Assessing the ASL and ASL-Stroop Versions of the Computerized Revised Token Test with Children

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Background: Hearing loss is a risk factor for delayed and disordered communication development. For children who use American Sign Language (ASL) as their primary mode of communication, evaluations in written English may not accurately reflect their true language abilities. The ASL and ASL-Stoop versions of the Computerized Revised Token Test (CRTT) have been developed and studied in adult Deaf and hearing ASL signers but not in children. In this preliminary study, a small group of Deaf and normally hearing children were administered language-appropriate versions of the CRTT to determine if school-aged children are capable of completing the test.

Procedures: Three Deaf children proficient in both written English and ASL, and five typically developing hearing children proficient in oral and written English completed the CRTT English Reading Word Fade (CRTT-R-WF) and English Reading Word Fade Stroop (CRTT-R- STROOP) versions of the test. The Deaf children also completed the ASL version of the CRTT (CRTT-ASL), ASL Stroop version of the CRTT (CRTT-ASL-STROOP), and ASL Reading Self-Paced version of the CRTT (CRTT-R-ASL). In addition, the hearing children completed the Listening CRTT (CRTT-L) but no ASL versions.

Results: The Deaf and hearing children scored below adult levels on the CRTT-ASL, CRTT-L and CRTT-R-WF. Despite the limited number of children assessed, it appeared that the language development histories of the Deaf children related to their performance on the CRTT-ASL and CRTT-R-WF. On the Stroop versions, a Stroop interference effect was demonstrated by all children on the English reading version, however, the Stroop effect was less pronounced on the CRTT-ASL-STROOP.

Conclusions: The Deaf and hearing school-aged children in this study were capable of completing the targeted CRTT test versions. Potential differences were observed, but in most cases the pattern of performance was comparable to previous data obtained from adult populations. Age of language acquisition also appeared to affect these Deaf children's performance on these language-processing tasks.

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Preface

This thesis contains work from January 2018 to April 2019. Many thanks to the project's mentor, Dr. Sheila Pratt, for her guidance. Additional thanks to Leslie Qi-Guang, Neil Szuminsky, Joseph Engelmeier, Sally Wellman, and Cecilia's supportive family and friends. The University of Pittsburgh Honors College provided funding for this research study.

1.0 INTRODUCTION

This document provides an overview of the considerations, methods, procedures, and results from a study conducted to determine if school-aged Deaf children who use American Sign Language (ASL) and read in English, and typically hearing children who use oral English and read in English are able to complete language-appropriate versions of the Computerized Revised Token Test (CRTT) (McNeil et al., 2015). These versions include the ASL (CRTT-ASL), ASL-Stroop (CRTT-ASL-STROOP) and ASL Self-Paced versions of the CRTT (CRTT- ASL-WF) – all of which were administered to the Deaf children. The CRTT also includes an English Reading Word-Fade (CRTT-R-WF), and English Stroop versions of the CRTT (CRTT-R-STROOP), which were administered to both groups of children. In addition, the hearing children completed an English listening version of the CRTT (CRTT-L).

The Revised Token Test (RTT) (McNeil & Prescott, 1978) was originally developed to assess the language processing and comprehension skills of people with aphasia. These individuals experience deficits in language processing, comprehension, attention, and verbal working memory as a result of brain damage, most commonly left hemisphere stroke. Although designed to diagnose people with aphasia, the RTT also was shown to detect learning disabilities in adults and subtle auditory processing deficits in children and appeared to be largely bias-free (Campbell, Dollaghan, Needleman, & Janosky, 1997; Campbell & McNeil , 1985). The RTT appeared to be largely bias-free compared to other clinical language tests and performance in typically developing children improved with age up until 13 years (Campbell et al., 1997; Gallardo, Guàrdia, Villaseñor, & McNeil, 2011; McNeil, Brauer, & Pratt, 1990).

More recently, the RTT was adapted to a computer-based format and expanded to include not only listening but also reading, Stroop, and speed of processing versions (Eberwein, Pratt, McNeil, Fossett, Szuminsky, & Doyle, 2007; McNeil et al., 2012; McNeil et al., 2015). It also was translated into multiple languages, including ASL (Chen, McNeil, Hill, & Pratt, 2013; Goldberg, 2015; Goldberg, 2017; Turkyılmaz & Belgin, 2012). Also, despite the test's original purpose, it has since been used to assess language-processing abilities in different populations across language modalities (Salvatore, Cannito, Brassil, Bene, & Sirmon-Taylor, 2017; Sung, McNeil & Pratt, 2010; Yoo & Salvatore, 2018; Zhen et al., 2019).

In the current study, CRTT and Stroop tasks in English and ASL were administered to Deaf and typically developing hearing children to determine if these school-aged children are capable of completing these tasks and understand how these Deaf children process ASL and English. Comparing Deaf children's performance to typically hearing children, this study hoped to gain insight into Deaf children's language processing, working memory, and executive function as measured with the CRTT.

1.1 COMPUTERIZED REVISED TOKEN TEST (CRTT)

The basic format of the RTT was retained in the CRTT. It includes 20 digital "tokens" in two shapes (circle and square), two sizes (big, little), and five colors (red, blue, green, black, white). The tokens are manipulated in response to commands that vary by shape, size and color adjectives, along with a limited set of actions (touch, put) and prepositions (front, before, under, above, below, behind, by, next, beside, on, left and right). Whereas the RTT was administered face-to-face with the commands presented orally with plastic tokens placed on a table top, the

CRTT commands are presented acoustically via loudspeaker, or by sign or text on a computer screen. Responses require manipulation of the tokens on the screen either with a computer mouse or touchscreen.

The test consists of 10 subtests with 10 commands each. The subtests vary in task difficulty based on command length and complexity, and the number of tokens available on the screen to manipulate (Figure 1). For example, the test begins with the command "touch the black circle" with 10 tokens available to manipulate (Subtest I) and concludes with the command "touch the big black square unless you have touched the little red circle" with 20 tokens available (Subtest X). By keeping vocabulary highly controlled and manipulating length and complexity, the test stresses underlying linguistic processing and working memory, and is highly sensitive to aphasia, learning disabilities, and second language differences (Eberwein et al., 2007; McNeil & Prescot, 1978; McNeil et al., 2015).

Computerization allowed the test to present the stimuli in a controlled and consistent manner and record responses in a more rule-based, bias-free manner. Timing also could be recorded. The recording of response timing permitted the inclusion of an efficiency metric and the introduction of reading versions that measure reading time (McNeil et al., 2015). Being able to record reading times was fundamental to the development of a sentence-level Stroop interference task. Finally, converting to a computer-based format also facilitated the translation of the test into various languages, including ASL. This also was aided by the limited vocabulary and sentence structure of the test.

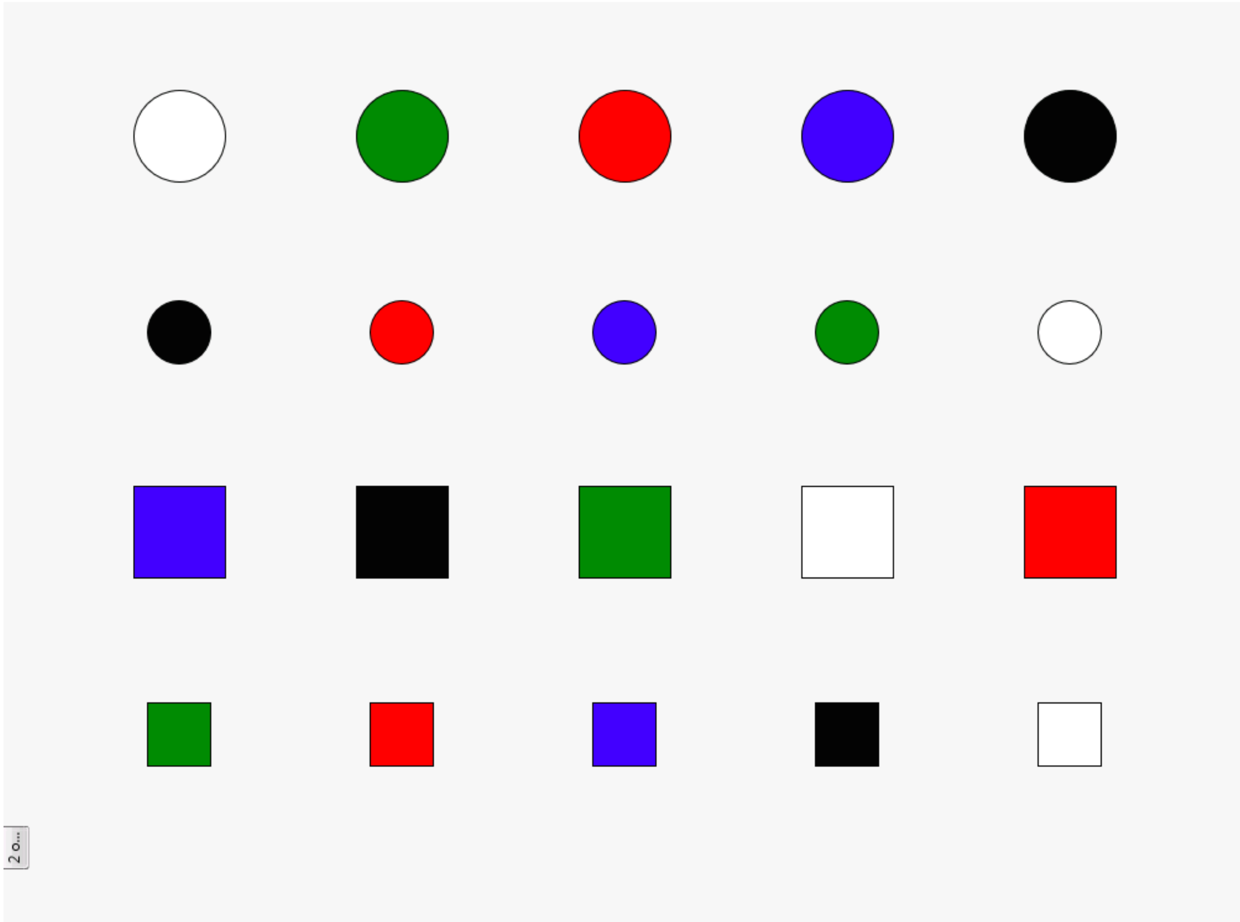


Figure 1. The CRTT response screen with 20 tokens (from Goldberg, 2015).

1.1.1 CRTT SCORING

With a few exceptions, the CRTT uses the same multidimensional scoring system as the RTT. The content words of each command are scored using the scoring system listed in Table 1. For example, the command “touch the black circle” contains the content words “touch” (verb), “black” (adjective), and “circle” (noun). The response to each of the content words is scored and then averaged to produce an item score. Each item score is then averaged to produce a subtest score and once the 10 subtests are completed, the average score across all subtests is referred to as the Mean CRTT Score. The scores also are adjusted for response time to estimate efficiency.

The adjustment occurs with each item and averaged within and across subtests to produce a mean Efficiency Score (ES), which is considered a measure of language-processing as a function of speed.

Table 1. CRTT scoring metric (Eberwein et al., 2007).

SCORE	DESCRIPTION OF RESPONSE
15	Correct
14	Subvocal Rehearsal
13	Delay
12	Incompleteness
11	Self-correct
10	Reversal
9	Needed Repeat
8	Needed Cue
7	Incorrect Response
6	Perseveration
5	Intelligible but incorrect response
4	Unintelligible (differentiated)
3	Unintelligible (perseverated)
2	Omission
1	No Response

1.1.2 ENGLISH VERSIONS OF THE CRTT

As indicated above, the commands of the RTT were presented orally. The CRTT version that most closely resembles the RTT is the listening version of the CRTT (CRTT-L), where patients listen to commands presented over a loudspeaker calibrated to 75 dB SPL at the level of the ear. As mentioned previously, there are multiple versions of the CRTT available across modalities. This includes several reading versions, where the commands are presented in text at the bottom of the computer screen (McNeil et al., 2015). The reading versions of the CRTT are of interest to this study because Deaf and hard-of-hearing individuals are typically able to read written English, allowing for comparisons of language-processing abilities across hearing and Deaf populations. The particular reading version used for the current study was the Reading Word-Fade version of the CRTT (CRTT-R-$_{WF}$). Word-Fade refers to the manner in which the commands are presented. The self-paced sentences are built word-by-word by the person taking the test by clicking the mouse, and as each new word appears on the screen the previous word disappears.

The self-paced nature of the CRTT-R-$_{WF}$ presentation has the advantage of permitting the recording of the time between clicks, but it also more closely resembles the nature of spoken language in that the linguistic information is serial and fleeting. In other words, once you hear a spoken word, it's gone. Similarly, with the CRTT-R-$_{WF,}$ once a reader clicks to the next word the previous word is no longer available, thus taxing short term/working memory in a manner similar to listening. Although the listening and reading versions of the CRTT have psychometric differences, both versions produce similar results and are considered valid and reliable (McNeil et al., 2015).

1.1.3 AMERICAN SIGN LANGUAGE CRTT

Translating the CRTT into other languages is possible due to the test's structure and being computerized. Goldberg (2015) translated the CRTT into ASL as part of an honors thesis. American Sign Language is a visual-manual language, so rather than presenting spoken or written commands the CRTT-ASL uses video clips of a Deaf native ASL signer (Figure 2). Goldberg (2015) assessed the validity and test-retest reliability of the CRTT-ASL by testing adult hearing non-native non-proficient, hearing non-native proficient, and Deaf native proficient ASL signers. The scores between the groups were compared across two sessions and the CRTT-ASL proved to be a reliable measure for the target population (Deaf ASL signers). Furthermore, because many Deaf individuals are able to read written English, Goldberg also compared the performance of her Deaf and hearing participants on the CRTT-R-WF.

Figure 2. Example of the signed stimuli in the CRTT-ASL (from Goldberg, 2015)
Note. Permission to include this picture was given through signed consent by the individual photographed.

1.1.4 THE RTT AND CHILD DEVELOPMENT

Although normative data have not been established for children on the CRTT, a number of studies used the RTT to assess children. Campbell and McNeil (1985) manipulated the RTT to investigate auditory comprehension in language-disordered and typically developing children. They simultaneously administered two versions of the RTT, one with a slower speech presentation rate and the second one maintaining a normal speech rate to allow for more processing time. It was assumed that the slower initial rate would facilitate auditory comprehension performance and improve comprehension of the normal rate condition compared to when both simultaneous presentations were presented at a normal speech rate. The RTT scores for each condition (slowed and normal speech presentation rate) from the two groups of children was compared and partially supported the argument that performance on the second task with a normal speech rate improved when the first task was presented at a slower speech rate. The results suggested that attention capacity and mental processing influenced the results. Rather than assuming that children with language impairment are simply slower at processing language, the allocation of attention across multiple tasks contributes to language-processing impairments.

