

**ASSESSING THE AMERICAN SIGN LANGUAGE VERSION OF THE  
COMPUTERIZED REVISED TOKEN TEST**

by

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# ASSESSING THE AMERICAN SIGN LANGUAGE VERSION OF THE COMPUTERIZED REVISED TOKEN TEST

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University of Pittsburgh, 2015

*Background:* Hearing loss and deafness in childhood is a risk factor for delayed communication (e.g., speech, language, and literacy) development, and the impact is dependent on a number of factors (e.g.: age of onset, severity, etc.). In the United States a subset of the population with severe-profound hearing loss uses American Sign Language (ASL) as their primary mode of communication.

In this study, an ASL version of the Computerized Revised Token Test (CRTT) was developed and assessed for test-retest reliability. ASL performance was compared to English reading performance.

*Procedures:* This study included 20 non-native non-proficient (Group A), 20 non-native proficient (Group B), and 10 Deaf native (Group C) ASL users. They completed both the ASL (CRTT-ASL) and English Reading Word-Fade (CRTT-R<sub>wf</sub>) versions of the CRTT.

*Results:* Pearson Product correlation coefficients were derived for Mean CRTT and Mean Efficiency Scores of two versions between sessions. For mean CRTT Scores for the CRTT-ASL Group C demonstrated correlations of .70 or above ( $r=.769$ ). For the Mean Efficiency Scores, Groups B and C produced acceptable correlations ( $r=.78$  and  $.75$  respectively). Group C produced correlations between CRTT-ASL and CRTT-R<sub>wf</sub>.

All three groups demonstrated improvements on both tests between sessions (specifically Group A on CRTT-ASL). Performance on the CRTT-R<sub>wf</sub> tended to be higher than on the

CRTT-ASL, especially for Groups A and B. These effects were confirmed with a Mixed Model ANOVA along with a significant Group effect. Secondary analyses indicated that Group C differed on the CRTT-R<sub>wf</sub>, but the groups were not different from each other on the CRTT-ASL for either session.

*Conclusions:* Group C produced acceptable levels of test-retest reliability on CRTT-ASL, and Group B met criterion with Mean Efficiency Scores. All three groups produced acceptable correlations on CRTT-R<sub>wf</sub>. Correlations between performance on CRTT-ASL and CRTT-R<sub>wf</sub> were high for Group C. All groups increased in performance between sessions on both test versions, indicating a learning effect. Magnitude of change was pronounced for Group A on CRTT-ASL. The effect for Group was likely due to differences between Groups. The pattern of results may be attributed to the diverse language-learning experiences of Group C.

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## **PREFACE**

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The University of Pittsburgh Honors College as well as Dr. Malcolm McNeil provided funding for this research study. Kenneth DeHaan accepted the position of signer in the CRTT-ASL and devoted several hours to be filmed for the purpose of the research study. Neil Szuminsky programmed the CRTT-ASL, thus the assessment could not have been created without his significant contributions. Angela Ryu, on behalf of University of Pittsburgh Television organization, assisted in all video editing. Douglas Roberts conducted filming for the American Sign Language CRTT. Many thanks for support from advisors, professors, and peers.

## 1.0 INTRODUCTION

This document provides an overview of the considerations, procedures, methods, and conclusions of a research study conducted to (1) determine the test-retest reliability of the American Sign Language (ASL) version of the Computerized-Revised Token Test (CRTT) and (2) provide data on the differences between performance of Deaf native ASL users, non-native proficient ASL users, and non-native non-proficient ASL users on the English Reading Fade CRTT (CRTT-R-<sub>wf</sub>) and American Sign Language CRTT (CRTT-ASL). The CRTT was adapted from the Revised Token Test (RTT), which was originally developed to examine the auditory language processing skills of persons with aphasia (McNeil & Prescott, 1978). Persons with aphasia typically have a left hemispheric lesion, often as a consequence of stroke, and have difficulty with language processing and production. Although originally developed for persons with aphasia, the RTT and CRTT have since been used to assess the language-processing skills of various populations – e.g., children with language impairments and adults with learning disabilities. The CRTT includes a listening version consistent with the RTT, as well as reading and Stroop versions (McNeil & Prescott, 1978; McNeil et al., 2012; McNeil et al., 2015). The CRTT has been translated into many different languages including Spanish, Korean, Turkish and Mandarin. The inclusion of a reading version allows for comparisons across written and auditory modalities, whereas the Stroop version can measure online executive function (McNeil & Prescott, 1978; McNeil et al., 2015; McNeil et al., 2012).

The response tasks for the CRTT are simple, and include touching or moving one of multiple geometric shapes (tokens) on a computer screen. The tokens vary in color, shape and size, and are manipulated in response to commands that range in difficulty. An example of a simple command is “Touch the big red square”, whereas a more lengthy and complex command is “Put the big blue circle to the left of the little green square.” The colors, shapes, sizes and overall vocabulary of the test are limited in difficulty and number, which allows for direct

translations to the vast number of spoken languages. The simple language of the test also allows for use with children and persons with reduced language abilities. Though the commands are simple, the test is highly sensitive to deficits in language processing, attention, and verbal working memory skills due to the redundancy of the stimuli and multidimensional scoring system used to evaluate each response.

### **1.0.1 ASL Versus English**

When considering English and ASL, differences in modality and linguistic structure need to be considered. For example, English phonology is based on a sound system produced by the respiratory system and the upper-airway articulators (e.g., velum, tongue, vocal cords, and lips). Perception of the sounds relies predominately on audition with augmentation from vision. In contrast, the phonology of ASL uses arms and hands in a sign space that ranges from the torso to the top of the head, and perception is based on the visual system (Bellugi & Fischer, 1972; Emmorey, Mehta, & Grabowski, 2007). Although oral English is produced in a largely linear, serial fashion, the content of ASL is more simultaneous and parallel (Klima & Bellugi, 1979). Despite these differences, however, comparisons of English and ASL suggest that both languages show left-hemisphere lateralization suggesting similar brain mechanisms (Campbell, MacSweeney & Waters, 2007; Petitto, Zatorre, Gauana, et al., 2000).

Mayberry, Chen, Witcher, and Klein (2011) used functional magnetic resonance imaging (fMRI) with deaf adults to investigate whether age of acquisition was represented in the linguistic organization in the adult brain. The study found that late acquisition impacted language-processing activation. The fMRI scans showed that participants born with severe-profound hearing loss and exposed to ASL early in life demonstrated neural activation in the classic language areas of the brain, but those participants who began acquiring ASL later in life did not show the same activation patterns. Specifically, there were negative linear effects between length of language deprivation and neural processing in the anterior brain areas that are responsible for high-level linguistic processing, and a positive linear relationship in the posterior brain areas that are responsible for low-level linguistic processing (Mayberry et al., 2011).

Mayberry, Lock and Kazmi (2002) also found that individuals who were born with severe-profound hearing loss and not exposed to language early in life had low performance on ASL usage compared to individuals who were born hearing, became Deaf later in life, and then learned ASL. They provided evidence that age of language acquisition, as well as overall language exposure, has a severe impact on language processing and capabilities.

In order to become proficient in a language, early and consistent exposure to, and interaction with a rich linguistic environment is necessary (Penicaud, Klein, Zattore, et al., 2013). Deaf infants are susceptible to language delays because the onset of first language exposure is commonly delayed, and the language-learning environment can be impoverished and inconsistent. Hearing infants born to Deaf parents who use sign language typically develop language in a manner consistent with hearing infants, but the vast majority of infants in the United States with hearing loss have parents who are hearing (90 to 95%), and very few of these parents have signing skills sufficient to support language development. Currently, most parents of infants with severe-profound hearing loss opt for cochlear implants and an aural-oral language training approach, but some infants are not candidates for cochlear implants, and others do not show sufficiently benefiting after implantation. There also are parents who decide, for various reasons, to have their infants and children learn sign language as the primary language or learn it simultaneously with the family's oral language. Furthermore, it is not uncommon for children with hearing loss to learn sign language in later childhood. This sometimes occurs due to changes in educational placement, but it often happens out of a desire by the child to be part of the Deaf community. These factors and decisions can influence language integrity and increases language variability across ASL users (Cormier, Schembri, Vinson & Orfanidou, 2012).

A number of English language diagnostic measures have been translated into ASL, but few have been fully standardized for Deaf children and adults. The appropriateness of these translations is of concern given the inherent differences between oral and signed languages. Even fewer language assessment measures have been developed specifically for ASL. The result is that Deaf signers are often examined in their second language, English print, or they are tested with the help of a Certified Deaf Interpreter (CDI). However, inconsistencies (such as variability in interpreters, or individual's familiarity with the interpreter) have been noted when CDIs serve as language bridges during standardized test administrations (Cawthon, Winton, Garberoglio, et al., 2011). Given the complex nuances of delayed or disordered language it is not surprising that

the use of CDIs is an unsatisfying solution. It also should be noted that ASL assessment measures have not been developed for patients with neurogenic communication disorders such as aphasia. Nor have measures been developed that can directly compare ASL with English language processing.

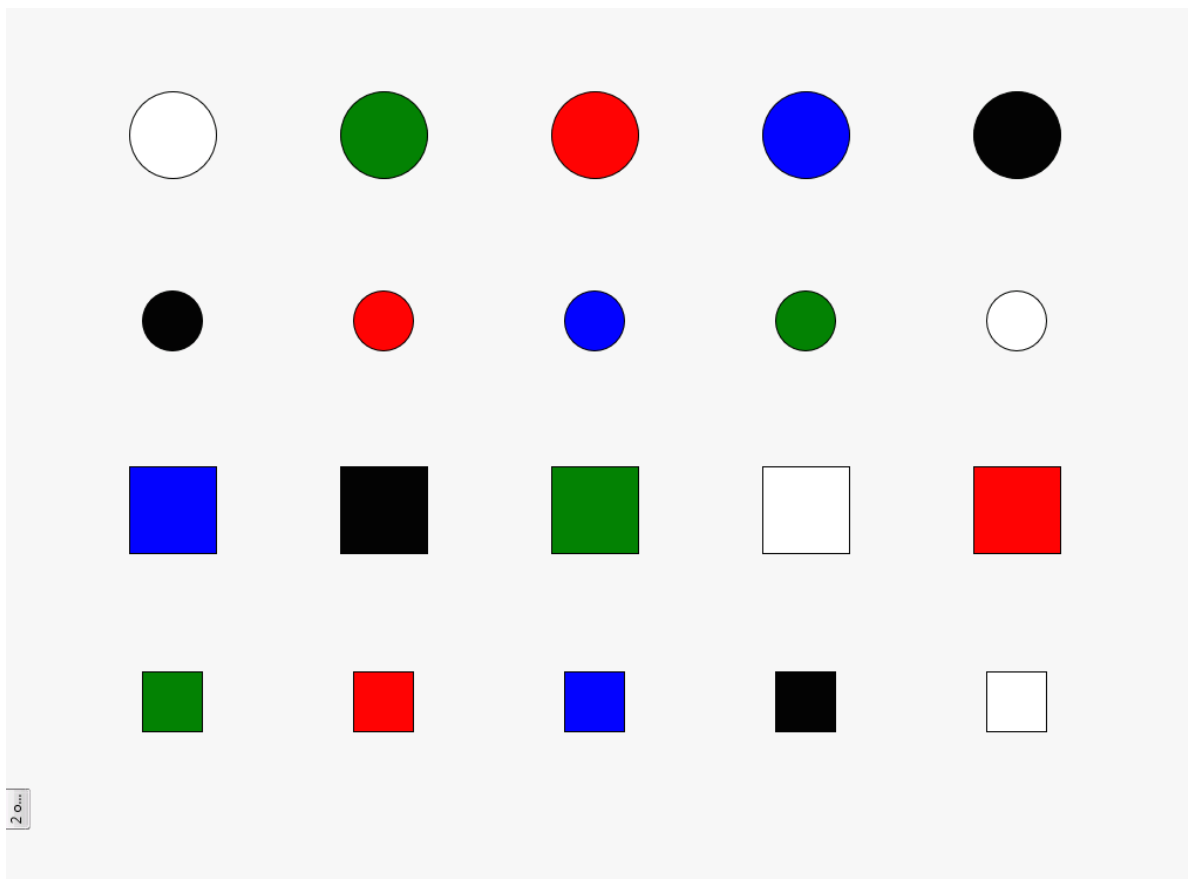
In order to adequately explain the background for this study, the introduction is broken into sections. Chapter 1.1 will provide an overview of the Revised Token Test (RTT), its evolution into the Computerized-Revised Token Test (CRTT), and the clinical relevance of the test. Chapter 1.2 will delve into details about ASL that are relevant to the study. Chapter 1.3 will provide the study's research questions and hypotheses.

## **1.1 CRTT BACKGROUND**

The Revised Token Test (RTT), the precursor to the CRTT, was developed to assess auditory processing inefficiencies and disorders that co-occur with brain injury, brain damage, aphasia, and language disabilities. The RTT materials include 20 tokens that the patient manipulates in response to commands provided by the examiner. The commands were constructed from a restricted set of actions, prepositions, shapes, colors and sizes: two actions (touch, put), ten prepositions (front, before, under, above, below, behind, by, next, beside, on), two shapes (circle and square) and five colors (black, white, red, blue, and green) (McNeil & Prescott, 1978). The RTT has ten subtests, and each subtest is increasingly more challenging in regards to attention and verbal working memory. As a patient progresses through the subtests, concepts such as touching more than one shape, dragging a shape to the left or right of another shape, and moving a shape “before,” “on,” “behind,” (along with other prepositional locaters) are incorporated into the assessment. The RTT has established construct, concurrent and content validity as well as high test-retest, and inter- and intra-judge reliabilities (McNeil & Prescott 1978; McNeil et al., 2015). Because the test was originally designed to assess persons suspected of auditory processing disorders due to brain injury or language disability, it has a heavy emphasis on the

relationship between attention, memory and language processing (Sung et al., 2009; Sung, McNeil, & Pratt, 2010; McNeil et al., 2015).

