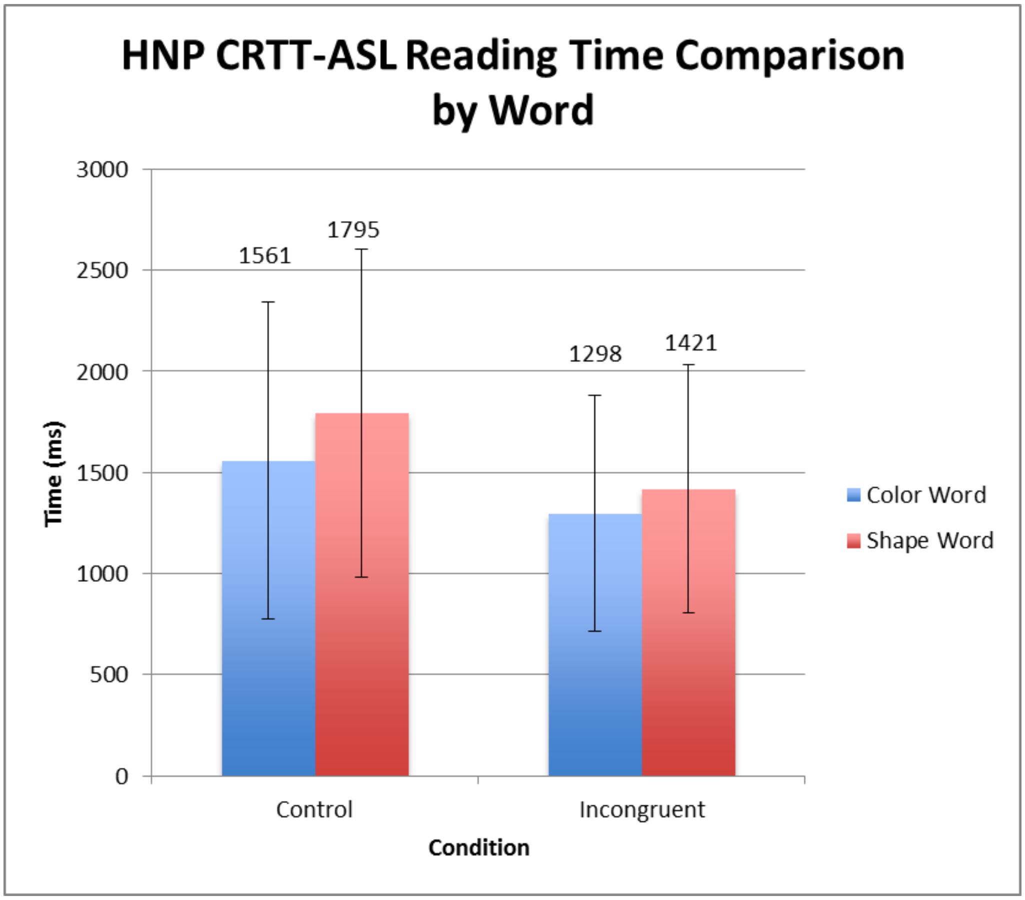

Figure 3. CRTT-ASL reading times for the control and incongruent conditions for final color word and final shape word for the HNP group.

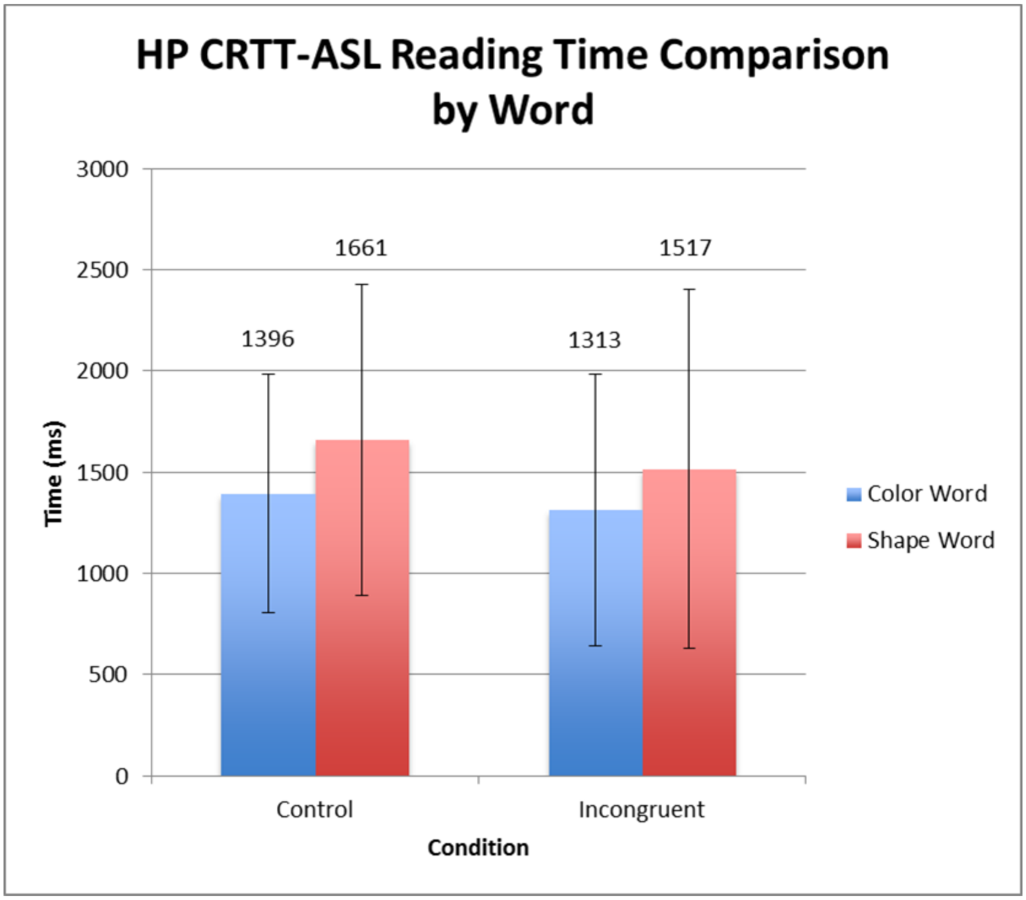

Figure 4. CRTT-ASL reading times for the control and incongruent conditions for final color word and final shape word for the HP group.

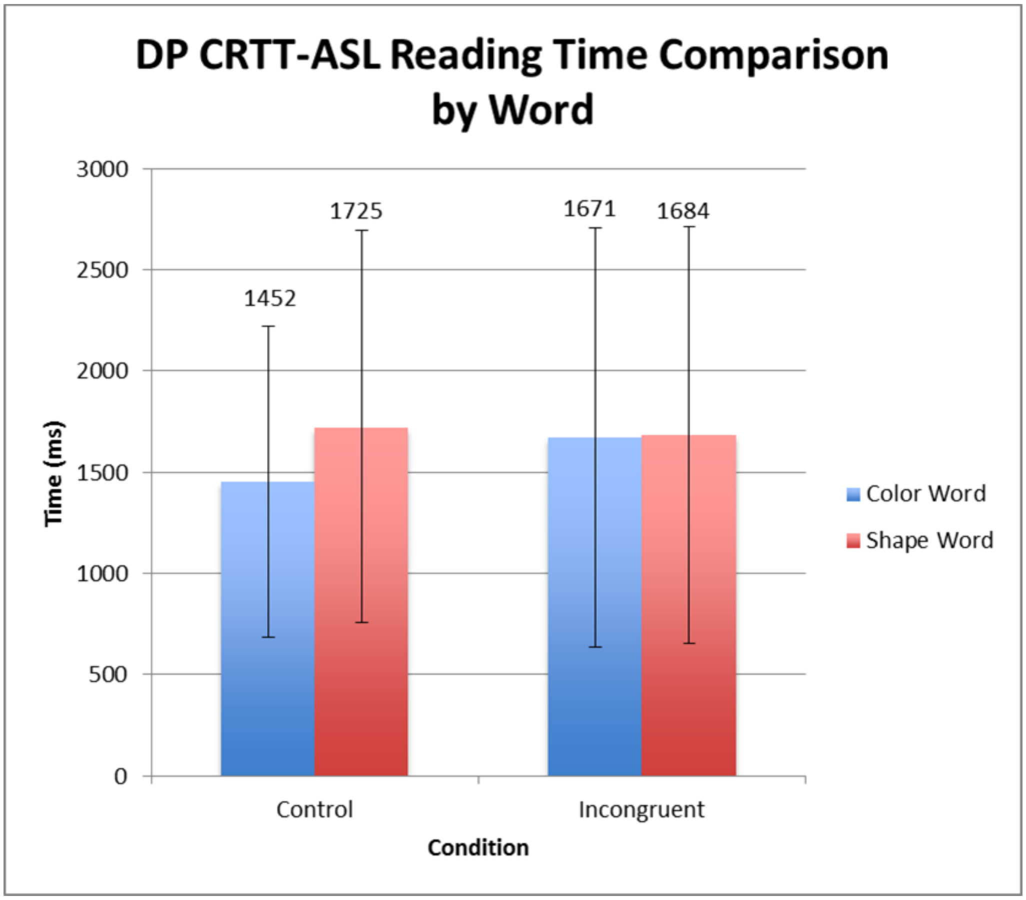

Figure 5. CRTT-ASL reading times for the control and incongruent conditions for final color word and final shape word for the DP group.

When mixed effect regression analyses were computed for all participants without group and with the Stroop condition as a fixed effect, nonsignificant negative/reverse Stroop effects (faster on the incongruent condition) on color and shape words were found. This finding was due to the magnitude of the reverse Stroop effect observed in the two hearing groups despite the positive Stroop effect for the DP group.

When group (hearing vs. Deaf) and condition (control vs. incongruent) reaction times were added as factors for the color word, no significant main effects were observed. However, a significant interaction between group and condition was observed, and attributable to the DP group demonstrating the Stroop effect and the negative effect observed in the HNP and HP groups (summarized in Table 14). Not only is the magnitude of Stroop effect smaller in the hearing groups compared to the DP group (by approximately 389 ms), it is also positive. Table 15 displays the results of identical analyses when applied to shape word. A significant main effect between the incongruent and control conditions was observed indicating a reliable negative/reversed Stroop effect (participants were faster in the incongruent condition compared to the control condition). The two hearing groups, who demonstrated facilitation for the incongruent conditions, accounted for this finding, whereas the DP group demonstrated a positive Stroop effect. The negative Stroop effect for the normal hearing participants and the significant positive Stroop effect for the DP group accounted for the significant interaction.

Table 14. Regression estimates, standard errors, and t-values for main effects for Stroop and group on color word, and interaction for the CRTT-ASL.