The performance of typically developing children, aged 5 – 13 years, on the RTT was compared to adults with aphasia by McNeil, Brauer and Pratt (1990). Language acquisition as a function of age in child and disordered language processing in adults with aphasia was investigated with the RTT. It was argued that the RTT scores of people with aphasia would differ more significantly from children's performance as the children's ages increased. Results confirmed a systematic increase in RTT performance and a decrease in variability with increases in child age, indicating that the RTT was sensitive to their developmental changes. As expected, the group of adults with aphasia demonstrated poor performance and higher variability, with RTT scores comparable to the younger age children tested.

Campbell, Needleman, Riess, and Tobin (2000) used the RTT, among other language processing measures, to search for language differences in children related to bone lead levels. They found that children with elevated lead levels had significantly depressed scores on the more challenging subtests of the RTT.

Gallardo et al. (2011) contended that the RTT lends itself to translation because of the limited vocabulary set and simple commands. They aimed to develop a standardized Spanish translation for pediatric populations, obtain normative data, and establish concurrent and construct validity and internal consistency. Again, despite the RTT's original purpose of diagnosing aphasia in adults, Gallardo et al. (2011) was able to create a highly reliable RTT translation that was used with Spanish-speaking children in Mexico to identify language-processing disorders. Consistent with McNeil et. al (1990), Gallardo et al. (2011) demonstrated that RTT performance increased with child age and education.

Lastly, Campbell et al. (1997) investigated bias in child language assessments; an applicable topic to Deaf and hard-of-hearing populations. Many assessments used to identify language disorders are dependent on children's prior knowledge and vocabulary. These "knowledge-dependent" tools are disadvantageous to children with language-learning differences due to differing backgrounds and experiences. In contrast, tests like the RTT have limited inherent bias because they are minimally dependent on prior knowledge and instead focus on language-processing abilities. Campbell et al. administered three "processing-dependent" tests, including the RTT, and one "knowledge-dependent measure" to majority and minority school-age children. The results showed that the children's scores on the RTT and other "processing-dependent" tests were equal across majority and minority groups, but the majority children scored significantly higher than the minority children on the "knowledge-dependent" tests. These results point to the RTT being largely independent of prior knowledge and cultural differences and as a useful tool for detecting language-processing disorders.

The sensitivity of the RTT and CRTT to language processing abilities, rather than language content differences, has multiple uses in pediatric Deaf and hard-of-hearing populations. Deaf children are at risk of delayed/disordered language because of delayed and inconsistent speech and language exposure. An assessment tool that is based heavily auditory learning and extensive English vocabulary may inaccurately measure a Deaf child's true language-processing abilities and falsely diagnose a language disorder, when in actuality the child comes from a non-typical language-learning experience and often times a different culture. In addition to being a "processing-dependent" measure, translating the CRTT into ASL further minimizes bias against Deaf children who sign because it tests children in their primary language.

1.2 THE STROOP EFFECT

John Ridley Stroop first studied inhibition and interference in reading in 1935 by comparing the time it took for participants to read a color word in black text versus the time it takes to label the font color when it is incongruent with the color word. For instance, the color word "blue" could be printed in a black font color (control condition) or a different color such as red (Strooped condition). Stroop (1935) found that reading response times increased when the font color did not match the word meaning. The difference in the time required to inhibit the prepotent lexical word and label the font color compared to the time taken to read the color word was interpreted as an interference effect and is commonly referred to as the "Stroop effect". A larger time difference between conditions indicates that there is more interference (a larger Stroop effect) because inhibiting the more automatic color word reading and then producing the word for the font color requires more processing time.

The Stroop effect is considered a measure of reading automaticity. Experienced readers have to inhibit reading the word when labeling an incongruent font color. Moreover, inexperienced readers, such as children, demonstrate less interference because their reading is not fully proficient and automatic, whereas more experienced readers show more interference and thus a larger Stroop effect because their reading has become automatic (Ligon, 1932). The Stroop effect does increase with age and reading proficiency, as reading becomes more automatic and more difficult to inhibit reading the text (MacLeod, 1991).

Deaf and hard-of-hearing children typically demonstrate below age-level performance on reading tasks. Consequentially, is possible that Deaf children will demonstrate less Stroop interference because their reading is not as automatic as typically-hearing children. Despite the notion that reduced reading abilities in Deaf individuals may reduce Stroop interference, the advantages of bilinguals on interference tasks should be considered. Dividing attention between two languages requires more cognitive control, as bilinguals must inhibit one language to use the other. This skill is advantageous in the Stroop task, and indeed, bilinguals spend less time than monolinguals when labeling the font color in the Strooped color word conditions and demonstrate a smaller Stroop effect (Bialystok, 2009). However, Deaf ASL users are a unique population because there is no written form of American Sign Language. Marschark (1988) conducted the first experiment that demonstrated the Stroop effect in ASL users. Using colored gloves, picture slides of live signs and Strooped numbers, Stroop effects in ASL were produced across ages in his Deaf participants, where the Stroop effect increased with age (Marschark, 1988).

1.2.1 CRTT STROOP VERSIONS

As previously discussed, the CRTT-L and CRTT-ASL were designed to test language processing ability and linguistic working memory and the CRTT-R-$_{WF,}$ a reading version, where word-by-word reading times could be used to measure speed of language processing. This version was further adapted to include a Stroop version to assess inhibition, executive function, and Stroop interference in persons with aphasia (McNeil, et al., 2010; Pompon, McNeil, Spencer, & Kendall, 2015).

This test version, known as the CRTT-R-STROOP, is nearly identical to the CRTT-R-WF except for the inclusion of incongruent color words. Instead of a command such as "touch the black circle", the same command is presented with the word "black" written in a red font color, as shown in Figure 3. Again, like the CRTT-R-WF, the CRTT-R-STROOP is self-paced. Each element of the commands is presented one word at a time under the control of the reader with a mouse click. The time between each click is recorded and the time allocated to the incongruent color words reflect the level of interference when compared to the time allocated to the same color word in the CRTT-R-WF version.

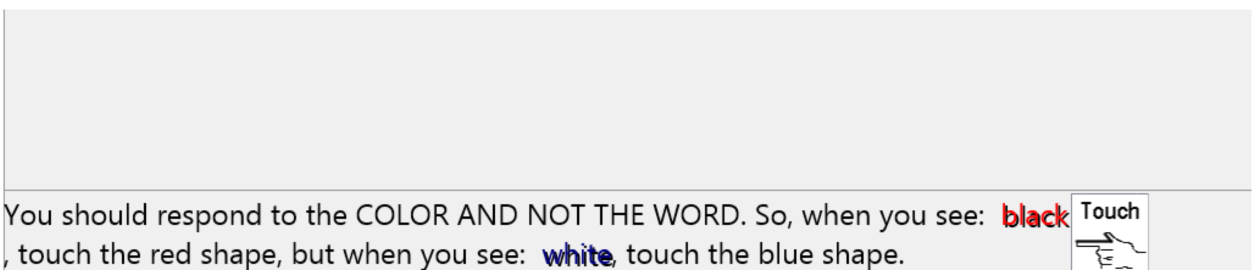


Figure 3. Instructions for the CRTT-R-STROOP.

The final test used in this study, the ASL Stroop version of the CRTT (CRTT-ASL-STROOP), was developed by Goldberg (2017) to provide information about Deaf individuals' language processing, comprehension, and executive functions. Just as the CRTT-R-WF was modified to produce a Stroop version (CRTT-R-STROOP), the CRTT-ASL was modified so that the original commands also had Strooped color words. The Stroop version was constructed by superimposing an incongruent translucent colored oval over the signer's hand each time a color-word is signed (Goldberg, 2017). The signer's hand is visible through the oval but encompassed by the color throughout the duration of the color word (Figure 4).

Figure 4. Screenshots of CRTT-ASL-STROOP stimuli, Goldberg (2017).
Note. Permission to include this picture was given through signed consent by the individual photographed.

For the CRTT-ASL-WF, a correct response is scored when the person being tested identifies the signed color word. However, the target response for the CRTT-ASL-STROOP was to attend to the color of the oval rather than the sign. After developing the CRTT-ASL-STROOP, the program was tested on hearing non-proficient signers, hearing proficient signers, and Deaf proficient signers, who all completed English Reading and ASL Strooped and non-Strooped versions the CRTT. Goldberg (2017) reported that although all three groups demonstrated a Stroop effect on the CRTT-R-STROOP, the Deaf proficient signers were the only group to demonstrate Stoop effects on the CRTT-ASL-STROOP, implying that ASL processing in Deaf ASL users is similar to English regarding inhibition and executive control functions. Conversely, less efficient users of ASL did not show a Stroop effect, presumably because they comprehend signs slower.

1.3 AMERICAN SIGN LANGUAGE AND LITERACY

American Sign Language is the language of the Deaf community used in the United States and Canada and a critical element of Deaf Culture. American Sign Language is a manual-visual-spatial language with five parameters making up the linguistic structure: (1) non-manual markers, (2) handshape, (3) palm orientation, (4) location, and (5) movement. Unlike speech, which expresses oral language through the vocal tract and speech articulators, ASL communicates linguistic information visually through movement, position, and orientation of the limbs within space in front of the body. Furthermore, ASL follows an Object-Subject-Verb sentence structure (Liddell, 2003; Stokoe, 1960). For example, the English sentence, "I like dogs" follows a Subject-Verb-Object structure but would be signed as "DOGS IX-ME LIKE" in ASL (Object-Subject-Verb). Given these differences, learning to read written English is often challenging for Deaf children because they not only lack exposure to the sound system of the oral language but also the syntactic structure and content.

Deaf children who use ASL as their primary form of communication often are bilingual. Some Deaf children develop oral speech through sensory devices (i.e., hearing aids and cochlear implants) and therapy, but many signing Deaf children learn the oral language through reading and writing because ASL has no written form (Hoffmeister, Moores, & Ellenberger, 1975). However, learning a second language through written text is difficult, so it is not surprising that the literacy skills of Deaf signing children often are compromised, in large part due to limited exposure to the speech sounds of the oral language from which text is based (Chamberlain, Morford, & Mayberry, 2000). Interviews of Deaf individuals regarding their experiences with language acquisition can shed light on the factors they believe are important for strong English reading skills (Mounty, Pucci, & Harmon, 2014). Some cite exposure to both the oral and sign language and surrounding Deaf children with a print-rich environment as critical. In sum, making text readily available at home and in school supports bilingual acquisition.

1.3.1 EARLY AND LATE LANGUAGE LEARNING

Many Deaf children in the United States suffer language deprivation because they receive inadequate acoustic linguistic input and are not exposed to native ASL signers (Humphries, Kushalnagar, Mathur, & Napoli, 2012). Language learning begins as soon as a baby is born by listening to people in their environments but for infants with a hearing loss there may be delays in receiving hearing aids and cochlear implants, or other interventions. Some infants may not receive full benefit from their sensory devices and therapy, and access to native signers may be limited. The resulting lack of linguistic input can delay language development and have a negative effect on future communication abilities and language processing (Lu, Jones, & Morgan, 2016). Some parents pursue the option of having their child learn ASL, but few hearing parents are proficient in ASL. As a result, many Deaf children are left with an impoverished linguistic environment that is unable to support normal language development.

The majority of Deaf children (approximately 90%) in the United States are born to hearing parents who use oral communication. Not surprisingly, the early language-learning environments of these children vary greatly, as their exposure to an accessible form of communication often is inconsistent or deferred. Again, in order for infants to learn language, they require early and consistent exposure to a rich linguistic environment (Pénicaud, Klein, Zatorre, & Chen, 2013). Although hearing technology and oral language can provide this level of exposure and support normal or near normal oral language and literacy development for some children, it is less effective for others. Yet, many hearing parents have limited sign language skills and typically are not able to provide the linguistic environment required for early ASL acquisition.

Because age of language acquisition has a strong influence on the development of language-processing and literacy skills, late language learners are at risk for language-processing and literacy deficits. Many Deaf children who sign may not have access to a complete language until they enroll in school, resulting in reduced lexicons and difficulty learning to read and write (Lu, Jones, & Morgan, 2016). Mayberry (1993) investigated the relationship between age of language acquisition and recall skills in ASL users. She compared Deaf individuals who learned ASL as a second language (after acquiring a first language earlier in life) to those who learned ASL as a first language later in life. The study found that the participants who learned language early had higher scores on tasks involving language-processing and working memory than the participants who learned language later. In other words, children who begin to learn either ASL or English earlier in life are more likely to develop stronger language-processing and literacy skills, independent of modality.

1.4 EXPERIMENTAL AIMS

The first aim of this preliminary study was to determine if these Deaf and normally hearing children are able to complete language-appropriate versions of the CRTT. A second aim was to obtain information about how the developmental and language experience influences test performance.

2.0 METHODS AND PROCEDURES

2.1 PARTICIPANTS

This study included eight children: Three Deaf children who used ASL as their primary mode of communication and were able to read written English, and five hearing children who communicated through oral English and who demonstrated typical English reading skills. Hearing, reading, and language abilities were based on preliminary procedures that the children completed prior to completing the CRTT tests. The children were 8 to 13 years of age and recruitment occurred through the use of approved informational sheets sent home to parents/guardians of children who attended the Western Pennsylvania School for the Deaf (WPSD). The hearing children were recruited through Pitt+Me recruitment platform. Demographic information is listed in Table 2. The Deaf group consisted of 2 females and 1 male and the hearing group consisted of 3 females and 2 males.

The University of Pittsburgh Internal Review Board and the Western Pennsylvania School for the Deaf approved this study. All of the children's parents/guardians provided oral and written informed consent, and the children provided assent prior to inclusion in the study. The children received $10.00 when they completed the study.

Table 2. Age and sex of participants.

Group	Median Age	Age Range	Female	Male
All Groups	11.7	8-13	5	3
Deaf Children	12.9	12-13	2	1
Hearing Children	10.5	8-12	3	2

2.1.1 INCLUSION AND PRELIMINARY PROCEDURES

All of the children completed a battery of preliminary procedures to qualify for inclusion in the study and for descriptive purposes. The parent/guardians of all of the children completed an informal background questionnaire and a pediatric version of the Language Experience and Proficiency Questionnaire (LEAP-Q) (Marian, Blumenfeld, & Kaushanskaya, 2007). The informal background questionnaire inquired about hearing, language, and educational histories. Table 3 shows selected responses from the background information form. Individual responses from all questions are found in Appendices 13 and 14.

Table 3. Individual Deaf group responses to select questions from the background information form.

Participant	Current Age	Age when Hearing Loss Identified	Hearing Loss Cause if Known	Age When Hearing Amplification (HA) Fitted	Age when First Began Learning ASL	Age when First Began Learning English
ASL-101	12.2 yrs.	3 yrs.	unknown genetic cause	3 yrs.	10 yrs.	birth
ASL-102	13.6 yrs.	9 mo.	unknown	currently considering HA	5 yrs.	5 yrs.
ASL-103	12.9 yrs.	birth	known genetic syndrome	1 yr.	1 yr.	1 yr.