Recently the RTT was adapted to a digital format (CRTT) and expanded to include reading and Stroop versions. The auditory version of the CRTT largely mirrors the original RTT. The commands are the same as in the RTT but they are presented at 75 dB SPL via loudspeaker and the patient responds on a touchscreen monitor or with a mouse-pointing device. Figure 1 is a display of all 20 tokens that are viewed during Subtests II, IV, VI, VIII, and X (size is included in only half of the subtests). Computerizing the test has allowed for consistent presentation of the stimuli, online recording and response scoring, and as a result, increased accuracy and temporal fidelity.



**Figure 1:** The computerized screen that includes all 20 tokens of the CRTT (McNeil, Pratt, Szuminsky, et al., 2015).



### 1.1.1 CRTT Scoring

The CRTT has retained most of the RTT multidimensional scoring system (Table 1). A score of 15 translates to “perfect response” (Eberwein et al., 2007). Also, the scoring scale demonstrates that an incorrect answer does not result in a score of 0, but instead warrants a score of 7. A score of 1 (the lowest possible score) is given when a patient fails to provide a response.

The scoring of the CRTT depends on the linguistic elements of the command. Each subtest contains 10 homogenous commands (McNeil & Prescott, 1978). The commands within one subtest are uniform in sentence length and linguistic elements, however differing subtests vary in sentence length (5 different lengths), syntactic complexity, and level of vocabulary (Eberwein et al., 2007). When scoring a patient’s performance, the linguistic elements in each sentence are averaged. For example, Subtest I contains three linguistic elements (“Touch [verb] the blue [adjective] circle [noun]”). The command “Touch the blue circle” will then be assigned three different scores based on the responsiveness, accuracy and completeness of the patient’s response (Table 1). The three scores are then averaged, and when all of the sentences within each subtest is completed the sentence scores are averaged. Finally, the 10 subtest scores are averaged and in this document are referred to as the Mean CRTT Score.

**Table 1.** CRTT scoring categories.

---

| <i>Score</i> | <i>Description of Response</i>      |
|--------------|-------------------------------------|
| 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                         |

(After Eberwein et al., 2007)

---

The temporal fidelity of the CRTT allows for the inclusion of an efficiency measure and other response timing measures. Like the Mean CRTT Score the efficiency measure (Mean Efficiency Score) is calculated per command, averaged across commands for each subtest, and then averaged across the subtests. The CRTT Efficiency Score is calculated by multiplying the CRTT score by the time (in seconds) that it takes the patient to complete the command and then is divided by the maximum time permitted to complete the task (Eberwein et al., 2007; Heilman, 2008).

### **1.1.2 English Reading Versions of the CRTT**

As indicated above, the CRTT includes English reading versions. The first of three reading versions is the Computerized Revised Token Test-Reading-Full Sentence (CRTT-R-<sub>FS</sub>), in which

commands are displayed at the bottom of the screen until a response is attempted (McNeil et al., 2015). The second reading version is the Computerized Revised Token Test-Reading-Word Constant (CRTT-R-<sub>wc</sub>). In the CRTT-R-<sub>wc</sub> the command is compiled word-by-word and each successive word stays on the screen until the patient provides a response. The final reading version of the CRTT is the Computerized Revised Token Test-Reading-Word Fade (CRTT-R-<sub>wf</sub>), which is self-paced and each word disappears with the onset of the next word in the sequence. The reading version that was used in the current study is the CRTT-R-<sub>wf</sub> because it records reading pace in response to a click/touch on the screen for each successive word to appear.

Recently, McNeil et al. (2015) investigated the psychometric properties of the English listening and reading versions of the CRTT (i.e., test-retest reliability and validity), and examined the performance of each version when testing persons with aphasia and healthy controls. Specifically, the investigators set out to determine differences across the three reading versions and the version that was most highly associated with the listening CRTT (CRTT-L). Despite psycholinguistic differences, all three reading versions of the CRTT produced similar results and corresponded well with the listening version.

### **1.1.3 Translating the CRTT**

To date, the CRTT has been translated into approximately 14 languages, including Spanish, Turkish, German, and Mandarin. Translating a standardized language test presents challenges, but the CRTT is conducive to translation because the grammatical structures and lexical forms are highly controlled, and the lexical content is simple and limited in number. For example, the CRTT uses geometric shapes and primary colors instead of objects or pictures of objects that might not have relevance across languages and cultures, or might be coded mentally as abstract mental images.

Chen, McNeil, Hill and Pratt (2013) investigated the validity of a Mandarin Chinese version of the CRTT-L by comparing it to the Concise Chinese Aphasia Test (CCAT). They

administered both tests to persons with aphasia and healthy controls from Taiwan who spoke Mandarin Chinese. To construct the stimuli a native Mandarin Chinese speaker was selected to translate the English CRTT-L to Mandarin Chinese and used a method of back translation to establish the comparability of the translations<sup>1</sup>. The study established a significantly positive correlation between the Mandarin CRTT and the CCAT, and thereby demonstrating concurrent validity. Although the current study is not aiming to investigate concurrent validity of the CRTT-ASL, the desire to successfully and accurately translate the CRTT to prove reliability and validity is closely aligned to the motives of the Chen, McNeil, Hill, and Pratt study (2013).

The Spanish version of the CRTT is being assessed, but a previous study has confirmed the viability of translating the CRTT into Spanish. Gallardo, Guardia, Villasenor, and McNeil (2011) examined data collected from children aged 4-12 years with a Mexican-Spanish version of the RTT. They compared it to a previously translated token test based on DeRenzi and Faglioni (1978) and found a moderately high correlation ( $r = .659$ ;  $p < .01$ ). Gallardo et al. concluded that the translated version of the RTT was a valid measure of auditory language processing of Mexican-Spanish-speaking children.

## 1.2 AMERICAN SIGN LANGUAGE BASICS

Before beginning the discussion on ASL, an important distinction should to be made. When writing about the deaf population there are two methods of writing the word “deaf”: (1) “Deaf,” – capital D and (2) “deaf” – lower case d. Each form has a separate meaning. When the word is presented as “deaf,” it is referring to the inability to hear (i.e., a severe-profound hearing loss). When the word is presented as “Deaf,” it is referring to the Deaf culture and community, which prizes ASL as its language of choice. Not all deaf individuals identify culturally or choose to learn ASL.

---

<sup>1</sup> Similarly, in the current CRTT-ASL study the principle investigator translated the English commands into American Sign Language gloss.

American Sign Language (ASL) is a visual-spatial language that is largely based on object-subject-verb (OSV) grammatical order. It has origins in French Sign Language as a consequence of Thomas Gallaudet traveling to France in the 1800s to observe a teacher of the Deaf. His goal was to learn how to effectively teach deaf students in the United States (Rutherford, 1988). Gallaudet brought a Deaf teacher, Laurent Clerc, back to the United States to teach students French Sign Language, and over time the French signs were adapted and modified by the indigenous American signers. Today 60% of ASL signs can be traced to French Sign Language, but the other 40% have been uniquely developed by American Deaf signers (Rutherford, 1988).

Since the publication of “Sign Language Structure: An Outline of the Visual Communication Systems of the American Deaf” by William Stokoe (1960), ASL has become formally recognized as a true language by various states and universities across the United States. Stokoe, a scholar and professor at Gallaudet University, provided evidence to support the claim that ASL is a legitimate language with its own grammar, syntax, and linguistic components (Stokoe, 1960). He characterized ASL using the Stokoe system, which is a notation system that looks at three parameters: (1) Handshape, (2) Location, and (3) Movement. Two extra parameters of ASL were added later: (4) Palm Orientation and (5) Non-Manual Signs (Bauer & Hienz, 2000). These five parameters are considered to be the basic phonological elements of ASL and can be equated to place, manner, and voice in spoken English (Emory & Korina, 1990).

The five parameters of ASL are the linguistic building blocks of the language, and each parameter serves a different role in overall communication. For example, facial expressions (an example of Non-Manual Signals) are vital in conveying information. In spoken English, the use of eyebrows (up, down, neutral) conveys emotion or stress, but in ASL the position of the eyebrows can drastically change the meaning of a sentence (Baker & Cokely, 1980). The notion of eyebrows impacting the meaning of a message has been experimentally proven by a study done in 2008 by Weast. For example, if someone signs the sentence “YOU EAT” with his/her eyebrows up, the message would be equivalent to the question “Did you eat?” If “YOU EAT” is signed with eyebrows down, the signer would be inquiring about where, when, what, and other “wh” questions. In essence, the use of eyebrows in ASL is equivalent to intonation in spoken English (Wilbur, 2009).

Another linguistic component of ASL is mouthing, which is considered another Non-Manual Sign parameter. Mouthing provides both morphemic and semantic information in ASL. When using mouthing, a signer will form a sign while concurrently producing a specific mouth shape that adds additional meaning. Two mouthing morphemes were incorporated into the translation of the ASL translation of the CRTT in the current study.

Because the perception of ASL is completely visual-spatial, sign space is a significant component of the language (Friedman, 1975). An average sign space generally ranges vertically from slightly above one's head to the bottom of an individual's torso. In ASL, role shifting is a part of the sign space and is when a signer shifts his/her body in order to further set up spatial information (Friedman, 1975). Role shifting can be used as a means to compare and contrast or set up dialogue when sharing an anecdote, among many other things. Another aspect of ASL that falls under the category of visual-spatial processing and is unique to the language is the signer's perspective. When using ASL, the individual perceiving a message must adopt the perspective of the individual who is signing. For example, if a signer were to tell someone that the closest bathroom is down the hall and to the left, the individual watching the signs must envision himself from the signer's point of reference.

A final component of ASL to be discussed for the purposes of this study is a form of syntactic structure known as rhetorical questions. In ASL, rhetorical questions are used to: (1) clarify what the signer is signing about, (2) connect information, (3) set up the delivery of important information, and (4) emphasize (Baker & Padden, 1987). Rhetorical question use is important for breaking down concepts or thoughts for greater specificity and to make them easier to follow, and to provide more details overall.

### **1.2.1 Deaf Bilingualism**

Deaf Americans who consider their native language to be ASL are often bilingual because they learn to read in English, due to the fact that 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 demonstrate frequent errors when writing and

reading English. Mouny, Pucci, and Harmon (2014) sought to investigate how Deaf ASL/English bilingual children acquired proficient reading skills and the strategies that were used. Eleven Deaf bilingual ASL and English-using adults and 1 Child of a Deaf Adult (CODA) were video recorded. The participants were interviewed about ASL/English acquisition, the relationship between ASL and English for Deaf individuals, views on the purpose of reading, identification of characteristics of Deaf skilled readers, and belief about strategies that facilitate proficient reading.

Mouny, Pucci, and Harmon (2014) found four themes in their interviews. The first was that, in order for children who use ASL to acquire proficient English reading skills, there must be exposure to both ASL and English. The participants of the study indicated that the two languages can support each other, as ASL develops simultaneously with English literacy. The second theme was that Deaf children should be supplied with a “print-rich culture” in order to connect visual signs with a written oral language. The third theme was that these children must have the opportunity to use both ASL and English reading in school and at home, and that they should be encouraged to think critically about both languages, leading to development of metalinguistic skills. The final theme was that fingerspelling is a tool that should be used to connect ASL and English reading. The Mouny et al. study also highlighted the substantive variability of Deaf individuals in their educational experiences, hearing loss, language history, and social and language-learning environments.

All of the factors associated with reduced literacy in ASL users have yet to be determined, but visual cognition is a consideration. Perceptually, ASL users depend heavily on vision. Belanger, Slattery, Mayberry and Rayner (2012) investigated whether deprivation of auditory input impacted low-level visual processing in literacy activities (2012). The study included three groups: skilled reading Deaf signers, non-skilled reading Deaf signers, and skilled hearing readers. In the past, investigations had looked at whether congenitally Deaf ASL users have stronger attention to stimuli presented to extrafoveal visual fields and demonstrate overall increased visual capabilities. Extrofoveal vision refers to vision outside of the fovea where visual capabilities generally drop to 20/200 (Bavelier, Dye & Hauser, 2006). However, the results from the Belanger et al. (2012) were mixed. The Deaf ASL users demonstrated increased attention to the peripheral vision field, and the skilled Deaf readers had enhanced perceptual span and tended to read ahead.