	Regression Estimate	Standard Error	t-value
Condition (Control/Incongruent)	-49.92	60.25	-0.829
Group	31.59	85.54	0.369
Interaction	-389.33	96.28	**-4.044***

Note. Bolded with * = significant t-value

Table 15. Regression estimates, standard errors, and t-values of main effect for Stroop and group on shape word, and interaction for CRTT-ASL.

	Regression Estimate	Standard Error	t-value
Condition (Control/Incongruent)	-153.68	59.62	**-2.577***
Group	-42.41	119.85	-0.352
Interaction	-159.27	121.96	-1.306

Note. Bolded and * = significant t-value

Within group analyses for the DP group were performed to investigate within-subject reading times on color and shape words between the control and incongruent conditions. The reason for analyzing the DP group independent of the two hearing groups was due to the variety of language and educational experiences of the DP group, which could have impacted the results when members were grouped together. On the color word, the Deaf group demonstrated a reliable and large Stroop effect of approximately 205 ms, and on the shape word the Deaf group demonstrated an insignificant negative Stroop effect. Appendix 9 illustrates that individual participant means illustrates that 10 of the DP group members exhibited interference on the final color word in ASL at the sentence level, however the individuals who exhibited the Stroop effect at the sentence level for ASL are not totally consistent with the 10 DP participants who exhibited the Stroop effect at the single-word level in ASL.

Main effects of condition and group and their interaction on Mean CRTT score for the CRTT-ASL were investigated, and results are reported in Table 16. These findings suggested no significant main effect of condition or group, however a significant interaction between condition and group was identified. Specifically, the hearing groups demonstrated higher Mean

CRTT scores on the incongruent stimuli compared to the control condition, but the Deaf group produced lower scores on the incongruent conditions. Group mean scores for each word within a sentence in ASL and English for both control conditions and incongruent conditions can be found in Appendices 10, 11, and 12.

Table 16. Regression estimates, standard errors, and t-values for main effects of Stroop and group on Mean CRTT scores, and interaction for CRTT-ASL.

	Regression Estimate	Standard Error	t-value
Condition (Control/Incongruent)	0.1263	0.1353	0.93
Group	0.4422	0.2445	1.81
Interaction	0.9098	0.2189	**4.16***

Note. Bolded with * = significant t-value

4.3 CRTT-R-$_{\text{WF-STROOP}}$

Reading English at the sentence level, provided two time comparisons of interest: (1) comparison between time spent on words embedded within sentences that contained information regarding color for regular and Stroop conditions and (2) comparison between time spent on the word that immediately followed the color word (noun) for regular and Stroop conditions. Group mean reaction times for the color word in both conditions and the difference between these times can be found in Table 17. The same values for the shape word are listed in Table 18. Like with the CRTT-ASL tasks, the mean values for color and shape words were derived from the final color and shape words in the sentences. Bar graphs representing the reaction times for each group on the final color and shape words can be found in Figures 6, 7, and 8, where condition (Stroop vs. control) is on the X axis , and reaction time (ms) in on the Y-axis. These descriptive data indicated that each group produced longer reaction times during the incongruent condition on the English reading version of the CRTT. Individual average reaction times for the color and shape words and the differences between those reaction times on both English reading conditions can be found sorted by group in Appendices 13, 14, and 15.

Table 17. Mean group RTs for the color word in the control and incongruent condition and difference between conditions for CRTT-R-$_{WF}$.

Group	Color Word RT Control Condition (ms)	Color Word RT Stroop Condition (ms)	Δ Color Word (RT Incongruent – RT Control)
HNP	434	632	198
HP	500	849	349
DP	547	1118	571

Table 18. Mean group RTs for shape word in control and incongruent conditions and difference between conditions for CRTT-R-$_{WF}$.

Group	Shape Word RT Control Condition (ms)	Shape Word RT Stroop Condition (ms)	Δ Shape Word (RT Incongruent – RT Control)
HNP	584	677	93
HP	616	789	173
DP	681	1029	348

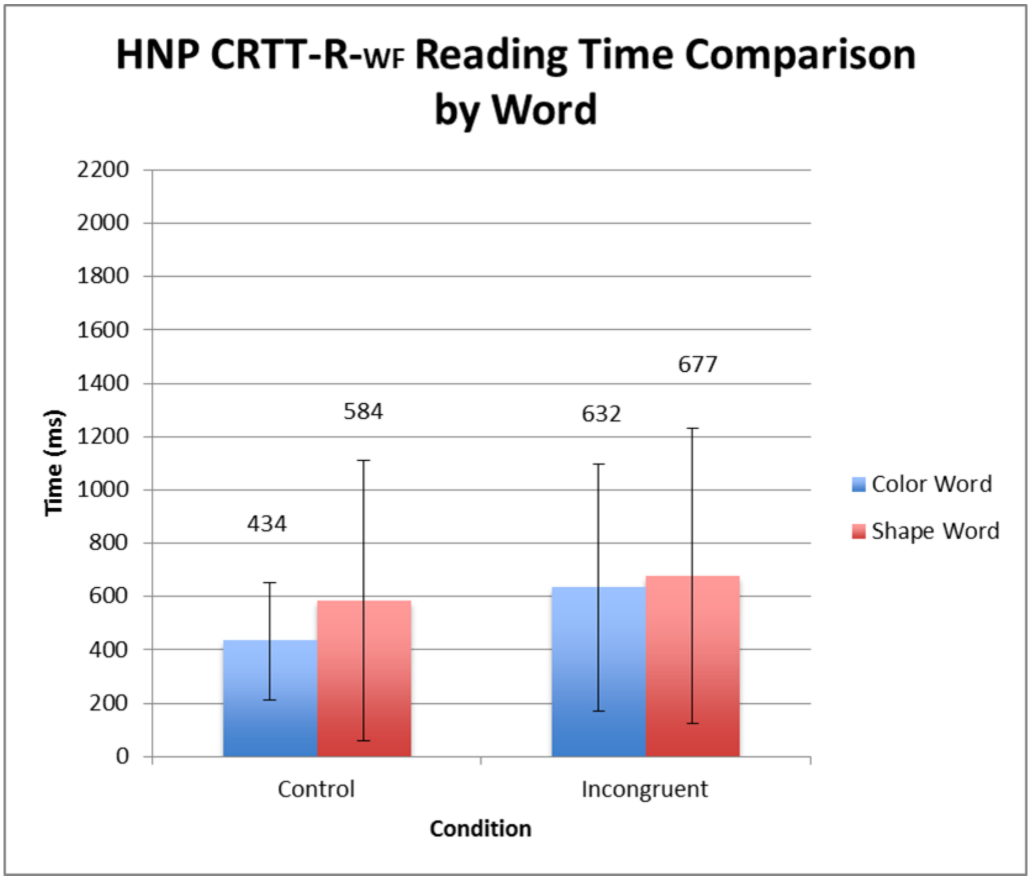

Figure 6. CRTT-R-$_{WF}$ reaction time comparison on final Color and Shape words for the HNP group.

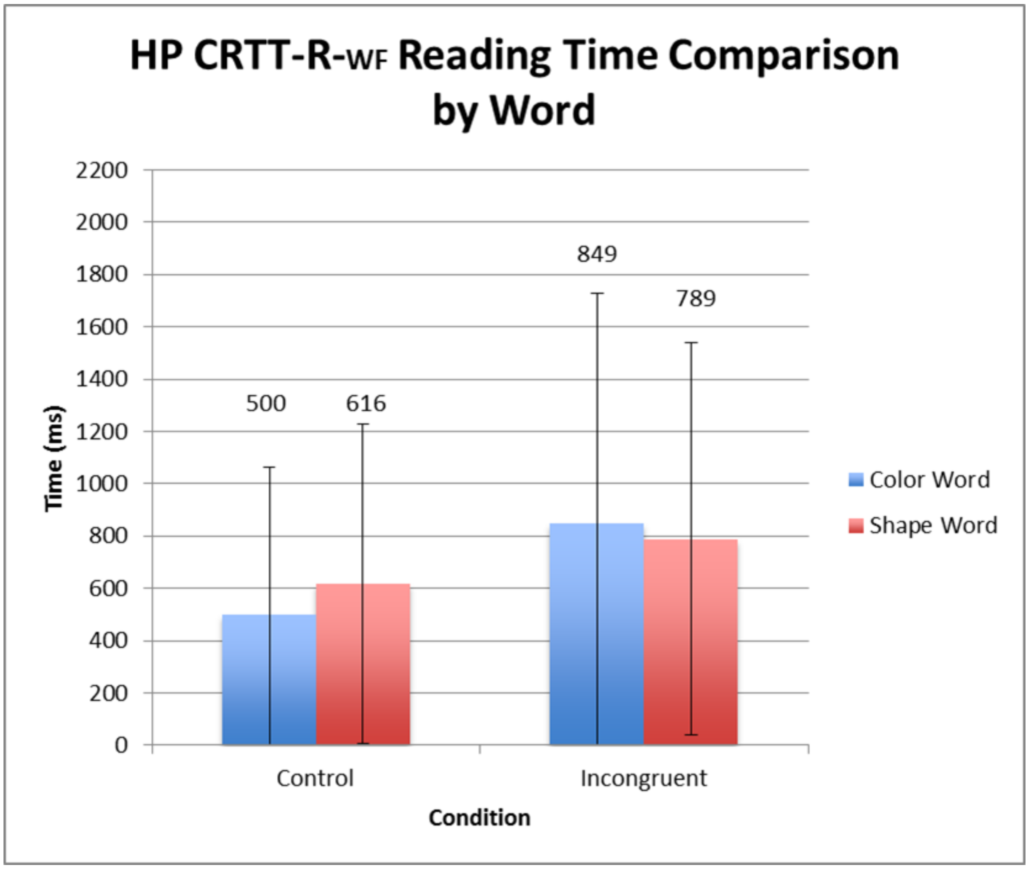

Figure 7. CRTT-R-$_{WF}$ reaction time comparison on final Color and Shape words for the HP group.

