LANGUAGE COMPREHENSION AS AN EFFECT OF AGING AND HAND PREFERENCE USING THE COMPUTERIZED REVISED TOKEN TEST-READING-WORD FADE

by

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LANGUAGE COMPREHENSION AS AN EFFECT OF AGING AND HAND PREFERENCE USING THE COMPUTERIZED REVISED TOKEN TEST-READING-WORD FADE

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Aims: The Computerized Revised Token Test (CRTT) is a standardized assessment of language comprehension and processing abilities. The CRTT-Reading-Word-Fade (CRTT-R-$_{WF}$) is a self-paced version of the CRTT in which the previous word in a sentence disappears with the onset of each new word. In addition to the language skills needed to complete the assessment, the CRTT also requires perceptual-motor and cognitive capabilities that have the potential to negatively influence participant results. The purpose of this study was to investigate the effect of age and hand preference as two of these potential influences on CRTT performance.

Methods: Sixty-four healthy, normal adults participated in this study. Participants were divided into two groups: younger adults (Group 1, 20-32 years) and older adults (Group 2, 65-78 years). Each group consisted of 32 participants (16 males and 16 females). All 64 participants completed the CRTT-R-$_{WF}$ version of the CRTT and CRTT-RT battery with both their right and left hand. The CRTT-R-$_{WF}$ mean scores, efficiency scores, and reading times were investigated to evaluate the effects of age and hand preference on the accuracy and efficiency of participant responses.

Results: Statistically significant main effects were observed for both age and hand use on CRTT-R-$_{WF}$ mean scores, efficiency scores, and reading plus response times. The older adults demonstrated significantly lower mean and efficiency scores, as well as significantly slower reading times. Mean scores, efficiency scores and reading plus response times achieved with the left hand were also significantly lower and slower than the right hand across participants.

Significant interactions between age and hand were found on CRTT-R-$_{WF}$ mean and efficiency scores. The older adult's mean and efficiency scores were over-additively reduced with their left hand.

Discussion: Decreased comprehension and efficiency of responses, as measured by the CRTT-R-$_{WF}$, were observed with age and with non-preferred hand use with a computer mouse. Slower reading plus response times were also observed as an effect of age. Theories of working memory, processing speed, and resource allocation were discussed as possible explanations as to why these results were observed.

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PREFACE

This research project would not have been possible without the numerous individuals who volunteered their time, knowledge and guidance. In particular, I would like to acknowledge: my committee members; Dr. Malcolm McNeil, Dr. Sheila Pratt, and Dr. J. Scott Yaruss, for their continued input, advice and support; my peer and co-investigator, Emily Hendricks, with whom it was an honor to complete this journey; Neil Szuminsky for serving as the programmer and problem-solver when glitches arose; my professors, for sharing their knowledge throughout my graduate schooling; the participants whose volunteered time made this study possible; my friends, classmates, and faculty at the School of Health and Rehabilitation Sciences for their ongoing assistance (especially with EndNote and Excel) during the entire process; and especially my family for always answering my phone calls without knowing what type of mood I am in. Everything I am you helped me to be. Thank you!

1.0 INTRODUCTION

An issue plaguing all assessment tools is one of task impurity. That is, to what extent does a test produce results that reflect only the construct, process or behavior targeted by that test? The Computerized Revised Token Test (CRTT) was designed to measure language comprehension and processing in persons with aphasia (PWA; McNeil et al., 2015b). In addition to language deficits, this population often presents with physical, perceptual and cognitive limitations which potentially impact CRTT results. Results would then reflect more than just language processing. Test results could also be influenced by cognitive, perceptual and motor changes that naturally occur with aging. Assessment tools intended for use across the lifespan need to consider age-related effects. In addition to the effects of age on test performance, hand use can impact performance. This is especially true for populations that need to use their non-dominant hand, such as those with hemiplegia.

This study assessed the effects of age and hand preference in healthy, normal adults on language comprehension and processing using the CRTT-Reading-Word Fade (CRTT-R-$_{WF}$) test. Simultaneously, a parallel study (Hendricks, n.d.) was performed to evaluate the effects of age and hand preference in the same participants on a battery of reaction time (RT) tasks. These RT tasks are hypothesized to target the primary underlying sensorimotor and cognitive functions required for participation on the CRTT-R-$_{WF}$. The eventual combination of the data collected from these two preliminary studies will help to determine if and/or to what extent these perceptual-motor and cognitive abilities contribute to performance on the CRTT.

1.1 BACKGROUND

A hospital can be an overwhelming place. When a person receives news that their loved one has been diagnosed with aphasia, they may not digest the information immediately after receiving it. It may take some time for family members to understand what that diagnosis means, and the consequences that accompany it. Often times, when a person is not familiar with a medical term they will “Google it” on the Internet. Merriam-Webster defines aphasia as, “a loss or impairment of the power to use or comprehend words usually resulting from brain damage” ("Asphia [Def. 2].", (n.d.)). However, from a clinical perspective, aphasia is much more involved than that. For the purposes of this study, aphasia is a “multimodality physiological inefficiency with verbal symbolic manipulations (e.g. association, storage, retrieval and rule implementation). In isolated form, it is caused by focal damage to cortical and/or subcortical structures of the hemisphere(s) dominant for such symbolic manipulations. It is affected by and affects other physiological information processes to the degree that they support, interact with, or are supported by the symbolic deficits” (McNeil, 1988, p. 693). This is a comprehensive definition that requires dissection to begin to understand the particulars of the disorder. Aphasia alone can occur after damage to either the outer layer of the brain, or structures found in the deeper layers of brain. It can impact any combination of the areas of communication – both understanding and producing language. These domains function on the mental process and symbolic representations used to retrieve and produce language through speech, gesturing or writing. However, rarely do areas of the brain operate in isolation. Additional regions of the brain responsible for other cognitive and executive functions and the areas responsible for language are interdependent. The severity of those signs and symptoms depends on how intricately the structures are intertwined. Since PWA present with deficits that involve spoken and written comprehension and production, it is essential to use a battery of tests that will assess an individual's strengths and weaknesses in all forms of communication. Speech-language pathologists (SLPs) are clinicians who are trained to assess, diagnose and treat patients with speech, language, communication and swallowing disorders across the lifespan. These clinicians especially understand that a dynamic assessment is imperative for the purposes of differential diagnoses and planning interventions so as to best serve their patients. The Computerized Revised Token Test (CRTT) was developed to aid in these functions. The CRTT can be administered via different modalities (auditorily or visually) and includes multiple versions with differential task demands. Therefore, the CRTT has the potential to be a key component of a battery of tests (McNeil et al., 2015b).

1.1.1 Revised Token Test (RTT)

The *Revised Token Test* (RTT) is a diagnostic tool designed to assess the auditory language processing skills of persons with aphasia. Its use has been extended to other populations with language processing problems (e.g., children with specific language impairment and brain injury, adults with learning disabilities and traumatic brain injury, and persons with central auditory processing disorders). The test was constructed to provide information about an individual's ability to process language while keeping word-level content simple and syntactic forms constrained. These constraints allow for stimulus manipulations that stress attention, working memory, and temporal processing mechanisms, thereby allowing for the examination of their impact on the ability to process language. The RTT requires the identification of plastic objects by touching or manipulating them in response to orally presented commands. Test administrators required extensive training on how to administer and score the test. The scoring system of the RTT is complex, as each part of speech in every sentence receives a score between 1 and 15. Scores are assigned depending on both the individual's response accuracy and the need for additional information such as a repeat or cue of the command (Heilman, 2008; McNeil & Prescott, 1978).

More recently, a computerized version of the RTT, the *Computerized Revised Token Test* (CRTT), was created to provide reliable, automated presentations and scoring of auditory stimuli. Instead of touching and manipulating tangible objects, the participant responds to the shapes present on a computer with a mouse or on a touch screen. The computer program also records the real-time, multidimensional scores of each of the subtests. This format diminishes many of the inter- and intra-judge reliability and training constraints associated with the clinician-administered and scored RTT (McNeil et al., 2015a). The auditory, or listening, version of the CRTT (CRTT-L) is almost identical to the original RTT. It consists of the same number of sentences per subtest, total number of subtests, and linguist constraints within each sentence. The CRTT was later expanded to include three CRTT reading (CRTT-R) versions: CRTT-Reading-Full Sentence (CRTT-R-$_{FS}$), CRTT-Reading-Word Constant (CRTT-R-$_{WC}$), and CRTT-Reading-Word Fade (CRTT-R-$_{WF}$). As a result, the CRTT can be used to compare listening and reading skills among PWA (McNeil et al., 2015b). While one study examined the effects of age on CRTT listening performance (Jorgensen et al., n.d.), to date, there have been no studies examining the effects of age on CRTT reading tasks. The Jorgensen et al study used stimuli intensity level adjustments to accommodate hearing loss. The results failed to find age effects on the CRTT-L when the acoustic stimuli were equated for audibility. The study also found that slower response times recorded by older participants did not impede response accuracy. No age effects were observed in the RTT (McNeil & Prescott, 1978). Silagi, Rabelo, Schochat, and Mansur (2015) reported an age effect on subtests 9 and 10 of the RTT, where adults (50-59 years of age) performed significantly better than young-old participants (60-69 years of age) and old-old participants (70-80 years of age). The Indiana University Tokens Test (IUTT) is an alternative paper and pencil token test designed to test listening comprehension and executive function of two- and three- step commands. The IUTT requires participants to respond to orally presented commands by pointing to shapes of various colors and sizes. The IUTT also relies on a multi-dimensional scoring system, but is much less complex than that of the RTT. Correct scores receive two points. If the response is incorrect on the first try, the command is repeated. A correct response after a repeated command receives a score of one. An incorrect response after a repeat receives a score of zero (Unverzagt, 1999). Using the IUTT, Snitz et al. (2009) did find an age effect, as well as an effect of gender, education and race. The current study seeks to compare the CRTT-R-$_{WF}$ scores across two different age groups. The CRTT-R-$_{WF}$ is discussed in greater detail in Chapter 2.2.1.