Because of early intervention and educational practices, most Deaf ASL users become bilingual (as they learn English while learning to read and write). Also, Deaf children (and adults) of hearing parents are typically delayed in their English literacy abilities with only a small subset able to read at age level (Hoffmeister & Caldwell-Harris, 2014). Learning written English as a second language is a significant challenge for Deaf children. Limited exposure to the sound, lexical and grammatical systems of oral English, and the differences between ASL and English all contribute to their delays in reading (Hoffmeister & Caldwell-Harris, 2014). Some deaf children are exposed to English before literacy instruction through their home environments and training methods (e.g., auditory training, speech and oral language therapy) or from using manual signing systems that have English origins such as Signing Exact English (SEE) or Pidgin Signed English (PSE) (Hoffmeister & Caldwell-Harris, 2014). Sign systems that code English manually, such as SEE and PSE, are problematic because they require language users to produce a sign for each phoneme or morpheme in a linear fashion, which tends to overload short term memory and interfere with language processing (Hoffmeister & Caldwell-Harris, 2014). It also impacts the prosody of the sign and any speech that might accompany it. Reliance on lip-reading also is unsatisfactory as an independent method of teaching English to children with severe-profound hearing loss because many English speech sounds are produced using similar articulations (e.g., /k/ and /g/ are plosives produced in a similar manner towards the back of the mouth).

Some Deaf children do learn to read English text proficiently, but the mechanisms for doing so are not well understood. Hoffmeister and Caldwell-Harris (2014) developed a model of how Deaf children successfully learn written English through formal instruction. The model includes three stages. The first stage is mapping translation equivalents. For example, the sign for “dog” is followed by pointing to the written English version of the word. The second stage is referred to as “from words to sentences: simple translation breakdown,” (pp. 4), which includes overt instruction of the differences between the ASL and English in order to assist the learner’s understanding of the rules of English. The final stage is the use of ASL to learn English via print in a bilingual learning mode, and is characterized by children understanding that a single English word does not translate directly to one single sign. A child most likely shows the beginnings of proficiency in both written English and ASL in this stage (Hoffmeister & Caldwell, 2014).



Given the linguistic constraints of testing Deaf ASL users in English, the lack of available ASL assessment tools usable by non-fluent clinicians, and the heterogeneous nature of the Deaf population, translating the CRTT into ASL should help address an unmet need.

### 1.3 EXPERIMENTAL QUESTION AND HYPOTHESES

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

- (1) Is the CRTT-ASL reliable as evidenced by test-retest reliability of .70 and above<sup>2</sup>?
- (2) Will proficient native, proficient non-native, and non-proficient non-native signers differ in their performance on the CRTT-ASL and on the CRTT-R-wf?

It was hypothesized that the CRTT-ASL would be reliable for all three groups of participants. It also was hypothesized that the two hearing non-native groups would perform better on the CRTT-R-wf than the CRTT-ASL, and that the native signers would perform better on the CRTT-ASL than the CRTT-R-wf. Furthermore, it was hypothesized that the two proficient groups would perform similarly on the CRTT-ASL but better than the non-proficient group of participants.

By creating an ASL version of the CRTT, this study aimed to provide a more accurate, consistent, and reliable measure of working memory and language processing in Deaf signers by demonstrating test-retest reliability. Also, by investigating ASL and a English reading versions of the CRTT with Deaf native signers, additional information may come to light about the differences and similarities in which the two languages are processed by Deaf and hearing populations.

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<sup>2</sup> A value of .70 was selected to account for half of the variance, based upon  $r^2$  values.

## 2.0 METHODS

### 2.1 PARTICIPANTS

This study included 50 participants divided into three groups: 20 hearing non-proficient non-native ASL users (Group A), 20 hearing proficient non-native ASL users (Group B), and 10 Deaf proficient native ASL users (Group C). Proficiency was based upon years of experience and information given regarding ASL experience during preliminary procedures that participants completed prior to the study. The participants ranged in age from 18-45 years. Recruitment of participants was facilitated through the use of approved flyers, a PowerPoint presentation, and a video log. Groups A and B were recruited at the University of Pittsburgh, mostly through classroom presentations. Group C was recruited through presentations at the Pittsburgh Association of the Deaf, the study flyer, and the video log created by a member of the Deaf community.

The median age and gender distributions of the groups are listed in Table 2. Group A consisted of 18 females and 2 males, Group B contained 20 females, and Group C contained 6 males and 4 females. Groups A and B were overpopulated with females because most of the participants within those groups were ASL Certificate students at the University of Pittsburgh; the ASL Certificate program is mostly comprised of females.

The majority of the participants self-identified as Non-Hispanic White or Euro American. Four participants identified as Black, Afro-Caribbean, or African American (2 within Group A, 1 within Group B, and 1 within Group C), and one identified as Latino or Hispanic American (within Group B).

This study was approved by the University of Pittsburgh Internal Review Board and all participants provided verbal/signed and written informed consent prior to inclusion in the study. The participants receive \$10.00 for remuneration at the end of the study.

**Table 2.** Age and sex of participants.

|         | Median Age | Age Range | % Female | % Male |
|---------|------------|-----------|----------|--------|
| Group A | 19.5       | 18 to 26  | 90%      | 10%    |
| Group B | 21         | 20 to 22  | 100%     | 0%     |
| Group C | 34         | 24 to 45  | 60%      | 40%    |

### **2.1.1 Inclusion and Preliminary Measures**

All participants completed two preliminary procedures, which included an informal language questionnaire and the Language Experience and Proficiency Questionnaire (LEAP-Q; Marian, Blumenfeld & Kaushanskaya, 2003). The informal questionnaire inquired about participants' hearing, language and educational histories. Table 3 lists all questions included in the informal questionnaire, and results from some of the questions can be found in Appendix, Table 1. Bilingual skills and experiences were assessed with the Language Experience and Proficiency Questionnaire (LEAP-Q; Marian Blumenfeld & Kaushanskaya, 2003) to obtain information about the participants' specific language experiences. One section of the LEAP-Q asked the participants to self-rate their proficiency in speaking/signing, understanding, and reading in both ASL and English individually. The median responses of each group are listed below in Table 4, and individual data can be found in Appendix, Table 2.

**Table 3.** 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? (options of a. Deaf School Manual, b. Deaf School/Mainstream Oral, c. Mainstream) |
| 7   | Rate your English reading skills (options of a. Poor, b. Average, c. Above Average, d. Native)                                     |
| 8   | If you have a hearing loss, what is the onset of your hearing loss? (options of a. profound, b. mild, c. able to hear)             |
| 9   | Do you use hearing aid(s) or cochlear implant(s)?                                                                                  |
| 9.a | If you answered yes, how old were you when you started using the device?                                                           |
| 10  | Approximately how many hours a week do you use American Sign Language?                                                             |

**Table 4.** Median self-rating of proficiency of English and ASL on the LEAP-Q.

| Group   | Comprehension Modality |                       |                 |                |                   |
|---------|------------------------|-----------------------|-----------------|----------------|-------------------|
|         | English Expression     | English Comprehension | English Reading | ASL Expression | ASL Comprehension |
| Group A | 10 (8-10)              | 9.5 (8-10)            | 9.5 (8-10)      | 5.5 (1-7)      | 7 (1-9)           |
| Group B | 10 (9-10)              | 10 (9-10)             | 10 (9-10)       | 7 (2-10)       | 7.5 (3-9)         |
| Group C | 5.5 (0-9)              | 6.5 (1-9)             | 8 (7-9)         | 9 (7-10)       | 9 (8-10)          |

*Note.* The range of scores are listed in parentheses.

The LEAP-Q is based upon a ranking 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).

There were also three criterion measures, the first of which was a visual screen. Vision was screened with a Snellen visual acuity chart and participants were required to be 20/30 or better (corrected/uncorrected) for inclusion. The second criterion measure investigated the literacy skills of participants. English reading performance was assessed with the reading pretest

(for ages 13-21) from the Clinical Evaluation of Language Fundamentals 5<sup>th</sup> Edition (CELF-5; Semel, Wiig & Secord, 2014) to document that the participants had sufficient reading skills to complete the experimental tasks. The assessment consisted of two passages; each passage was followed by questions to assess comprehension. Mean and standard deviation scores can be found in Table 5 and individual data can be found in Appendix, Table 3.

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

| Group   | Passage 1 |      | Passage 2 |      |
|---------|-----------|------|-----------|------|
|         | Mean      | SD   | Mean      | SD   |
| Group A | 9.85      | .366 | 8.8       | .41  |
| Group B | 10.2      | 2.12 | 8.95      | .223 |
| Group C | 9.2       | 1.32 | 8.9       | .316 |

*Note.* SD = Standard Deviation

The final criterion measure required the participant to complete the CRTT Pretest in his or her primary language. The non-native populations completed their pretest in English reading and the native population completed their pretest in ASL (which was created along with the CRTT-ASL). The CRTT pretest functioned to orient the participants to the program and to determine if the participants had the visual, motor, and vocabulary skills to complete the test. Once the participant completed the pretest in their native language, they were ready to proceed to the experiment.

## 2.2 STIMULI

To construct the CRTT-ASL visual stimuli, a Deaf native ASL user volunteered to serve as the signer for the construction of the CRTT-ASL. Because commands in the listening version of the English CRTT (CRTT-L) are narrated by a male voice, a male signer was chosen for the ASL version. Prior to filming, all of the English acoustic commands of the CRTT-L were transcribed

and translated into ASL gloss. Gloss is not to be confused with a written form of ASL; gloss is frequently used by ASL instructors to assist ASL students to learn how to decode ASL and can serve as a linguistic map. It is written using English words and written notations that represent signs (Hoffmeister, Moores, & Ellenberg, 1975). After translating the CRTT-L commands into ASL gloss, the glossed commands were referenced and edited by a Deaf native signer from the Pittsburgh community.

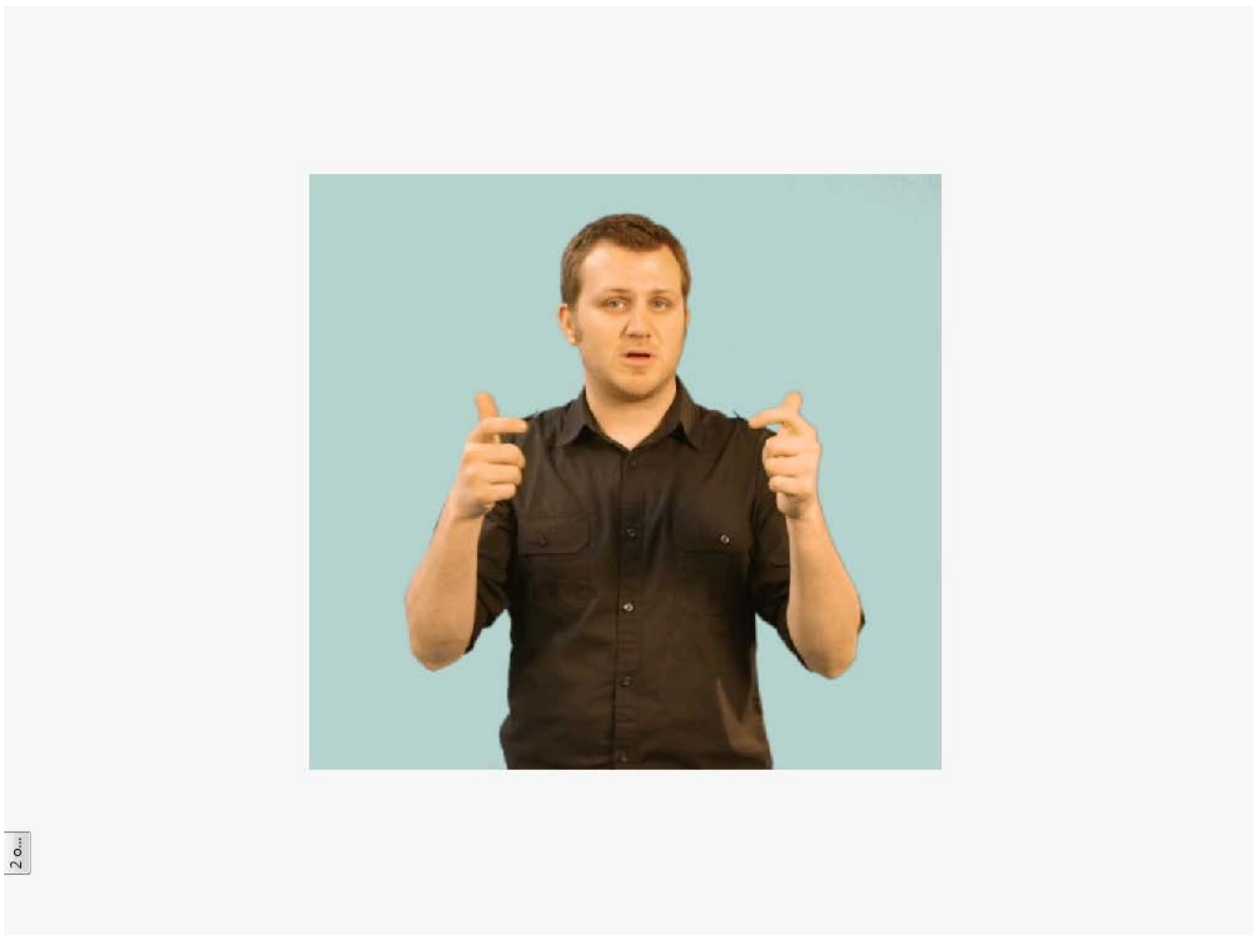
The ASL stimuli were then recorded using a Canon C100 video camera with the signer standing in front of a green screen backdrop to allow for subsequent editing. The filming occurred over the span of two days and required about four hours. The signer produced at least 5 samples of each command, instruction and cue. He also was instructed to have his hands begin and end in the same resting position. This was to minimize potential confusion with command onset and offset. It also provided visual consistency within the video frame. Because the English CRTT-L uses speech produced with a flat, monotonous voice, this study attempted to replicate the “monotony” without compromising the linguistic significance of facial expressions in ASL. The use of eyebrow postures also were slightly reduced in magnitude in comparison to normal, in an effort to be consistent with the limited variability in the vocal intonation in the English CRTT-L. However, facial expressions were more apparent in the test cues in order to serve as an aid for the participants, as testing cues appeared if a participant experienced issues or struggles during a command.