The LEAP-Q is based on a scale of 0-10 where 0=none, 1=very low, 2=low, 3=fair, 4=slightly less than adequate, 5=adequate, 6=slightly more than adequate, 7=good, 8=very good, 9-excellent, 10=perfect. The LEAP-Q typically is used to assess oral language skills in multilingual people but was adapted for this study by changing the question format from "spoken" to "spoken/signed". The mean responses of each group are listed below in Table 5, and the individual data can be found in Appendix, Table 15.

Table 4. Mean self-rating of proficiency on the LEAP-Q.

Group	Comprehension Modality				
	English Expression	English Comprehension	English Reading	ASL Expression	ASL Comprehension
Deaf Children	5.33	5.33	5.33	8	9
Hearing Children	9.4	9.4	8.4	n/a	n/a

Table 5 lists the language dominance and acquisition histories of the Deaf children. Table 6 lists the age at which each participant in the Deaf group began learning ASL and English, according to the parent/guardian responses on the LEAP-Q. These data are important because, as previously discussed, age of language acquisition is a contributor to language-processing skills later in life. Some information was missing on the LEAP-Q for two of the Deaf children (ASL-102 and ASL-103) because they were adopted and information before their adoption was not available.

Table 5. Language acquisition and dominance of the Deaf children.

Participant	Age	Languages in Order of Dominance	Languages in Order of Acquisition
ASL-101	12	English, ASL	English ASL
ASL-102	13	ASL, English	ASL, English
ASL-103	12	ASL, English	English, ASL

Table 6. Deaf children language-learning histories.

Participant	Age	Hearing/Seeing on a Regular Basis		Single Words		Two Words		Sentences	
		ASL	English	ASL	English	ASL	English	ASL	English
ASL-101	12	3 yrs. 8 mo.	birth	n/a at home	10 mo.	n/a at home	16 mo.	n/a at home	4 yrs.
ASL-102	13	5 yrs.	5 yrs.	5 yrs.	5 yrs.	5 yrs.	5 yrs.	5 yrs. 3 mo.	5 yrs. 6 mo.
ASL-103	12		birth		unknown		unknown		unknown

Tables 3, 5, and 6 illustrate, even in this small sample, the variability of experiences commonly found among Deaf children. One child uses a hearing aid (ASL-101), one child doesn't use any amplification (ASL-102), and the final child had a bone-anchored hearing aid (ASL-103) (Table 3). Table 3 also indicates that one participant did not have access to either ASL or English before age 5, and another participant did not begin learning ASL until age 10. This developmental information is again reflected in their order of language dominance and acquisition (Table 5) and language milestones (Table 6). The Deaf children's linguistic experiences contrast with the hearing children, where all had immediate access to English at birth (Appendix, Table 14).

Various measures were used to determine participant eligibility for inclusion in the study. All of the children were screened for vision impairment using a Snellen visual acuity chart and were required to score 20/30 or better (corrected/uncorrected) for inclusion. The Clinical

Evaluation of Language Fundamentals 5th Edition (CELF-5) reading subtest also was used to determine if the children had sufficient literacy skills to complete the experimental tasks (Coret & McCrimmon, 2015). To qualify for the study, the children had to score within 2.5 standard deviations of the mean for their age. Mean and standard deviation (SD) raw and scaled scores for each group can be found in Table 8 and individual data can be found in Table 16 in the Appendix.

Table 7. Group results on the reading subtest of the CELF-5.

Group	CELF-5 Scaled Score Means	Passage 1	Passage 2
		Mean % Correct	Mean % Correct
Deaf Children	13	83.33%	59%
Hearing Children	9.66	90%	87.5%

The hearing children were administered otoscopy, tympanometry, and a pure tone hearing screening at 25 dB HL for the standard audiometric frequencies (250, 500, 1000, 2000, 4000 Hz). They also completed the Peabody Picture Vocabulary Test (PPVT) (Dunn, Dunn, & Pearson Assessments, 2007) to document normal receptive vocabulary. To qualify, the hearing children had to score within 3 standard deviations of the age mean.

The American Sign Language Vocabulary Test (ASL-VT) was administered to the Deaf children (Mann et al., 2016). Specifically, Set B was chosen because it most closely resembles the PPVT format. The ASL-VT is a computer-based test that required the Deaf children to select a video of a person signing that correctly matched a picture. For example, when the picture is of a cook, the children watch four videos of a person signing four different words (cook, salad, cooking, cleaning-person) and click on the correct response (see Figure 5). To qualify for the study, children needed to fall within 2.5 standard deviations of the mean ASL-VT, Set B score. Mann (2016) reported, for set B, a mean of 88% correct, a standard deviation of 5.19, and a range of 80%-96% for 20 participants.

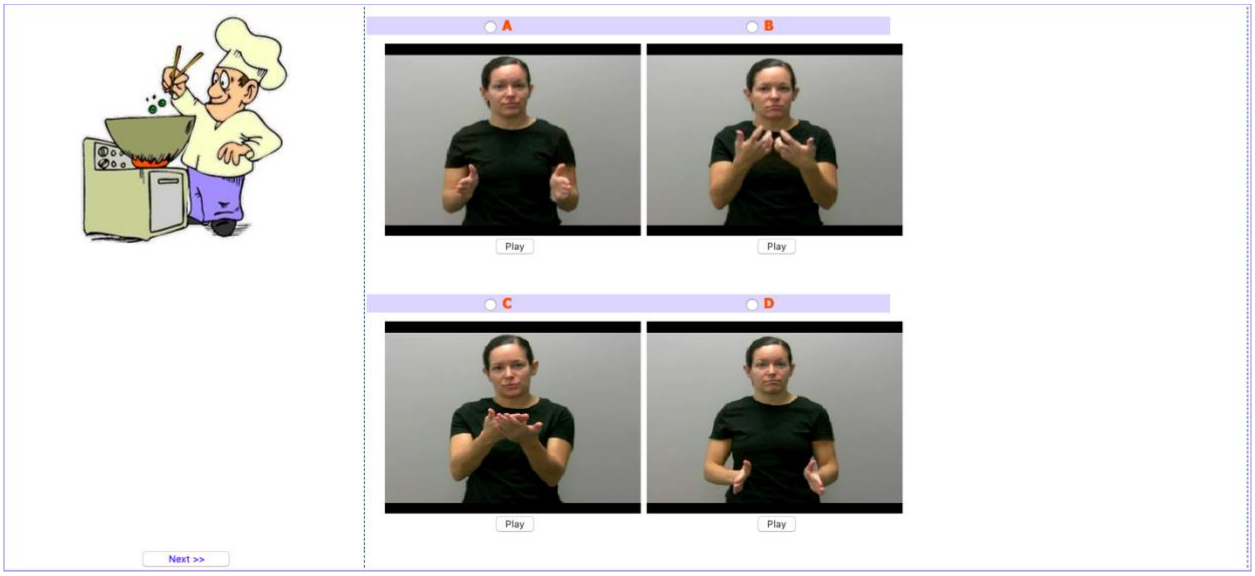


Figure 5. ASL-VT, Set B practice example, Mann et al. (2016).

The PPVT and the ASL-VT were used to screen and document the children's ability to recognize vocabulary words and provide another measure of their language skills. Individual, mean, and standard deviation (SD) scores for the ASL-VT and PPVT can be found in Table 8. Performance variability on the language tasks, particularly on the CELF-5, should be noted.

Table 8. Individual and group vocabulary results.

Group	PPVT			ASL-VT, Set B	
	Raw Score	Standard Score	Percentile	Score out of 40	% Correct
ASL-101				40/40	100
ASL-102				38/40	95
ASL-103				31/40	77
Deaf Children Average				36.33	91
ENG-101	142	101	53		
ENG-102	168	103	58		
ENG-103	158	100	50		
ENG-104	119	80	9		
ENG_105	194	119	90		
Hearing Children Average	156.8	100.6	52		

The children also completed an informal color/shape familiarity word screening where they were asked to point to pictures of colors (red, blue, green, black, white) and shapes (circle, square) that were spoken/signed and read with 100% accuracy to be included in the study. Finally, participants completed the CRTT and Stroop pretests for their corresponding experimental tests. The pretests confirmed that the children had the visual, motor, and vocabulary skills required to complete the CRTT and were oriented to each task requirement.

2.2 PROCEDURES

Once the children passed the screening procedures and pretests they completed their language appropriate CRTT versions. All of the children completed the first three subtests of CRTT-Speed of Processing Battery (Tap, Simple RT & Movement RT), which measures speed of processing (Appendix, Table 28), the CRTT-R-WF, and the CRTT-R-STROOP. The Deaf children completed the CRTT-R-WF, CRTT-ASL, CRTT-ASL-WF and CRTT-ASL-STROOP. The hearing children also completed the CRTT-L but no ASL tasks. The order was quasi-randomized and shown in Table 9.

The groups had two randomization options: the Deaf children could receive the two ASL tests first and the two Reading tests second, or the reverse. Likewise, the hearing children could receive the two Reading tests first and the one Listening test second, or the reverse. The experimental procedures were quasi-randomized so the longest task, either the CRTT-ASL or CRTT-L was always administered first. The CRTT-R-WF, CRTT-R-STROOP, CRTT-ASL-WF, and the CRTT-ASL-STROOP were shorter in duration. All of the tests were presented on a PC laptop with a computer mouse. At the end of the session the participants received their remuneration and signed the payment log/receipt.

Table 9. Experimental procedures and quasi-random test order.

Task (X=administered)	Deaf Children	Hearing Children
CRTT Reaction Time Task	X	X
CRTT-ASL *(always first with the Deaf children)*	X	
CRTT-L *(either first or second with hearing children)*		X
CRTT-R-WF & RTT-R-STROOP) *(either first or second with Deaf and hearing children)*	X	X
CRTT-ASL-WF & CRTT-ASL-STROOP *(either first or second with Deaf children)*	X	

3.0 RESULTS

3.1 DESCRIPTIVE DATA AND CRTT COMPARISON

The mean and standard deviations for the Mean CRTT Score (measure of performance accuracy) and Efficiency Score (measure of language-processing accuracy relative to speed) are displayed below (Tables 10 and 11). The adult Deaf ASL-proficient and hearing ASL-proficient data from Goldberg (2015) are included for some of the tests as a developmental reference. Mean CRTT and Efficiency Scores for both groups of children were substantively lower on the CRTT-ASL and CRTT-L in their respective modalities and were more variable than the Deaf and hearing adults from the Goldberg study (Figures 6 and 7).

In terms of age of language acquisition, the child who learned ASL before age 2 had scored higher on the CRTT-ASL than the two children who learned ASL after age 2 (Figure 8), and the two children who learned English before age 2 scored higher on the CRTR-R-$_{\text{WF}}$ than the child who acquired English after age 2 (Figure 12). Figure 9 displays the individual Deaf children's Mean CRTT Scores and the group average Mean CRTT Score for the Deaf and proficient hearing adults from the Goldberg (2015) study. Also plotted is the Mean CRTT-L Score for individual hearing children. These data are plotted on a growth curve from McNeil et al., (1990) which illustrates normal child and adult aphasic performance on the RTT.

Although both child groups demonstrated lower scores than their respective adult groups on the CRTT-R-$_{\text{WF}}$, the Deaf children had higher mean scores than the hearing children (Figure 10). This may be due to age differences between the two groups. However, the hearing child closest in age (12 yrs.) to the mean age of the Deaf group (12.9 yrs.) had a higher Mean CRTT-R-$_{WF}$ score (14.21) than any of the Deaf participants (Figure 13).

3.1.1 CRTT-ASL AND CRTT-L

The Mean accuracy and efficiency scores for the CRTT-ASL and CRTT-L are displayed in Table 6 and Figures 6 and 7. Figure 8 plots the age of ASL acquisition (obtained from the background information form) against the Mean CRTT-ASL Score. Figure 9 plots the individual data points of the mean score for the Deaf children on the CRTT-ASL, the hearing children on the CRTT-L, and the average Deaf Adult CRTT-ASL score from Goldberg (2015) against the graph from Campbell and McNeil's (1985) data showing child age vs. mean RTT score. Individual data points for the CRTT-ASL and CRTT-L are listed in the Appendix, Tables 21 and 22, respectively.

Table 10. Mean CRTT and Efficiency Scores of the CRTT-ASL and CRTT-L compared to Deaf adults.

Group	Mean CRTT Score	Standard Deviation of Mean CRTT Score	Mean Efficiency Score	Standard Deviation of Mean Efficiency Score
Deaf Children (CRTT-ASL)	12.03	.64	10.25	.51
Hearing Children (CRTT-L)	13.46	1.51	11.5	1.31
Deaf ASL-Proficient Adult CRTT-ASL, Session 1 (Goldberg, 2015)	13.91	0.42	12.37	.69
Hearing ASL-Proficient Adult CRTT-ASL, Session 1 (Goldberg, 2015)	13.97	.38	12.59	.51

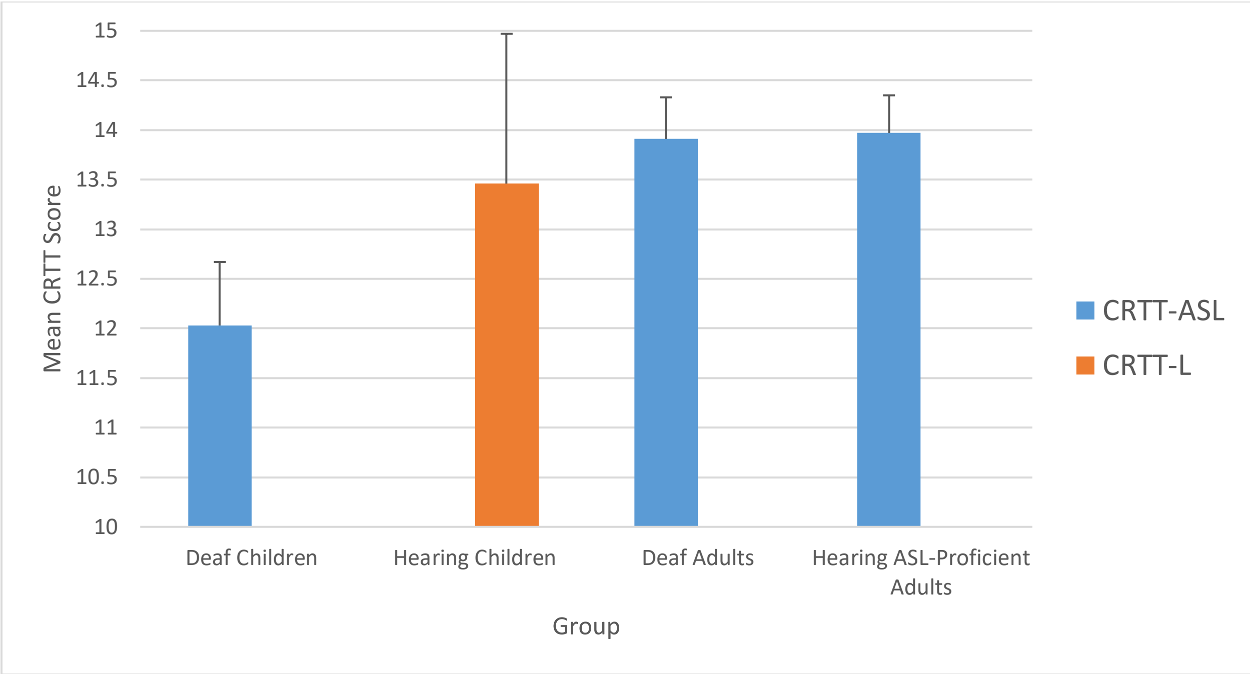


Figure 6. Mean CRTT Scores on the CRTT-ASL and CRTT-L.