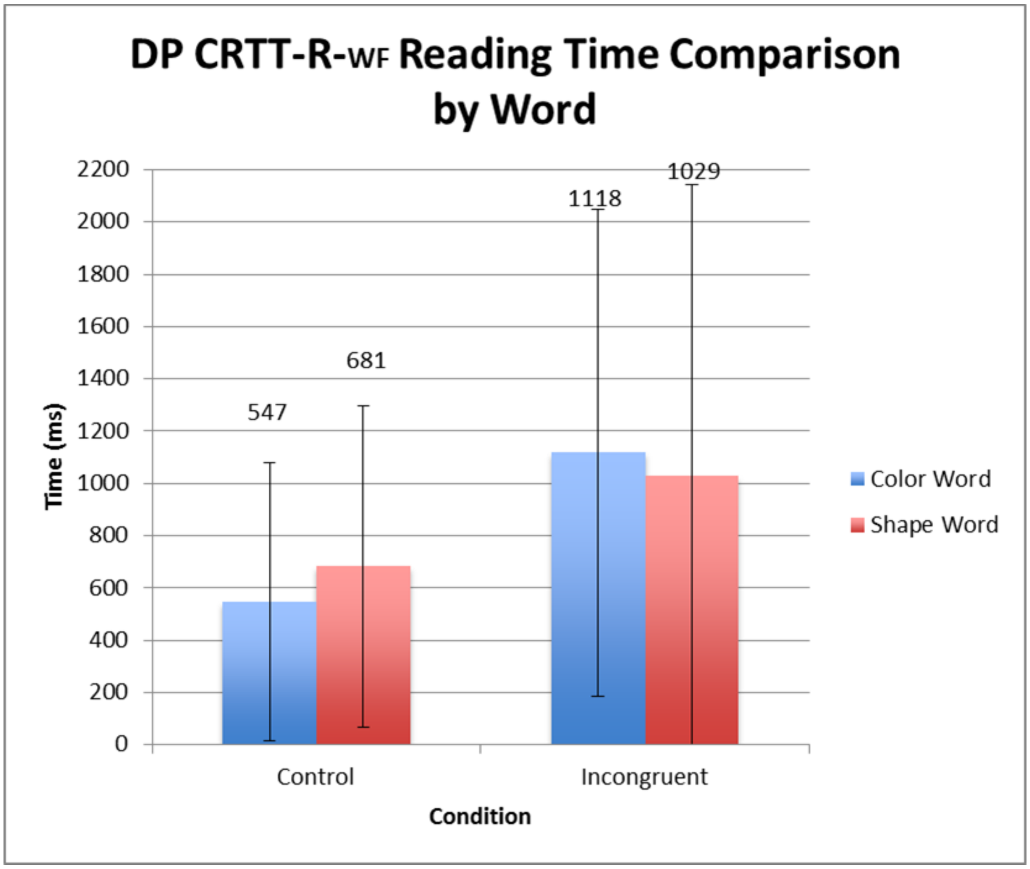

Figure 8. CRTT-R-$_{WF}$ reaction time comparison on final Color and Shape words for the DP group.

The results of the mixed effects regression analyses investigating main effects of condition and group, and the interaction between those variables are summarized in Table 19 for the color word and Table 20 for the shape word. These results supported the observations above regarding the descriptive data whereby there was no group effect with all groups demonstrating significant Stroop effects on both color and shape words.

Table 19. Regression estimates, standard errors, and t-values for main effects for Stroop and group on color word, and interaction for CRTT-R-$_{WF}$.

	Regression Estimate	Standard Error	t-value
Condition (Control/Incongruent)	370.7	47.9	**7.474***
Group	-79.74	67.53	-1.81
Interaction	-302.52	95.20	**-3.178***

Table 20. Regression estimates, standard errors, and t-values for main effects for Stroop and group on shape word, and interaction for CRTT-R-$_{WF}$.

	Regression Estimate	Standard Error	t-value
Condition (Control/Incongruent)	204.84	51.37	**12.204***
Group	-80.79	102.36	-0.789
Interaction	-215.32	82.42	**-2.613***

Note. Bolded with * = significant t-value

Additional analyses were performed for the DP group in order to investigate within subject performance of reading time for color and shape words between the CRTT-R-$_{WF}$ and the CRTT-R-$_{WF\text{-}STROOP}$ tasks. On both color and shape words, the Deaf group demonstrated a significant and large Stroop effect of approximately 572 ms (color) and 348 ms (shape).

Main effects of condition and group and their interaction on Mean CRTT score for the CRTT-R-$_{WF}$ also were investigated, and results are reported in Table 21. The scores were lower across all groups for the incongruent condition compared to the control condition. The hearing groups performed significantly higher than the Deaf group on Mean CRTT scores for the CRTT-R-$_{\text{WF-STROOP}}$. There was no interaction between condition and group on Mean CRTT scores.

Table 21. Regression estimates, standard errors, and t-values for main effects for Stroop and group on Mean CRTT score, and interaction for CRTT-R-$_{\text{WF}}$.

	Regression Estimate	Standard Error	t-value
Condition (Control/Incongruent)	-0.33545	0.12969	**-2.59***
Group	0.66839	0.24376	**2.74***
Interaction	0.05545	0.26273	0.21

Note. Bolded with * = significant t-value

4.4 RELATIONSHIP BETWEEN PROFICIENCY AND STROOP EFFECT

Several mixed effects models were run in order to investigate the relationship between the LEAP-Q self-rated language proficiency and the presence of the Stroop effect. First, the self-rated English reading comprehension scores for the DP group were analyzed, and results for reading times on the English color word are presented in Table 22. This table contains results for the main effect of condition and self-rated LEAP-Q score of comprehending written English, as well as the interaction between condition and LEAP-Q scores. The analyses failed to show a significant effect for condition when the LEAP-Q scores were added to the model. This means that self-rated English proficiency accounted for most of the variance in performance within the DP group. These results revealed that for every 1-point added to a LEAP-Q self-rating in understanding written English, there was an 88 ms decrease in reaction time for the color word. Similar analyses were completed for the reading times on the noun, and are summarized in Table 23. The previously found significant Stroop effect became non-significant when self-rated English Proficiency was added to the model, with self-rated proficiency accounting for most variance. A 1-point increase in LEAP-Q self-ratings on understanding English was associated with a 96 ms decrease in reading time for shape word, and there was no significant interaction between LEAP-Q score and Stroop effect.

Similar analyses were conducted to investigate the interaction of self-rated ASL proficiency and condition on color and shape word reading times on the CRTT-ASL tasks in the DP group. The results are summarized in Table 24 (for color word) and Table 25 (for shape word). The findings indicate that the Stroop effect became non-significant when ASL proficiency was added to the model, which means that ASL proficiency self-ratings account for the variance in the model. Due to lack of interaction between condition and LEAP-Q rating, results indicate that self-reported language proficiency does not predict reading times on control and incongruent stimuli, and thus does not predict Stroop effect. Additional analyses revealed that for every additional 1 point on self-rated ASL comprehension LEAP-Q score, participants responded to the color word 86 ms faster. For ASL shape word, the addition of ASL comprehension LEAP-Q score to the mixed effect model resulted in a Stroop effect becoming negative. With each additional 1 point assigned on the LEAP-Q, the difference between incongruent and control conditions reduced by 148 ms for the DP group.

When investigating the relationship between self-rated ASL comprehension and Stroop effect in reading English, the Stroop effect became non-significant, which means that ASL comprehension proficiency accounted for most of the variance in the model. Main effects and interactions for the relationship between self-rated ASL comprehension and Stroop effect on the CRTT-R-$_{WF}$ can be found in Table 26 for color word and Table 27 for shape word. Each additional point on the LEAP-Q resulted in 109 ms decrease in reaction time for color word, and a 116 ms decrease in reaction time for shape word.

Table 22. Main effects and interactions for LEAP-Q English understanding score and condition of DP group on CRTT-R-$_{WF}$ color word reading time.

	Regression Estimate	Standard Error	t-value
Condition (Control/Incongruent)	548.085	325.767	1.682
LEAP-Q Understanding English Score	-87.610	20.659	**-4.241***
Interaction	3.201	39.731	0.081

Note. Bolded with * = significant t-value

Table 23. Main effects and interactions for LEAP-Q English understanding score and condition of DP group on CRTT-R-$_{WF}$ shape word reading time.

	Regression Estimate	Standard Error	t-value
Condition (Control/Incongruent)	409.293	287.310	1.425
LEAP-Q Understanding English Score	-96.124	36.522	**-2.632***
Interaction	-7.732	34.968	-0.221

Note. Bolded with * = significant t-value

Table 24. Main effects and interactions for LEAP-Q ASL understanding score and condition of DP group on CRTT-ASL color word reading time.

	Regression Estimate	Standard Error	t-value
Condition (Control/Incongruent)	704.04	539.86	1.304
ASL LEAP-Q Comprehension	-85.60	43.99	-1.946
Interaction	-58.00	61.63	-0.941

Table 25. Main effects and interaction of LEAP-Q ASL understanding score and condition of DP group on CRTT-ASL shape word reading time.

	Regression Estimate	Standard Error	t-value
Condition (Control/Incongruent)	-1323.47	690.31	-1.917
ASL LEAP-Q Comprehension	-91.49	79.22	-1.155
Interaction	148.06	78.89	1.877

Table 26. Main effects and interaction of LEAP-Q ASL understanding score and condition of DP group on CRTT-R-$_{WF}$ color reading time.

	Regression Estimate	Standard Error	t-value
Condition (Control/Incongruent)	799.23	568.21	1.407
ASL LEAP-Q Comprehension	-108.94	37.34	**-2.918**
Interaction	-26.35	64.85	-4.06

Note. Bolded with * = significant t-value

Table 27. Main effects and interaction of LEAP-Q ASL understanding score and condition of DP group on CRTT-R-$_{WF}$ shape reading time.

	Regression Estimate	Standard Error	t-value
Condition (Control/Incongruent)	434.670	504.092	0.862
ASL LEAP-Q Comprehension	-116.285	65.105	-1.786
Interaction	-9.956	57.469	-0.173

Self-rated comprehension of ASL, as measured by the LEAP-Q and its relationship to the Stroop effect, also were investigated in both of the hearing groups for the CRTT-ASL. Main effects and interactions for ASL LEAP-Q scores, congruent and incongruent word conditions, and reaction times for the hearing groups on the color word are summarized in Table 28. Self-rated ASL proficiency predicted a reliable reversed Stroop effect on color word in both hearing groups. That is, every additional point assigned for self-rated proficiency resulted in a reverse Stroop effect (decreased time on the incongruent stimuli relative to the control stimuli) of 65 ms or smaller. This means that more proficient hearing ASL users produced faster reaction times on the incongruent color word. Identical analyses were performed on reaction times for shape word. The result yielded similar findings with a reliable reversed Stroop effect on the shape (noun) word for both hearing groups that was predicted by LEAP-Q scores for understanding ASL (See Table 29). Specifically, with every additional point assigned to the LEAP-Q, reading time performance on the incongruent condition decreased by 52 ms.

Table 28. Main effects and interactions for LEAP-Q ASL understanding score and condition of HP and HNP groups on color word reading time.

	Regression Estimate	Standard Error	t-value
Condition (Control/Incongruent)	-555.02	134.04	**-4.141***
LEAP-Q Understanding English Score	-40.36	21.78	-1.85
Interaction	64.61	20.29	**3.184***

Note. Bolded with * = significant t-value

Table 29. Main effects and interactions for LEAP-Q ASL understanding score and condition of HNP and HP groups on shape word reading time.