The best version of each sample was selected by the author and edited using Premiere Pro CC 2014 (Adobe, version 2014.1). The original programmer of the CRTT modified the program so that the video functioned within the CRTT platform. The size and framing of the videos were held consistent across subtests but differed for the instructions. The aspect ratio of the pretest videos was slightly modified to allow visibility of the token images along with the signed instructions.

To ensure that the signed stimuli were acceptable translations from English to ASL, they were reverse translated by two volunteers who were Deaf native ASL users from the Pittsburgh community. They also watched all the pretest commands, subtest cues, and subtest commands used in the CRTT-ASL. After every video, the volunteers typed in English what they perceived. The sentences that they produced were then compared to the original CRTT-L commands based on conceptual content rather individual English elements; this was completed by two individuals

familiar with the CRTT (Scorer 1 and Scorer 2). Level of agreement between transcribed CRTT-L commands and the content of CRTT-ASL commands based on the first Deaf volunteer was 94.9% (calculated by Scorer 1) and 99.1% (scored by Scorer 2). Level of agreement of the translations produced by the second Deaf translator was 96.7% (calculated by Scorer 1) and 98.1% (calculated by Scorer 2).

The final videos were then imported into the CRTT software platform and the CRTT-ASL was kept consistent with the CRTT-L. For example, when administering the CRTT-L, the patient is presented the acoustic stimuli (e.g., command), the response window opens with the tokens, and then the patient responds by acting on the tokens. Similarly, in the CRTT-ASL the patient sees the video stimuli first, the response window opens, and the tokens appear. Figure 2 provides a screen-shot of the signer and how the videos were positioned within the CRTT command window.



**Figure 2.** Example of the position of the signed stimuli.

*Note.* Permission to include this picture was given through signed consent by the individual photographed.

### 2.2.1 Inclusion of Five Parameters Into the Stimuli

The five parameters of ASL were discussed previously in this paper and were applied to the creation of the CRTT-ASL. Facial expressions were used in designing Subtests IX and X of the CRTT-ASL. In spoken English, a portion of the commands of Subtests IX and X say, “Instead of the \_\_\_\_\_ touch the \_\_\_\_\_.” In ASL, this message was conveyed using a facial expression known as “NEG” (negative) and NOD (affirmation) (Wilbur, 2009). A signer uses the negative facial expression by lowering his/her eyebrows and shaking his/her head (Wilbur, 2009). In the CRTT-ASL, we asked the signer to sign commands that required negation and/or affirmation as the following:

\_\_\_\_\_ t NEG \_\_\_\_\_ t NOD  
GREEN SQUARE TOUCH, BLUE CIRCLE TOUCH

In this sentence, the “t” above the first word of the sentence stands for “topic” and signifies that the signer’s eyebrows should be up only for the duration of the first sign. By shaking the head when producing the sign “touch” for the green square, the message that the CRTT-ASL signer conveys is to not touch the green square (Hoffmeister, Moores & Ellenberg, 1975). A positive or affirmative facial morpheme requires a nod (Wilbur, 2009). By nodding his head when producing the sign “touch” in regards to the blue circle, the message conveys that the blue circle should be touched.

Role shifting was used in the example of Subtests IX and X for sentences such as “Instead of the green square touch the blue square.” In this video command, the signer signed the first shape a little more shifted towards the left, and would then sign the second shape towards the right (opposite side). As previously discussed, role shifting creates a comparative situation where, in this example, there is an obvious distinction between the two shapes.

In designing the cues for the CRTT-ASL subtests, rhetorical questions were sometimes used for their ability to provide clearer instructions. For example, Subtest III cue command number one in English says, “I want you to first touch the green square and then touch the black square.” In ASL, the glossed version resembles the following:





to ensure that they had sufficient skills to complete the test. All of the participants successfully completed their pretests.

The participants returned for their second session 7-14 days after their first session. At the end of the second session the participants were asked to complete a post-assessment questionnaire, received their remuneration, and signed a payment log and receipt.

## **3.0 RESULTS**

### **3.1 TEST-RETEST RELIABILITY PER GROUP**

#### **3.1.1 Descriptive Measures Per Group**

The mean, standard deviations, difference scores ( $\Delta$  Score) between performance in Session 1 and Session 2, and standard error of the Mean CRTT Scores and Mean Efficiency Scores (the scores that incorporate timing) for the CRTT-ASL are found in Tables 6 and 7 respectively. The same type of descriptive data for the CRTT-R<sub>wf</sub> are presented in Tables 8 and 9. They also are displayed in Figure 3. These descriptive data show a consistent increase in performance across the two sessions regardless of group and test, and a relatively high level of variability on the first administration of the CRTT-ASL. In general, Group C had larger standard deviations than the other groups. Groups A and B had higher performance on the CRTT-R<sub>wf</sub> test than the CRTT-ASL, whereas performance on the two tests were more comparable for Group C.

**Table 6.** Mean CRTT Score descriptive data for the CRTT-ASL.

| Group     | Session | Mean  | Standard Deviation | $\Delta$ Score | Standard Error |
|-----------|---------|-------|--------------------|----------------|----------------|
| All Group | 1       | 13.81 | .52                | .387128        | .734           |
|           | 2       | 14.21 | .35                |                | .494           |
| Group A   | 1       | 13.61 | .63                | .50616         | .085           |
|           | 2       | 14.13 | .39                |                | .059           |
| Group B   | 1       | 13.97 | .38                | .36413         | .085           |
|           | 2       | 14.33 | .27                |                | .059           |
| Group C   | 1       | 13.91 | .42                | .1947          | .120           |
|           | 2       | 14.11 | .47                |                | .084           |

**Table 7.** Mean Efficiency Score descriptive data for the CRTT-ASL.

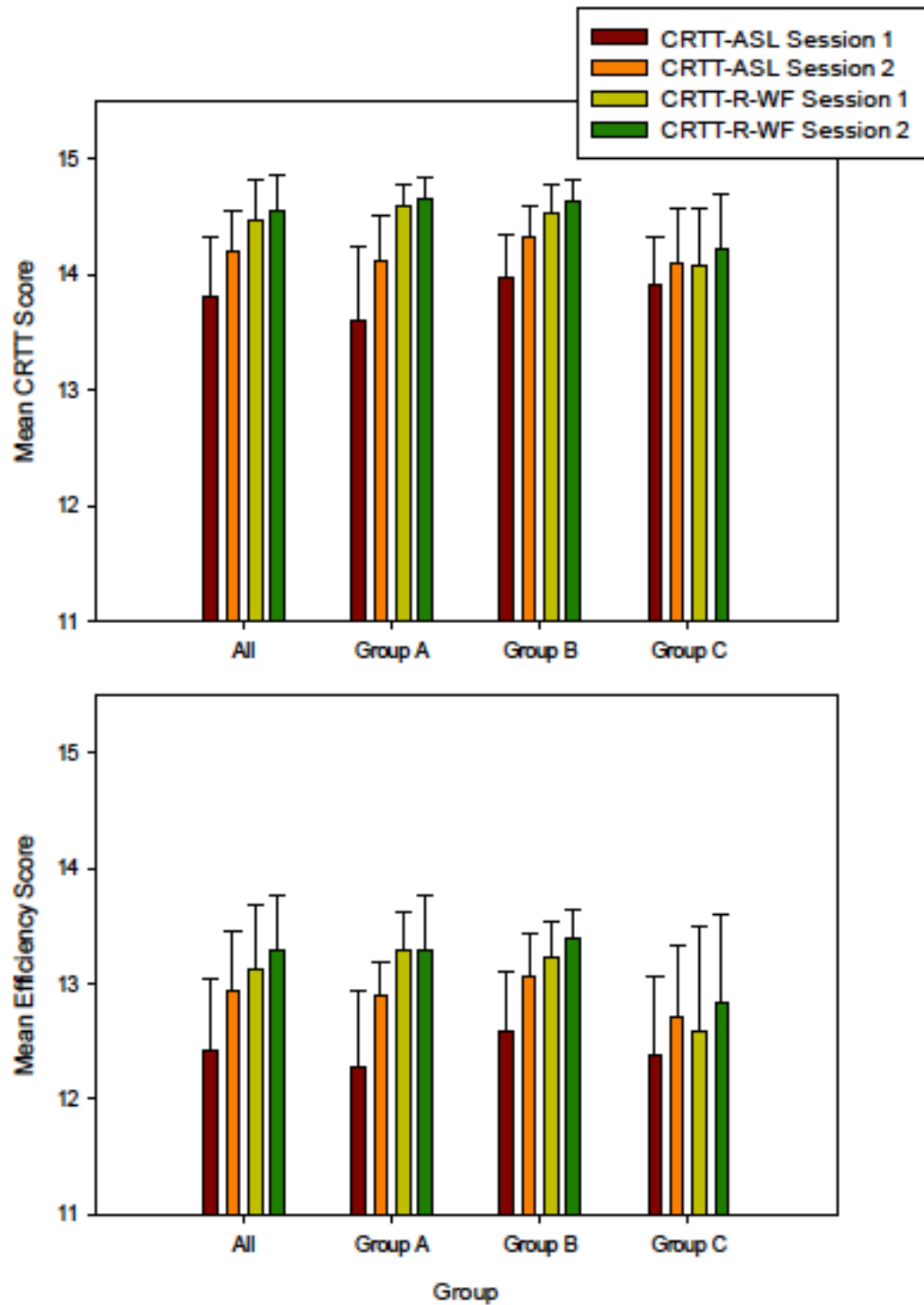
| Group     | Session | Mean  | Standard Deviation | $\Delta$ Score | Standard Error |
|-----------|---------|-------|--------------------|----------------|----------------|
| All Group | 1       | 12.42 | .62                | .48893         | .088           |
|           | 2       | 12.93 | .53                |                | .076           |
| Group A   | 1       | 12.27 | .67                | .56636         | .118           |
|           | 2       | 12.90 | .28                |                | .098           |
| Group B   | 1       | 12.59 | .51                | .48157         | .118           |
|           | 2       | 13.07 | .36                |                | .098           |
| Group C   | 1       | 12.37 | .69                | .34881         | .167           |
|           | 2       | 12.72 | .61                |                | .138           |

**Table 8.** Mean CRTT Score descriptive data of the CRTT-R<sub>wf</sub>.

| Group     | Session | Mean  | Standard Deviation | $\Delta$ Score | Standard Error |
|-----------|---------|-------|--------------------|----------------|----------------|
| All Group | 1       | 14.47 | .35                | .09138         | .050           |
|           | 2       | 14.56 | .31                |                | .044           |
| Group A   | 1       | 14.60 | .18                | .05025         | .073           |
|           | 2       | 14.66 | .18                |                | .058           |
| Group B   | 1       | 14.53 | .25                | .09845         | .073           |
|           | 2       | 14.63 | .19                |                | .580           |
| Group C   | 1       | 14.07 | .50                | .15951         | .103           |
|           | 2       | 14.23 | .47                |                | .083           |

**Table 9.** Mean Efficiency Score descriptive data for the CRTT-R<sub>wf</sub>.

| Group     | Session | Mean  | Standard Deviation | $\Delta$ Score | Standard Error |
|-----------|---------|-------|--------------------|----------------|----------------|
| All Group | 1       | 13.13 | .55                | .13585         | .078           |
|           | 2       | 13.30 | .47                |                | .066           |
| Group A   | 1       | 13.30 | .32                | .15914         | .107           |
|           | 2       | 13.44 | .28                |                | .094           |
| Group B   | 1       | 13.23 | .30                | .16745         | .107           |
|           | 2       | 13.39 | .26                |                | .094           |
| Group C   | 1       | 12.58 | .91                | .26046         | .151           |
|           | 2       | 12.84 | .77                |                | .133           |



**Figure 3.** Mean CRTT Score and Mean Efficiency Score performance across two sessions on the CRTT-ASL and CRTT-R-wf.

### 3.1.2 Correlations

To assess the test-retest reliability of the two tests, Pearson Product correlation coefficients were derived for the Mean CRTT Score and Mean Efficiency Score for both test versions from Session 1 to Session 2 (IBM Statistical Package for the Social Sciences, SPSS v. 22). The following data were organized by group: All Group (all data combined), Group A, Group B, and Group C. Tables 11 through 18 include the correlations separated by group and type of score (Mean CRTT Scores vs. Mean Efficiency Score). Table 19 lists all of the group by test combinations with correlations of .70 or higher for the Mean CRTT Scores, and Table 20 lists all of the combinations producing correlations of .70 or higher for the Mean Efficiency Scores. The  $r^2$  values are included in all tables as a reflection of the amount of variance accounted for by the correlations.