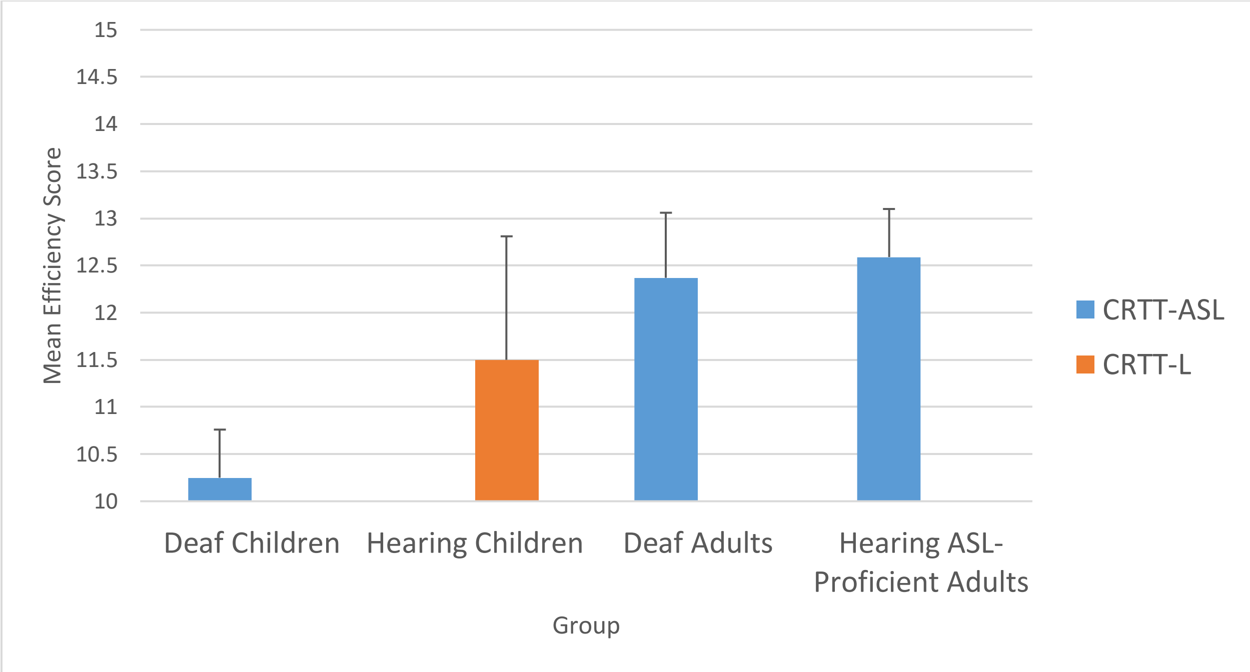


Figure 7 Mean Efficiency Scores on the CRTT-ASL and CRTT-L.

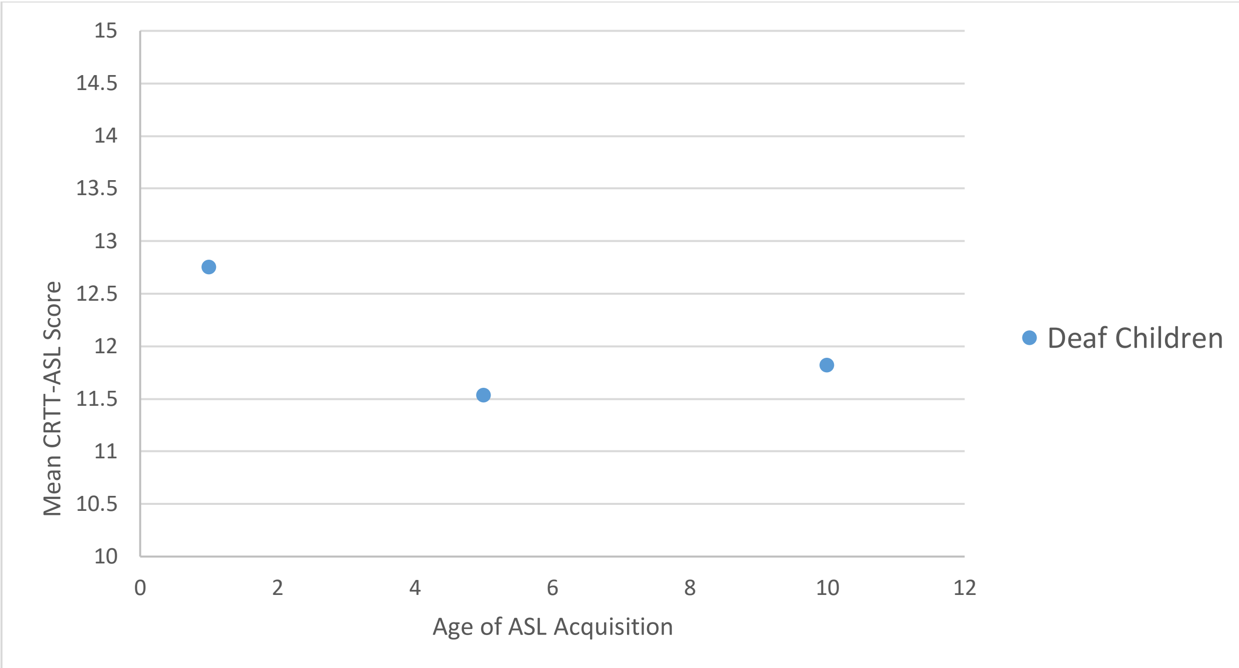


Figure 8. Deaf children Mean CRTT-ASL Score vs. age of ASL acquisition.

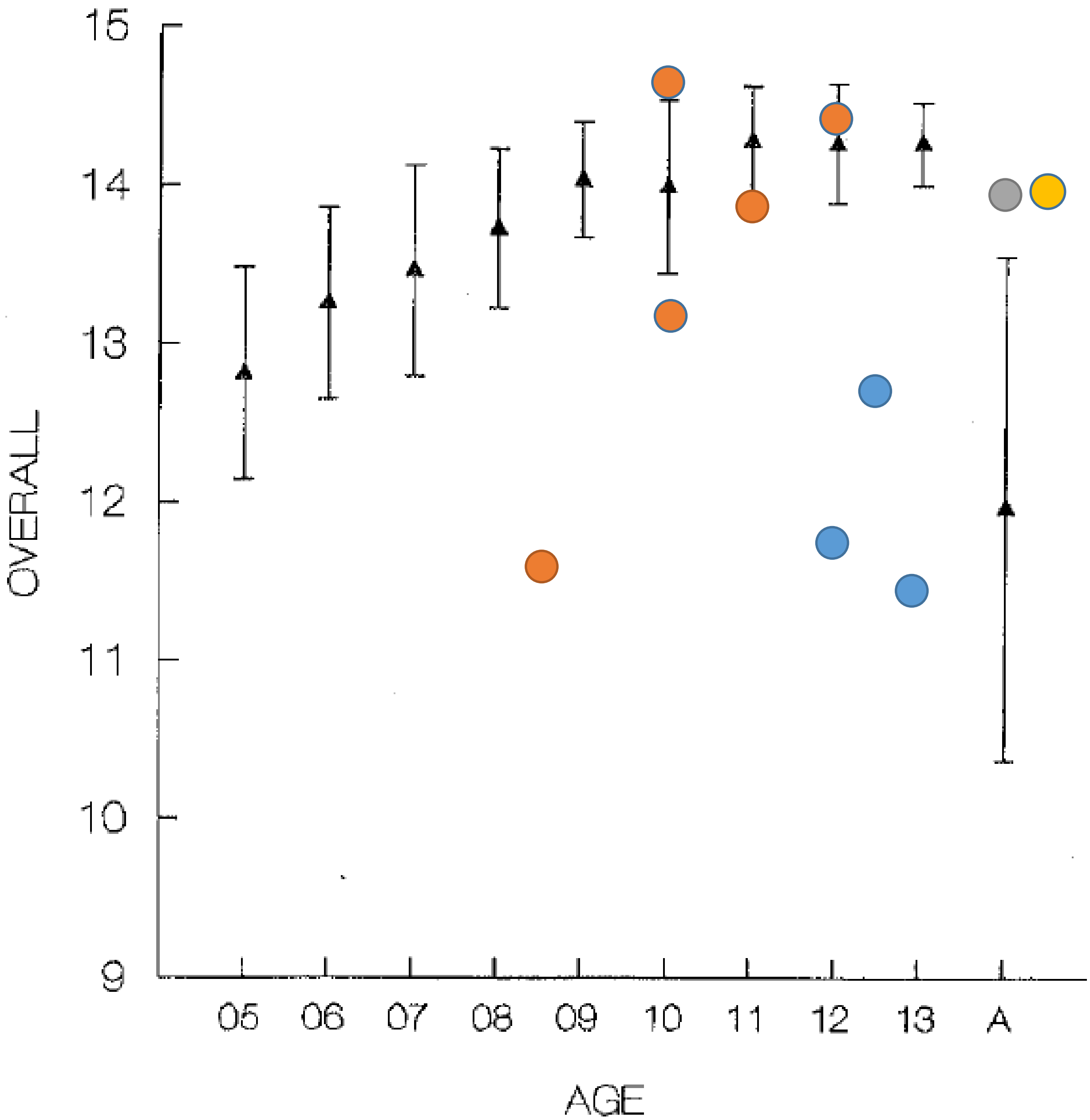
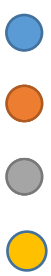


Figure 9. Group means and standard deviations of the RTT on children from McNeil, Brauer, & Pratt (1990).



= Individual Deaf Children CRTT-ASL Mean CRTT Score

= Individual Hearing Children CRTT-L Mean CRTT Score

= Mean Deaf Adult CRTT-ASL Mean CRTT Score

= Mean ASL-Proficient Adult CRTT-ASL Mean CRTT Score

3.1.2 CRTT-R-WF AND CRTT-ASL-WF

The CRTT-WF mean and efficiency scores are displayed in Table 11 and scores for the CRTT-R-WF are displayed in Figures 10 and 11. Figure 10 plots the Deaf children's age of English acquisition against their mean CRTT-R-WF score and Figure 13 illustrates the age of the participants in both groups compared to their mean CRTT-R-WF score. Individual data for both groups for the CRTT-R-WF and CRTT-ASL-WF are listed in the Appendix, Table 23 and 24, respectively.

Table 11. Mean CRTT and Efficiency Scores on the CRTT-R-WF and CRTT-ASL-WF compared to Deaf and hearing adults from Goldberg (2015).

Group	Mean CRTT Score	Standard Deviation of Mean CRTT Score	Mean Efficiency Score	Standard Deviation of Mean Efficiency Score
Deaf Children (CRTT- ASL-WF)	11.51	.71	9.27	1.54
Deaf Children (CRTT-R-WF)	13.48	.63	11.35	1.52
Hearing Children (CRTT-R-WF)	13.04	1.03	10.78	1.54
Deaf ASL-Proficient Adult CRTT-R-WF (Gloldberg, 2015)	14.07	0.5	12.58	0.91
Hearing Proficient Adult CRTT-R-WF (Goldberg, 2015)	14.53	.25	13.23	.30

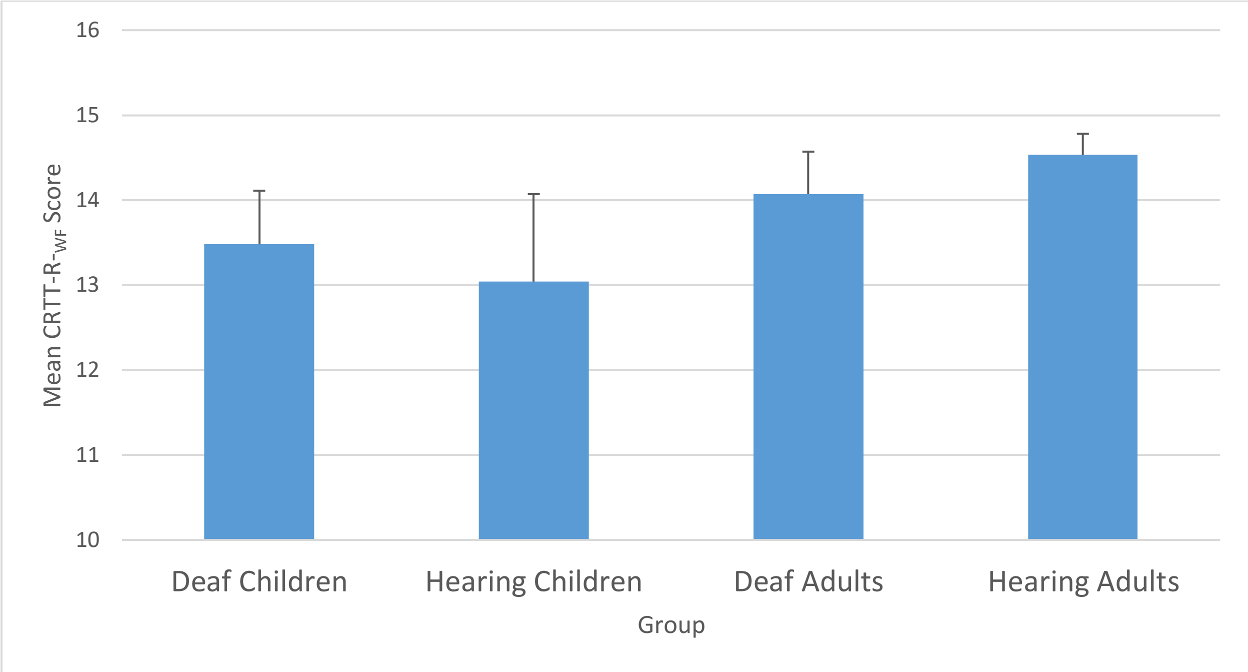


Figure 10. Mean CRTT-R-$_{WF}$ Scores.