1.1.2 Aging Theories on Cognition and Language

Aging is accompanied by neuroanatomical, neurophysiological and cognitive changes. These changes may be present in healthy older adults as a result of normal aging, as well as a consequence of disease that may be associated with aging (Birren & Woodruff, 1983). It is important to understand what comprises cognition, how it affects language, and how function change with age. Language is a symbolic system that is governed by rules and regulations. When the system is arranged in specific patterns, it can be used to express thoughts. The language system is comprised of five domains: phonology (sounds), morphology (words), syntax (sentences), semantics (meaning), and pragmatics (within a social context). Thoughts can be expressed through a variety of modalities, including speech, writing and gestures. Cognition includes cognitive processes (attention, perception, memory, organization, executive functioning) and the neurological systems that operate them. Many of these processes are involved in producing or understanding language. When either the cognitive processes that support language or the components of language are primarily or secondarily impaired, an individual may have functional deficits in behavioral self-regulation, social interactions, and learning and academic performance (American Speech-Language-Hearing Assocication, 2005).

Current research provides conflicting evidence as to when age-related cognitive declines begin in healthy adults. Some research has shown that after cognitive efficiency peaks during a person's mid-twenties, there is a gradual decline of functioning until they enter their fifties. At that age, the rate of decline may increase (Thomas, Dave, & Bonura, 2010). Others have found that age-related cognitive declines vary across abilities (Salthouse, 2004), but can begin in healthy, educated adults in as early as their third or fourth decade (Salthouse, 2009).

Research involving the effects of aging on cognition is vast and has been explored by researchers within several disciplines. Burke and Shafto (2008) discuss six theories of cognitive aging and their relation to language processing. The *resource theory* is centered around the notion that a person has a restricted quantity of resources that is shared by psychological processes that occur at or around the same time. The limited availability of resources constrains the system's ability to encode and decode information accurately and efficiently. Age-related declines in resources cause certain operations to be more difficult than others, draining the resources available for these "simpler" cognitive tasks in older adults more so than in younger adults. Though sometimes controversial, the term "resources" is often considered to include some of the previously mentioned cognitive processes, such as processing speed, working memory, attention and inhibition.

More recent research has shifted towards an attempt in isolating underlying mechanisms that relate to the resource. Working memory is often considered an aspect of short-term memory that is used to store information that is currently in use. Working memory is thought to be involved in the receiving and encoding of information, the retrieval of previous information, and the manipulation of that information. Finally, the manipulation then allows a person to perform the desired action. If demands differentially placed on retrieval, storage, or computation are too great, there will be a cost to other functions. For example, if there are a large number of demands placed on the retrieval of information, there could be less cognitive resources available to process incoming information (Siegel, 1994). Therefore, *working memory theories* are shaped by models that assume working memory has both storage and processing responsibilities. Working memory theories differ from resource theories when considering where limitations occur. Proponents of the resources theory believe that verbal working memory is constrained by the language system as a whole, whereas working memory theorists consider working memory to be its own component limited by its own capacity. In working memory theories associated with cognitive aging, aging decreases working memory's storage capacity, making it more difficult for older adults to understand and produce complex linguistic information (Burke & Shafto, 2008). As previously mentioned, the sentences within the CRTT are constructed with the specific intent of constraining word-level and syntactic forms. In the full-sentence reading version of the

CRTT, these constraints limit the demands placed on working memory. The CRTT-R-$_{WF}$, unlike the other reading versions, prevents participants from re-reading previously presented stimuli. One could then argue that the CRTT-R-$_{WF}$ increases the cognitive demands of short-term and working memory of the test taker when compared to other reading versions.

Other theories are based on the idea that an inhibitory process regulates attention and working memory. This process is believed to prevent unnecessary information from distracting a person from the cognitive tasks to which they are attending. The *inhibition deficit theory* claims that these inhibitory processes deteriorate with age, which could impact many cognitive abilities, including language comprehension and production. For example, older adults may be more easily distracted by competing noise when reading or listening (Burke & Shafto, 2008; Hasher & Zacks, 1988).

The *transmission deficit theory* proposes that there are connections among representational components within the language system that are activated and strengthened by consistent use. In this theory, aging collectively weakens the strength of these connections. This hypothetical decrease in connection strength reduces the ability to activate already constructed representations, resulting in deficits across cognitive processes as opposed to a specific one. The functional impact that these deficits have on language depends on the design of the symbolic representations. Language components that have multiple connections may be less susceptible than units that only have one connection (Burke & Shafto, 2008).

The *sensory/perceptual deficit* (degraded signal) *theory* states that aging yields declines in sensory and perceptual processes. Declines in these areas allow partial or inaccurate information to alter phonological and orthographic codes. These alterations impair an older adult's ability to correctly select words and other components required for computations.

Although it is the least developed theory, it hypothesizes that equalizing language perception across ages would eliminate word recognition deficiencies (Burke & Shafto, 2008). This theory appears to be consistent with the results of Jorgensen et al. (n.d.).

Perhaps the most investigated theory of aging is the *general slowing theory.* This theory argues that declines in cognitive performance as an effect of age are due to a global slowing of the hypothesized underlying mechanisms, most commonly referred to as processing speed. Declines seen in perceptual-motor speed further support this theory, proposing that older adults process information less efficiently, and are therefore slower to perform perceptual-motor tasks (Salthouse, 1996). Such tasks have shown similar age-related variance as language tasks (Burke & Shafto, 2008; Salthouse, 1985). This theory has been used to explain why older adults have more difficulty comprehending faster speech than younger adults (Wingfield, 1996).

Because of the interactive nature between language and cognition, it is difficult to isolate the processing level of each language domain. Aspects of language production as an effect of age were deemed outside the scope of this paper, as language comprehension more closely aligns with the requirements of reading comprehension. The effects of aging on reading comprehension is described in more detail in the following section.

1.1.3 Aging and Reading Comprehension

The assessment tool used in this study requires the comprehension of written text. It is therefore important to consider how age impacts reading comprehension. It is difficult to assess how aging influences comprehension abilities, as many cognitive processes come into play when assessing reading comprehension. In order to comprehend a sentence, one must first recognize the words through whole word recognition or through grapheme to phoneme conversion, build relationships among the words, and associate a meaning to the sentence in its entirety (DeDe & Flax, 2016). Older adults have been observed to take longer to reach a level of comprehension comparable to younger readers. This could suggest that changes in cognitive abilities, as opposed to deficits with linguistic knowledge account for the comprehension reductions (DeDe & Flax, 2016). Supporting this claim, when comparing older and younger adults, Hannon and Daneman (2009) reported declines in older participants' ability to remember new information within a text, make inferences about the new information, access prior knowledge in long-term memory, and integrate prior knowledge with the new information.

Working memory is an important, though not the only, cognitive process that is engaged during reading. During reading, one component of working memory aids in the processing of incoming words and sentences and storing them long enough so that longer units can also be comprehended. Another part of working memory is retrieving prior knowledge of grammatical rules and word meanings (Siegel, 1994). Working memory, as measured by digit span and reading span tasks, has been shown to decline with age (Carpenter, Miyake, & Just, 1994). If these tasks measure performance of the same working memory processes during sentence reading, limitations of working memory could explain age-related changes in language processing. Kemper and Herman (2006) reported that syntactic processes rely on the same working memory resources that are also allocated for non-syntactic tasks. Their results support a single-resource model of working memory. That is, increases in sentence complexity and decreases in working-memory capacity (from either an imposed memory load or secondary to aging) make online language processing more difficult. Reduced online processing can negatively impact overall comprehension and recall (Kemper & Herman, 2006).

Some areas of language, such vocabulary size, are relatively well maintained throughout the lifespan. Deficits in language as an effect of age are commonly seen in word retrieval and comprehension of spoken language. This is especially true with increased rate of speech and background noise. Whether the decrease in comprehension is due to sensory deficits (i.e. hearing loss) or cognitive deficits is difficult to determine (Clark-Cotton, Williams, Goral, & Obler, 2007).While Jorgensen et al. (n.d.) examined age effects on the listening version of the CRTT (CRTT-L), no studies comparing CRTT-R accuracy or speed of performance as an effect of age have been conducted. Reading times are often a dependent variable in comprehension studies, as they are believed to provide insight into task requirements during reading. When assessing the reading times on a word-by-word basis, which is similar to the word-by-word presentation of the CRTT-R-$_{WF}$, Stine (1990) older adults paused longer at clause boundaries than younger adults. Pauses at the end of a sentence are believed to allow for "wrap-up" operations, whereby a reader ensures that there are no inconsistencies within a sentence and syntactic integration can occur (Just & Carpenter, 1980). Perhaps older adults did not pause at the end of the sentence because working memory limitations prevented them from maintaining the information long enough to reach the end of the sentence. Instead, limitations in working memory capacity forced older adults to pause within the sentence at clause boundaries (Stine, 1990)

1.1.4 Cognitive Aging, Motor Performance, and Hand Preference

An important aspect to consider in the understanding of sentence comprehension is that essentially all language comprehension measures require both the processing of auditory or visual stimuli and a motor response. The CRTT version used in this study is one such measure. Therefore, it is crucial to explore cognitive aging effects on sensorimotor performance.