Although, a number of the correlations met the  $p=.05$  level of significance many did not reach the minimum criterion of .70 set for acceptable test-retest reliability. Group C produced correlations on both tests that met the minimum criterion, but Group A met the criterion only for the CRTT-R-<sub>wf</sub> (Mean CRTT Score and Mean Efficiency Score). Group B met the criterion for the CRTT-ASL based on Mean Efficiency Score and for the CRTT-R-<sub>wf</sub> for both types of scores. Group C also produced higher correlations between the two tests, whereas Groups A and B showed little to no relationship in performance between the two tests, suggesting a possible difference in how the hearing and Deaf participants used language on the two tests.

**Table 10.** Mean CRTT Score correlations for All Groups combined.

| Test                 | Session   | CRTT-ASL  |                                                     | CRTT-R <sub>wf</sub>                          |                                                      |
|----------------------|-----------|-----------|-----------------------------------------------------|-----------------------------------------------|------------------------------------------------------|
|                      |           | Session 1 | Session 2                                           | Session 1                                     | Session 2                                            |
| CRTT-ASL             | Session 1 | 1         | <b>.617</b><br>( $r^2=.381$ )<br>( $p=.0002^{-5}$ ) | .142<br>( $r^2=.020$ )<br>( $p=.324$ )        | .129<br>( $r^2=.0167$ )<br>( $p=.371$ )              |
|                      | Session 2 |           | 1                                                   | <b>.408</b><br>( $r^2=.183$ )<br>( $p=.003$ ) | <b>.456</b><br>( $r^2=.208$ )<br>( $p=.001$ )        |
| CRTT-R <sub>wf</sub> | Session 1 |           |                                                     | 1                                             | <b>.873</b><br>( $r^2=.762$ )<br>( $p=.0001^{-13}$ ) |
|                      | Session 2 |           |                                                     |                                               | 1                                                    |

Note. Bolded = significantly different from 0 at the  $p=.05$  level.



**Table 11.** Mean Efficiency Score correlations for All Groups combined.

| Test      | Session   | CRTT-ASL  |                                                                             | CRTT-R-wf                                                                   |                                                                             |
|-----------|-----------|-----------|-----------------------------------------------------------------------------|-----------------------------------------------------------------------------|-----------------------------------------------------------------------------|
|           |           | Session 1 | Session 2                                                                   | Session 1                                                                   | Session 2                                                                   |
| CRTT-ASL  | Session 1 | 1         | <b>.711</b><br><i>(r<sup>2</sup>=.506)</i><br><i>(p=.0007<sup>-5</sup>)</i> | <b>.434</b><br><i>(r<sup>2</sup>=.189)</i><br><i>(p=.002)</i>               | <b>.382</b><br><i>(r<sup>2</sup>=.146)</i><br><i>(p=.006)</i>               |
|           | Session 2 |           | 1                                                                           | <b>.603</b><br><i>(r<sup>2</sup>=.364)</i><br><i>(p=.0004<sup>-2</sup>)</i> | <b>.585</b><br><i>(r<sup>2</sup>=.342)</i><br><i>(p=.0008<sup>-2</sup>)</i> |
| CRTT-R-wf | Session 1 |           |                                                                             | 1                                                                           | <b>.915</b><br><i>(r<sup>2</sup>=.837)</i><br><i>(p=0001<sup>-16</sup>)</i> |
|           | Session 2 |           |                                                                             |                                                                             | 1                                                                           |

*Note.* Bolded = significantly different from 0 at the  $p=.05$  level.

**Table 12:** Group A Mean CRTT Score correlations

| Test      | Session   | CRTT-ASL  |                                               | CRTT-R-wf                              |                                               |
|-----------|-----------|-----------|-----------------------------------------------|----------------------------------------|-----------------------------------------------|
|           |           | Session 1 | Session 2                                     | Session 1                              | Session 2                                     |
| CRTT-ASL  | Session 1 | 1         | <b>.596</b><br>( $r^2=.320$ )<br>( $p=.006$ ) | .207<br>( $r^2=.043$ )<br>( $p=.381$ ) | -.062<br>( $r^2=.003844$ )<br>( $p=.797$ )    |
|           | Session 2 |           | 1                                             | .327<br>( $r^2=.107$ )<br>( $p=.159$ ) | .378<br>( $r^2=.143$ )<br>( $p=.100$ )        |
| CRTT-R-wf | Session 1 |           |                                               | 1                                      | <b>.705</b><br>( $r^2=.497$ )<br>( $p=.001$ ) |
|           | Session 2 |           |                                               |                                        | 1                                             |

*Note.* Bolded = significantly different from 0 at the  $p=.05$  level.

**Table 13.** Group A Mean Efficiency Score correlations.

| Test      | Session   | CRTT-ASL  |                                               | CRTT-R-wf                                     |                                               |
|-----------|-----------|-----------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|
|           |           | Session 1 | Session 2                                     | Session 1                                     | Session 2                                     |
| CRTT-ASL  | Session 1 | 1         | <b>.666</b><br>( $r^2=.444$ )<br>( $p=.001$ ) | <b>.526</b><br>( $r^2=.277$ )<br>( $p=.017$ ) | .155<br>( $r^2=.024$ )<br>( $p=.515$ )        |
|           | Session 2 |           | 1                                             | <b>.612</b><br>( $r^2=.375$ )<br>( $p=.004$ ) | .431<br>( $r^2=.186$ )<br>( $p=.058$ )        |
| CRTT-R-wf | Session 1 |           |                                               | 1                                             | <b>.695</b><br>( $r^2=.483$ )<br>( $p=.001$ ) |
|           | Session 2 |           |                                               |                                               | 1                                             |

*Note.* Bolded = significantly different from 0 at the  $p=.05$  level.

**Table 14.** Group B Mean CRTT Score correlations.

| Test                  | Session   | CRTT-ASL  |                                                                                      | CRTT-R <sub>-wf</sub>                                       |                                                                                       |
|-----------------------|-----------|-----------|--------------------------------------------------------------------------------------|-------------------------------------------------------------|---------------------------------------------------------------------------------------|
|                       |           | Session 1 | Session 2                                                                            | Session 1                                                   | Session 2                                                                             |
| CRTT-ASL              | Session 1 | 1         | <b>.544</b><br>( <i>r</i> <sup>2</sup> = <b>.296</b> )<br>( <i>p</i> = <b>.013</b> ) | .229<br>( <i>r</i> <sup>2</sup> =.052)<br>( <i>p</i> =.331) | .243<br>( <i>r</i> <sup>2</sup> =.059)<br>( <i>p</i> =.302)                           |
|                       | Session 2 |           | 1                                                                                    | .386<br>( <i>r</i> <sup>2</sup> =.149)<br>( <i>p</i> =.093) | .267<br>( <i>r</i> <sup>2</sup> =.135)<br>( <i>p</i> =.256)                           |
| CRTT-R <sub>-wf</sub> | Session 1 |           |                                                                                      | 1                                                           | <b>.764</b><br>( <i>r</i> <sup>2</sup> = <b>.584</b> )<br>( <i>p</i> = <b>.0001</b> ) |
|                       | Session 2 |           |                                                                                      |                                                             | 1                                                                                     |

*Note.* Bolded = significantly different from 0 at the *p*=.05 level.

**Table 15.** Group B Mean Efficiency Score correlations.

| Test                  | Session   | CRTT-ASL  |                                                     | CRTT-R <sub>-wf</sub>                         |                                                     |
|-----------------------|-----------|-----------|-----------------------------------------------------|-----------------------------------------------|-----------------------------------------------------|
|                       |           | Session 1 | Session 2                                           | Session 1                                     | Session 2                                           |
| CRTT-ASL              | Session 1 | 1         | <b>.783</b><br>( $r^2=.613$ )<br>( $p=.0044^{-2}$ ) | .336<br>( $r^2=.113$ )<br>( $p=.147$ )        | <b>.482</b><br>( $r^2=.232$ )<br>( $p=.031$ )       |
|                       | Session 2 |           | 1                                                   | <b>.489</b><br>( $r^2=.239$ )<br>( $p=.029$ ) | <b>.508</b><br>( $r^2=.258$ )<br>( $p=.022$ )       |
| CRTT-R <sub>-wf</sub> | Session 1 |           |                                                     | 1                                             | <b>.815</b><br>( $r^2=.664$ )<br>( $p=.0001^{-1}$ ) |
|                       | Session 2 |           |                                                     |                                               | 1                                                   |

*Note.* Bolded = significantly different from 0 at the  $p=.05$  level.

**Table 16.** Group C Mean CRTT Score correlations.

| Test                 | Session   | CRTT-ASL  |                                                                                      | CRTT-R <sub>wf</sub>                                                                 |                                                                                      |
|----------------------|-----------|-----------|--------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|
|                      |           | Session 1 | Session 2                                                                            | Session 1                                                                            | Session 2                                                                            |
| CRTT-ASL             | Session 1 | 1         | <b>.769</b><br>( <i>r</i> <sup>2</sup> = <b>.591</b> )<br>( <i>p</i> = <b>.009</b> ) | <b>.604</b><br>( <i>r</i> <sup>2</sup> = <b>.365</b> )<br>( <i>p</i> = <b>.064</b> ) | <b>.741</b><br>( <i>r</i> <sup>2</sup> = <b>.549</b> )<br>( <i>p</i> = <b>.168</b> ) |
|                      | Session 2 |           | 1                                                                                    | <b>.731</b><br>( <i>r</i> <sup>2</sup> = <b>.534</b> )<br>( <i>p</i> = <b>.016</b> ) | <b>.853</b><br>( <i>r</i> <sup>2</sup> = <b>.728</b> )<br>( <i>p</i> = <b>.002</b> ) |
| CRTT-R <sub>wf</sub> | Session 1 |           |                                                                                      | 1                                                                                    | <b>.880</b><br>( <i>r</i> <sup>2</sup> = <b>.774</b> )<br>( <i>p</i> = <b>.001</b> ) |
|                      | Session 2 |           |                                                                                      |                                                                                      | 1                                                                                    |

*Note.* Bolded = significantly different from 0 at the *p*=.05 level.

**Table 17.** Group C Mean Efficiency Score correlations.

| Test      | Session   | CRTT-ASL  |                                                               | CRTT-R-wf                                                     |                                                                             |
|-----------|-----------|-----------|---------------------------------------------------------------|---------------------------------------------------------------|-----------------------------------------------------------------------------|
|           |           | Session 1 | Session 2                                                     | Session 1                                                     | Session 2                                                                   |
| CRTT-ASL  | Session 1 | 1         | <b>.754</b><br><i>(r<sup>2</sup>=.569)</i><br><i>(p=.012)</i> | <b>.719</b><br><i>(r<sup>2</sup>=.517)</i><br><i>(p=.019)</i> | <b>.747</b><br><i>(r<sup>2</sup>=.558)</i><br><i>(p=.013)</i>               |
|           | Session 2 |           | 1                                                             | <b>.819</b><br><i>(r<sup>2</sup>=.671)</i><br><i>(p=.004)</i> | <b>.884</b><br><i>(r<sup>2</sup>=.781)</i><br><i>(p=.001)</i>               |
| CRTT-R-wf | Session 1 |           |                                                               | 1                                                             | <b>.956</b><br><i>(r<sup>2</sup>=.914)</i><br><i>(p=.0002<sup>-1</sup>)</i> |
|           | Session 2 |           |                                                               |                                                               | 1                                                                           |

*Note.* Bolded = significantly different from 0 at the  $p=.05$  level.

**Table 18.** Mean CRTT Score comparisons with correlations of .70 or higher.

| Test                  | Session   | CRTT-ASL  |                                                           | CRTT-R <sub>-wf</sub>                                     |                                                                                                                                                                                                                                                                              |
|-----------------------|-----------|-----------|-----------------------------------------------------------|-----------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                       |           | Session 1 | Session 2                                                 | Session 1                                                 | Session 2                                                                                                                                                                                                                                                                    |
| CRTT-ASL              | Session 1 |           | <b>Group C:</b><br>$r=.769$<br>$(r^2=.591)$<br>$(p=.009)$ |                                                           | <b>Group C:</b><br>$r=.741$<br>$(r^2=.549)$<br>$(p=.168)$                                                                                                                                                                                                                    |
|                       | Session 2 |           |                                                           | <b>Group C:</b><br>$r=.731$<br>$(r^2=.534)$<br>$(p=.016)$ | <b>Group C:</b><br>$r=.853$<br>$(r^2=.728)$<br>$(p=.002)$                                                                                                                                                                                                                    |
| CRTT-R <sub>-wf</sub> | Session 1 |           |                                                           |                                                           | <b>All Group:</b><br>$r=.873$<br>$(r^2=.762)$<br>$(p=.0001^{-13})$<br><br><b>Group A:</b><br>$r=.705$<br>$(r^2=.837)$<br>$(p=0001^{-16})$<br><br><b>Group B:</b><br>$r=.764$<br>$(r^2=.584)$<br>$(p=.0001)$<br><br><b>Group C:</b><br>$r=.880$<br>$(r^2=.774)$<br>$(p=.001)$ |