	Regression Estimate	Standard Error	t-value
Condition (Control/Incongruent)	-512.994	161.056	**-3.184***
LEAP-Q Understanding English Score	-8.315	27.151	-0.306
Interaction	52.451	25.899	**2.025***

Note. Bolded with * = significant t-value

5.0 DISCUSSION

This study aimed to investigate four main experimental questions. First, the study aimed to determine whether Deaf proficient ASL users demonstrated significant Stroop effects in ASL and written English using sentence-level stimuli (via the CRTT-ASL-$_{STROOP}$ and CRTT-R-$_{WF-STROOP}$). The answer to this question was yes. The DP group demonstrated significant Stroop effects in both ASL and written English Stroop versions of the CRTT. The results also suggested that the DP group processed the two languages somewhat differently as evidenced by a spillover effect on the written English sentence-level stimuli and an absence of this effect on the CRTT-ASL-$_{STROOP}$.

The second aim was to determine whether DP ASL users differed on performance using English and ASL CRTT Stroop tasks compared to hearing proficient and hearing non-proficient signers. The answer to this question also was yes. On the CRTT-ASL-$_{STROOP}$ task, the DP group was the only group to demonstrate a significant Stroop effect. On the CRTT-R-$_{WF-STROOP}$ task, all groups demonstrated Stroop effects, but the DP group demonstrated a significantly larger difference between incongruent and control conditions when compared to the hearing groups. Moreover, they also demonstrated generally slower reading times compared to the hearing groups.

The third question related to how the groups differed in reading times and presence of a Stroop effect at the single-word level and how the results at the single-word level compared to those at the sentence level. The two hearing groups did not demonstrate a Stroop effect at either word or sentence levels on the ASL tasks. The DP group, as a whole, also did not show a Stroop effect on the single-word ASL Stroop task; whereas they did show a Stroop effect at the sentence level. Yet, examination of performance at the individual level showed that 10 of the 15 DP group members demonstrated a Stroop effect at the single-word level.

Finally, the study aimed to assess whether a relationship existed between self-rated language proficiency and observable Stroop effects in both ASL and written English across all groups. Overall, the study found that self-rated language proficiency did not correlate with observable Stroop effects. However, the findings did suggest a potential relationship between self-rated language proficiency and quicker reading times overall, suggesting that more proficient language users evidenced faster language processing.

5.1 THE ASL SINGLE-WORD STROOP TASK

It was hypothesized that the HP and DP groups would demonstrate linguistic interference as evidenced by reliable positive Stroop effects on the ASL single-word Stroop task. However, these hypotheses were not confirmed, and reading times were similar between conditions for all groups. One potential explanation for the absence of a Stroop effect for the single-word ASL task was that there were too many consecutive incongruent trials, resulting in participants becoming desensitized or adapted to the task. The congruent and incongruent stimuli were each presented in a blocked design, and randomized presentation of the congruent and incongruent stimuli is known to optimize a positive Stroop effect.

Another potential reason that the single-word level Stroop effect was not elicited in any of the groups could be that the method of establishing the incongruency did not optimize the task effect. That is, the current study used a transparent oval covering the signer's hand, whereas previous studies that have successfully elicited the Stroop effect in ASL at the single-word level used full-screen color flashes or dyed gloves (Dupuis & Berent, 2015; Marschark, 1998). Although this was a possibility, the Stroop effect was elicited at the ASL sentence-level by the DP group using the transparent oval elicitation method, which diminished the likelihood of this explanation. Another possibility was that the additional processing requirements for sentence-level stimuli elicited the effect, but the oval method at the single-word level was not enough to evoke the Stroop effect.

Although the DP participants indicated using ASL as their primary mode of communication, there was considerable heterogeneity within the group in terms of educational experiences, language used by parents throughout childhood, use of auditory sensory technology, and reported years of ASL use. It was therefore of interest to examine each DP participant's performance on the ASL single-word Stroop task. Appendix 6 summarizes the subject-by-subject coefficients that were calculated using the mixed effects analysis. Those coefficients represent the time difference between incongruent and control conditions. Based on these results, on the ASL Stroop word task 10 of the 15 DP participants experienced an interference effect (longer times for incongruent stimuli and for the control English word stimuli) ranging from 95 ms to 266 ms, placing them between those found by Dupuis and Berent (2015) who reported a significant Stroop effect averaging 35 ms for their Deaf participants, and Marschark and Shroyer (1993) who found a Stroop effect averaging 350 ms. As a whole, the Deaf group in the current study did not show a significant Stroop effect, largely due to the magnitude of the reverse Stroop effects of 5 Deaf participants who responded substantively faster during the incongruent conditions.

When investigating factors that could have contributed to some DP participants demonstrating the Stroop effect at the word-level and others not, some interesting patterns emerged. Of the DP participants who demonstrated the Stroop effect at the single-word level, four began using hearing aids at an average age of 5 years (15 mos-11 years – ages considered delayed by current professional standards) but two out of the five participants who did *not* demonstrate a Stroop effect on the ASL single-word task did not use hearing aids until later childhood (mean of 10 years). It is possible that age of device fitting impacted language interference for a subset of the DP individuals. Hearing loss severity was variable across the group of DP participants who showed Stroop effects and those who did not, which is consistent with previous findings that suggest that lexical development is problematic in infants and children with hearing loss, regardless of hearing loss severity and largely independent of grammatical skill development. The lack of a Stroop effect could reflect lexical weakness for a subset of the DP participants, meaning that the language skills of some DP group members did not match those skills of others within the same group. It also is possible that some of the DP group members developed strategies, such as squinting their eyes, during stimuli presentation to ignore the lexical information.

Consistent with the lexical strength/reading skill hypotheses, those participants who demonstrated interference on the task, had an average self-rating score of 9.33 for ASL comprehension on the LEAP-Q, but the participants who showed no interference had an average LEAP-Q score of 7.67. When comparing average times spent on control and incongruent words in ASL for the DP group members who demonstrated a Stroop effect and those DP members who did not, there appears to be general reading proficiency differences. Specifically, the Deaf participants who demonstrated the Stroop effect on the ASL single-word tasked averaged 1895 ms on the control condition words and 2005 ms on the incongruent condition words; a difference of 110 ms. The DP group members who did not demonstrate the Stroop effect spent an average of 4034 ms on control condition words (more than twice as long as those who showed the Stroop effect) and 3568 ms on incongruent condition words; a difference of 466 ms. A scatter plot contrasting the 5 DP individuals who did not demonstrate the Stroop effect and the 10 DP individuals who did can be found in Figure 9. The Deaf individuals who experienced interference at the single-word level rated themselves as being more proficient and responded to words faster than those who scored themselves as less proficient. Identical scatterplots can be found in Figures 10 and 11 for the HNP and HP groups, respectively.

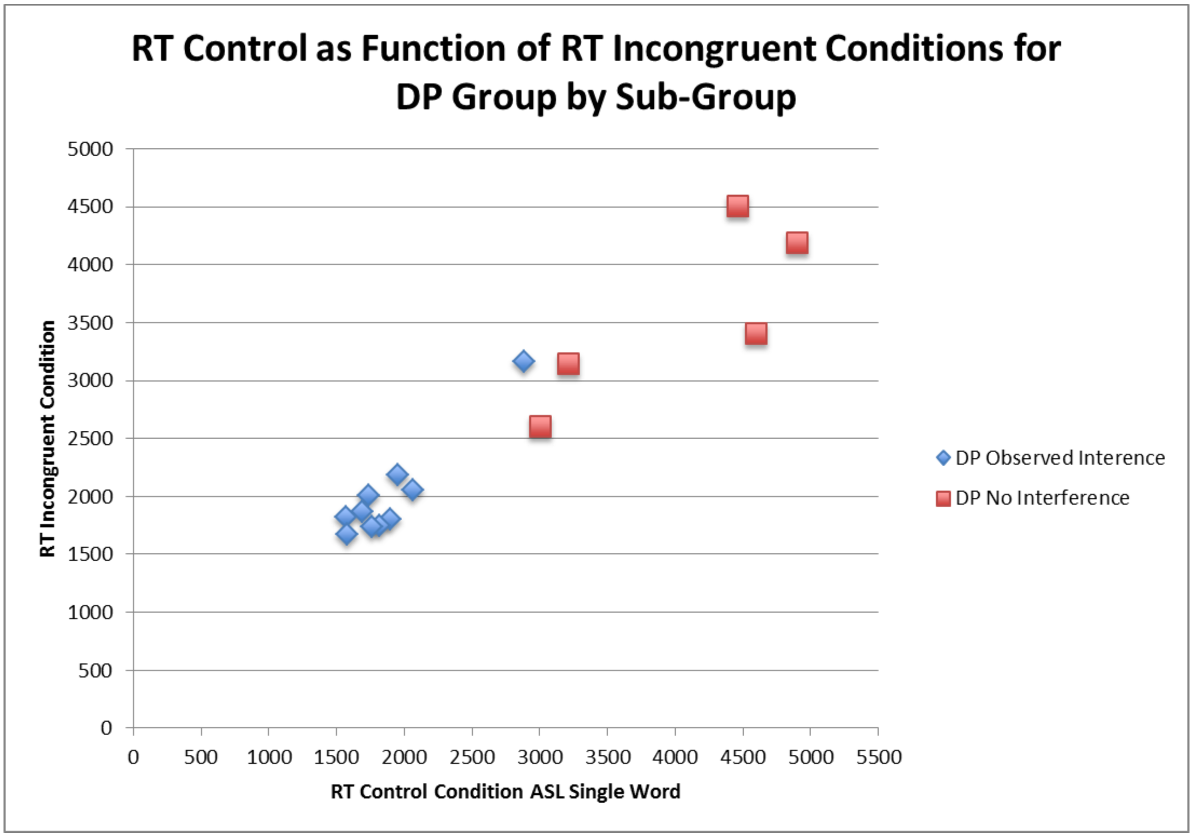

Figure 9. Reading times for the control condition as a function of reading times for the incongruent condition sorted by DP members who did and did not demonstrate interference on the ASL single-word task.