Although an interdependence of cognitive aging and declines in motor performance has been mentioned, the links between cognitive aging, motor functioning and motor learning have only been suggested rather than demonstrated (Ren, Wu, Chan, & Yan, 2013; Yan, Aberneth, & Li, 2009). Indeed, many of the previously mentioned cognitive processes needed for language also are needed for normal motor performance. One hypothesized explanation of the link between cognitive aging and motor performance is a reduction in attention as an effect of aging. Attention can be considered as the ability to assign mental resources to a specific target and its associated, and defining elements such as location, orientation and dimension in the case of visual tasks. The amount of attention a person is able to devote to a task or target has been shown to decline with age (Ren et al., 2013). Response speed in tasks requiring participants to find specific targets, has been shown to be slower in older adults (Hommel, Li, & Li, 2004). Similar perceptual-motor functions are required in the CRTT. Another task demand in the performance of the CRTT is related to the hand used for response selection. Due to neurological deficits, some individuals for whom the test is intended are required to use their non-preferred hand. It is therefore imperative that such effects on performance be evaluated. Additionally, it is essential to evaluate whether any effects of aging are equivalent across preferred and non-preferred hands. While little research to date has been published on the effects of hand use on CRTT performance, McNeil et al. (2009) did report a nonsignificant main effect for hand on the CRTT-L when comparing touchscreen versus computer mouse access mode, left versus right hand use, and individuals with aphasia versus normal adult healthy controls.

Hand preference, the habitual use of one hand over the other, has been established as an innate human asymmetry (Peters, 1981; Triggs, Calvanio, Levine, Heaton, & Heilman, 2000). Most individuals demonstrate a hand preference when participating in activities that require both skilled and unskilled performance. Research has supported this notion by suggesting an interrelation between handedness and the allocation of attention (Song & Bédard, 2013); a greater number of attentional resources being distributed to the individual's non-dominant hand when performing fine motor activities. A large body of research has investigated the differences between right- and left-handed participants on cognitive and motor tasks. However, few studies have compared preferred and non-preferred hand differences within an individual. Kourtis and Vingerhoets (2016) identified both handedness and degree of handedness (i.e. how consistently a person uses the preferred hand) as important components for determining where and to what extent attention is allocated to hand movement. Results suggest that the amount of use has more of an impact on movement control than hand dominance.

1.2 EXPERIMENTAL QUESTIONS AND HYPOTHESIS

As the average age of the population continues to rise in the United States, it is imperative to gain a better understanding of how age, language comprehension, and motor performance are related. This is relevant for clinicians who manage adults with communication deficits, where it is likely that language assessments may have to be completed by many individuals using their non-dominant hand following a stroke, traumatic brain injury or degenerative disease. The primary goal of this study was to explore the effects of aging and hand dominance on CRTT performance in healthy adults. The following questions were investigated:

1. Is there a significant ($p \leq .05$) difference in CRTT-R-$_{WF}$ mean scores between younger and older groups?

2. Is there a significant ($p \leq .05$) difference in CRTT-R-$_{WF}$ mean scores between right and left hand used?
3. Is there a significant ($p \leq .05$) difference in CRTT-R-$_{WF}$ efficiency scores between younger and older groups?
4. Is there a significant ($p \leq .05$) difference in CRTT-R-$_{WF}$ efficiency scores between right and left hand used?
5. Are there significant ($p \leq .05$) interactions between groups and hand used for the mean score or for the efficiency score?

Secondary questions were also addressed. These include:

1. Is there a significant ($p \leq .05$ difference in CRTT-R-WF reading plus response times between right and left hand used?
2. Is there a significant ($p \leq .05$) difference in CRTT-R-WF reading plus response times between younger and older groups?
3. Are there significant ($p \leq .05$) interactions between groups and hand used for the reading plus response times? With sex as a covariate?

Given the background information on working memory demands and cognitive slowing with age, it was predicted that the older normal healthy control participants would evidence significantly lower mean and efficiency scores on the CRTT-R-$_{WF}$ than the younger age group. Little research has been done on the effects of hand preference in language tasks that require behavioral responses. However, it was assumed that participants would be less familiar and motorically unpracticed using a computer mouse with their non-preferred hand. This unfamiliarity was predicted to result in more attention being directed towards the motor components required for accurately moving the mouse, subsequently slowing performance. Therefore, it was predicted that the non-preferred hand would result in a longer response times, negatively influencing a participant's efficiency score, but not their mean score.

2.0 METHODS

2.1 PARTICIPANTS

Sixty-four healthy, normal adults completed this study. Participants were divided into two groups with 16 males and 16 females per group in order to balance differences across tasks, especially during the RT tasks (Dykiert, Der, Starr, & Deary, 2012). Group 1 (young) consisted of individuals recruited between the ages of 20-35 years (mean: 23.8 years; range 20-32 years). Group 2 (old) included individuals recruited between the ages of 65-79 years (mean: 71.8 years; range 65-78 years).

Sixty-two participants self-identified as Caucasian; one participant in Group 1 self-identified as African-American, and one participant in Group 2 identified as Latino American (See Appendix A, Table 10 and Table 11). All participants reported English as their native language. Only one participant identified as bilingual. Appendix A contains additional sex, age, race, education level, and occupation demographic information for each participant.

The University of Pittsburgh Institutional Review Board approved this study (PRO16030419). A parallel study was simultaneously conducted that examined the effects of age and hand used on reaction time (RT) performance using the CRTT-RT battery. These RT tasks are described in Appendix B. Participants completed both the CRTT-R-$_{WF}$ and CRTT-RT, with their preferred and non-preferred hands, in random order during a single session. Language processing and RT data was then separated and analyzed by the appropriate researcher for their respective study. Verbal and written informed consent was obtained from all participants prior to initiating the study protocol. Upon completion of the study, each participant received $15.00 compensation. Participants were recruited via flyers approved by the University of Pittsburgh and through communication among participants.

2.1.1 Inclusionary Criterion and Preliminary Procedures

Research in cognitive aging suggests variations of cognitive processing skills as an effect of aging, such as processing speed, attention, perception and working memory (Dennis & Cabeza, 2008; Salthouse, 2004, 2009; Thomas et al., 2010). This study's criteria for determining a "healthy, normal adult" accepted these age-related differences.

Participants qualified for this study using six criterion measures: (1) Participants completed a self-reported questionnaire (see Appendix C) adapted from Heilman (2008) that provided qualitative information regarding their native language, years of education and occupational history (see Appendix A, Table 10 and Table 11). Participants were excluded from this study if they self-reported a medical, psychological, or other cognitive conditions that could impact performance (e.g. stroke, alcoholism, depression, Parkinson's Disease, Alzheimer's Disease, etc.) and/or physical impairments that would limit the use of their hands, wrists, or arms during the protocol; (2) All participants completed a vision screening using the Reduced Snellen Chart (Snellen, 1862) with a visual acuity of 20/40 or better, corrected or uncorrected; (3) The *Clinical Evaluation of Fundamentals 5th Edition* (CELF-5) (Wiig, Semel, & Secord, 2013) reading subtest for ages 13-21 year was used to assess reading comprehension. Participants read two passages and responded to orally presented reading comprehension questions. Participants were required to achieve a combined raw score of 17 or greater (see Appendix A, Table 14 and Table 15); (4) The intermediate/delayed story retell task from the *Arizona Battery of Communication Disorders of Dementia* (ABCD; Bayles & Tomoeda, 1993) was used to screen immediate and delayed memory capabilities. Participants were required to achieve a ratio (delayed recall / immediate recall) of .70 or greater (see Appendix A, Table 16 and Table 17); (5) Participants were required to achieve a scaled score of 8 or greater when compared to age-matched normative data the Digit Span Forward and Backward subtest of the *Wechsler Adult Intelligence Scale – Fourth Edition* (WAIS-IV; Wechsler, 2008) (see Appendix A, Table 18 and Table 19); (6) Participants were required to pass the Fade Reading Pretest of the CRTT-R-$_{WF}$. By doing so, they demonstrated their ability to accurately identify "big/little," "circle/square," and "black/white/red/green/blue." This pretest also ensured appropriate vision, color discrimination, and the ability to accurately move and select the stimulus from the screen using the computer mouse; all of which are required functions and abilities to complete the tasks.

Two other preliminary procedures were included in the study protocol as descriptive measures: (1) The Language Experience and Proficiency Questionnaire (LEAP-Q; Marian, Blumenfeld, & Kaushanskaya, 2007) was completed to obtain subjective reports of each individual's language experiences. The LEAP-Q allowed participants to indicate the percentage of current exposure to each language they reported knowing, as well as the percentage of time they choose to read and speak in each language (see Appendix A, Table 20 and Table 21); (2) The Edinburgh Handedness Inventory (Oldfield, 1971) was used to identify participant hand dominance on various activities (see Appendix A, Table 22 and Table 23; Appendix D). Participant also reported hand preference during computer-related activities and estimated their computer use in hours per day on the Subject History Form (see Appendix A, Table 12 and Table 13; Appendix C).

One participant did not meet the self-reported medical conditions criterion, and was therefore ineligible for participation in the study. That participant was not compensated.

2.2 PROTOCOL

Every participant completed the CRTT-R-$_{WF}$ and the six RT tasks from the CRTT-RT Battery. Each participant completed these procedures twice, once with their left hand and once with their right hand. This resulted in four task conditions per participant: CRTT-R-$_{WF}$ Right, CRTT-R-$_{WF}$ Left, RT Right Hand, and RT Left Hand. The order of completion of these four tasks was randomized for each participant to minimize possible order effects (see Appendix A, Table 24). Subtests within each task were not randomized in order to conform to the original test designs. The components of the CRTT-R-$_{WF}$ and the data collection for these tasks are discussed in greater detail in the following sections. The CRTT-RT battery is detailed in Appendix B. Two different laptop computers were used during administration of the primary dependent measures (CRTT-R-$_{WF}$ and CRTT-RT battery). Both computers used standard, wired mouse (Staples Wired Mouse, Model # 23415). Data was collected in quite laboratories or office spaces within Forbes Tower. Data collected outside of Forbes Tower occurred in a participant’s private quarters, in a room free of distractions, with no individuals present except for study personnel and the participant.