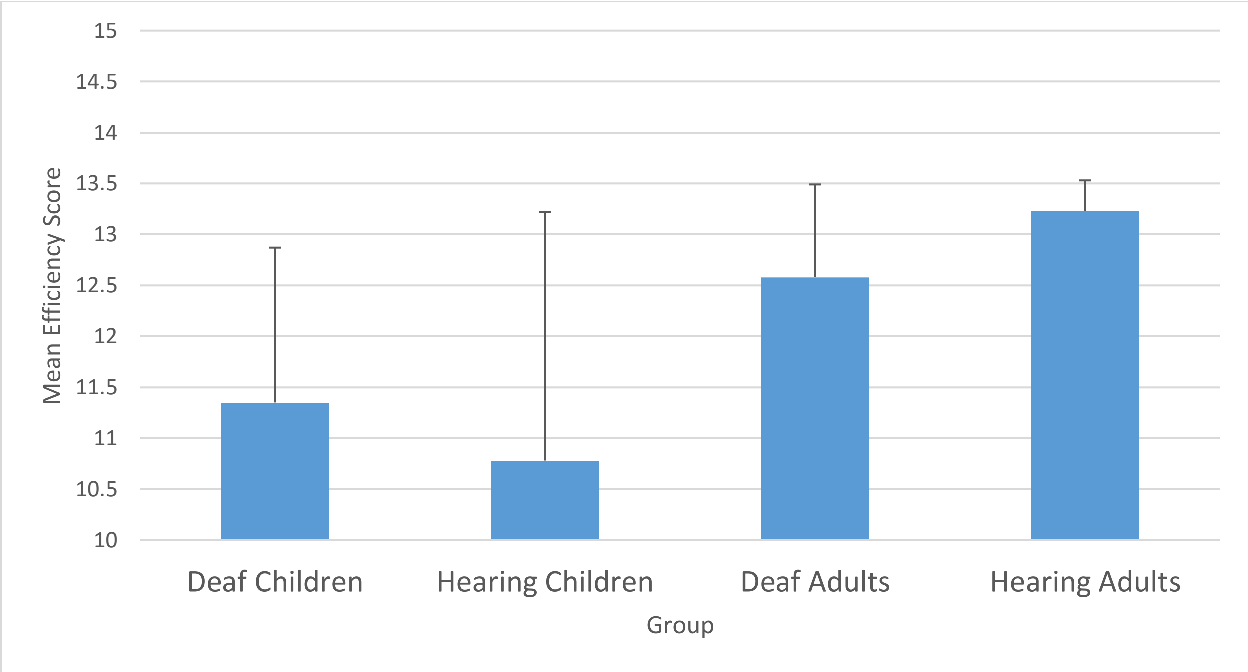


Figure 11. Mean Efficiency Scores on the CRTT-R-$_{WF}$.

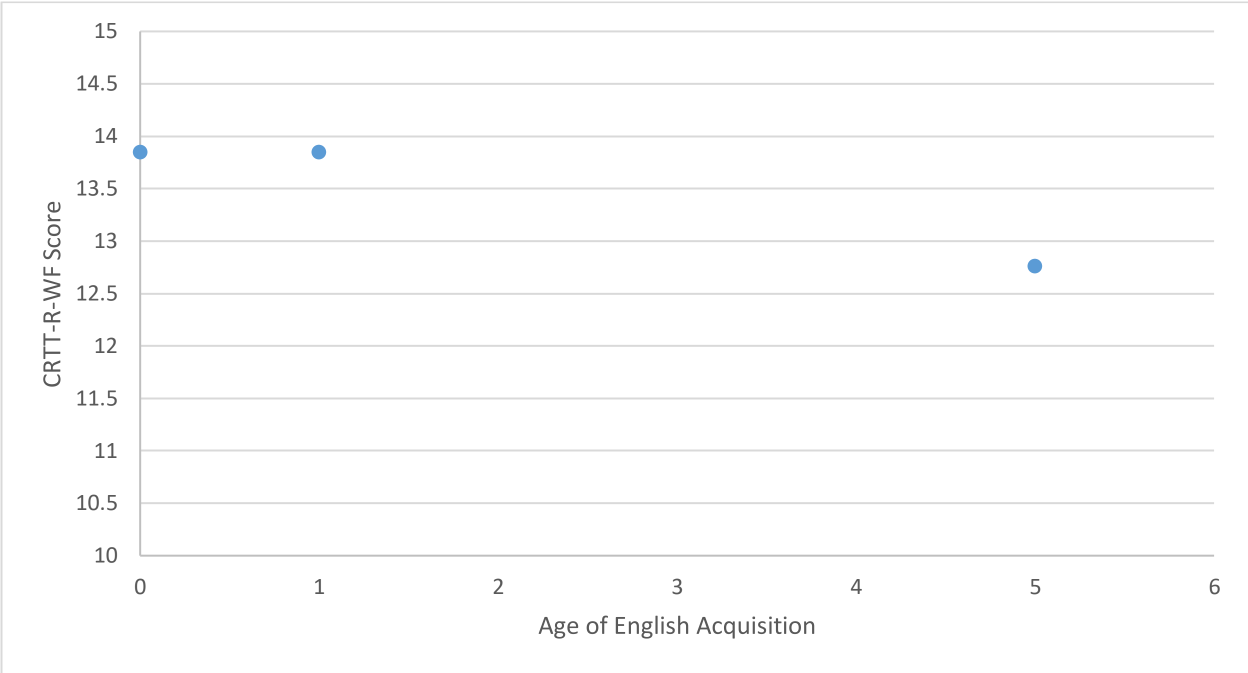


Figure 12. Deaf children Mean CRTT-R-$_{WF}$ Score vs. age of English acquisition.

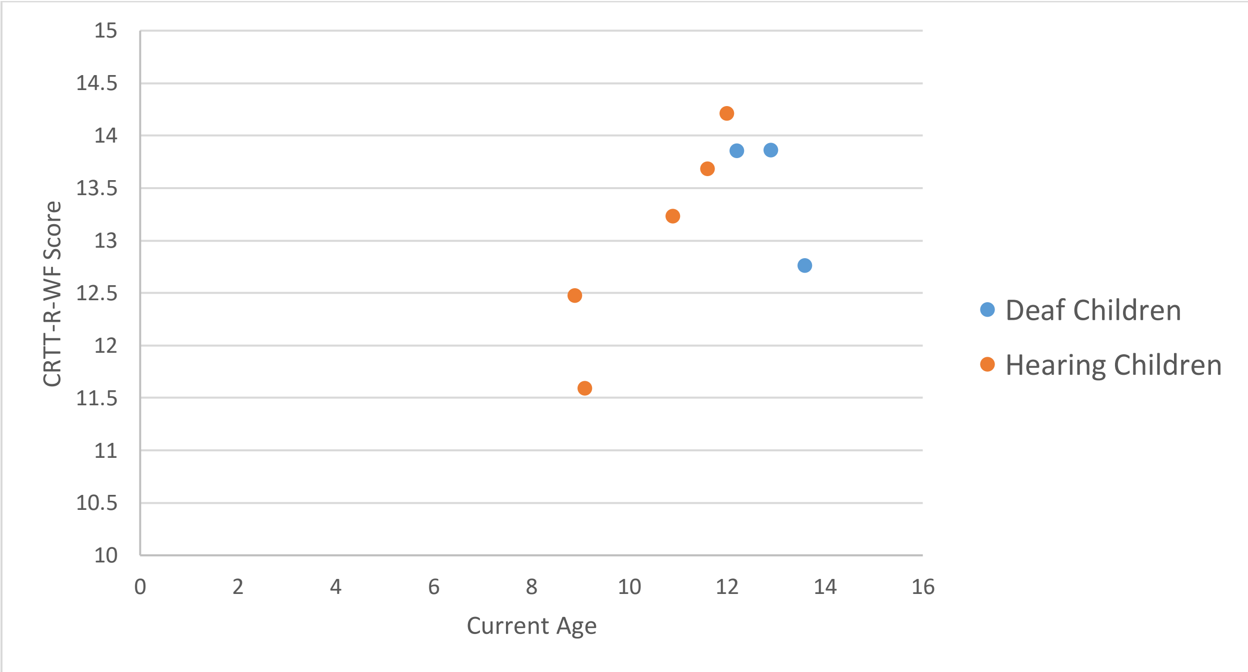


Figure 13. Mean CRTT-R-$_{WF}$ Score as a function of child age.

3.2 DESCRIPTIVE STROOP ANALYSIS

The mean reading time (RT) and RT differences of the final color and shape words from the control and Stooped conditions are displayed in Tables 12 and 13. Data from Goldberg (2017) with Deaf ASL-proficient adults and hearing ASL-proficient adults completing the same tasks are included for developmental comparisons. Overall, the data showed that all groups demonstrated a Stroop effect on the CRTT-R-STROOP (Figures 15 and 17), whereas only some groups showed it on the CRTT-ASL-STROOP, with some even demonstrating a negative Stroop effect (Figures 21 and 23). The Deaf children displayed a larger Stroop effect than the hearing group (Figures 15 and 17), which is similar to the effects observed in the adult Deaf and hearing groups in Goldberg (2017).

In terms of language acquisition, the Deaf children who acquired either ASL or English early demonstrated a smaller Stroop effect than the Deaf children who acquired language later on both the CRTT-R-STROOP and the CRTT-ASL-STROOP (Figure 18 and Figure 24). Across both child groups, increased age was generally associated with increased Stroop interference on the CRTT-R-STROOP (Figure 19). Individual participant data for the Individual Mean and Efficiency Scores on the CRTT-ASL-STROOP and the CRTT-R-STROOP are summarized in Table 25 within the Appendix.

3.2.1 CRTT-ASL-STROOP AND CRTT-R-STROOP

Consistent with the findings Goldberg (2017), only the final color and shape word RTs were used to calculate the Stroop effect. The mean reading time and reading time differences for the final color words between the control (CRTT-R-WF) and Strooped (CRTT-R-STROOP) CRTT conditions are summarized in Table 12 and displayed in Figure 14. Figure 15 displays the Stroop interference on the color word, calculated by subtracting the Stroop condition RT (CRTT-R-STROOP) from the control condition RT (CRTT-R-WF). Individual reading times and reading time difference results for the final color and shape words on the CRTT-R-WF and the CRTT-R-STROOP are listed in Table 26 within the Appendix.

Table 12. Mean RTs for the final color word in the control and Strooped conditions and difference between conditions for the CRTT-R-STROOP.

Group	Mean Color Word RT Control Condition (ms)	SD of Mean Color Word RT Control Condition	Mean Color Word RT Stroop Condition (ms)	SD of Mean Color Word RT Stroop Condition	Δ Color Word (RT-Stroop-RT Control)	SD of Δ Color Word
Deaf Children	524.66	74.58	1516.66	274.27	992	215.84
Hearing Children	509.8	171.61	780.6	293.26	270.8	212.13
Deaf ASL-Proficient Adult (Goldberg, 2017)	547.4	264.79	1120.4	528.16	573	396.63
Hearing ASL-Proficient Adult (Goldberg, 2017)	499.66	226.25	840	367.17	340.34	245.74

RT = reading time

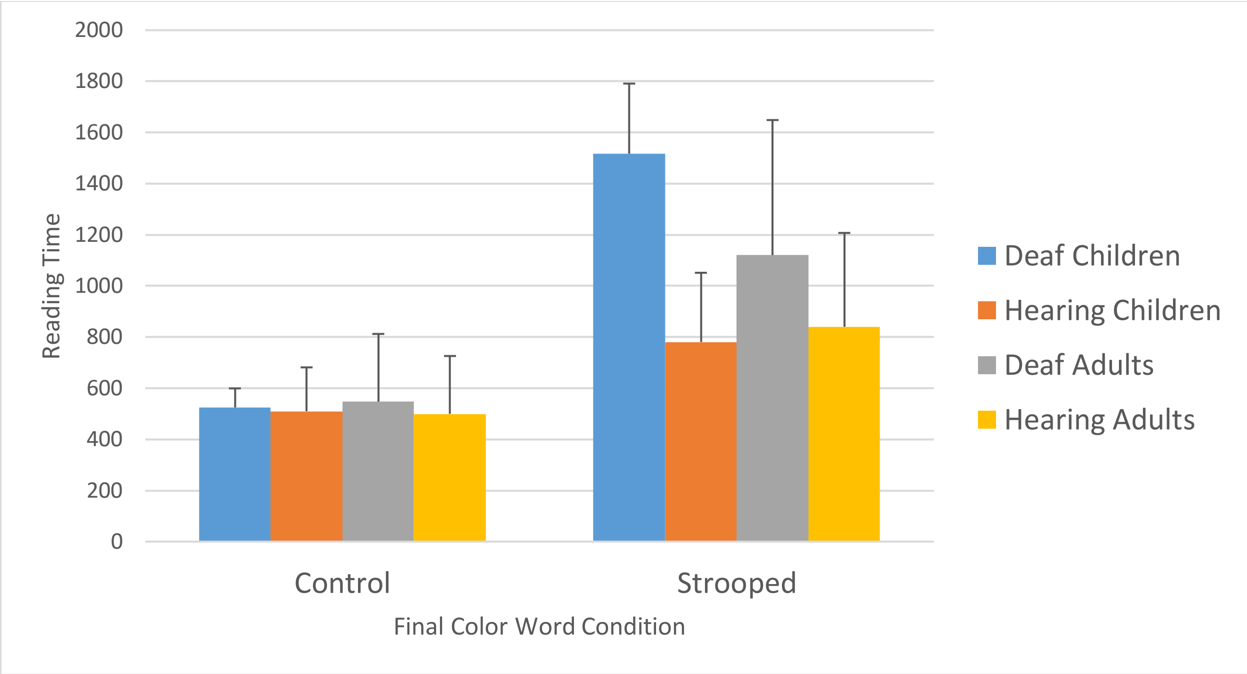


Figure 14. Mean RTs for the final color word in the control and Strooped conditions and difference between conditions on the CRTT-R-$_{WF}$ and CRTT-R-$_{-STROOP}$.

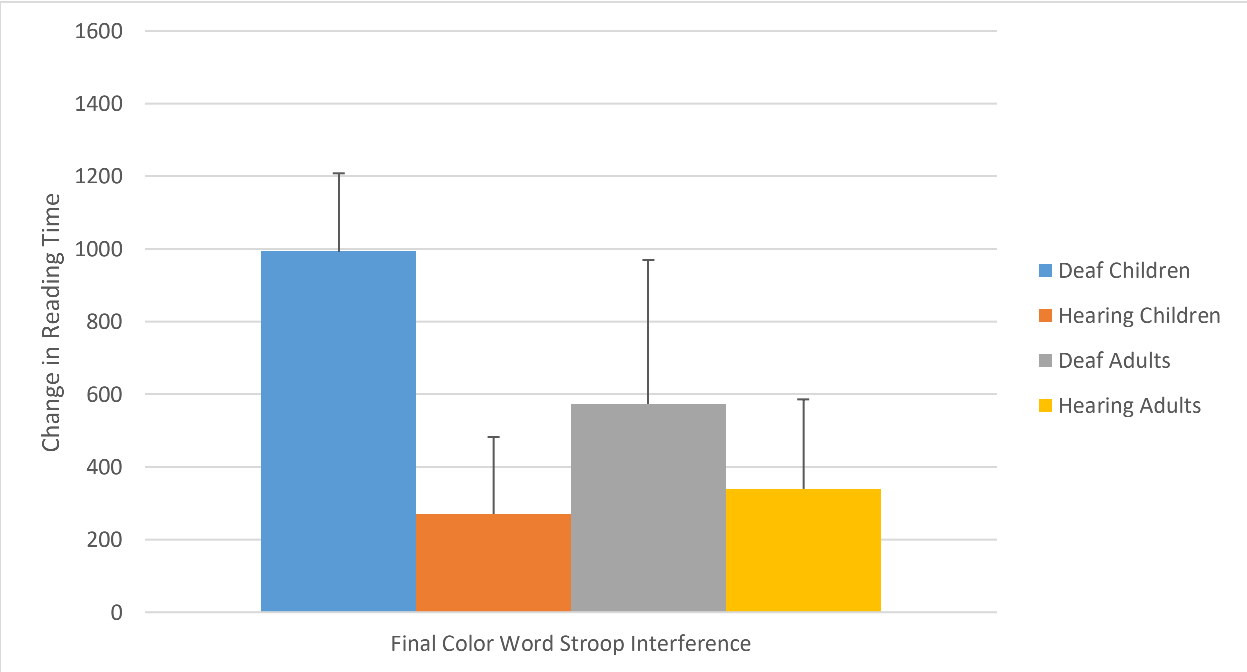


Figure 15. Stroop interference for the final color word on the CRTT-R-$_{WF}$ and CRTT-$_{-STROOP}$.