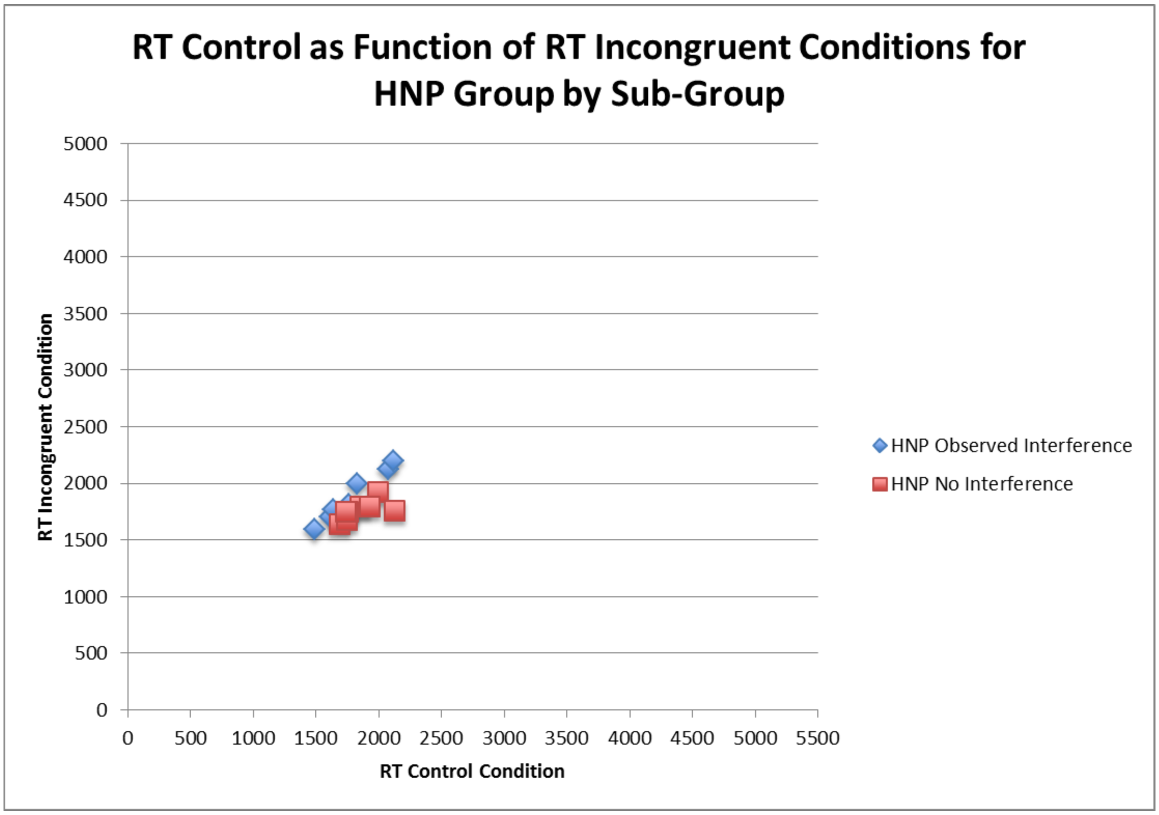

Figure 10. Reading times for the control condition as a function of reading times for the incongruent condition sorted by HNP members who did and did not demonstrate interference on the ASL single-word task.

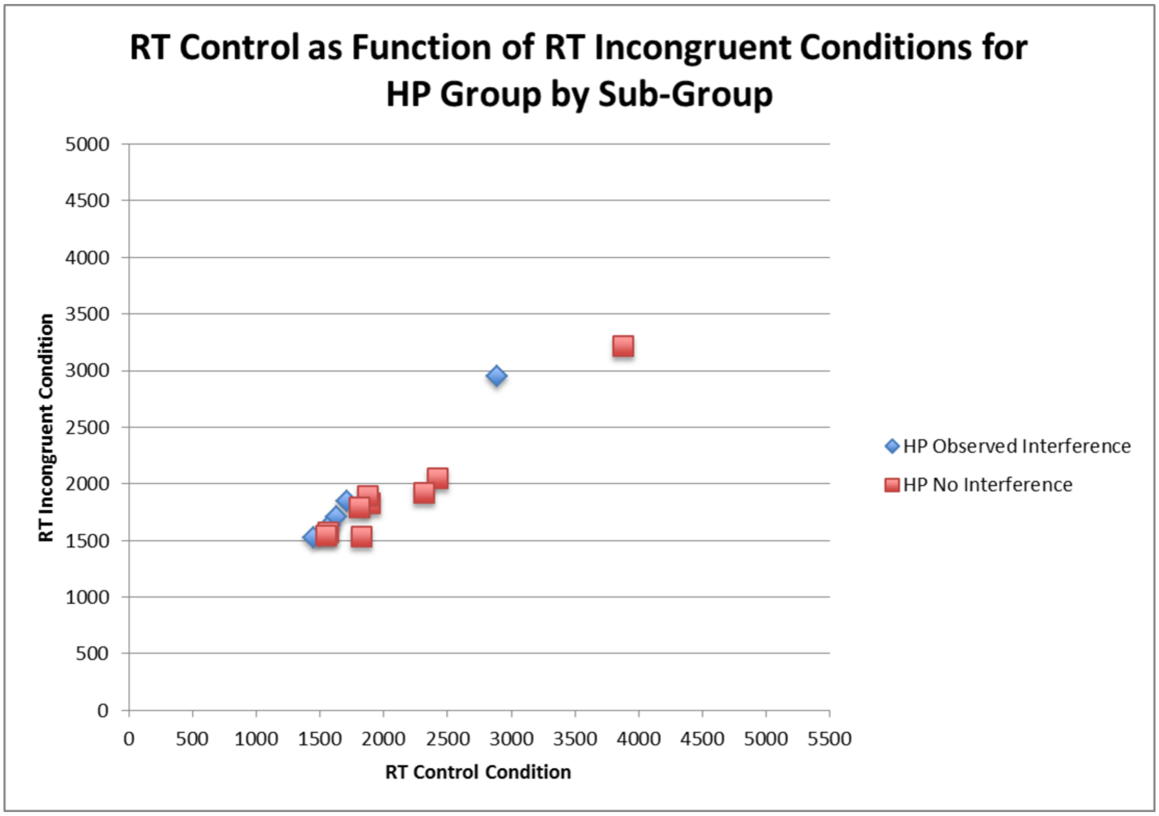

Figure 11. Reading times for the control condition as a function of reading times for the incongruent condition sorted by HP members who did and did not demonstrate interference on the ASL single-word task.

When comparing the HNP and HP groups to the DP group on the single-word ASL task across both conditions, the findings suggest that the DP group required more time (approximately 693 ms) to respond to the stimuli compared to the two hearing groups. Reading times on this single-word task, especially on the control condition, provided insight into time spent processing language at the word-level. As stated above, the group of 10 DP individuals who demonstrated interference, produced an average time on the control condition of 1895 ms, which falls between the averages of the HNP (1824 ms) and HP groups (1988 ms). That is, the DP individuals who demonstrated a Stroop effect and reported higher proficiency skill levels demonstrated reading times that were similar to those of the hearing groups. The reading time average for the 5 DP group members who did not demonstrate interference were longer, suggesting slower processing compared to the other 10 DP group members. Level of language proficiency is a likely explanation for these differences.

It is important to highlight the fact that individual differences within the DP population were not reflected by the group average. Had the within group differences not been investigated, the finding that the majority of the DP group members did demonstrate Stroop effects at the word-level would have been missed. Heterogeneity and individual performance is a critical consideration when conducting research with the Deaf population and the present study further supports this notion.

5.2 CRTT-R-$_{WF}$ AND CRTT-R-$_{STROOP}$ ENGLISH SENTENCE-LEVEL PERFORMANCE

It was hypothesized that the HP and HNP groups would demonstrate significant Stroop effects and that the DP group would demonstrate a reduced Stroop effect on the English sentence reading condition. This hypothesis was partially confirmed. Both hearing groups demonstrated a significant Stroop effect on both the color and shape words. Due to English nativity, it was not surprising that the hearing groups demonstrated a color word Stroop effect on the CRTT-R-$_{WF}$ sentence stimuli. The two hearing groups also experienced a spillover in processing the word immediately following the word that contained the incongruency. The DP group demonstrated the Stroop effect on the English sentence-level color and shape words, which provided evidence that the DP group demonstrated efficient lexical-level reading. Appendix 12 presents individual mean DP reading times for color2 word and shape2 word, and the differences between the incongruent and control conditions for the English Stroop task. There was only one DP group member who did not show the Stroop effect on the English color word (Participant DP04). That participant and one other did not show interference on the shape word. All other DP group members did show interference on color and shape words in written English. These findings suggest that the DP group members performed consistent with each other on the English sentence level Stroop task, but varied from each other on the ASL sentence-level Stroop Task, as well as the ASL single-word Stroop task.

Although the DP group experienced a Stroop effect in CRTT-R-$_{WF}$ conditions, the effect for the DP group was 302 ms longer than for the hearing participants. Further, there were no significant differences among the groups in reading time for the color adjective in the control condition. This suggests that the DP group took significantly longer to inhibit the otherwise timely activated color word. What is important to recognize is that, regardless of magnitude, the Stroop effect was elicited in the DP group. This is consistent with relatively automatic English lexical activation. This interpretation adds additional support for the longer inhibition interpretation because the DP group results parallel those of the hearing groups who were, by selection, proficient English readers.

On the CRTT-ASL-$_{STROOP}$, the DP group demonstrated language interference on the color word only, whereas on the CRTT-R-$_{WF}$ the DP group demonstrated a spillover effect, where the word immediately following the color took longer to process in the incongruent condition compared to the control condition. This finding suggests that the DP group processed ASL and English differently; which is not surprising due to the differences between the two languages. It is likely that the difference in a spillover effect between ASL and English is due to fact that the two languages have different processing requirements. The HNP and HP groups also demonstrated spillover effects on the English reading Stroop task, which suggests similar processing by these different populations.

The DP group demonstrated Stroop effects on the English reading tasks, however, they also demonstrated lower Mean CRTT-R-$_{WF}$ scores when compared to the hearing groups (in both English and ASL). What accounts for this discrepancy remains a topic for additional research.

5.3 CRTT-ASL AND CRTT-ASL-$_{STROOP}$ SENTENCE-LEVEL PERFORMANCE

It was hypothesized that the HNP group would not demonstrate the Stroop effect on the CRTT-ASL-$_{STROOP}$ task but the HP and DP groups would. This hypothesis was partially confirmed. The DP group demonstrated a Stroop effect as evidenced by longer reading times on the final color word during the incongruent condition compared to the control condition. As mentioned above, no spillover effect was found for this group, as they did not demonstrate a Stroop effect on the final noun. This suggested that the DP participants processed the color word before moving on to the next word in the sentence without further interference. This is an important finding, as a spillover effect was found for written English (previously addressed in section 5.2). Most signs in ASL are arbitrary, such as color words, whereas others are highly iconic. In the CRTT-ASL tasks, the shape words are depicted using iconic tracing of the shape (circle or square). As such, it is possible that the iconicity of signed shapes eliminated spillover effects in the DP group.

The DP group was the only group to demonstrate interference in ASL, evidenced by the presence of a Stroop effect on the color word. This finding is consistent with the interpretation that only the DP participants read signs with sufficient automaticity such that they required inhibition when confronted with incongruent signs. This group performed with a Mean CRTT score of 12.85 on the incongruent ASL sentence condition, and an average Mean CRTT score of 13.24 on the control ASL sentence condition. This finding also is consistent with a general resource inefficiency explanation (McNeil, Odell & Tseng, 1991), whereby shared attentional resources were consumed by the inhibition requirements of the Stroop task, causing overall reduced processing performance on the sentence.