2.2.1 Computerized Revised Token Test – Reading – Word Fade

The participants were administered the 100-item, word-fade reading comprehension version of the CRTT (CRTT-R-$_{WF}$), which is comprised of 10 sentences for each of the 10 subtests. As in the original RTT, the CRTT includes 10 or 20 tokens (alternating between subtests) that participants are required to touch or move in response to imperative sentences. Commands were presented in text at the bottom of the computer screen in a word-by-word, self-paced moving window. That is, the one word appears for every mouse-click, with the previous word disappearing with onset of each new word (McNeil et al., 2015b). Participants must hold each part of speech in their short-term memory, comprehend the sentence in its entirety, and respond accordingly. The tokens appear on the screen after the participant clicks the mouse after reading the final word in the sentence. Unlike other reading versions of the CRTT, this method of presentation prevents participants from re-reading previously presented stimuli and allows the measurement of reading times for each word. These times are analyzable to better identify the point of increased processing demands within each sentence. The commands are comprised of combinations of two actions (touch, put), two shapes (circle, square), two sizes (big, small), five colors (black, white, red, green, blue), 10 prepositions (above, before, behind, below, beside, by, in front of, on, next, under) and five different adverbial clauses (instead of, unless, either, if there is, if you have not) (McNeil et al., 2015b; McNeil & Prescott, 1978). Figure 1 displays the 20 tokens seen during Subtests II, IV, VI, VIII, and X. The remaining five subtests use only the 10 big tokens. Subtests systematically increase in syntactic complexity. The subtests differ from one another in sentence length and syntactic complexity. They also vary from simple one-part commands (e.g. “touch the red circle” or “touch the little red circle”) to compound two-part commands (e.g. “touch the red circle and blue square” or “touch the little red circle and the big blue square"). Each command is assigned different scores based on the responsiveness, accuracy, promptness, efficiency, and completeness of the patient's response (see **Error! Reference source not found.**). Each lexical item within the command is scored separately on a multidimensional scoring system, described in the next paragraph. Item and mean scores, efficiency scores, reading times, response times, and overall times can be calculated for parts of speech, each sentence, each subtest, and the test overall.

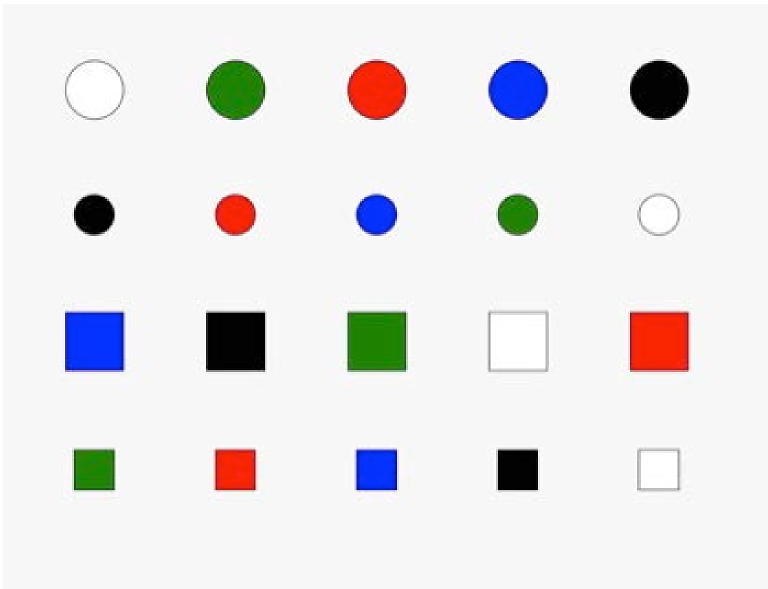

Figure 1: The Computerized Screen of the 20 CRTT Tokens (McNeil et al., 2015a)

The CRTT uses a multidimensional scoring system, similar to that of the RTT. Table 1 displays the RTT scores and descriptions (Eberwein, Pratt, McNeil, Szuminsky, & Doyle, 2008; McNeil et al., 2015a). It is important to note that an incorrect response to each part of speech (e.g. touching a circle for a square) yields a score of 7 for that noun, as opposed to a score of 0. If a patient fails to respond after a repeat (score of 9) and a cue (score of 8), they receive a score of

1 (the lowest score possible). Each of the 10 subtests contains 10 uniform commands of equal sentence length and linguistic complexity (McNeil & Prescott, 1978).

Table 1: CRTT Scoring Categories – Adaption (Eberwein et al., 2008)

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

In instances where a “1” appeared in the generated score report, the command was considered to be a program error as every participant was observed to respond to every command. The values within the entire command were therefore removed from the subtest and overall scores and averages. In these situations, subtests then contained 9 commands. Score reports were generated from the CRTT program databases. On occasion, a score was reported twice, and the subtest scores were calculated across 11 commands. Instances where scores were repeated were also deemed a program error. The values within the entire command were again removed. However, once repetitions were removed, the subtest then contained 10 uniform commands. A total of 6 commands were removed from a grand total of 6,400 commands within the database (see Table 2).

Table 2: Total Number of Commands Removed Per Subtest (Combined Right and Left Hands)

Total Number of Commands Removed Per Subtest										
	Subtest I	Subtest II	Subtest III	Subtest IV	Subtest V	Subtest VI	Subtest VII	Subtest VIII	Subtest IX	Subtest X
Repetitions			9		1					
Scores of 1				2	1	1	1	1		

An additional scoring feature within the CRTT that was not possible with the RTT is the efficiency score (ES). The ES is a value that incorporates the accuracy and time of the test participant's responses. The ES can be calculated for individual commands, subtests, and for the entire test. For the purposes of this study, the ES was obtained for each overall subtest and for the entire test. The ES is calculated by multiplying the CRTT score by the ratio of length of time (t), in seconds, that it takes to complete the command to the maximum time (mt) allowed for the command (ES = CRTT [t/tm]). The default *mt* value is set at 30 seconds (McNeil et al., 2015a).

2.2.2 Computerized Revised Token Test – Reaction Time Battery

As previously stated, participants also completed a battery of simple and choice reaction time tasks with both their preferred and non-preferred hand. While the CRTT assesses language processing and comprehension, there are perceptual-motor demands that potentially influence test scores. The Reaction Time (RT) tasks are designed to assess non-linguistic, perceptual-motor and cognitive skills at various levels of processing (e.g. motor speed, movement control, response selection mapping, response inhibition, and vigilance). The difficulty of each task increases with each subtest. Data collected from the Computerized Revised Token Test – Reaction Time (CRTT-RT) battery was analyzed in a parallel study by (Hendricks, n.d.) Refer to Appendix B for a description of each task, and to Table 25 for the combined task totals by age group and by hand used.

3.0 RESULTS

3.1 STATISTICAL ANALYSIS

The mean CRTT-R-$_{WF}$ Scores and CRTT-R-$_{WF}$ Efficiency Scores were analyzed using two separate 2-way ANOVAs with repetition on hand (group x hand). The test-wise alpha was controlled at the $p = \leq .05$ level. Secondary analyses also were conducted to look at reading plus response time. It was assessed with a 2-way ANOVA with repetition on hand (group x hand). The reading plus response times also were displayed on a Brinley plot to illustrate group reading/response slowing for each hand, across subtests. Additional post-hoc testing was completed with paired *t*-tests and univariate ANOVAs.

3.1.1 Mean CRTT-R-$_{WF}$ Scores

The ANOVA for the mean CRTT score data showed a significant within-subjects main effect for Hand, $F(1,62) = 75.520$, $p = 2.5326^{-12}$, *partial* $\eta^2 = .549$, with the left hand mean scores significantly lower than the right hand for both groups. Between group comparisons revealed a statistically significant effect of Age, $F(1,62) = 54.841$, $p = 4.2615^{-10}$, *partial* $\eta^2 = .469$, with the younger group's mean scores being significantly higher than the scores for the older group. In addition, a statistically significant interaction was found between Group and Hand, $F(1,62) = 11.722$, $p = .0011$, *partial* $\eta^2 = .159$, with the older group showing a larger reduction in mean score with their left hand. Figure 2 depicts the average mean scores and standard deviation by Age and Hand. Significant differences are illustrated with a bracket above the bars, and the asterisk represents the source of the significant interaction. The data used to create the graph also can be found in Table 3 and Table 4.

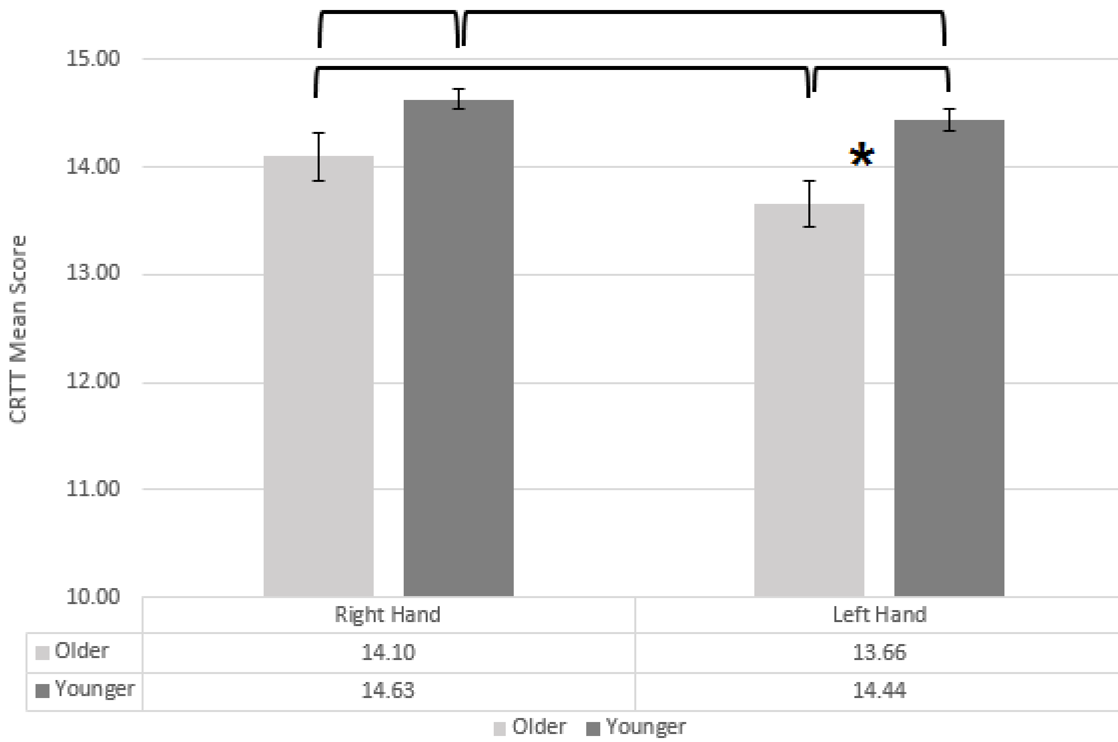

Figure 2: Overall Mean CRTT-R-$_{WF}$ Scores by Age and Hand

Table 3: Older Group Average Mean CRTT-R-$_{WF}$ Scores and Standard Deviations by Subtest and Hand