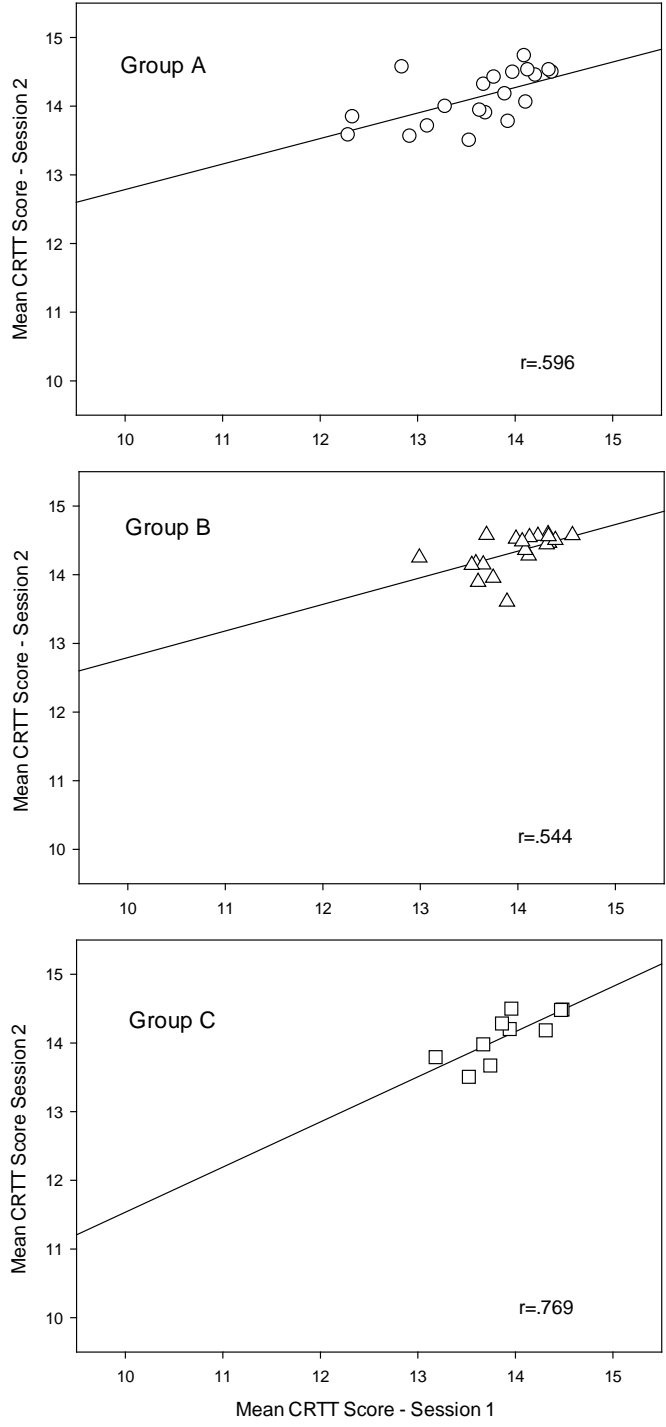


**Table 19.** Mean Efficiency Score comparisons with correlations of .70 or higher

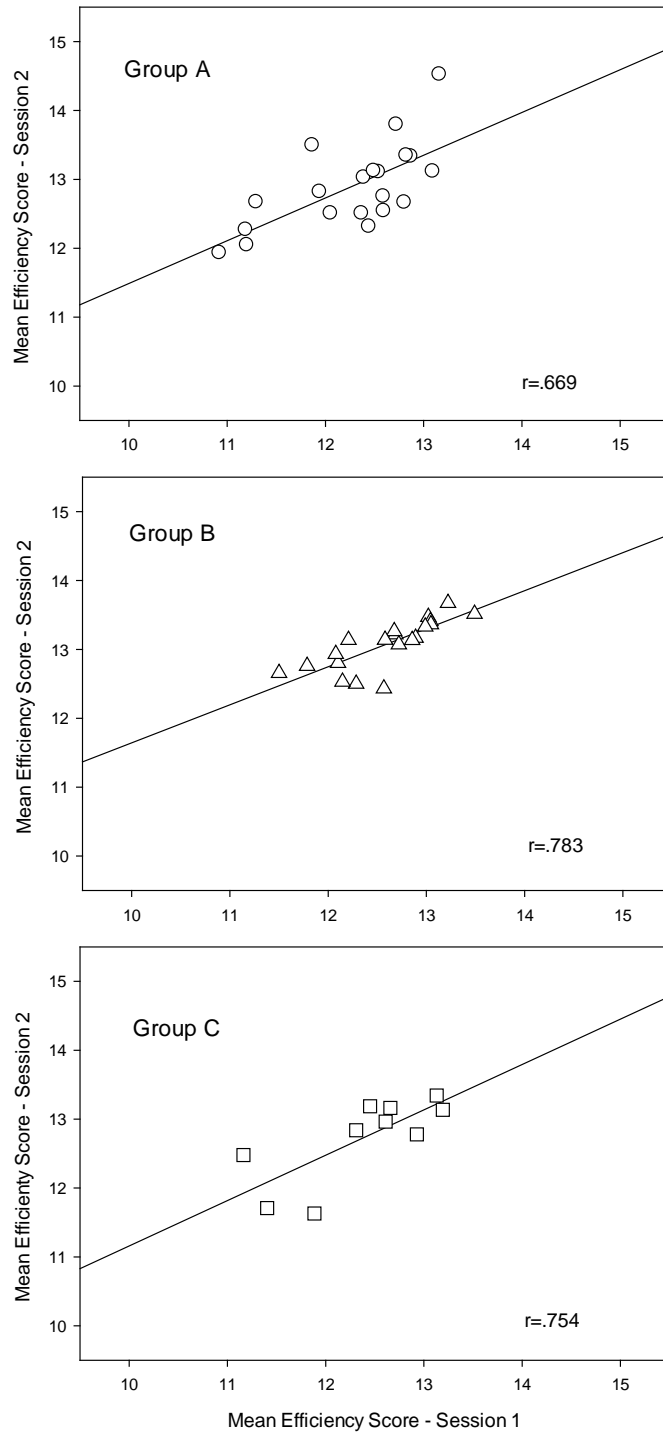
| Test      | Session   | CRTT-ASL  |                                                                                                                                                                                                           | CRTT-R-wf                                                 |                                                                                                                                     |
|-----------|-----------|-----------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------|
|           |           | Session 1 | Session 2                                                                                                                                                                                                 | Session 1                                                 | Session 2                                                                                                                           |
| CRTT-ASL  | Session 1 |           | <b>All Group:</b><br>$r=.711$<br>$(r^2=.506)$<br>$(p=.0007^{-5})$<br><br><b>Group B:</b><br>$r=.783$<br>$(r^2=.613)$<br>$(p=.0044^{-2})$<br><br><b>Group C:</b><br>$r=.754$<br>$(r^2=.569)$<br>$(p=.012)$ | <b>Group C:</b><br>$r=.719$<br>$(r^2=.517)$<br>$(p=.019)$ | <b>Group C:</b><br>$r=.747$<br>$(r^2=.558)$<br>$(p=.013)$                                                                           |
|           | Session 2 |           |                                                                                                                                                                                                           | <b>Group C:</b><br>$r=.819$<br>$(r^2=.671)$<br>$(p=.004)$ | <b>Group C:</b><br>$r=.884$<br>$(r^2=.781)$<br>$(p=.001)$                                                                           |
| CRTT-R-wf | Session 1 |           |                                                                                                                                                                                                           |                                                           | <b>All Group:</b><br>$r=.915$<br>$(r^2=.837)$<br>$(p=.0001^{-16})$<br><br><b>Group A:</b><br>$r=.695$<br>$(r^2=.483)$<br>$(p=.001)$ |

|  |  |  |  |  |                                                                                                                                        |
|--|--|--|--|--|----------------------------------------------------------------------------------------------------------------------------------------|
|  |  |  |  |  | <b>Group B:</b><br>$r=.815$<br>$(r^2=.664)$<br>$(p=.0001^{-1})$<br><br><b>Group C:</b><br>$r=.956$<br>$(r^2=.914)$<br>$(p=.0002^{-1})$ |
|--|--|--|--|--|----------------------------------------------------------------------------------------------------------------------------------------|

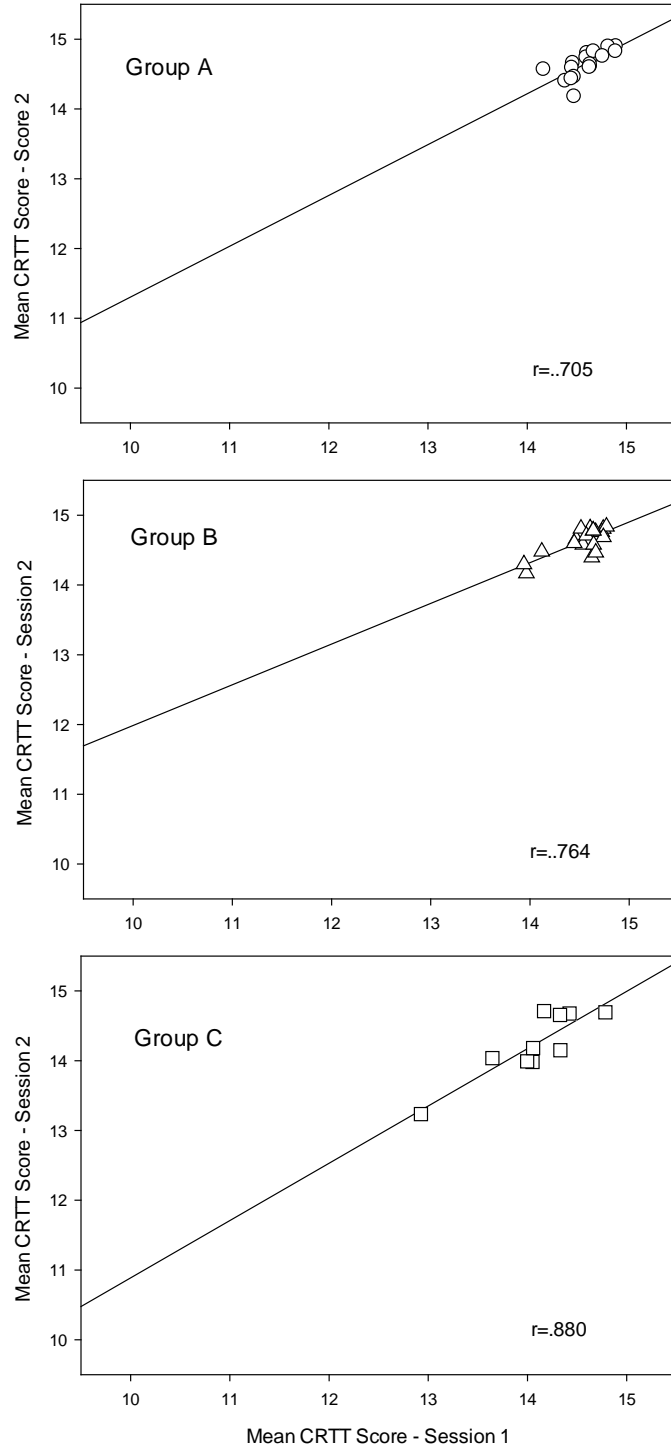
The relationships between Sessions 1 and 2 for the three groups per test also are depicted in the following scatter plots. Limited distributional spread and almost reached ceiled performance levels may explain some of the reduced correlations found for Groups A and B in the face of relatively small difference scores ( $\Delta$  Score) and standard errors (in Tables 7 through 10 above). There appeared to be a wider distribution of scores for the Mean Efficiency Score than for the Mean CRTT Score.



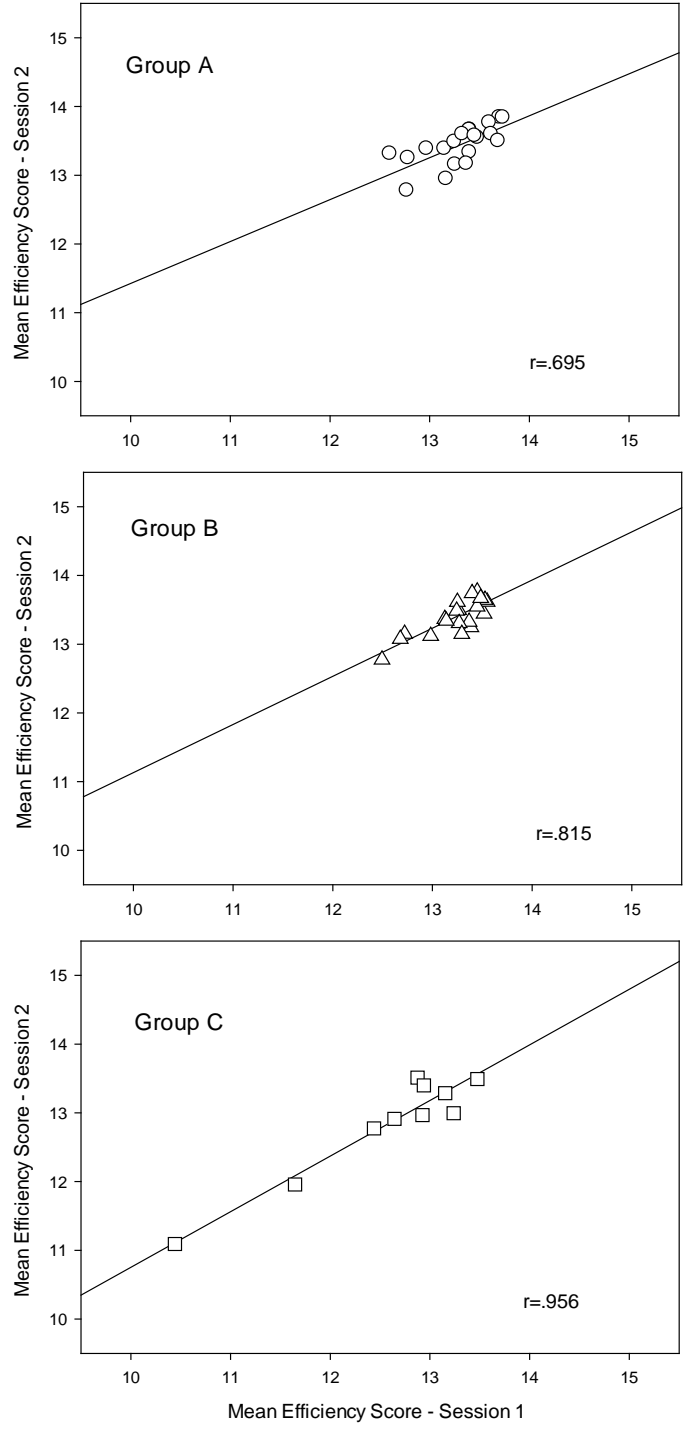
**Figure 4.** Scatter plots for Mean CRTT Scores on the CRTT-ASL between Session 1 and Session 2 on the CRTT-ASL per group.