Overall, the two hearing groups were faster than the DP group in reading times during the incongruent conditions. The novice HNP signers in this study behaved similarly to young children on Stroop reading tasks who demonstrated reduced interference due to a lack of language experience and skill (Ikeda et al., 2011). A surprising finding regarding the HNP group was the observable and significant negative Stroop effect, meaning that the incongruent condition facilitated reading time. Perhaps the HNP group members were able to ignore the linguistic information to the point that they responded faster during incongruent conditions, also known as a facilitation effect. Facilitation during the Stroop task can occur when an individual is not proficient in a language, and therefore only focuses on the color of the stimulus and is able to ignore the lexical information. These signers may have been able to ignore the signs during the incongruent conditions, but were required to pay attention to the signs during the control condition.

It was not anticipated that the HP group would behave similarly to the HNP group. Both hearing groups likely failed to demonstrate an interference effect due to their levels of ASL proficiency, resulting from the large difference in use of ASL between the hearing and DP groups. Most participants of the DP group indicated using ASL 112 hours per week (16 hours per day), but the HP group averaged 19 hours of ASL use per week (2.7 hours per day).

Additionally, each participant in the DP group indicated ASL as their primary method of communication, whereas participants in the HP group reported English as their dominant language. It is likely that the frequency of ASL use impacted ASL study results. Language background of the HP group also could have played a role in performance. Many of the HP group members were ASL interpreters or students studying to be interpreters. The ASL interpreters frequently perform simultaneous bilingual processing when interpreting. They hear a message in English and must present the information instantaneously in ASL. It is possible to speculate that the HP group did not demonstrate a Stroop effect in ASL due to their well practiced ability to task switch, with automatic control of language activation/inhibition. However, these same participants did demonstrate a Stroop effect in the English sentence task, which is perhaps inconsistent with this explanation.

Though the DP group demonstrated greater automaticity with ASL than with written English, they also evidenced lower scores that the other groups in completing English and ASL CRTT tasks. The Mean CRTT overall scores that were analyzed take into account responses on content retrieved from the entire sentence, and are therefore not word-specific. However, the database from which the CRTT operates provides word-specific efficiency and timing data. Appendix 10 presents average CRTT scores achieved for each word in the control and incongruent conditions for the HNP group, Appendix 11 for the HP group, and Appendix 12 for the DP group. The DP group produced lower scores on all words in the incongruent compared to the control condition. It is possible that the DP group demonstrated reduced Mean CRTT scores across all words due to overloading the participants' memory capacities, which is speculated to be in the Deaf population (Marschark, Sarchet, & Trani, 2016).

The hearing groups were more efficient during the incongruent conditions, which further supports the interpretation of a reduced interference by these groups. The source of this reduced interference is critical to determine. That is, whether the less proficient ASL users were slower ASL readers, and hence didn't experience the same degree of interference as the DP group, requires further investigation. It has been speculated that slower readers do not demonstrate the Stroop effect, indicating less interference (Fassbinder et al, 2015).

5.4 LANGUAGE PROFICIENCY AND THE STROOP EFFECT

It was hypothesized that self-rated language proficiency would relate to performance on the Stroop tasks. This hypothesis was not fully confirmed for any of the groups for either language, but several interesting findings related to language proficiency were found.

Rather than a Stroop effect, the two hearing groups demonstrated a reverse Stroop on the ASL tasks. That is, the hearing participants were faster on the incongruent than the control conditions for the color and shape words. However, the magnitude of this reverse Stroop may have been moderated by ASL proficiency. Every additional point that a hearing participant assigned on the LEAP-Q for ASL comprehension resulted in a more positive reverse Stroop effect. However, when divided into their respective groups, the HP and HNP groups diverged somewhat. The HP participants were expected to produce a Stroop effect on the ASL tasks because of their signing skill level but instead showed a reduced reverse Stroop magnitude (i.e., 65 ms for color, 52 ms for shape) compared to the HNP group. This reduction in their reverse Stroop effect might have reflected their reduced signing proficiency.

The DP group's relationship between their self-rated English proficiency and performance on the CRTT-R-$_{WF}$ also was complex. For each additional point assigned on the LEAP-Q, the DP participants were 88 ms faster on the color word and 96 ms faster on the shape word across both control and incongruent tasks, indicating that the more proficient DP participants were with English, the faster they responded overall. This finding suggested that the more proficient DP participants were faster readers or processors of language, and thus faster responders than the less proficient Deaf participants regardless of condition. Consistent with this argument was the observation that the more proficient DP participants spent less time on the shape word in the CRTT-R-$_{WF}$ than the less proficient DP participants. Participants comprising the DP group demonstrated interference, evidenced by prolonged processing time on the incongruent condition; however, the average processing times across both control and incongruent conditions of those DP individuals who rated themselves as being more proficient were smaller. This was consistent with the interpretation that the more proficient readers within the DP group were faster at inhibiting the colored font in the incongruent condition for the CRTT-R-$_{WF\text{-}STROOP}$ task.

It was reasonable to expect that proficient language users would demonstrate longer reading times on incongruent stimuli due to the required inhibition; however, what is known about the bilingual advantage is that individuals who are more proficient in two languages show reduced interference due to more automatic cognitive control. It does not appear that the DP group demonstrated a bilingual advantage because the magnitude of interference was not correlated with participant's self-rated language proficiency although it may have been evident in some of the Deaf participants.

When the DP group's LEAP-Q self-ratings on ASL comprehension were compared to the Stroop effect on the CRTT-ASL, the LEAP-Q values did not predict a Stroop effect on the color or shape words on the CRTT-ASL. Although the LEAP-Q scores accounted for a substantive amount of the variance within the DP group the scores did not predict Stroop effects in ASL. Similar to English, the ASL results showed that the higher a Deaf participant rated their comprehension of ASL, the faster their reading times for the color word for control and incongruent sentence level ASL tasks. This is an example of a potential language processing advantage for the more proficient DP participants. Self-rated ASL proficiency was added to the model for processing time on the shape word, to investigate how ASL proficiency related to Stroop results. The results indicated that the difference between incongruent and control conditions for ASL signers who reported being more proficient (demonstrated by larger self-rating scores on the LEAP-Q) in ASL was smaller than for ASL signers who reported being less proficient in ASL. Those who were proficient were able to identify the shape more automatically, recovering from the interference experienced on the color word more quickly.

The relationship between self-rated LEAP-Q ASL comprehension scores and the Stroop effect in reading written English also was investigated because of the interdependent relationship that ASL and English have on language development for many Deaf individuals. For example, it is believed that some Deaf individuals recode written English via ASL. Therefore, the ASL LEAP-Q comprehension scores were added to the English reading Stroop model, which eliminated the Stroop effect for the English reading tasks. Self-rated ASL comprehension LEAP-Q scores accounted for a substantive amount of variance in the model. What also is interesting is that with each additional point on the LEAP-Q in ASL resulted in faster reading times on English color words by 109 ms and shape words by 116 ms. This means that the Deaf participants who were more skilled at comprehending ASL also processed written English faster, possibly due to being natively better language users and bringing these attributes to both language tasks. This finding also suggested a relationship between ASL skills and processing of written English. In thinking about the variety of language experiences reported by the DP group members, many of these individuals experienced linguistic deprivation at critical language learning ages; however, despite potential for language deprivation, the majority of the DP group members experienced interference in their second language. This makes sense, as ASL is often the dominant language used by Deaf ASL users, and is often used to scaffold literacy development. These findings highlight the importance of language proficiency and the role it plays in general language processing. Perhaps frequent language experiences and exposure provided strong language models, impact language processing and subsequent performance on cognitive-linguistic tasks such as the Stroop effect.

5.5 IMPLICATIONS OF FINDINGS

The results of this study possess immediate and future clinical implications for professionals or individuals who interact with the Deaf and hard of hearing population. First, the study used a previously created (Goldberg, 2015) sentence-level test for the comprehension of American Sign Language and extended its utility by creating and gathering preliminary data on a version for exploring executive functions involved in the comprehension process. Both of these ASL tests have the potential for standardization and future clinical use. There are few, if any, norm-referenced and standardized language comprehension assessments created in ASL. Using pre-recorded video stimuli in a computer-administered format, with well specified and validated scoring procedures, has validity and reliability advantages compared to ASL interpreters during live assessments. Due to the simple language used by the CRTT, concerns regarding the consideration of ASL dialectical differences influencing performance are eliminated, which further strengthens the practicality of the ASL versions of the CRTT as clinical tools for assessment. The CRTT-ASL assessments can be standardized and used across institutions for specific populations such as individuals learning ASL and those with specific cognitive and linguistic impairments.

In addition to gathering information on language comprehension and executive functions through use of the CRTT-STROOP assessments, another benefit of the assessment is that reading times and Mean CRTT scores gathered on the written English and ASL Stroop versions of the CRTT can be compared. This reading and performance comparison has the potential to yield information regarding language-specific performance of Deaf ASL users. The majority of the Deaf signing population is bilingual, and those comprising this unique language group rely on both ASL and English to communicate. However, it has been demonstrated that a subset of Deaf individuals exhibit poorer linguistic skills in written English and ASL compared to hearing peers. By administering the CRTT-$_{\text{STROOP}}$ and CRTT-$_{\text{WF}}$ assessments in both written English and ASL, and comparing performance across both languages, it is possible to identify an individual's relative strengths and areas of deficiency across both languages.

The CRTT-$_{\text{STROOP}}$ assessment also can provide relevant baseline information on language processing, comprehension, and executive functions. Baseline capabilities are important to gather when deciding treatment goals/objectives and designing treatment programs for patients. Deaf individuals might experience a predisposed disadvantage on tasks such as the CRTT, therefore it is important to separate which language deficits originate from deafness, and which originate from a more general separate or acquired language disorder. This distinction is useful for the creation of language rehabilitation, and relates to the concept that standardized ASL language assessments have the potential to be useful clinical tools for the Deaf population. When treating children or adults with language difficulties, speech language pathologists and other professionals should be aware of potential, pre-existing language adversities, and adapt treatment in order to suit the need of the individual.

In addition to clinical implications, the results of this study have theoretical implications as well. Specifically, pre-existing research consistently supports that Deaf individuals exhibit lower literacy skills compared to hearing individuals. The present study demonstrated that Deaf ASL users process written English at a sufficiently skilled level to evidence interference effects, and with greater magnitude compared to the hearing groups. Both hearing and Deaf groups exhibited the Stroop effect in written English, however the larger magnitude in the DP group could suggest a lack of inhibitory control in the DP participants. The DP group also produced lower Mean CRTT scores in written English compared to hearing participants, which suggests further difficulty inhibiting and organizing information. Longitudinal studies regarding the Stroop effect suggest that adults exhibit more inhibitory control, and thus more executive function control, when compared to hearing children who are skilled readers. This developmental effect is thought to be due to maturation of executive functions. By the DP group producing a larger magnitude of Stroop effect in written English when compared to native hearing English speakers, this suggests that executive functions in the DP participants are not fully matured. Due to the role that executive functions play in writing and reading, these findings offer an explanation as to why Deaf individuals exhibit frequent errors in reading/writing English: reduced control of executive functions.