	Subtest										
	I	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**Overall**
Right Hand AVE	13.99	14.44	13.98	13.77	13.83	13.96	14.11	13.79	14.48	14.64	14.10
Right Hand SD	0.52	0.54	0.71	0.87	0.77	0.78	0.53	0.71	1.09	0.44	.50
Left Hand AVE	13.19	13.73	13.36	13.47	13.23	13.45	13.58	13.40	13.80	14.64	13.66
Left Hand SD	0.49	0.64	0.96	0.76	0.77	0.97	0.67	0.93	0.51	0.39	0.49

Table 4: Younger Group Average Mean CRTT-R-$_{WF}$ Scores and Standard Deviations by Subtest and Hand

	Subtest										
	I	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**Overall**
Right Hand AVE	14.91	14.93	14.76	14.74	14.28	14.32	14.46	14.31	14.73	14.87	14.63
Right Hand SD	0.15	0.12	0.43	0.48	0.38	0.51	0.36	0.37	0.32	0.24	0.16
Left Hand AVE	14.39	14.80	14.38	14.61	14.01	14.14	14.14	14.26	14.79	14.84	14.44
Left Hand SD	0.47	0.22	0.45	0.43	0.73	0.63	0.53	0.39	0.22	0.26	0.24

3.1.2 CRTT-R-$_{WF}$ Efficiency Scores

The ANOVA for Efficiency Score showed a significant main effect for Hand, F(1,62) = 113.489, $p = 1.2228^{-15}$, *partial* $\eta^2 = .674$, with the left hand Efficiency Scores being significant lower than the right hand for both groups. A significant difference also was observed between Groups, F(1, 62) = 82.319, $p = 5.5724^{-13}$, *partial* $\eta^2 = .570$, with the older group demonstrating significantly lower efficiency scores than the younger group. In addition, a statistically significant interaction was found between Group and Hand, F(62, 1) = 6.287, $p = .015$, *partial* $\eta^2 = .092$, with the older group showing a larger reduction in Efficiency Score with their left hand. Figure 3 depicts the average efficiency scores and standard deviation by Age and Hand. Significant differences are again illustrated with a bracket above the bars and the asterisk represents the likely source of the significant interaction. The data used to create the graph can be found in Table 5 and Table 6.

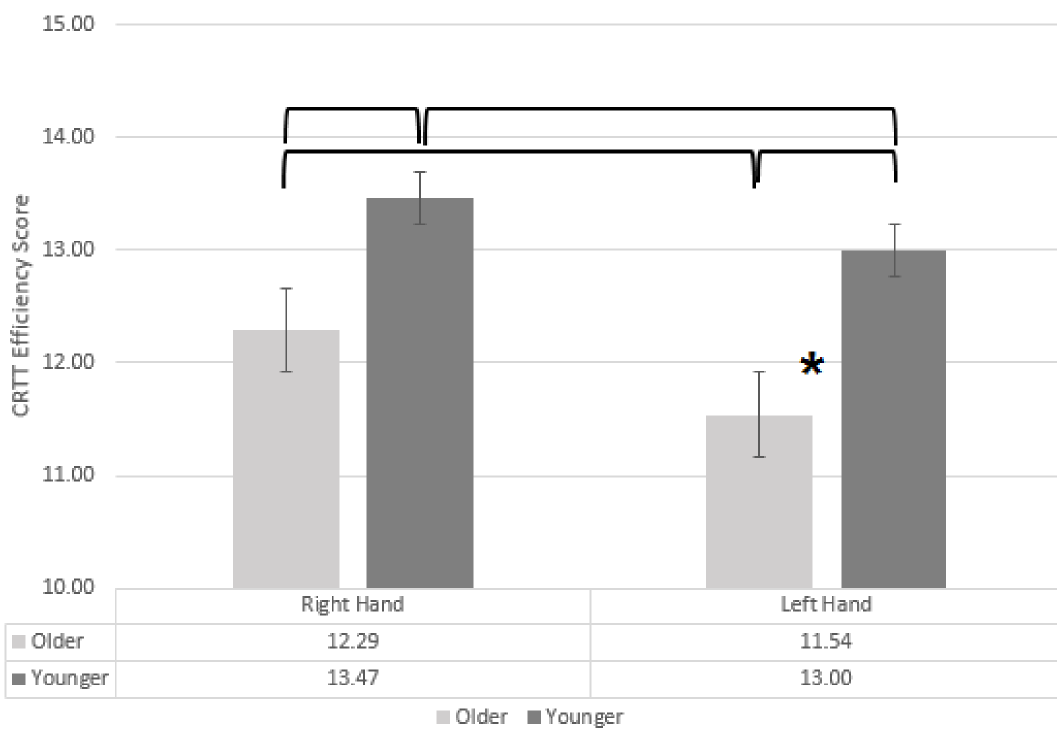

Figure 3: Overall Efficiency CRTT-R-$_{WF}$ Scores by Age and Hand

Table 5: Older Group CRTT-R-WF Average Efficiency Scores and Standard Deviations by Subtest and Hand

	Subtest										
	I	II	III	IV	V	VI	VII	VIII	IX	X	Overall
Right Hand AVE	13.06	13.40	12.29	11.80	11.47	11.36	11.78	11.11	13.16	13.48	12.29
Right Hand SD	0.66	0.75	0.93	1.11	1.28	1.19	0.88	1.20	1.32	0.70	0.77
Left Hand AVE	11.85	12.41	11.22	11.05	10.57	10.50	10.94	10.51	13.09	13.28	11.54
Left Hand SD	0.74	0.89	1.09	1.17	1.15	1.32	1.16	1.36	0.81	0.69	0.84

Table 6: Younger Group CRTT-R-WF Average Efficiency Scores and Standard Deviations by Subtest and Hand

	Subtest										
	I	II	III	IV	V	VI	VII	VIII	IX	X	Overall
Right Hand AVE	14.29	14.22	13.67	13.56	12.67	12.62	12.99	21.62	13.89	14.11	13.47
Right Hand SD	0.20	0.19	0.49	0.50	0.57	0.76	0.50	0.52	0.51	0.36	0.28
Left Hand AVE	13.59	13.91	12.98	13.04	12.18	12.04	12.33	12.27	13.79	13.9	13.00
Left Hand SD	0.54	0.28	0.51	0.47	0.78	0.79	0.61	0.57	0.37	0.37	0.36

3.2 SECONDARY ANALYSES

3.2.1 Reading Plus Response Times

As a secondary analysis, overall reading plus response times (i.e., the time taken from the onset of the command signaled by the appearance of a stoplight, to the participant's selection of a token on the screen with a mouse click), were investigated. This measure most strongly parallels the reaction time measures that were examined by Hendricks (n.d.). There was a statistically significant main effect for Group, F(62,1) = 116.176, $p = 7.6053^{-16}$, *partial* $\eta^2 = .652$, with the older group performing significantly slower than the younger group. A statistically significant main effect also was observed for Hand, F(62, 1) = 10.877, $p = .002$, *partial* $\eta^2 = .149$, with the left hand performing significantly slower than the right hand for both groups. There was no significant Group by Hand interactions. Figure 4 illustrates the average Reading Plus Response times (measured in milliseconds) and standard deviations by Age and Hand. Significant differences are illustrated with a bracket above the bars. The data used to create this figure can be found in Table 7 and Table 8.