The mean reading time and reading time differences for the final shape words from the control (CRTT-R-WF) and Strooped (CRTT-R-STROOP) CRTT conditions are summarized in Table 13 and displayed Figure 16. Figure 17 displays the Stroop interference on the shape word, calculated by subtracting the Stroop condition from the control condition reading time. Figure 18 displays the Deaf group's age of English acquisition against the final color and shape word Stroop interference on the CRTT-R-STROOP. Figure 19 displays both groups by age against the final color and shape word Stroop interference on the CRTT-R-STROOP.

Table 13. Mean reading times for the final shape word in the control and Strooped conditions and difference between conditions for the CRTT-R-STROOP.

Group	Mean Shape Word RT Control Condition (ms)	SD of Mean Shape Word RT Control Condition	Mean Shape Word RT Stroop Condition (ms)	SD of Mean Shape Word RT Stroop Condition	Δ Shape Word (RT-Stroop-RT Control)	SD of Δ Shape Word
Deaf Children	531	124.83	980	447.02	499	468.34
Hearing Children	658	240.83	799.8	153.05	121.8	180.45
Deaf ASL-Proficient Adult (Goldberg, 2017)	682	439.63	1029.53	707.82	347.4	170.04
Hearing ASL-Proficient Adult (Goldberg, 2017)	615	289.78	789.33	301.32	173.4	122.26

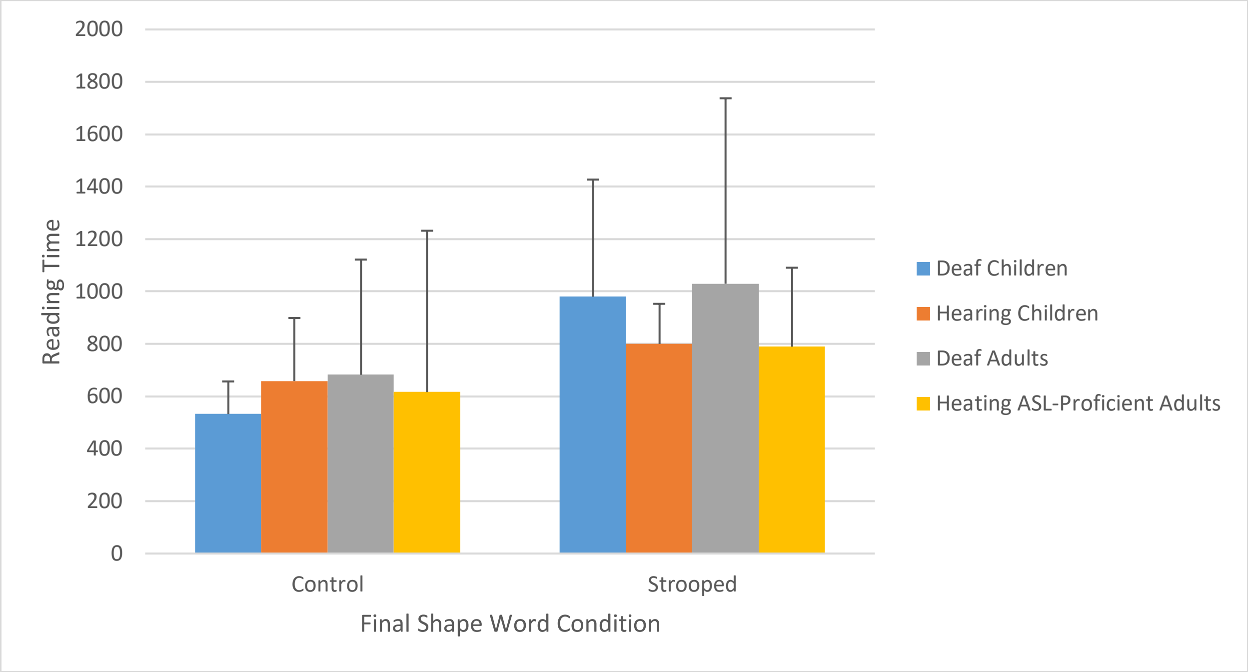


Figure 16. Mean reading times for the final shape word in the control and Strooped conditions and difference between conditions for the CRTT-R-$_{WF}$ and CRTT-R-$_{STROOP}$.

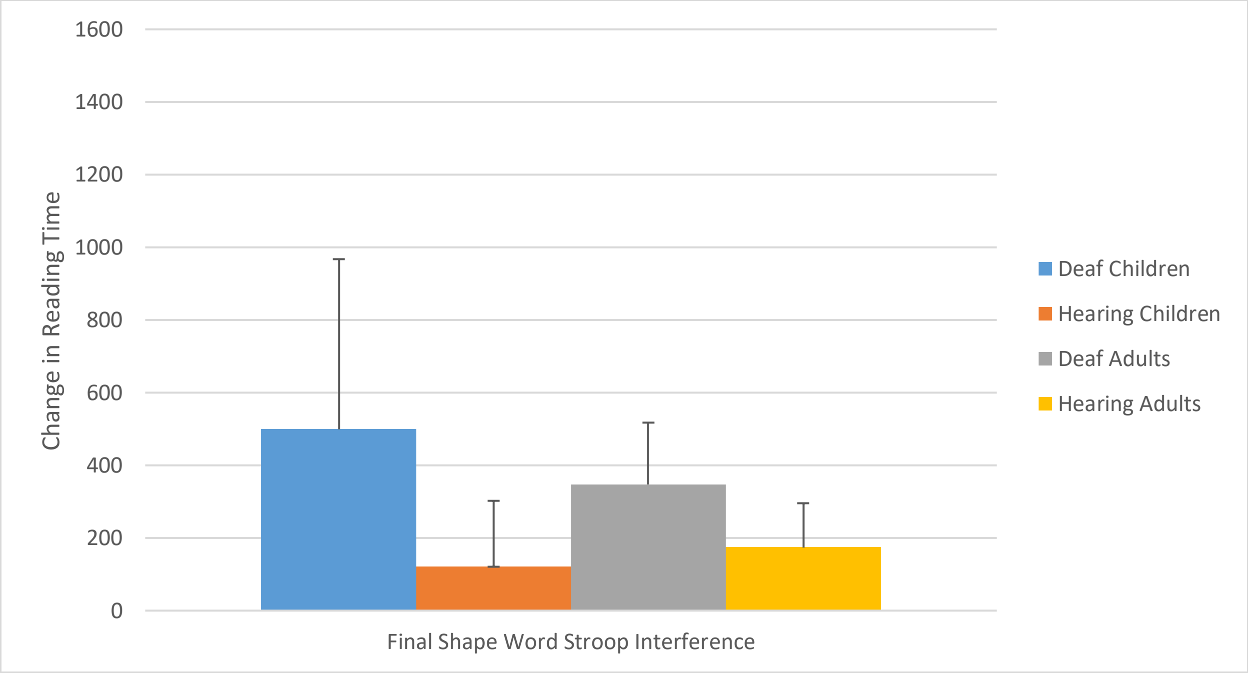


Figure 17. Stroop interference for the final shape word on the CRTT-R-$_{WF}$ and CRTT-R-$_{STROOP}$.

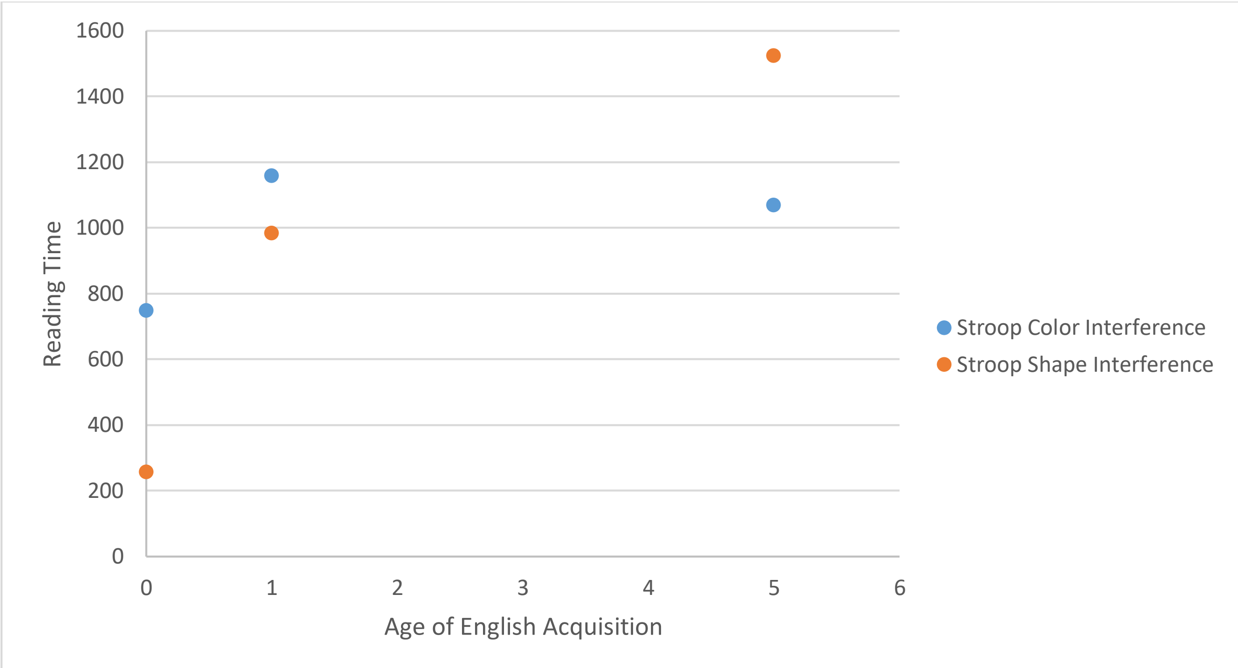


Figure 18. Age of English acquisition for the final color and shape word Stroop interference on the CRTT-STROOP.

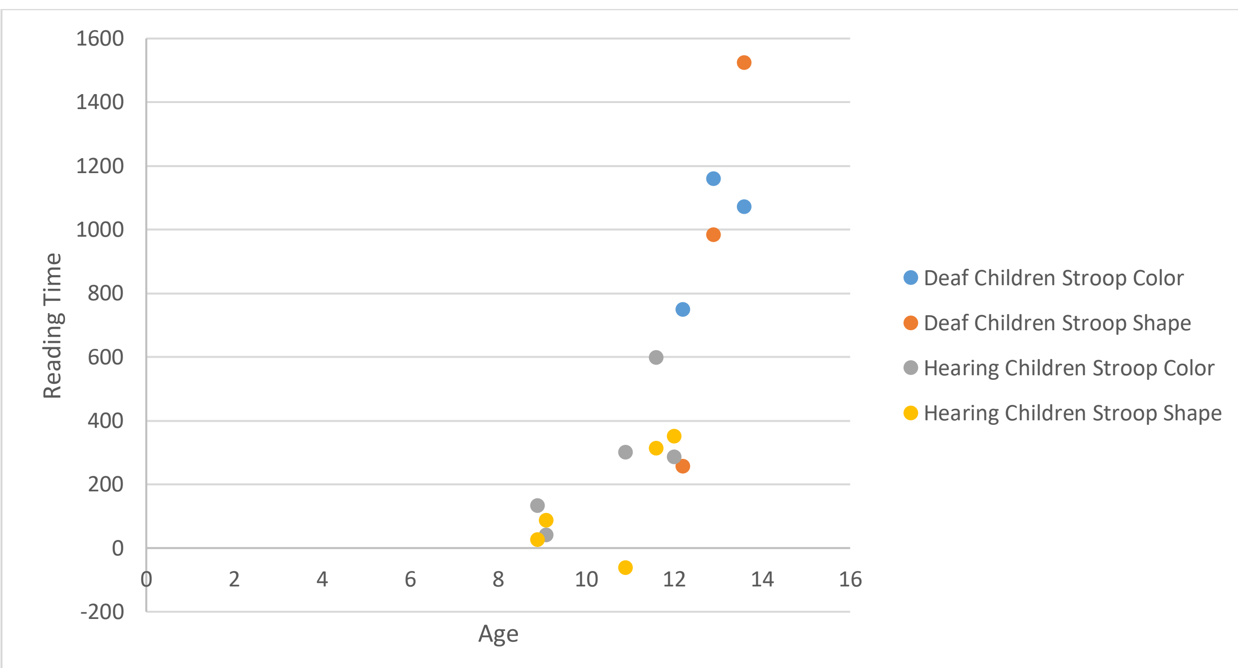


Figure 19. Participant age for the final shape and color word Stroop interference on the CRTT-R-STROOP.

Consistent with the finding from Goldberg (2017), only the final color and shape word reading times were used to calculate the Stroop interference effect. The mean reading time and reading time differences for the final color words from the control (CRTT-ASL-$_{WF}$) and Strooped (CRTT-ASL-$_{-STROOP}$) conditions are summarized in Table 15 and displayed in Figure 20, with Figure 21 displaying the Stroop interference. Table 14 (and Appendix, Table 27) presents the individual reading time data for the Deaf children for the color and shape words on the CRTT-ASL-$_{WF}$ and CRTT-ASL-$_{STROOP}$. There is substantive variability across the children so that the means do not fully represent the relationships.

Table 14. Individual reading times for the final color and shape words in the control and Strooped conditions and difference between conditions for the CRTT-ASL-$_{WF}$ and the CRTT-ASL-$_{STROOP}$.