**Figure 5.** Scatter plots for Mean Efficiency Scores on the CRTT-ASL between Session 1 and Session 2 on the CRTT-ASL per group.



**Figure 6.** Scatter plots for Mean CRTT Scores on the CRTT-R<sub>wf</sub> between Session 1 and Session 2 on the CRTT-R<sub>wf</sub> per group.



**Figure 7.** Scatter plots for Mean Efficiency Scores on the CRTT-R-wf between Session 1 and Session 2 per group.

## 3.2 TEST OF DIFFERENCE

### 3.2.1 Mean CRTT Score

In addition to the correlations, a Mixed Model ANOVA, with repetition on the CRTT-ASL and CRTT-R-WF was used to test for differences. Sphericity could be assumed, so no normalization procedures. The alpha level was set at 0.05, and Bonferroni corrections were used for multiple comparisons where needed.

The results of the Mixed Model indicated a significant effect for Group,  $F = 3.72 (2, 47)$ ,  $p = .0326$ ,  $\eta^2 = .137$ . Differences also were found across sessions for the CRTT-ASL,  $F = 66.753 (1, 47)$ ,  $p = .0142^{-8}$ ,  $\eta^2 = .757$ , and for the CRTT-R-wf,  $F = 46.566 (1, 47)$ ,  $p = .051^{-6}$ ,  $\eta^2 = .498$ . The differences across sessions suggested that participants experienced learning effects for both tests, with improvements demonstrated by all three groups. An interaction effect was detected between Group and Session on the ASL-CRTT,  $F = 10.228 (2, 47)$ ,  $p = .0002$ ,  $\eta^2 = .303$ ; this interaction was found specifically for Group A. A three-way interaction between Group A, CRTT-ASL, and CRTT-R-wf was obtained,  $F = 3.619 (2, 47)$ ,  $p = .035$ ,  $\eta^2 = .133$  but no interactions were found for Group by Session on the CRTT-R-wf or between the two assessments.

The significant interactions likely originated from Group A having comparatively greater gains on the CRTT-ASL test across sessions, but further examination of the CRTT-ASL results by individual group indicated that the three groups did not differ at each session. Although there was no interaction noted for Group by Session on CRTT-R-wf, it should be noted that Group C had significantly lower scores than Groups A and B on the CRTT-R-wf for both sessions,  $t = 3.922-4.648$ ,  $p = .0003-.00003$ ,  $\eta^2 = .196-.298$ , whereas, Groups A and B did not differ. These results indicated that the overall Group effect likely was not due to performance on the CRTT-ASL, but rather the CRTT-R-wf, and was largely attributable to Group C.

### 3.2.2 Mean Efficiency Scores

The same statistical analyses applied to the Mean CRTT Scores were replicated for the Mean Efficiency Scores. The effects were consistent to those found with the Mean CRTT Scores with the exception that the three-way interaction failed to reach significance.

### 3.3 POST-ASSESSMENT QUESTIONNAIRE

Upon completing the study, the participants were asked to rate the quality of the sign and the difficulty of the CRTT-ASL on a five-point scale. The prompts were: (1) “On a scale of 1 to 5 (1= bad and 5 = very good), please rate the quality of signing during the assessment”, and (2) “On a scale of 1 to 5 (1 = very easy and 5 = very hard), please rate the level of difficulty of the assessment”. Results of individual data are listed in Appendix, Table 4. Summary of the responses are listed in Table 20 and indicate that the quality of the signing and difficulty of the assessment were similar across groups.

**Table 20.** Medians and ranges of rankings produced by all groups on the post-assessment questionnaire.

| Group   | Quality of Signing |        | Difficulty of the Assessment |        |
|---------|--------------------|--------|------------------------------|--------|
|         | Median             | Range  | Median                       | Range  |
| Group A | 5                  | 4 to 5 | 3                            | 2 to 5 |
| Group B | 5                  | 4 to 5 | 3                            | 1 to 4 |
| Group C | 5                  | 3 to 5 | 3.5                          | 1 to 5 |



## 4.0 DISCUSSION

The hypotheses for this study were only partially confirmed. The correlations listed in Tables 11 – 17 showed that the CRTT-ASL was acceptably reliable for Group C, but not for Group A, and only for Group B when considering the Mean Efficiency Score. All three groups showed acceptable reliability for the CRTT-R<sub>wf</sub> test, but only Group C demonstrated high correlations between CRTT-ASL and CRTT-R<sub>wf</sub> performance.

The modest correlations found for Groups A and B on the CRTT-ASL were in contrast to the relatively small differences between administrations and the standard errors, and for Group B could be accounted for by the limited dispersion of scores and ceiling effects.

All three groups demonstrated learning effects on both test versions but the greatest magnitude of change occurred for the CRTT-ASL. The first CRTT-ASL administration was particularly low and variable for Group A, but also more variable for all groups when compared to the results from Session 2.

As expected Groups A and B performed at higher levels on the CRTT-R<sub>wf</sub> than the CRTT-ASL, but the test versions were more equivalent for Group C, which was not expected. The expectation was that Group C would perform more highly on the CRTT-ASL than the CRTT-R<sub>wf</sub>

Group differences also were found with the Mixed Model, with a main effect for Group, and Group by session interaction on the CRTT-ASL. The interaction was attributable to the large gain in performance demonstrated by Group A across sessions, but at each session the groups did not differ on the CRTT-ASL. The group difference was likely a function of Group C performing at a lower level than the other groups on the CRTT-R<sub>wf</sub> regardless of session – a finding that was anticipated.

#### 4.1 OBSERVED GROUP BEHAVIORAL DIFFERENCES

During administration of the tests for participants in Groups A and B, it was noted that participants from Groups A and B frequently struggled with Subtests III and IV. In Subtests III and IV, the instructions are “Touch the \_\_\_\_\_ and the \_\_\_\_\_.” In ASL, the signer demonstrates touching two objects with the handshape “X” to represent “click.” Despite successfully completing the CRTT-ASL Pretest, many of the non-native participants did not understand the vocabulary and chose to drag the shapes instead of clicking them independently. On Subtest III, Group A had an averaged a Mean CRTT Score of 13.05, Group B had a score of 14.23, and Group C had a score of 14.06. One potential reason could be the lack of instruction on vocabulary involving computer technology in introductory ASL courses - computer jargon might not be commonly taught in the ASL classroom. It was observed and noted that both of the non-native groups demonstrated challenges with understanding verbs used in the CRTT-ASL, whereas Group C did not. During the CRTT-ASL Pretest, several participants from Group A and Group B needed further cueing in order to produce a correct response, but they all passed the Pretest. It is possible that more training is needed for less proficient signers to produce reliable test results on the CRTT-ASL.

Although Group C did not struggle with verbs on the CRTT-ASL, the participants in this group frequently made errors on shape, color, and size. Based upon the validity of translations mentioned in Section 2, the discrepancies were not attributable to the signing in the video clips. One potential source for these differences is the impact of modality on verbal working memory. It is possible that managing visual-spatial language in the working memory is more difficult than reading on the CRTT task, especially if sign was learned late. If ASL is learned as a second language for individual who learned a first language during their critical language period, such as Groups A and B along with Deaf individuals who learn ASL as a second language, it could be possible that they are using their first language to aid their language processing, thus they might not only be processing the language in ASL (Mayberry, 1993).

## 4.2 DEAF LANGUAGE EXPERIENCES

The ten Deaf participants of this study exemplify heterogeneity of the Deaf population as demonstrated by their language-learning experiences that ranged from birth to present (Appendix, Table, 1) as well as varying performance on the CRTT-ASL and CRTT-R<sub>wf</sub>. Based upon a Deaf participants' language experience, absolute proficiency in ASL likely varied substantially although they all rated themselves as proficient.

It is crucial to consider the varying language experiences of the Deaf population when considering the applicability of the CRTT-ASL. For example, a native ASL user who began learning ASL from birth most likely has ASL that is richer, more easily accessed, and more nuanced than a signer who began using ASL later in life (both types of individuals were represented in this study). Appendix, Table 1 provides data on the number of years the Group C participants had been using ASL. The range was large and many of them indicated that their parents used English or SEE during their childhood. This variety and diversity of language-learning experiences might have contributed to the results on the two CRTT versions. Another contributor factor could be that Deaf Americans are bilingual and learn to read English in diverse ways, as there is no standard way to teach Deaf children written English (Hoffmeister & Caldwell Harris, 2014).

Morford and Carlson (2011) investigated whether non-native ASL signers experienced problems in comprehending all of ASL or only specific components. They found that non-native Deaf signers performed similarly to Deaf native signers on rapidity and accuracy on a hand location-monitoring task, but that non-native signers differed from native signers in recognizing signs. Even more interesting, the hearing non-proficient signers performed similarly to the groups of Deaf signers on sign recognition tasks. In the current study, the proficient non-native signers often had Mean CRTT Scores that surpassed those of the proficient native signers. The original hypothesis for the CRTT-ASL study was that the proficient non-native signers would perform at levels similar to the native signers, this was the case for the group as a whole but some performed better than the proficient native group. That being said, it is important to remember that the proficient non-native group in the current study had twice the number of participants, which might have influenced the results.

A current debate in the literature is whether Deaf ASL and hearing English users differ in short term memory and working verbal memory skills. Bavalier et al. (2006b) argued that the short-term memory of individuals who use sign language is not similar to those who use spoken English. Their study supported the notion that native ASL users have less facility with short-term memory than native English speakers (Bavalier et al., 2006b). If the claims made by Bavalier (2006a) and Bavalier et al. (2006b) are true then some of the patterns seen in the current study may have been influenced by reduced short-term memory skills.

More consistent with the current study is work by Supalla, Hauser, and Bavelier (2014), who hypothesized that the memory function of ASL users are similar to those of English speakers. Their study used the American Sign Language Sentence Reproduction Test (ASL-SRT) to assess verbal working memory. The ASL-SRT requires test-takers watch sentences signed in ASL and reproduce those sentences. The sentences become increasingly longer, and more difficult and complex, and like the CRTT-ASL, it evaluates working memory and language processing. Supalla et al. examined Deaf children, Deaf adults, and hearing proficient ASL users, and discovered that the verbal working memory function of a signer depended upon their language-learning experiences. When looking at the individual data, this pattern tended to hold true for the Deaf participants in the current study.

Age of language acquisition also is a strong influence on language capabilities, language comprehension and verbal working memory. Mayberry (1993) examined the language recall skills of Deaf adults based on the age at which they acquired language and whether ASL was their first or second language. The study discovered that the participants who had learned ASL as a second language performed better than the participants who were born Deaf and started learning ASL as their first language from late infancy through childhood. The late first-language learners demonstrated difficulty with many language-processing characteristics, including working memory. One reason of this outcome, as explained by Mayberry, is that the late second language learners can use their working memory to recode language into their first language, but individuals who are delayed in learning a first language do not have this capability. This could serve as an explanation for why Group C demonstrated poorer than expected performance on the CRTT-ASL.

### **4.3 LIMITATIONS**

One limitation to the current study was the small sample size of Group C ( $n=10$ ). Recruiting Deaf participants was more difficult than anticipated, and the participants that did complete the study varied in known risk factors such as their language used while growing up, the number of years using ASL, education, and use of assistive technologies. Another limitation was the overwhelming percentage of female participants, although gender was not thought to have influenced the data. Finally, testing order may have been a consideration for some of the participants. To avoid an order effect the order of test administration for all participants was randomized; however it is possible that some of the participants in Groups A learned how to better take the CRTT-ASL in Session 2 after being exposed to the CRTT-R-<sub>wf</sub> in Session 1, which could explain why the performance gain across visits for the CRTT-ASL was so large for this group. It also fits with the errors and behaviors observed for this group, and argues for additional pre-training.

### **4.4 FUTURE CONSIDERATIONS**

In looking towards the future, there are several video revisions that the CRTT-ASL would benefit from after noticing specific nuances of Deaf CRTT-ASL test-takers. Also, data were collected on the response time for every command of each subtest. It would be informative to investigate the differences in response time between groups and see if it interacts with overall performance. One future investigation could be assessing performance of Deaf individuals who have Aphasia on the CRTT-ASL.