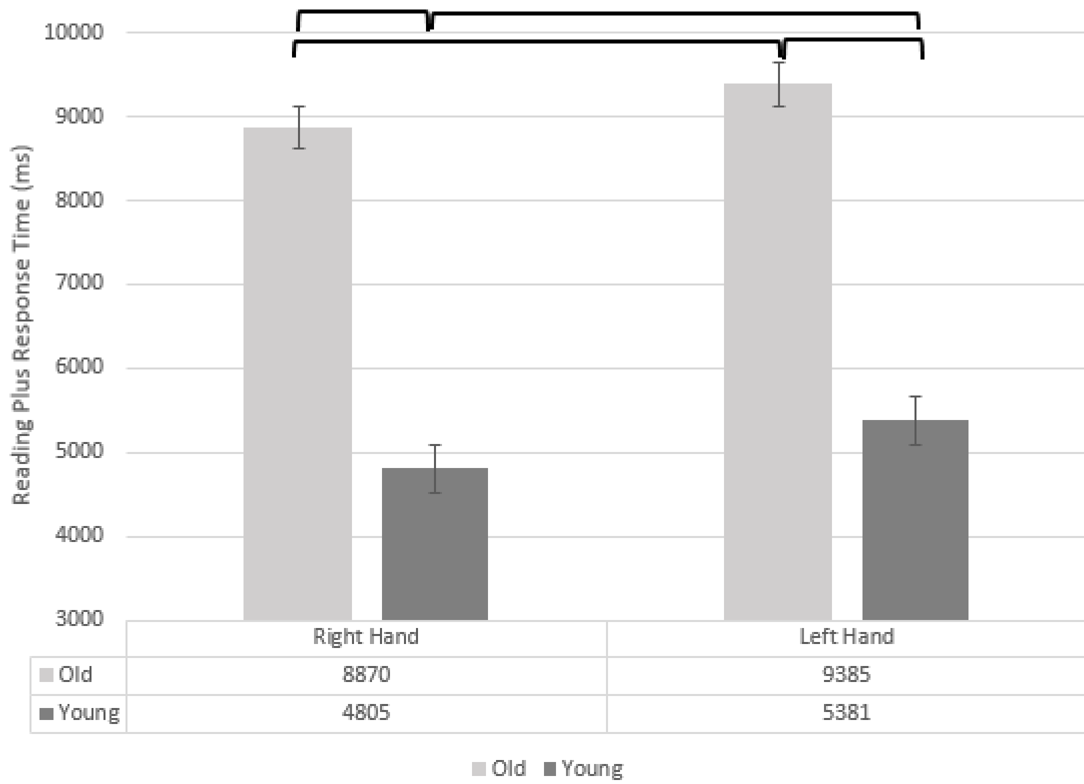

Figure 4: Overall CRTT-R-$_{WF}$ Reading Plus Response Times (msec) by Age and Hand

Table 7: Older Group CRTT-R-$_{WF}$ Average Reading Plus Response Times (msec) and Standard Deviations by Subtest and Hand

	Subtest										
	I	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**Overall**
Right Hand AVE	4652	5233	7573	9898	8675	10774	10675	12879	9206	9129	8869
Right Hand SD	1065	1276	2267	3213	2435	2826	2789	3842	3045	2076	2180
Left Hand AVE	6222	5881	8050	10136	9195	11269	11112	13015	9374	9589	9384
Left Hand SD	2041	1571	1966	2777	2527	2706	2321	3325	1775	1919	1920

Table 8: Younger Group CRTT-R-$_{WF}$ Average Reading Plus Response Times (msec) and Standard Deviations by Subtest and Hand

	Subtest										
	I	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**Overall**
Right Hand AVE	2460	2923	3868	4995	4760	6209	5389	6680	5311	5452	4805
Right Hand SD	487	614	853	1099	1272	1724	1470	1643	1554	1260	1091
Left Hand AVE	3823	3440	4525	5677	5153	6472	6033	7039	5697	5941	5380
Left Hand SD	3802	659	868	1193	1093	1238	1289	1650	1211	1413	1040

A 3-way ANOVA (Group x Hand x Subtest) was then performed on the Reading Plus Response Time data. A statistically significant main effect was observed for Hand, $F(1,62) = 10.877$, $p = .002$, *partial* $\eta^2 = .149$, with the left hand performing significantly slower than the right hand. A significant main effect for Subtest also was observed, $F(1,62) = 449.800$, $p = 4.1033^{-30}$, *partial* $\eta^2 = .879$, with all subtest scores differing from one other, except for Subtests 1 and 2, 4 and 9, 4 and 10, and 9 and 10. Additionally, there was a main effect observed by Group, $F(1,62) = 116.176$, $p = 7.6053^{-16}$, *partial* $\eta^2 = .652$, with the older group performing significantly slower than the younger group. Two 2-way interaction was observed of Subtest by Group, $F(1,62) = 28.136$, $p = .000002$, *partial* $\eta^2 = .312$, and for Subtest by Hand, $F(1,62) = 5.448$, $p = .023$, *partial* $\eta^2 = .081$. There was no 2-way interaction of Hand by Group. There were no 3-way interactions. These patterns are similar to those seen in the 2-way ANOVAs.

To account for the significant Subtest by Hand interaction, paired *t*-tests were computed to test for Hand differences in Reading Plus Response Times per subtest. Significant differences were found for Subtests I, II, III, VII, and X but not for IV, VI, VIII, and IX. False Discovery was used to adjust the alpha for multiple comparisons. Refer to Table 9 for *t*-values and *p*-values. Significant values are indicated with a bolded asterisk.

Table 9: Paired *t*-tests to Examine Subtest by Hand Effects

Paired *t*-Test (Subtest x Hand)			
Subtest	*t*-value	*df*	*p*-value
I	3.796	63	**.000333***
II	4.225	63	**.000078***
III	3.098	63	**.003***
IV	1.772	63	.081
V	2.174	63	.033
VI	1.883	63	.064
VII	2.711	63	**.009***
VIII	.864	63	.391
IX	.842	63	.403
X	2.549	63	**.012***

To account for the Subtest by Group (Subtest x Group) interaction, univariate comparisons of groups were conducted for each subtest. The older adults had significantly slower times than the younger adults on all of the subtests, but the size of the effects varied across the subtests. This variance likely contributed to the interaction. False Discovery was used to adjust the alpha for multiple comparisons. Figure 5 illustrates the mean Reading Plus Response Times by Group for each Subtest. Significant differences are identified with a bracket above the bars, and the effect size (*partial* η^2) is written above the significance brackets. It should be noted that the effect sizes varied from .192 for Subtest I to .608 for Subtest VIII.

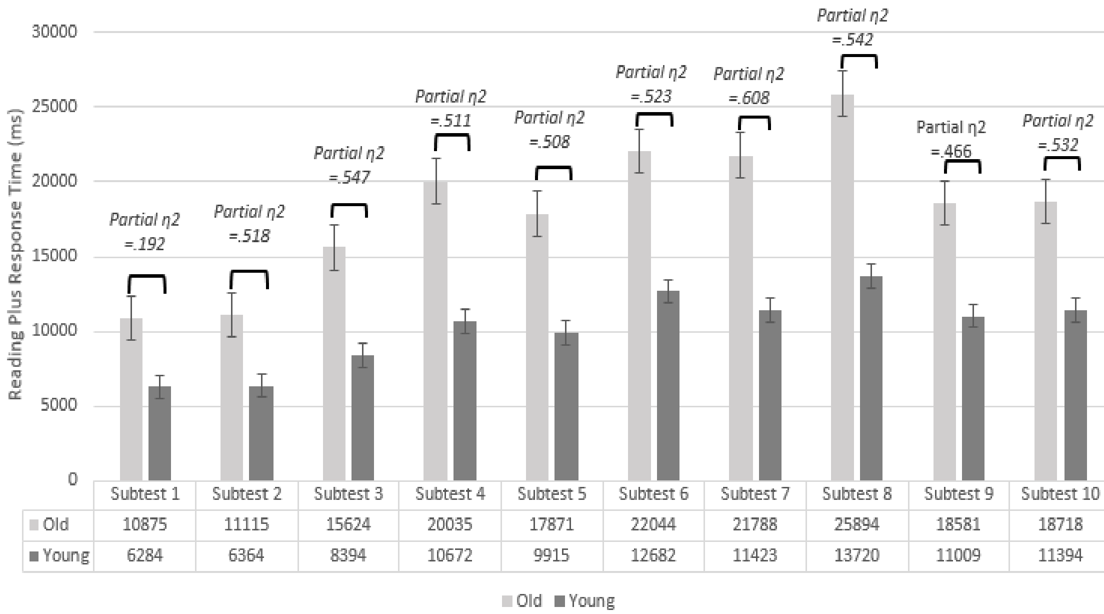

Figure 5: CRTT-R-WF Reading Plus Response Times of Group by Subtest (effect size is written above significance brackets)

3.2.2 Sex Differences

An additional secondary analysis of covariance (ANCOVA) was conducted with Sex as the covariate (Group X Hand X Sex) at the level of overall Mean Scores, Efficiency Scores, and Reading Plus Response Times. Sex was not significant for any of the ANCOVAs and did not interact with any other variable. These results did not change the patterns of results revealed in the 2-way ANOVAs summarized above.

3.3 BRINLEY PLOT

A Brinley plot was generated to show the relationships among average reading plus response times of younger adults relative to those same times from the older participants across subtests, with both their right and left hands. Linear regression lines are plotted for each hand in Figure 6. Slope values and correlation coefficients between hands are summarized in the text box within the figure. This figure depicts the general slowing (slope of 1.81 and 1.89 for the right and left hand respectively) for the older group relative to the younger group. It also depicts the linear slowing across subtests for both hands.