Participant	Color2 Control	Color2 Strooped	Δ Color2	Shape2 Control	Shape2 Strooped	Δ Shape2
ASL-101	1473	1623	150	1448	1465	17
ASL-102	2737	1615	-1,122	1697	1257	-440
ASL-103	567	1618	1051	637	2584	1947

Table 15. Mean reading times for the final color word in the control and Strooped conditions and difference between conditions for the CRTT-R-ASL and the CRTT-ASL-STROOP.

Group	Mean Color Word RT Control Condition (ms)	SD	Mean Color Word RT Stroop Condition (ms)	SD	Δ Color Word (RT-Stroop-RT Control)	SD
Deaf Children	1592.33	1089.91	1618.66	4.04	26.33	484.79
Deaf ASL-Proficient Adult (Goldberg, 2017)	1451.13	276.57	1667.93	519.82	216.8	378.65
Hearing ASL-Proficient Adult (Goldberg, 2017)	1397.73	199.16	1314.6	282.15	-83.13	181.61

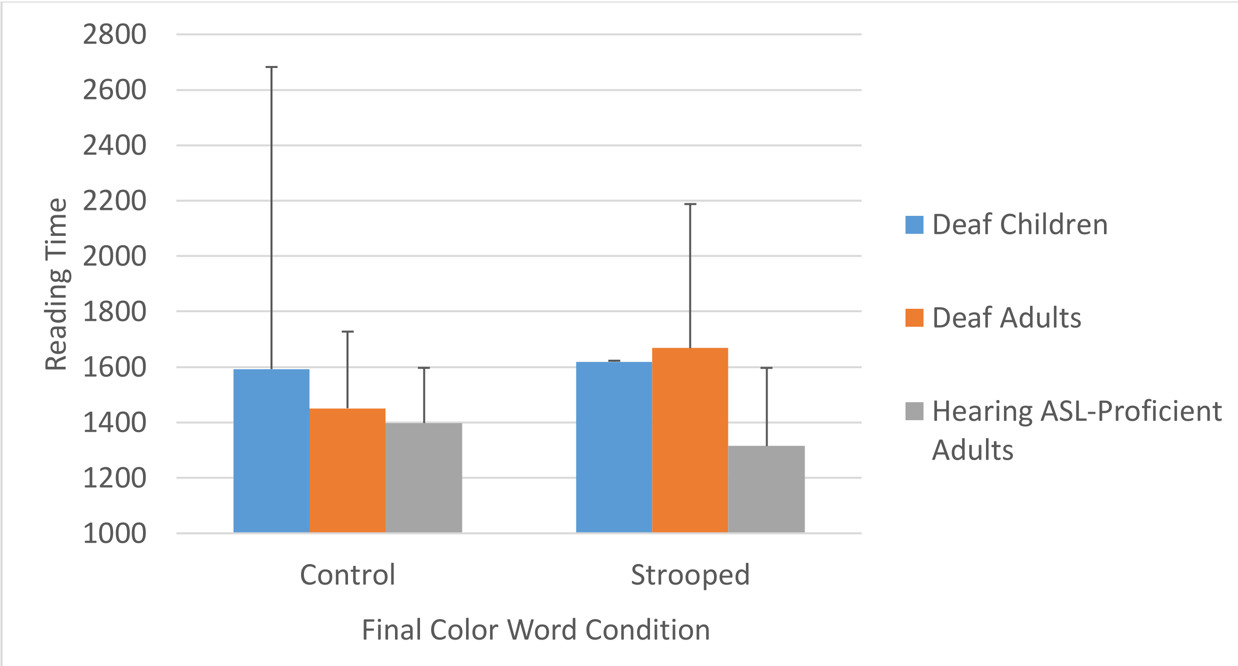


Figure 20. Mean reading times for the final color word in the control and Strooped conditions and difference between conditions for the CRTT-R-ASL and CRTT-ASL-STROOP.

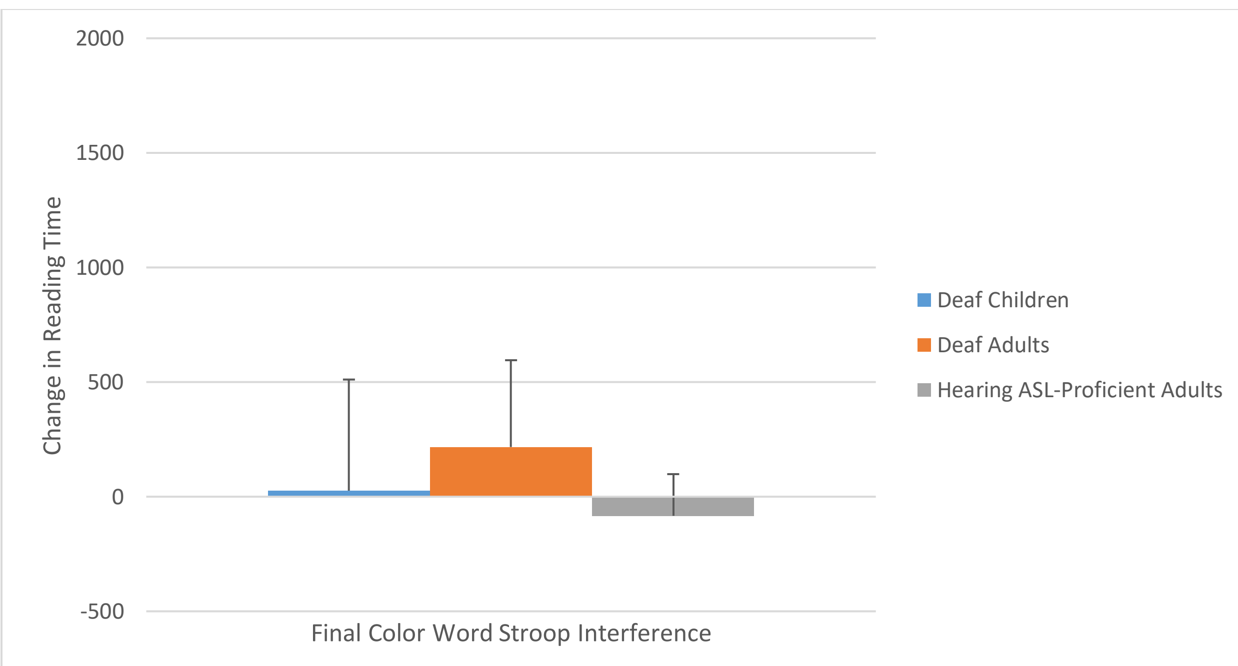


Figure 21. Stroop interference for the final color word on the CRTT-ASL-WF and CRTT-ASL-STROOP.

The mean reading time and reading time differences for the final shape words from the control (CRTT-ASL-WF) and Strooped (CRTT-ASL--STROOP) CRTT conditions are presented in Table 16 and displayed in Figure 22, with Figure 23 displaying the Stroop interference. Figure 24 displays the Deaf children's age of ASL acquisition for the final color and shape word Stroop interference on the CRTT-ASL-STROOP.

Table 16. Mean RTs for the final shape word in the control and Strooped conditions and difference between conditions for the CRTT-ASL-WF and the CRTT-ASL-STROOP.

Group	Mean Shape2 Word RT Control Condition (ms)	SD	Mean Shape2 Word RT Stroop Condition (ms)	SD	Δ Shape Word (RT-Stroop-RT Control)	SD
Deaf Children	1260.66	554.27	1768.66	713.72	507.34	1226.99
Deaf ASL-Proficient Adult (Goldberg, 2017)	1772.93	488.50	1673.20	634.57	-99.73	493.45
Hearing ASL-Proficient Adult (Goldberg, 2017)	1665.06	344.35	1518.66	454.21	-146.4	387.36

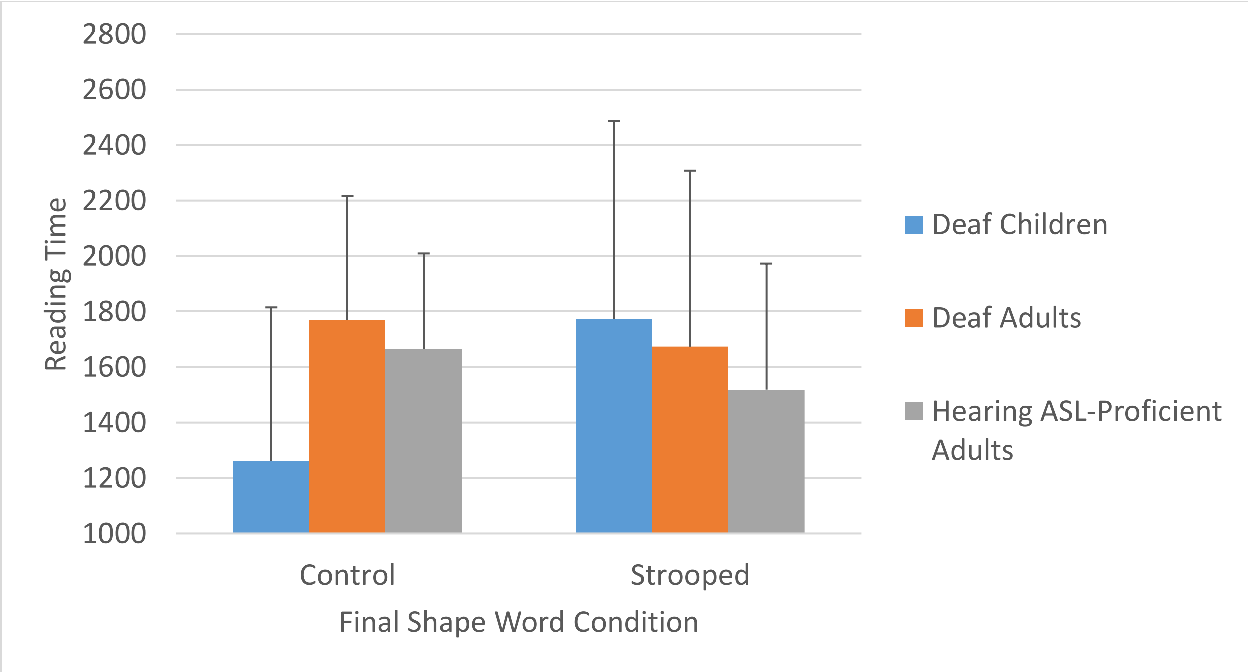


Figure 22. Mean reading times for the final shape word in the control and Strooped conditions and difference between conditions for the CRTT-ASL-WF and CRTT-ASL-STROOP.

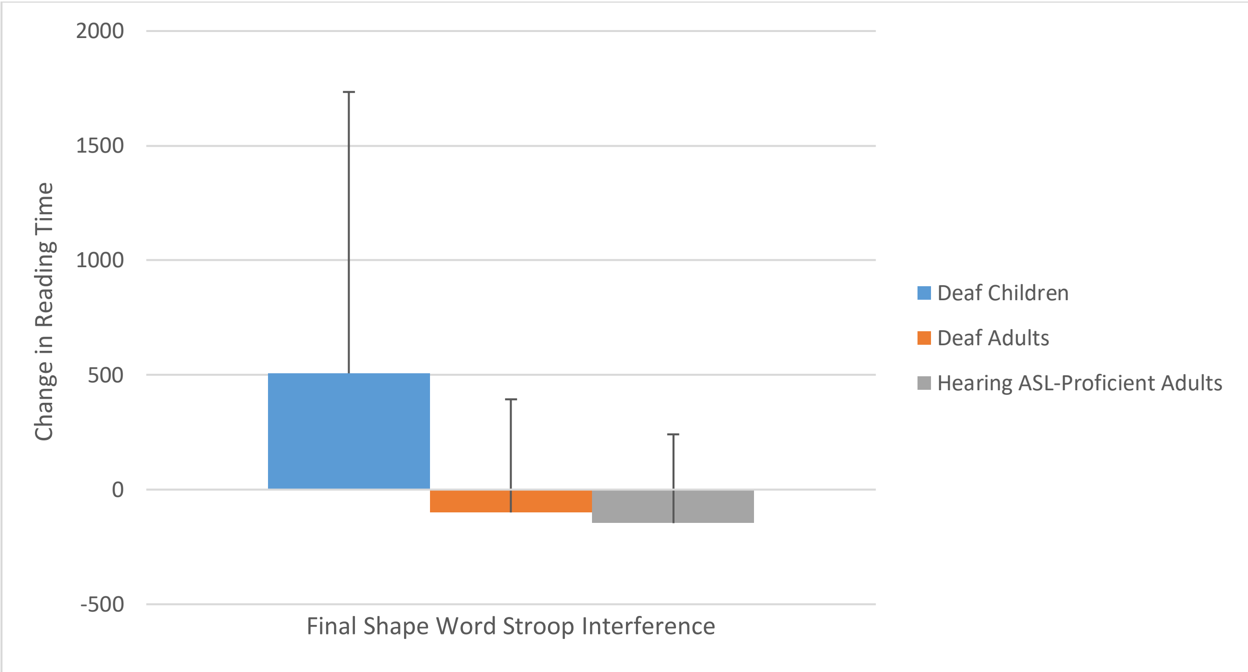


Figure 23. Stroop interference for the final shape word on the CRTT-ASL-WF and CRTT-ASL-STROOP.

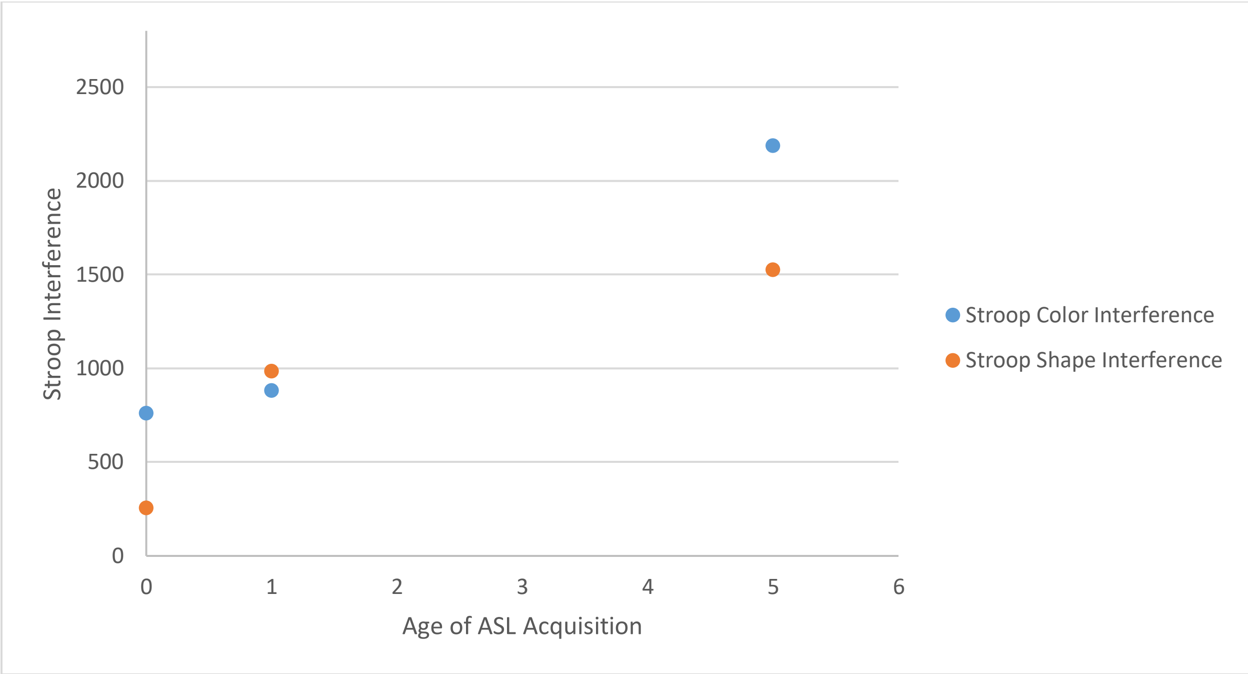


Figure 24. Age of ASL acquisition for the final color and shape word Stroop interference on the CRTT-ASL-STROOP.