6.0 FUTURE CONSIDERATIONS

This study generated many unanswered questions beyond the main questions addressed and stimulated several ideas for future research. The results only begin to describe the language processing and executive functioning of adult Deaf ASL users, which motivates many areas for future research projects.

Based on the ASL single-word data, it would be worthwhile to investigate if trial number influenced the Stroop effect by determining if they were elicited more frequently in the early trials but diminished after repeated presentations. The reason that it is of interest to investigate item number as a main effect for the ASL single-word task is due to the potential for participants to become habituated to the Stroop task, or develop strategies to inhibit lexical information with repetition of incongruent stimuli. It is possible that more of the DP and HP group members demonstrated Stroop effects on early appearing items for the ASL single-word task, but that these occurrences of interference were masked by future faster inhibitory times. Likewise, a mixed presentation of control and incongruent stimuli, especially in the single-word Stroop task may prevent any habituation or strategy formation and increase the likelihood of demonstrating a Stroop effect.

An additional topic worthy of future consideration is the lack of spillover by the DP participants on the CRTT-Stroop task despite a spillover demonstrated on the CRTT-R-$_{\text{WF-STROOP}}$. These results suggest potential difference in language processing between Deaf and hearing ASL users. The structure of the ASL sentences in the CRTT-Stroop may provide a window into these processing differences with the more arbitrary color signs followed by the more iconic shape signs. It is important to investigate language-processing differences by Deaf individuals on ASL and written English, because the two languages have been cited to develop together and depend on each other for overall language development. If Deaf ASL users recode written English using ASL, it would be interesting to discover processing differences between these two languages to better understand why and how Deaf individuals understand and use language. The Deaf population has historically exhibited poorer English reading skills compared to hearing English readers, and by beginning to understand how the processing of their dominant language (ASL) and second language (written English) differ, it will become easier to understand language independent skills.

Although the DP group demonstrated language interference, they simultaneously demonstrated some difficulty comprehending language as evidenced by lower CRTT Scores than the hearing groups. It would be interesting to investigate why these errors occurred, such as investigating the contributions of various cognitive functions on performance such as memory and attention. In addition to investigating these domain general factors, it would be beneficial to compare performance on both linguistic and non-linguistic based tasks in order to distinguish domain general from domain specific processes. These types of investigations could provide insight into the bilingual advantage and its existence in the Deaf and hearing signing populations on language-dependent and independent computations.

The CRTT-ASL and CRTT-ASL-$_{\text{STROOP}}$ tasks were developed from a standardized test but have yet to be normed on the Deaf ASL-using populations. The CRTT-ASL exhibited high test-retest reliability in a small group of adult Deaf ASL users, however, both ASL versions require further testing and investigation before they can be recommended for clinical use (Goldberg, 2015). The CRTT-ASL and CRTT-ASL-$_{STROOP}$ have the potential for clinical use with Deaf signers who have a communication disorder, such as aphasia subsequent to stroke or traumatic brain injury or developmental learning disabilities.

Gathering normative data on the Deaf signers is needed to capture the characteristics of the intended population for the test but this will be difficult due to the heterogeneity of Deaf ASL users on many factors (i.e. nativity, years of ASL use, auditory technologies used, presentation of hearing loss, educational experiences, language used by parents, etc.). Research studies that have investigated the language capabilities of Deaf ASL users have typically contained one group of Deaf individuals and compared their performance to hearing peers. The language learning environment and skills associated with the Deaf ASL-using populations depend on many factors not commonly germane to most hearing populations. Therefore, it might be beneficial to revisit the data from the current study and divide the Deaf group by factors that might have influenced the study results. One factor of interest is the ASL acquisition history across the participants in the DP group (e.g., native vs. non-native group). Prospectively, it would be informative to study different Deaf groups on the study tasks. These types of studies would contribute to the establishment of clinical assessments for the Deaf ASL- using population.

APPENDIX

Appendix, Table 1. Individual scores obtained on two passages of the CELF-5.

Participant	Passage 1	Passage 2
HNP01	10	9
HNP02	10	9
HNP03	8	9
HNP04	10	9
HNP05	10	9
HNP06	10	9
HNP07	10	9
HNP08	10	9
HNP09	9	9
HNP10	9	9
HNP11	10	9
HNP12	10	9
HNP13	10	9
HNP14	10	9
HNP15	10	8
HP01	10	9
HP02	9	9
HP03	10	9
HP04	9	9
HP05	9	9
HP06	10	9
HP07	9	9
HP08	10	9
HP09	9	9
HP10	10	9
HP11	10	9
HP12	9	9
HP13	10	9
HP14	9	9
HP15	10	9
DP01	10	9
DP02	10	9
DP03	9	9
DP04	9	9
DP05	9	9
DP06	10	9

DP07	8	9
DP08	9	9
DP09	9	9
DP10	10	8
DP11	10	9
DP12	9	9
DP13	10	9
DP14	10	9
DP15	9	9

Appendix, Table 2. Individual responses to portion of the background questionnaire

Participant	Primary Language	Language Used by Parents	Length of time using ASL	# of Hours per Week Using ASL
HNP01	English	English	5 months	5
HNP02	English	English	6 months	5
HNP03	English	English	6 months	7
HNP04	English	English	6 months	5
HNP05	English	English and German	5 months	4
HNP06	English	English and German	1 year	6
HNP07	English	English	5 months	6
HNP08	English	Igbo	1 year	5
HNP09	English	English	5 months	4.5
HNP10	English	English	1.5 years	<1
HNP11	English	English	5 months	5
HNP12	English	English	5 months	5
HNP13	English	English	5 months	5
HNP14	English	English	1 year	7
HNP15	English	Tamil	6 months	4.5
HP01	English	English	4 years	40
HP02	English	ASL	21 years	2-3
HP03	English	English	4 years	5
HP04	ASL/English	ASL	20 years	4
HP05	English	English	5 years	10
HP06	English	English	5 years	20
HP07	English	English	5 years	7
HP08	English	English	4 years	10
HP09	English	English	4 years	10
HP10	English	English	4 years	25
HP11	English	English	24 years	>20
HP12	English	English	23 years	30

HP13	English	English	3 years	60
HP14	English	English	6 years	>40
HP15	English	English	3 years	3
DP01	ASL and English	ASL and English	29 years	24/7
DP02	ASL	Spanish and English	18 years	24/7
DP03	ASL	ASL and Home Signs	28 years	24/7
DP04	ASL	English and ASL	25 years	24/7
DP05	ASL	Signing Exact English (SEE II)	>20 years	24/7
DP06	English	Home signs with spoken English	10 years	24/7
DP07	ASL	English, some ASL	15 years	35
DP08	ASL	English	10 years	24/7
DP09	ASL and Written English	Signing Exact English, Pidgin Sign English, Spoken and Written English	17 years	56
DP10	ASL and English Bilingual	ASL and Written English	19 years	45
DP11	ASL	ASL	28 years	24/7
DP12	ASL	English, Tagalog, Spanish, French	15 years	24/7
DP13	ASL	English	5 years	24/7
DP14	ASL	English	30 years	>40
DP15	ASL and English	ASL and English	45 years	24/7

Appendix, Table 3. Deaf participant reports on educational setting and use of auditory technology.

Participant	Self-Reported Educational Experiences	Onset of Hearing Loss	Use hearing aids or cochlear implants?	Age of device use onset
DP01	Mainstream with ASL interpreter from kindergarten to 7th grade, Deaf school from 8th to 11th grade, mainstream school 12th grade.	Profound	Yes (hearing aid)	15 months
DP02	Mainstream	Profound	Yes	2 years old
DP03	Deaf manual for preschool, mainstream from 1st to 4th grades, Deaf manual school 5th to 8th grade, mainstream 9th to 12th grade.	Profound	No	N/A
DP04	Deaf School (Manual)	Profound	Yes	4 years old
DP05	Mainstream Pre-K to 6th grades, Deaf manual school 6th to 12th grades.	Profound	No	N/A
DP06	Deaf manual school kindergarten to 8th grades, mainstream from 9th to 12th grades.	Profound	Yes	2 years old
DP07	Mainstream with use of ASL interpreter	Mild	No	N/A
DP08	Mainstream from kindergarten to fourth grade, deaf institution 5th and 6th grades, mainstream 7th and 8th grades, Deaf institution 9th to 12th grades.	Mild (unilateral)	Yes (hearing aid)	11 years old
DP09	Deaf manual school	Profound	No	N/A
DP10	-----------------------------	Mild	No	N/A
DP11	Deaf Manual School	Profound	No	N/A
DP12	Deaf School/Mainstream Oral	Mild	Yes	Birth
DP13	Mainstream	Mild	Yes	26 years old
DP14	Mainstream/Oral	Profound	Yes (hearing aid)	3 years old
DP15	Mainstream	Profound	No	N/A

Appendix, Table 4. Individual LEAP-Q ratings in ASL and English and years of education

Participant	LoP Speaking English	LoP Understanding English	LoP Reading English	LoP Signing ASL	LoP Understanding ASL	# Years of Formal Education
HNP01	10	10	10	3	3	15
HNP02	10	10	20	2	3	13
HNP03	8	19	8	5	5	16
HNP04	10	10	9	2	3	14
HNP05	10	10	10	3	3	18
HNP06	10	10	10	4	6	15
HNP07	10	10	9	3	4	14
HNP08	7	9	8	7	6	15
HNP09	9	9	8	3	3	7.5
HNP10	10	10	10	6	5	15
HNP11	10	10	10	3	3	16
HNP12	8	9	8	2	3	13
HNP13	10	10	10	2	4	14
HNP14	10	10	9	6	7	15
HNP15	10	10	10	4	4	15
HP01	10	10	10	7	7	19
HP02	10	10	10	9	10	15
HP03	9	9	9	6	7	16.5
HP04	9	9	10	9	9	15
HP05	9	10	9	7	8	20
HP06	10	10	10	8	8	15
HP07	9	9	8	6	7	16
HP08	10	10	10	8	7	16
HP09	9	9	9	8	7	16.5
HP10	8	9	8	6	5	16
HP11	10	10	9	8	8	16
HP12	10	10	10	7	6	26
HP13	9	9	7	7	8	19
HP14	9	10	10	9	9	18
HP15	10	10	10	7	7	13
DP01	7	5	9	10	10	20
DP02	8	7	8	9	9	15
DP03	0	0	8	10	10	26
DP04	5	5	10	10	10	15
DP05	2	5	9	9	9	15
DP06	7	5	7	8	8	15.5
DP07	0	0	4	5	5	15
DP08	7	7	7	8	8	15
DP09	0	1	9	8	9	15

DP10	4	4	9	10	10	13
DP11	0	5	10	10	10	18
DP12	0	1	4	7	7	22
DP13	2	5	3	7	6	15
DP14	10	9	10	9	9	19
DP15	6	4	9	10	10	16

Appendix, Table 5. Individual SLPI Responses.