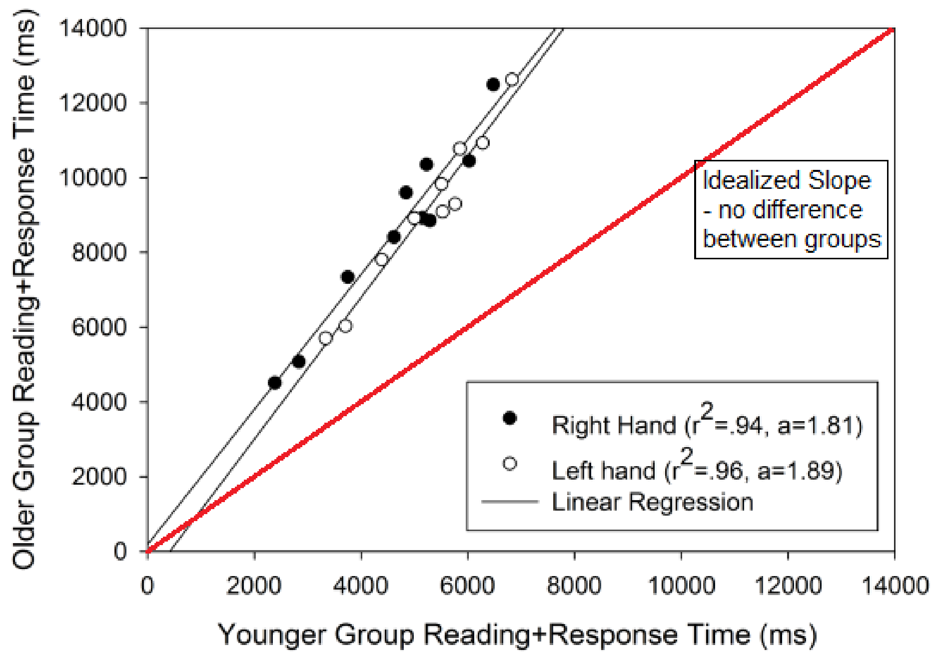

Figure 6: Brinley Plot of CRTT-R-WF Average Reading Plus Response Times of Younger Adults by Older Adults

4.0 DISCUSSION

This study examined the CRTT-R-$_{WF}$ mean and efficiency scores as an effect of age and hand use. The CRTT was originally designed to assess language comprehension and processing, while limiting the demands on working memory and attention. The CRTT-R-$_{WF}$, however, may increase the demands on working memory given its word-by-word presentation format. Theories of cognitive aging and reaction time studies were referenced to hypothesize how the CRTT-R-$_{WF}$ mean and efficiency scores would change across age and hand. The hypotheses and results of the age and hand use effects on CRTT-R-$_{WF}$ performance are discussed below.

4.1 AGING

The first and third experimental questions asked whether or not CRTT-R-$_{WF}$ mean and efficiency scores would significantly differ as an effect of age. It was hypothesized that both mean and efficiency scores would show a significant age effect. The older group showed significantly lower mean and efficiency scores than the younger group. These observations confirmed the original hypothesis, or failed to reject its null. To explain this finding, it is important to mention the stimulus presentation format of the CRTT-R-$_{WF}$. The disappearance of a word with the onset of a new word prevents individuals from re-reading the command. This structure is more similar to the presentation of the listening CRTT-L test where spoken words are presented serially, with each word disappearing with the onset of the next word. However, incoming auditory stimuli and visual information involve difference processing resources. The stimulus presentation format of the CRTT-R-$_{WF}$, involving both written language and word-by-word presentation, could increase demands on working memory more so than other reading and listening versions of the CRTT.

Mean scores represent a measure of response success with accuracy, responsiveness, promptness and efficiency built into the multidimensional scoring system. Scores are not binarily based on whether or not the individual selected the correct shape, color, size, etc. Although the overall CRTT-R-$_{WF}$ scores were relatively high for the older group, scores were still significantly lower than the younger group. *Working memory theories* propose that capacity limitations diminish older adults' ability to comprehend and produce complex semantic content and syntactic structure (Burke & Shafto, 2008). However, the sentences within the CRTT constrain word-level and syntactic forms. Perhaps, then, the decrease in scores seen by older adults could be explained by a decrease in working memory capacity. These results would then be consistent with *resource theories*. Efficiency scores incorporate both response correctness and time, with a special weighting on time. Significantly lower efficiency scores observed by the older group could also be accounted for by the *resource theory*, as some of the "resources" are believed to include attention and working memory. The significant interaction between hand and age could also support this theory, hypothesizing that the older group allocated more resources to the left hand, which diminished mean and efficiency scores. The significant difference in reading plus response time across groups is consistent with both the *generalized slowing theory* and *resource theory*. It is possible that the older adults, having less efficient processing speeds, requiring more time to execute the commands. Similarly, older adults have less resources available to ensure that all of the sentence components were maintained in order to process the sentence as a whole, and then provide an accurate and efficient response. *Inhibition deficit theories* were discounted as explanations, as participants were encouraged to take breaks as needed to maintain focus and attention. Semantic and syntactic constraints within the commands limited the amount of irrelevant linguistic information. *Sensory/perceptual deficit theories* were also diminished as likely explanations for the results achieved due to the vision criterion required for eligibility. Lastly, transmission deficit theories were not a sufficient explanation for the results of this study, as these theories depend on the hypothetical structure of the representational models of language. The linguistic constraints placed in the sentence commands of the CRTT limit the activations from lexical representations.

4.2 HAND USE

The second and fourth experimental questions sought to determine if the hand used would have a significant impact on mean and efficiency scores. In this study, the term "hand-preference" was favored over "hand-dominance." This was due to the fact that most computer mouses produced are designed to be used with an individual's right hand. Most left-handers have thus adapted to and adopted the right-hand mouse. While a participant may consider themselves left-hand dominant for fine or gross motor activities, they may prefer to use a computer mouse with their right hand. It was assumed that unfamiliarity with their non-preferred hand would result in a slowing performance, while comprehension of the commands would remain the same. It was therefore hypothesized that the hand used to complete the assessment would only impact the efficiency scores, not the mean scores. This hypothesis was partially rejected. Left hand efficiency scores and mean scores were significantly lower than those achieved with the right hand across participants. This was the non-preferred hand for all but two participants. These findings support the notion that more resources could be devoted to an individual’s non-dominant or non-automatized hand (Song & Bédard, 2013). This finding again supports the *resource theory*. As more resources were allocated to overcoming the unfamiliarity of using their non-preferred hand, less resources were available to working memory and processing speed. As a result, mean and efficiency scores were reduced. The statistically significant interactions found between mean score and hand, as well as efficiency score and hand, again support the *generalized slowing theories*. Scores of older adults, when using their left hand, were over additively slowed compared to the left-hand use for the younger group; whose performance was also slower with their left hand.

These results are clinically significant for the continued use of the CRTT. These findings call for the norming of the CRTT-R-$_{WF}$ for both age and hand. Additionally, for any test of language comprehension that requires a motor response, clinicians should be cognizant of the hand used. Unless test data demonstrate clearly that no effect of hand was identified, having an individual complete motor-perceptual tasks with their non-dominant hand may diminish test scores.

4.3 READING PLUS RESPONSE TIMES

Reading Plus Response Time was used to capture the time taken from the onset of the reading stimulus, to the participant’s selection of a token on the screen with a mouse click. When examining the results at an overall level as a secondary analysis, it was observed that the older group performed significantly slower than the younger group. The older group was almost twice as slow as they younger group. The older group was approximately 46% slower than the younger group with their right hand, and approximately 43% slower than the younger group with their left hand. It also was observed that the left hand performed significantly slower than the right hand for both groups. The younger group was approximately 11% slower with their left hand than their right, and the older group performed about 5% slower with their left hand than their right. This trend is further supported by the trends visualized in the Brinley plot (see Figure 6). By comparing the slope (a-values) of the regression lines across subtests, compared to an idealized slope of 1.0, indicating no difference between groups, the older group is shown to be nearly twice as slow as the younger group. The linearity of the Brinley plot suggests a generalized slowing for the older group in spite of the significant differences across hands and subtests. High correlation coefficients between hands for both groups provides support for this generalized slowing interpretation.

Significant interactions also were identified. In an attempt to identify the source of these significant interactions, additional analyses were conducted. The first interaction revealed that the left hand Reading Plus Response Times were significantly slower on each subtest, regardless of Group. Paired *t*-tests were computed to further analyze this hand by subtest interaction. At the subtest level, once alpha was controlled for, some subtests (I, II, III, VI, VII, X) remained significantly different by hand. Others (IV, V, VIII, IX) did not show a significant difference. This pattern of differences versus no differences is believed to be the source of the interaction. Univariate analyses were then conducted to further analyze the Subtest by Group interaction, where, older adults performed significantly slower across subtests than younger adults. Examination of the effect size for each subtest revealed that Subtest I had an unusually small effect size (.192), while Subtest VII had a much larger effect size (.608). All other effect sizes were relatively similar, except for that of Subtest IX which was slightly smaller (.466). The discrepancy in the magnitude of these effect sizes is believed to be the source of this interaction.

This measure most strongly parallels the reaction time measures that were examined by Hendricks (n.d.). Hendricks (n.d.) found that the reaction time task requiring movement control, that which is most similar to the underlying sensorimotor and cognitive functions required for responses to the CRTT-R-$_{WF}$ commands, also showed a statistically significant effect of age and hand used.

5.0 LIMITATIONS AND OBSERVATIONS

5.1 STUDY LIMITATIONS

Several limitations in study design and data collection were identified by the co-investigators, and should be taken into consideration when determining the overall strength of this study. It is difficult to identify if and/or to what extent these variables increased the variance or the variability within or among participants. However, it is important not to overlook the possibility. First, the CRTT program was run using two computers. These computers were different brands and had different screen sizes. Secondly, most of the data was collected outside of a university lab space where environmental differences in lighting and background noises were observed. Another limitation is that the time of testing varied considerably. The earliest session began at 8am, whereas the latest session concluded at 9pm. Depending on the testing timeframe, personal factors (fatigue, hunger, boredom) may have influenced performance. A relatively large sample size (n = 64) and experimental design controls such as randomization were used to control the impacts of these uncontrolled variables. While the CRTT is a computer-administered and scored test, inter and intra-judge reliability between researchers should be considered regarding the administration of the preliminary procedures. It was also observed that participants were more familiar with expectations the second time they completed the language processing and reaction time tasks.

5.2 OBSERVATIONS FOR FURTURE RESEARCH

By 2050, projections indicate that the population aged 65 and older will be 83.9 million people in the United States (Ortman, Velkoff, & Hogan, 2014). At this rate, the demand for SLPs who serve the geriatric population are predicted to rise proportionally. In order to best serve this population, it is imperative that clinicians gain a better understanding of how normal, age-related changes impact scores on diagnostic measures and performance on treatment protocols. Like all research studies conducted, this study requires replication.