4.0 DISCUSSION

The hypothesis for the study was confirmed in that those Deaf and normally hearing children who met the criteria for the study were able to complete language-appropriate versions of the CRTT. Regarding the influence of developmental and language experiences, the Deaf children who began learning ASL and English before age 2 had higher scores on the CRTT-ASL and CRTT-R-$_{\text{WF}}$ than the children who began learning the language after age 2 (without reaching adult levels). An unexpected finding was that the Deaf group's performance on the CRTT-R-$_{\text{WF}}$ was higher than their performance on the CRTT-ASL and the hearing children's scores on the CRTT-R-$_{\text{WF}}$. This may be attributable to a difference in group mean age and accidental pre-screening from WPSD where stronger readers were encouraged to participate.

Additionally, the hearing children had higher scores on the CRTT in their respective modality (CRTT-L) than the Deaf children (CRTT-ASL). However, some of the hearing children and all of the Deaf children's Mean CRTT Scores for their respective modality were below the RTT pediatric normative data outlined Figure 9 from McNeil, Brauer, and Pratt (1990). The difference in test administration procedures between the RTT (live-voice with 3-dimentional objects and online clinician scoring) and the CRTT (computer screen with mouse access) may be more consequential in children than adults.

Both groups of children demonstrated a Stroop interference on the CRTT-R-$_{\text{STROOP},}$ and Stroop interference increased with child age. Deaf children also demonstrated more Stroop interference than hearing children on the CRTT-R-$_{\text{STROOP}}$, mirroring the pattern in adults. This finding, although consistent with Goldberg (2017), was surprising and may point to differences in Deaf individuals' inhibition skills or ways of processing written text. Learning English through text, without auditory access to the phonetics and phonemes of the oral language could change how Deaf individuals map written words and their meaning. It also may be true that Deaf individuals exhibit less inhibition overall.

Another unanticipated finding was that Deaf children who were early-language learners demonstrated less Stroop interference than Deaf children who were late-language learners on both the CRTT-R-STROOP and CRTT-ASL-STROOP. Lastly, there was high variability on the ASL Stroop task in children, similar to previous adult patterns (Goldberg, 2017). While some participants demonstrated a positive Stroop effect, others demonstrated a negative effect, which refers to a participant being able to suppress or inhibit the incongruent color word and performing the Stroop condition faster than the control condition.

4.1 LIMITATIONS AND FUTURE CONSIDERATIONS

The main limitation to the current study was the small sample size of both Deaf (n=3) and hearing children (*n*=5). Recruiting child participants during the school year while accommodating parent/guardian schedules was more challenging than expected. Additionally, for the study to be approved at WPSD, the students were not permitted to be taken out of class for testing. The sample population was a mix of residential and commuter students, so testing occurred in segmented time slots during study hall or time after-school. This deviated from the original planned protocol where students would have 2 sessions lasting 90 to 120 minutes each.

Looking ahead, this study would benefit from additional subjects to complete statistical analysis. It would also be beneficial to establish test-retest reliability with the CRTT-ASL and CRTT-ASL-STROOP in this population. There are few norm-referenced and standardized language comprehension assessments available in American Sign Language. If the CRTT-ASL and CRTT-ASL-STROOP were standardized, there would be immediate clinical use in pediatric populations that use ASL to measure cognitive and linguistic abilities.

5.0 CONCLUSION

Although this was a preliminary study, the age of ASL and English acquisition did appear to impact these Deaf children's performance on the CRTT-ASL and CRTT-R-$_{\text{WF}}$, but the age of language acquisition had the opposite effect when compared to performance on the Stroop tasks. Although all children demonstrated Stroop effects on the CRTT-R-$_{\text{STROOP}}$, only one Deaf child demonstrated a clear Stroop effects on the CRTT-ASL-$_{\text{STROOP}}$. This was consistent with previous findings in adult populations. Additionally, Deaf children and adults appear to exhibit a larger Stroop effect on the CRTT-R-$_{\text{STROOP}}$ than hearing children and adults. This finding surprising given the variable language-learning experiences common to Deaf individuals. Previous research has dependably indicated that Deaf individuals exhibit lower literacy skills compared to hearing individuals. However, in addition to Goldberg (2015; 2017), the present study demonstrated that Deaf individuals can be skilled enough readers to produce a Stroop interference in written English. Although the findings of this study cannot be generalized to the Deaf pediatric population as a whole, they supported importance of early access to language and highlighted the need for more research on the development and assessment of Deaf children's language-processing abilities.

APPENDIX

Appendix, Table 17. Individual responses to the background information form, Deaf group.

	Participant	ASL-101	ASL-102	ASL-103
#	Questions			
1	Your child's age	12.2	13.6	12.9
2	Your child's gender	F	F	M
3	Age When Hearing Loss was Identified	3 years	9 months	birth
4	Cause of Hearing Loss if Known	unknown-genetic	unknown-adopted	known genetic syndrome
5	Age When First Fitted with Hearing Aids	3 years	n/a, currently considering	BAHA 1 year
6	Age When First Fitted with Cochlear Implants	n/a	n/a	n/a
7	Age When First Began Learning ASL	10 years	5 years	1 year
8	Age When First Began Learning English (written or oral)	birth	5 years	1 year

9	Does your child use oral English to Communicate?	yes	no	yes
10	If yes, which language is used more often (Oral English more than ASL, ASL more than oral English, About the same)?	same	ASL	same
11	Language Environment at Home	mostly English with pidgin sign	ASL with parents and babysitter, written English with other family	English (primary) ASL (secondary)
12	Language Environment at School	school for the Deaf, ASL and English	ASL is the primary mode of communication, English (written) for classwork on her own	English and ASL
13	Highest level of education completed by mother	B.S.	graduate school (MLS)	some college

14	Highest level of education completed by father	B.S.	graduate school (MD)	some college

Appendix, Table 18. Individual responses to the background information form, hearing group.

	Participant	ENG-101	ENG-102	ENG-103	ENG-104	ENG-105
#	Questions					
1	Your child's age	8.9	11.6	10.9	9.1	12.0
2	Your child's gender	M	F	M	F	F
3	Age When Hearing Loss was Identified	n/a	n/a	n/a	n/a	n/a
4	Cause of Hearing Loss if Known	n/a	n/a	n/a	n/a	n/a
5	Age When First Fitted with Hearing Aids	n/a	n/a	n/a	n/a	n/a
6	Age When First Fitted with Cochlear Implants	n/a	n/a	n/a	n/a	n/a
7	Age When First Began Learning ASL	n/a	n/a	n/a	n/a	n/a
8	Age When First Began Learning English (written or oral)	birth	birth	birth	birth	birth

9	Does your child use oral English to Communicate?	yes	yes	yes	yes	yes
10	If yes, which language is used more often (Oral English more than ASL, ASL more than oral English, About the same)?	English	English	English	English	English
11	Language Environment at Home	English	English and German	English	English	English
12	Language Environment at School	English	English	English	English	English
13	Highest level of education completed by mother	some college	B.A.	Masters	11th grade	B.A.
14	Highest level of education completed by father	GED	Ph.D.	Masters	12th grade	Associates

Appendix, Table 19. Individual self-rating scores of language proficiency on specific capabilities.

Participant	Speaking English	Understanding English	Reading English	Signing ASL	Understanding ASL
ASL-101	7	7	9	6	
ASL-102	1	1	4	10	9
ASL-103	8	8	3		
ENG-101	9	9	8	n/a	n/a
ENG-102	9	9	9	n/a	n/a
ENG-103	9	9	7	n/a	n/a
ENG-104	10	10	8	n/a	n/a
ENG-105	10	10	10	n/a	n/a

Appendix, Table 20 Individual and scaled scores on the reading subtests of the CELF-5.

Participant	Scaled Score	Passage #1	Passage #2
ASL-101	9	6/8	6/8
ASL-102	14	10/10	9/9
ASL-103	6	6/8	2/8
ENG-101	15	9/9	9/9
ENG-102	16	8/8	8/8
ENG-103	13	8/8	8/8
ENG-104	6	4/8	3/8
ENG-105	15	8/8	8/8

Appendix, Table 21 Individual Mean CRTT and Efficiency Scores of the CRTT-ASL.

Participant	Mean CRTT Score	Standard Deviation of Mean CRTT Score	Mean Efficiency Score	Standard Deviation of Mean Efficiency Score
ASL-101 (CRTT-ASL)	11.82	3.69	10.69	3.87
ASL-102 (CRTT-ASL)	11.53	3.05	9.69	3.78
ASL-103 (CRTT-ASL)	12.75	2.45	10.37	2.91
Adult Deaf Native Signers, Session 1 (CRTT-ASL) (Goldberg, 2015)	13.91	0.42	12.37	0.69
Hearing ASL-Proficient Adult CRTT-ASL, Session 1 (Goldberg, 2015)	13.97	.38	12.59	.51

Appendix, Table 22. Individual Mean CRTT and Efficiency Scores of the CRTT-L.

Participant	Mean CRTT Score	Standard Deviation of Mean CRTT Score	Mean Efficiency Score	Standard Deviation of Mean Efficiency Score
ENG-101 (CRTT-L)	11.47	3.16	9.25	3.61
ENG-102 (CRTT-L)	13.83	1.7	11.75	2.51
ENG-103 (CRTT-L)	14.7	1.58	12.53	2.69
ENG-104 (CRTT-L)	12.97	1.41	11.02	2.01
ENG-105 (CRTT-L)	14.33	1.3	12.97	1.53

Appendix, Table 23. Group A individual Mean CRTT and Efficiency Scores of the CRTT-R-$_{WF}$ and CRTT-ASL-$_{WF}$.

Participant	Mean CRTT Score	Standard Deviation of Mean CRTT Score	Mean Efficiency Score	Standard Deviation of Mean Efficiency Score
ASL-101 (CRTT-R-$_{WF}$)	13.85	1.71	12.62	1.91
ASL-102 (CRTT-R-$_{WF}$)	12.76	1.61	9.67	4.13
ASL-103 (CRTT-R-$_{WF}$)	13.85	.81	11.76	2.96
ASL-101 (CRTT-ASL-$_{WF}$)	11.42	3.25	9.96	4.03

ASL-102 (CRTT-ASL-WF)	10.33	2.13	7.51	4.03
ASL-103 (CRTT-ASL-WF)	12.78	1.11	10.34	1.93
Deaf Adult CRTT-R-WF (Goldberg, 2015)	14.07	0 .5	12.58	0.91

Appendix, Table 24. Group B individual Mean CRTT and Efficiency Scores of the CRTT-R-WF.

Participant	Mean CRTT Score	Standard Deviation of Mean CRTT Score	Mean Efficiency Score	Standard Deviation of Mean Efficiency Score
ENG-101 (CRTT-R-WF)	12.47	2.14	9.73	3.47
ENG-102 (CRTT-R-WF)	13.68	1.75	11.99	1.92
ENG-103 (CRTT-R-WF)	13.23	1.47	10.52	2.01
ENG-104 (CRTT-R-WF)	11.59	2.14	8.98	3.17
ENG-105 (CRTT-R-WF)	14.21	1.49	12.7	1.64
Hearing Adult ASL-Proficient CRTT-R-WF (Goldberg, 2015)	14.53	.25	13.23	.30

Appendix, Table 25. Mean CRTT and Efficiency Scores of the CRTT-R-STROOP and CRTT-ASL-STROOP.

Participant	Mean CRTT-Stroop Score	Standard Deviation of Mean-CRTT Stroop Score	Mean Efficiency Score	Standard Deviation of Mean Efficiency Score
ASL-101 (CRTT-R-STROOP)	13.9	1.81	12.7	1.88
ASL-102 (CRTT-R-STROOP)	12.04	3.5	10.89	3.38
ASL-103 (CRTT-R-STROOP)	13.43	1.48	11.28	2.07
ASL-101 (CRTT-ASL-STROOP)	11.78	3.28	10.99	3.21
ASL-102 (CRTT-ASL-STROOP)	12.71	2.29	11.79	2.16
ASL-103 (CRTT-ASL-STROOP)	11.3	2.36	8.94	3.13
ENG-101 (CRTT-R-STROOP)	12.47	2.14	9.73	3.47
ENG-102 (CRTT-R-STROOP)	13.81	1.68	12.06	2.22
ENG-103 (CRTT-R-STROOP)	13.06	1.69	10.82	2.06
ENG-104 (CRTT-R-STROOP)	11.08	3.24	8.18	3.81
ENG-105 (CRTT-R-STROOP)	13.39	1.94	11.65	2.12

Appendix, Table 26. Individual RTs for the final color and shape words in the control and Strooped conditions and difference between conditions for the CRTT-R-$_{WF}$ and CRTT-R-$_{STROOP}$.

Participant	Color2 Control	Color2 Strooped	Δ Color2	Shape2 Control	Shape2 Strooped	Δ Shape2
ASL-101	452	1200	748	418	674	256
ASL-102	601	1671	1070	665	773	108
ASL-103	521	1679	1158	510	1493	983
ENG-101	427	559	132	594	619	25
ENG-102	539	1136	597	631	943	312
ENG-103	765	1065	300	1037	975	-62
ENG-104	520	560	40	659	744	85
ENG-105	298	583	285	639	718	349

Appendix, Table 27. Individual RTs for the final color and shape words in the control and Strooped conditions and difference between conditions for the CRTT-ASL-WF and the CRTT-ASL-$_{STROOP}$.

Participant	Color2 Control	Color2 Strooped	Δ Color2	Shape2 Control	Shape2 Strooped	Δ Shape2
ASL-101	1473	1623	150	1448	1465	17
ASL-102	2737	1615	-1,122	1697	1257	-440
ASL-103	567	1618	1051	637	2584	1947

Table 28. Individual Reaction Time Task.

Participant	Simple	Movement	Taps per Sec.
ASL-101	487	1498	4.35
ASL-102	1389	1397	2.74
ASL-103	475	1207	2.21

ENG-101	635	1645	1.62
ENG-102	433	1080	3.85
ENG-103	433	1080	3.85
ENG-104	1857	2561	.63
ENG-105	427	1458	.25

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