Participant	Self-Rated SLPI Level
HNP01	Novice Plus
HNP02	Survival Plus
HNP03	Intermediate
HNP04	Novice
HNP05	Survival Plus
HNP06	Survival Plus
HNP07	Novice Plus
HNP08	Intermediate
HNP09	Survival
HNP10	Intermediate Plus
HNP11	Novice Plus
HNP12	Novice
HNP13	Novice
HNP14	Intermediate
HNP15	Survival Plus
HP01	Advanced
HP02	Superior Plus
HP03	Intermediate
HP04	Superior Plus
HP05	Advanced
HP06	Advanced
HP07	Intermediate
HP08	Advanced
HP09	Advanced
HP10	Advanced
HP11	Superior
HP12	Intermediate Plus
HP13	Intermediate
HP14	Superior
HP15	Advanced
DP01	Superior Plus
DP02	Advanced Plus
DP03	Superior Plus
DP04	Superior Plus
DP05	Superior Plus
DP06	Superior
DP07	Advanced
DP08	Advanced
DP09	Advanced Plus
DP10	Superior Plus
DP11	Superior Plus

DP12	Intermediate Plus
DP13	Advanced
DP14	Superior Plus
DP15	Superior Plus

Appendix, Table 6. DP group only Stroop effect on ASL single-word task.

Participant	Stroop Effect (ms)
DP01	222
DP02	96
DP03	246
DP04	122
DP05	160
DP06	180
DP07	**-182**
DP08	217
DP09	266
DP10	248
DP11	**-124**
DP12	**-279**
DP13	**-574**
DP14	**-649**
DP!5	160

***Note*.** **BOLD** indicates those DP participants who demonstrated a reverse Stroop effect.

Appendix, Table 7. HNP Participant Mean RTs on Color2 and Shape2 on control and incongruent conditions, and differences between conditions for CRTT-ASL-$_{\text{STROOP}}$.

Participant	Color2 Control	Color2 Incongruent	Δ Color2	Shape2 Control	Shape2 Incongruent	Δ Shape2
HNP01	1257	1293	36	1521	1598	78
HNP02	1321	1145	-176	1758	1275	-483
HNP03	1705	1444	-261	2318	1760	-558
HNP04	2156	1345	-811	2136	1529	-607
HNP05	1464	1120	-344	1486	1222	-263
HNP06	1010	903	-107	1174	910	-263
HNP07	1483	1284	-199	1502	1468	-34
HNP08	1774	2062	288	2299	2159	-140
HNP09	1319	966	-353	1532	1109	-423
HNP10	1506	1636	130	1951	1529	-422
HNP11	1845	1163	-683	1933	1251	-682
HNP12	1586	1414	-172	2077	1358	-719
HNP13	2077	1470	-607	2061	1521	-540
HNP14	1508	1270	-238	1718	1565	-153
HNP15	1393	1000	-393	1474	1103	-371

Appendix, Table 8. HP Participant Mean RTs on Color2 and Shape2 control and incongruent conditions, and differences between conditions for CRTT-ASL-$_{\text{STROOP}}$.

Participant	Color2 Control	Color2 Incongruent	Δ Color2	Shape2 Control	Shape2 Incongruent	Δ Shape2
HP01	995	909	-85	1139	1198	59
HP02	1513	1333	-180	1844	1594	-250
HP03	1184	1072	-112	1294	971	-323
HP04	1208	1168	-39	1472	1380	-92
HP05	1473	1943	470	1517	2569	1052
HP06	1190	1034	-156	1411	1218	-193
HP07	1298	1104	-194	1298	1307	9
HP08	1373	1260	-113	1852	1411	-441
HP09	1663	1657	-7	2276	1760	-516
HP10	1465	1265	-199	1838	1313	-524
HP11	1600	1649	49	2292	2386	94
HP12	1697	1448	-248	1725	1427	-298
HP13	1430	1107	-323	1736	1371	-365
HP14	1559	1537	-22	1880	1834	-46
HP15	1318	1234	-84	1402	1041	-362

Appendix, Table 9. DP participant Mean RTs on Color2 and Shape2 on control and incongruent conditions, and differences between conditions for CRTT-ASL-$_{\text{STROOP}}$.

Participant	Color2 Control	Color2 Incongruent	Δ Color2	Shape2 Control	Shape2 Incongruent	Δ Shape2
DP01	1570	2298	728	1921	1953	33
DP02	1378	1147	-231	1252	1061	-191
DP03	1489	1791	301	1945	2577	631
DP04	1131	490	-641	1188	296	-893
DP05	1037	1125	88	1143	1133	-9
DP06	1327	1315	-11	1500	1280	-220
DP07	1634	2190	556	1562	1270	-291
DP08	1811	2295	484	2401	2078	-323
DP09	1232	1635	403	1340	2213	874
DP10	1345	1331	-14	1425	1226	-199
DP11	1184	1513	329	1326	1371	45
DP12	1345	2120	774	1979	2054	75
DP13	2095	2051	-44	2835	1882	-953
DP14	1594	1680	85	2079	2301	221
DP15	1595	2038	443	1948	2403	455

Appendix, Table 10. HNP scores on each word on the CRTT-ASL-$_{\text{STROOP}}$ and CRTT-R-$_{\text{WF-STROOP}}$ for both control and incongruent conditions.

Condition	Verb1	Size1	Color1	Shape1	Verb2	Size2	Color2	Shape2	Place	Overall Scores
ASL Control	14.45	13.60	13.40	13.70	14.27	13.72	13.06	13.61	13.68	13.63
ASL Incongruent	14.69	14.73	14.20	14.32	14.73	14.27	13.97	14.19	14.28	14.27
English Control	14.87	14.81	14.67	14.67	14.77	14.60	14.43	14.62	14.62	14.62
English Incongruent	14.67	14.09	13.33	14.13	14.61	14.01	13.03	14.23	13.95	13.96

Appendix, Table 11. HP scores on each word on the CRTT-ASL-$_{STROOP}$ and CRTT-R-$_{WF-STROOP}$ for both control and incongruent conditions.

Condition	Verb1	Size1	Color1	Shape1	Verb2	Size2	Color2	Shape2	Place	Overall Scores
ASL Control	14.55	13.81	13.55	13.78	14.43	13.85	13.43	13.64	13.86	13.73
ASL Incongruent	14.56	14.10	13.70	13.94	14.37	13.90	13.22	13.76	13.90	13.94
English Control	14.85	14.71	14.66	14.68	14.81	14.36	14.32	14.51	13.34	14.37
English Incongruent	14.74	14.32	14.25	14.42	14.68	13.90	13.70	14.35	13.17	14.40

Appendix, Table 12. DP scores on each word on the CRTT-ASL-$_{STROOP}$ and CRTT-R-$_{WF-STROOP}$ for both control and incongruent conditions.

Condition	Verb1	Size1	Color1	Shape1	Verb2	Size2	Color2	Shape2	Place	Overall Scores
ASL Control	14.35	13.27	12.87	13.21	14.18	13.38	12.71	13.20	11.83	13.24
ASL Incongruent	14.01	12.97	12.59	12.66	13.23	12.82	11.79	12.38	11.34	12.85
English Control	14.57	14.10	13.81	13.97	14.45	13.69	13.28	13.66	12.26	13.83
English Incongruent	14.45	13.62	13.33	13.56	14.20	13.30	12.54	13.15	12.29	13.45

Appendix, Table 13. HNP participant Mean RTs on Color2 and Shape2 on control and incongruent conditions, and differences between conditions for CRTT-R-$_{\text{WF-STROOP}}$.

Participant	Color2 Control	Color2 Incongruent	Δ Color2	Shape2 Control	Shape2 Incongruent	Δ Shape2
HNP01	233	533	301	294	472	178
HNP02	307	414	107	359	582	223
HNP03	429	824	395	741	1177	436
HNP04	627	536	-91	594	519	-74
HNP05	416	427	11	544	610	66
HNP06	278	288	10	302	297	-5
HNP07	400	802	402	416	426	10
HNP08	541	1181	640	591	919	327
HNP09	382	342	-40	484	457	-28
HNP10	511	421	-91	1009	477	-532
HNP11	381	667	286	624	741	117
HNP12	491	1109	618	720	1054	334
HNP13	462	508	46	703	1178	476
HNP14	658	1008	350	914	720	-194
HNP15	398	426	27	466	526	60

Appendix, Table 14. HP participant Mean RTs on Color2 and Shape2 on control and incongruent conditions, and differences between conditions for CRTT-R-$_{\text{WF-STROOP}}$.

Participant	Color2 Control	Color2 Incongruent	Δ Color2	Shape2 Control	Shape2 Incongruent	Δ Shape2
HP01	193	322	129	247	490	243
HP02	557	723	165	679	629	-50
HP03	413	1026	613	443	806	363
HP04	343	543	199	372	536	163
HP05	1126	1667	540	1110	1287	177
HP06	285	463	178	362	559	197
HP07	485	798	313	682	1005	324
HP08	568	1020	451	523	819	295
HP09	425	1360	936	1261	1515	254
HP10	422	798	376	514	629	115
HP11	773	771	-2	740	727	-13
HP12	673	1246	573	930	1031	101
HP13	426	610	185	501	509	8
HP14	445	768	323	497	722	224
HP15	361	490	129	378	576	198

Appendix, Table 15. DP participant Mean RTs on Color2 and Shape2 on control and incongruent conditions, and differences between conditions for CRTT-R-$_{\text{WF-STROOP}}$.

Participant	Color2 Control	Color2 Incongruent	Δ Color2	Shape2 Control	Shape2 Incongruent	Δ Shape2
DP01	486	1576	1090	486	810	324
DP02	320	617	297	399	672	273
DP03	551	868	318	567	756	189
DP04	211	216	5	227	218	-9
DP05	296	570	274	313	483	170
DP06	370	700	330	451	712	260
DP07	628	1392	764	595	891	296
DP08	626	1610	984	577	943	366
DP09	461	1649	1187	689	1068	379
DP10	389	506	116	550	476	-74
DP11	529	1313	784	537	926	388
DP12	853	1022	170	993	1583	590
DP13	1301	1909	608	1889	2293	404
DP14	545	1073	529	538	745	206
DP15	645	1785	1140	1421	2867	1446

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