## 5.0 SUMMARY AND CONCLUSION

In response to the first research question posed in this study, Groups A and B did not produce correlations of .70 or above for Mean CRTT Score on the CRTT-ASL, although Group B did produce an acceptable correlation for Mean Efficiency Score. In contrast, Group C demonstrated acceptable test-retest reliability on the CRTT-ASL for both score types.

The second experimental question asked whether non-proficient non-native, proficient non-native, and proficient native ASL users would perform differently on the CRTT-ASL when compared to the CRTT-R<sub>wf</sub>. The study found that all Groups performed better on the CRTT-R<sub>wf</sub> than the CRTT-ASL, and produced higher and more acceptable correlations on the CRTT-R<sub>wf</sub>.

## APPENDIX

**Appendix, Table 1.** Individual responses to the background questionnaire

| Participant | Length of Time<br>using ASL | Average #<br>Hours/week of ASL<br>Use | Education  | Self-Rated English<br>Reading Skills |
|-------------|-----------------------------|---------------------------------------|------------|--------------------------------------|
| A1          | 4.5 Months                  | 4 Hours                               | Mainstream | Native                               |
| A2          | 1 Year                      | 0 Hours                               | Mainstream | Native                               |
| A3          | 4 Months                    | 1 Hour                                | Mainstream | Native                               |
| A4          | 7 Months                    | 6 Hours                               | Mainstream | Native                               |
| A5          | 6 Months                    | 5 Hours                               | Mainstream | Native                               |
| A6          | 7 Months                    | 0 Hours                               | Mainstream | Above Average                        |
| A7          | 1 Year                      | 6.5 Hours                             | Mainstream | Native                               |
| A8          | 7 Months                    | 5 Hours                               | Mainstream | Native                               |
| A9          | 6 Months                    | 4.5 Hours                             | Mainstream | Native                               |
| A10         | 6 Months                    | 5 Hours                               | Mainstream | Native                               |
| A11         | 6 Months                    | 4 Hours                               | Mainstream | Native                               |
| A12         | 4 Years                     | 0 Hours                               | Mainstream | Native                               |
| A13         | 7 Months                    | 4 Hours                               | Mainstream | Native                               |
| A14         | 1 Year                      | 5 Hours                               | Mainstream | Native                               |
| A15         | 9 Months                    | <1 Hour                               | Mainstream | Average                              |
| A16         | 4 Months                    | 1 Hour                                | Mainstream | Native                               |
| A17         | 1 Year                      | 3 Hours                               | Mainstream | Native                               |
| A18         | <1 Year                     | 7 Hours                               | Mainstream | Native                               |
| A19         | 3 Years                     | 7.5 Hours                             | Mainstream | Native                               |

|     |           |           |                                   |               |
|-----|-----------|-----------|-----------------------------------|---------------|
| A20 | 6 Years   | 5 Hours   | Mainstream                        | Native        |
| B1  | 2 Years   | 2.5 Hours | Mainstream                        | Native        |
| B2  | 3 Years   | 5 Hours   | Mainstream                        | Native        |
| B3  | 3 Years   | 2.5 Hours | Mainstream                        | Native        |
| B4  | 6 Years   | 8 Hours   | Mainstream                        | Native        |
| B5  | 2 Years   | 0 Hours   | Mainstream                        | Native        |
| B6  | 3 Years   | 6.5 Hours | Mainstream                        | Native        |
| B7  | 2.5 Years | 4 Hours   | Mainstream                        | Native        |
| B8  | 3 Years   | 4 Hours   | Mainstream                        | Native        |
| B9  | 2 Years   | 5 Hours   | Mainstream                        | Native        |
| B10 | 4.5 Years | 3 Hours   | Mainstream                        | Native        |
| B11 | 2 Years   | 3.5 Hours | Mainstream                        | Native        |
| B12 | 2 Years   | 9.5 Hours | Mainstream                        | Native        |
| B13 | 1 Year    | 15 Hours  | Mainstream                        | Native        |
| B14 | 1.5 Years | 6 Hours   | Mainstream                        | Native        |
| B15 | 4 Years   | 3 Hours   | Mainstream                        | Native        |
| B16 | 2 Years   | 6 Hours   | Mainstream                        | Native        |
| B17 | 3.5 Years | 4 Hours   | Mainstream                        | Above Average |
| B18 | 17 Months | 10 Hours  | Mainstream                        | Native        |
| B19 | 2 Years   | 8 Hours   | Mainstream                        | Native        |
| B20 | 4 Years   | 6 Hours   | Mainstream                        | Native        |
| C1  | 37 Years  | 28 Hours  | Deaf<br>School/Mainstream<br>Oral | Above Average |
| C2  | 17 Years  | 24/7      | Deaf<br>School/Mainstream<br>Oral | Above Average |
| C3  | 42 Years  | 24/7      | Mainstream                        | Above Average |
| C4  | 15+ Years | 10+ Hours | Mainstream                        | Average       |
| C5  | 31 Years  | 80 Hours  | Mainstream                        | Above Average |



|     |          |           |                                  |               |
|-----|----------|-----------|----------------------------------|---------------|
| C6  | 25 Years | 24/7      | Mainstream                       | Average       |
| C7  | 27 Years | 24/7      | Deaf School<br>Manual/Mainstream | Average       |
| C8  | 15 Years | 24/7      | Mainstream<br>Oral/Mainstream    | Above Average |
| C9  | 21 Years | 140 Hours | Deaf<br>School/Mainstream        | Above Average |
| C10 | 43 Years | 24/7      | Deaf School<br>Manual            | Above Average |

**Appendix, Table 2.** Individual self-rating scores on level of proficiency of specific language capabilities.

| Participant | Speaking<br>English | Understanding<br>English | Reading<br>English | Signing<br>ASL | Understanding<br>ASL |
|-------------|---------------------|--------------------------|--------------------|----------------|----------------------|
| A1          | 9                   | 8                        | 8                  | 2              | 4                    |
| A2          | 10                  | 10                       | 10                 | 1              | 1                    |
| A3          | 10                  | 10                       | 10                 | 3              | 4                    |
| A4          | 10                  | 10                       | 10                 | 7              | 9                    |
| A5          | 10                  | 10                       | 10                 | 5              | 5                    |
| A6          | 10                  | 10                       | 10                 | 5              | 6                    |
| A7          | 9                   | 9                        | 9                  | 4              | 4                    |
| A8          | 10                  | 10                       | 10                 | 5              | 7                    |
| A9          | 9                   | 9                        | 9                  | 3              | 3                    |
| A10         | 10                  | 10                       | 10                 | 4              | 4                    |
| A11         | 10                  | 10                       | 10                 | 5              | 5                    |
| A12         | 10                  | 10                       | 10                 | 3              | 2                    |
| A13         | 10                  | 10                       | 10                 | 6              | 7                    |
| A14         | 10                  | 10                       | 10                 | 5              | 5                    |
| A15         | 9                   | 9                        | 8                  | 3              | 3                    |

|     |    |    |    |    |    |
|-----|----|----|----|----|----|
| A16 | 9  | 9  | 9  | 5  | 5  |
| A17 | 8  | 9  | 9  | 4  | 5  |
| A18 | 9  | 9  | 9  | 3  | 3  |
| A19 | 9  | 9  | 9  | 6  | 7  |
| A20 | 10 | 10 | 10 | 7  | 8  |
| B1  | 10 | 10 | 10 | 7  | 7  |
| B2  | 10 | 10 | 10 | 7  | 8  |
| B3  | 10 | 10 | 10 | 6  | 6  |
| B4  | 10 | 10 | 10 | 8  | 8  |
| B5  | 10 | 10 | 9  | 7  | 7  |
| B6  | 10 | 10 | 10 | 7  | 7  |
| B7  | 10 | 10 | 10 | 7  | 8  |
| B8  | 10 | 10 | 10 | 7  | 7  |
| B9  | 10 | 10 | 10 | 7  | 8  |
| B10 | 10 | 9  | 10 | 8  | 7  |
| B11 | 10 | 10 | 10 | 3  | 3  |
| B12 | 10 | 9  | 9  | 2  | 3  |
| B13 | 10 | 10 | 10 | 7  | 8  |
| B14 | 10 | 10 | 10 | 5  | 6  |
| B15 | 9  | 9  | 9  | 5  | 7  |
| B16 | 10 | 10 | 10 | 8  | 9  |
| B17 | 9  | 9  | 9  | 7  | 7  |
| B18 | 9  | 10 | 9  | 5  | 5  |
| B19 | 10 | 10 | 10 | 7  | 8  |
| B20 | 10 | 10 | 10 | 7  | 8  |
| C1  | 1  | 1  | 7  | 8  | 9  |
| C2  | 8  | 8  | 8  | 8  | 8  |
| C3  | 6  | 6  | 9  | 10 | 10 |
| C4  | 3  | 9  | 9  | 10 | 10 |
| C5  | 6  | 2  | 8  | 8  | 8  |

|     |   |   |   |    |    |
|-----|---|---|---|----|----|
| C6  | 3 | 3 | 7 | 8  | 8  |
| C7  | 0 | 7 | 7 | 8  | 8  |
| C8  | 9 | 9 | 9 | 10 | 10 |
| C9  | 8 | 8 | 8 | 9  | 10 |
| C10 | 5 | 5 | 7 | 7  | 10 |

*Note.* Based upon a ranking 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.

**Appendix, Table 3.** Individual scores on the reading subtests of the CELF-5.

| Participant | Passage #1 | Passage #2 |
|-------------|------------|------------|
| A1          | 10         | 9          |
| A2          | 9          | 9          |
| A3          | 10         | 8          |
| A4          | 10         | 8          |
| A5          | 10         | 9          |
| A6          | 10         | 8          |
| A7          | 10         | 8          |
| A8          | 10         | 9          |
| A9          | 10         | 9          |
| A10         | 10         | 9          |
| A11         | 10         | 9          |
| A12         | 9          | 9          |
| A13         | 10         | 9          |
| A14         | 10         | 9          |
| A15         | 10         | 9          |
| A16         | 10         | 9          |
| A17         | 9          | 9          |
| A18         | 10         | 9          |
| A19         | 10         | 9          |

|     |    |   |
|-----|----|---|
| A20 | 10 | 9 |
| B1  | 10 | 9 |
| B2  | 19 | 9 |
| B3  | 10 | 9 |
| B4  | 10 | 9 |
| B5  | 10 | 9 |
| B6  | 10 | 9 |
| B7  | 10 | 9 |
| B8  | 9  | 9 |
| B9  | 10 | 9 |
| B10 | 9  | 9 |
| B11 | 10 | 9 |
| B12 | 9  | 9 |
| B13 | 10 | 9 |
| B14 | 9  | 9 |
| B15 | 10 | 9 |
| B16 | 9  | 9 |
| B17 | 10 | 8 |
| B18 | 10 | 9 |
| B19 | 10 | 9 |
| B20 | 10 | 9 |
| C1  | 10 | 9 |
| C2  | 10 | 9 |
| C3  | 9  | 9 |
| C4  | 10 | 9 |
| C5  | 10 | 9 |
| C6  | 8  | 9 |
| C7  | 10 | 8 |
| C8  | 10 | 9 |
| C9  | 6  | 9 |

|     |   |   |
|-----|---|---|
| C10 | 9 | 9 |
|-----|---|---|

*Note.* The first passage was scored out of 10 questions, and the second passage was scored out of 9 questions.

**Appendix, Table 4.** Individual subject post-assessment questionnaire results.

| Subject | Quality of Signing Rating | Level of Difficulty Rating |
|---------|---------------------------|----------------------------|
| A1      | 5                         | 3                          |
| A2      | 5                         | 2                          |
| A3      | 5                         | 2                          |
| A4      | 5                         | 3                          |
| A5      | 5                         | 3                          |
| A6      | 5                         | 3                          |
| A7      | 4                         | 3                          |
| A8      | 4                         | 2                          |
| A9      | 5                         | 2                          |
| A10     | 5                         | 3                          |
| A11     | 5                         | 2                          |
| A12     | 5                         | 5                          |
| A13     | 5                         | 2                          |
| A14     | 4                         | 5                          |
| A15     | 5                         | 4                          |
| A16     | 5                         | 3                          |
| A17     | 5                         | 3                          |
| A18     | 5                         | 3                          |
| A19     | 5                         | 4                          |
| A20     | 4                         | 3                          |
| B1      | 4                         | 3                          |
| B2      | 5                         | 4                          |

|      |   |   |
|------|---|---|
| B3   | 5 | 3 |
| B4   | 5 | 4 |
| B5   | 5 | 2 |
| B6   | 5 | 2 |
| B7   | 5 | 4 |
| B8   | 5 | 2 |
| B9   | 5 | 4 |
| B10  | 5 | 4 |
| B11  | 5 | 3 |
| B12  | 5 | 2 |
| B113 | 5 | 1 |
| B14  | 5 | 1 |
| B15  | 5 | 4 |
| B16  | 5 | 2 |
| B17  | 5 | 3 |
| B18  | 5 | 4 |
| B19  | 4 | 2 |
| B20  | 5 | 3 |
| C1   | 5 | 1 |
| C2   | 5 | 3 |
| C3   | 5 | 3 |
| C4   | 5 | 2 |
| C5   | 4 | 2 |
| C6   | 3 | 4 |
| C7   | 5 | 5 |
| C8   | 5 | 4 |
| C9   | 5 | 4 |
| C10  | 5 | 4 |

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