The results of this study revealed a significant age effect between two groups of participants: a younger group (20-32 years) and an older group (65-78 years). Further research should include the range of ages in-between these two groups (35-64 years). Including the middle age range could allow for a better understanding of the rate at which CRTT-R-$_{WF}$ mean and efficiency scores decline with age. Additional studies should both increase and decrease the age intervals for groups of participants. This could also lead to a more accurate point of optimal age-related performance as well as the deflection point in the decline from optimal performance.

This study found a significant difference in CRTT-R-$_{WF}$ mean scores, efficiency scores, and reading plus response times as an effect of hand use. The frequency with which an individual uses a computer mouse, and with which hand, should also be studied. Likewise, an individual who is left-hand dominant but prefers to use the computer mouse with their right hand could score differently than a left-hand dominant individual who also uses a computer mouse with their left hand.

Normative data should continue to be collected both by age and by hand at least for healthy individuals, based on the statistically significant main effects and interactions found between age and hand use on the CRTT-R-$_{WF}$ mean and efficiency scores. Whether these effects will be replicated with pathological populations is another opportunity for further research. This study should also be replicated using other CRTT listening reading versions to determine if the observed age and hand effects are also evident in these test protocols. New data is also emerging that shorter versions of the CRTT (three commands per subtest as opposed to 10) may accurately predict an individual's overall performance (Fassbinder et al., 2017). This study could be replicated using the shorter versions of the CRTT to see if the main effects and interactions of age and hand use are observed in this test version as well.

This study was conducted simultaneously with a parallel study run by Hendricks (n.d.). Hendricks compared the CRTT-RT battery performance on the same participants within this study protocol. By comparing participants' reaction time data with their performance on the CRTT-R-$_{WF}$, researchers may be able to gain a better understanding of how sensori-motor, perceptual, and cognitive variables impact overall performance on the CRTT.

6.0 SUMMARY AND CONCLUSION

This study was conducted in order to investigate the effects of age and hand use on CRTT-R-$_{WF}$ mean and efficiency scores. There were statistically significant main effects for both age and hand use on both the mean and efficiency scores. There also were statistically significant interactions observed for both the mean and efficiency scores, revealing an over-additive slowing with the left hand for the older group. A secondary analysis showed statistically significant main effects for both age and hand use on Reading Plus Response Time. However, no statistically significant interaction was observed for this dependent measure. It is difficult to determine if the age effect results were due to a decrease in cognitive capabilities supporting language, or due to a primary decrease in language comprehension. The CRTT is a diagnostic tool used experimentally and clinically to measure language comprehension and processing in persons with aphasia. This preliminary study adds to the normative data being collected from healthy, normal participants. The effects of age and hand present verify that normative data should not only be collected across the age-span, but also by hand used. This may have special relevance for the estimates of severity for the diagnosis of aphasia, as they often present with hemiplegia and may be required to complete this assessment with their non-preferred hand.

These data will eventually be combined with the data analyzed by Hendricks (n.d.). This research will be used to explore if and/or to what extent an individual's language comprehension and processing abilities, as measured by the CRTT-R-$_{WF}$, are affected by perceptual-motor-cognitive skills required to complete the test, as measured by the CRTT-RT Battery Tasks. This combination of data will offer insight into the locus of the deficit revealed by performance on the test.

APPENDIX A: Demographics

Table 10: Younger Group Participant Demographics (Based on Subject History Questionnaire)

Demographics - Younger					
Subject #	Gender	Age	Race	Highest Level of Education	Occupation
101	F	20	Caucasian	High School	Student
105	M	21	Caucasian	High School	Student
108	F	23	Caucasian	Bachelor’s Degree	Student
109	F	23	Caucasian	Some Graduate School	Student
110	M	25	Caucasian	Bachelor’s Degree	Program Manager
111	F	23	Caucasian	Bachelor’s Degree	Student
112	F	24	Caucasian	Bachelor’s Degree	Student
113	F	24	Caucasian	Some Graduate School	Student
114	F	32	Caucasian	Bachelor’s Degree	Student
115	M	28	Caucasian	Master’s Degree	Student
116	M	24	Caucasian	High School	Marketing
117	M	23	Caucasian	Bachelor’s Degree	Engineer
118	M	21	Caucasian	High school	Student
121	M	24	Caucasian	Bachelor’s Degree	Student
122	F	24	Caucasian	Bachelor’s Degree	Student
203	M	26	Caucasian	Bachelor’s Degree	Event Planner
204	F	23	Caucasian	Bachelor’s Degree	Student
205	M	27	African American	Bachelor’s Degree	Student
206	M	23	Caucasian	Bachelor’s Degree	Student
207	M	24	Caucasian	Bachelor’s Degree	Civil Engineer
208	F	25	Caucasian	Bachelor’s Degree	Student
209	F	25	Caucasian	Master’s Degree	Speech Language Pathologist
210	F	23	Caucasian	Some Graduate School	Student
211	F	26	Caucasian	Master’s Degree	Student
212	M	25	Caucasian	Master’s Degree	Speech Language Pathologist
218	M	26	Caucasian	Bachelor's Degree	Software Consultant
224	M	22	Caucasian	Bachelor’s Degree	Student/Guest Services

225	M	23	Caucasian	Bachelor’s Degree	Student
229	M	23	Caucasian	Bachelor’s Degree	Student
301	F	20	Caucasian	Some College	Student
401	F	21	Caucasian	Bachelor’s Degree	Student
501	F	20	Caucasian	Some College	Student

Table 11: Older Group Participant Demographics (Based on Subject History Questionnaire)

Demographics - Older					
Subject #	Gender	Age	Race	Highest Level of Education	Occupation
103	F	78	Caucasian	High School	Retired
104	F	77	Caucasian	High School	Retired
119	M	69	Caucasian	Some college	Retired
120	M	70	Caucasian	Master's Degree	Retired
123	M	69	Caucasian	Master's Degree	Retired
124	F	78	Caucasian	High School	Retired
125	F	68	Caucasian	Some College	Retired
126	F	68	Caucasian	Bachelor's Degree	Retired
127	M	70	Caucasian	Graduate (M.D.)	Physician
128	M	73	Caucasian	Master's Degree	Retired
129	M	74	Caucasian	Military/Professional Training	Retired
130	M	77	Caucasian	Bachelor's Degree	Retired
131	M	78	Caucasian	Associate's Degree	Retired
213	F	65	Caucasian	Associate's Degree	Retired
214	F	70	Caucasian	Ph.D.	Retired
215	M	66	Caucasian	Bachelor's Degree	Occupational Therapist
216	M	74	Caucasian	High School	Retired
217	F	72	Other	Associate's Degree	Retired
219	F	73	Caucasian	Some College	Retired
220	M	70	Caucasian	Master's Degree	Retired
221	F	77	Caucasian	Bachelor's Degree	Registered Nurse
222	F	71	Caucasian	Master's Degree	Retired
223	M	71	Caucasian	Bachelor's Degree	Retired
226	F	66	Caucasian	Nursing School	Registered Nurse
227	M	68	Caucasian	High School	Labor Relations Director
228	M	78	Caucasian	Masters Equivalent	Teacher
230	F	75	Caucasian	Master's Degree	Social Worker/Counselor
231	F	77	Caucasian	Some College	Retired (Admin)
232	F	72	Caucasian	Ph.D.	Retired (Org. Develop. Consultant)
233	M	65	Caucasian	Bachelor's Degree	Retired
234	M	73	Caucasian	Master's Degree	Retired (Mech. Engineer)
302	F	66	Caucasian	Master of Science	Retired (software engineering manager)

Table 12: Younger Group Hand Preference (Based on Subject History Questionnaire)

Hand Preferences - Younger			
Subject #	Preferred Hand	Hand Uses Mouse With	Hours Per Day Using Mouse
101	R Hand	R Hand	0
105	R Hand	R hand	0-1
108	R Hand	R hand	0
109	R Hand	R hand	2-3
110	R Hand	R hand	2
111	L Hand	L Hand	0
112	R Hand	R hand	6
113	R Hand	R hand	0
114	R Hand	R hand	0
115	R Hand	R hand	0
116	L Hand	R hand	1
117	R Hand	R Hand	6
118	R Hand	R Hand	0
121	L Hand	R Hand	1
122	R Hand	R Hand	2
203	R Hand	R Hand	6
204	R Hand	R Hand	1
205	L Hand	R Hand	2-3
206	R Hand	R Hand	0
207	R Hand	R Hand	9
208	R Hand	R Hand	2-3
209	L Hand	R Hand	5
210	L Hand	R Hand	2
211	R Hand	R Hand	0
212	R Hand	R Hand	4
218	R Hand	R Hand	11
224	L Hand	R Hand	6
225	R Hand	R Hand	0-1
229	R Hand	R Hand	1
301	R Hand	R hand	2
401	R Hand	R Hand	0
501	R Hand	R Hand	0

Table 13: Older Group Hand Preference (Based on Subject History Questionnaire)

Hand Preferences - Older			
Subject #	Preferred Hand	Hand Uses Mouse With	Hours Per Day Using Mouse
103	R Hand	R hand	0
104	R Hand	R hand	0.5
119	R Hand	R Hand	0
120	L Hand	L Hand	2
123	R Hand	R Hand	0.5
124	R Hand	R Hand	1
125	R Hand	R Hand	1
126	R Hand	R Hand	1
127	R Hand	R Hand	3
128	R Hand	R Hand	0.5
129	R Hand	R Hand	1
130	R Hand	R Hand	2
131	R Hand	R Hand	2-3
213	R Hand	R Hand	0-1
214	R Hand	R Hand	3
215	R Hand	R Hand	4
216	R Hand	R Hand	2
217	R Hand	R Hand	1
219	R Hand	R Hand	0-1
220	R Hand	R Hand	2
221	R Hand	R Hand	1.5
222	R Hand	R Hand	0.5
223	R Hand	R Hand	<1
226	R Hand	R Hand	1 to 3
227	L Hand	R Hand	<1
228	R Hand	R Hand	1
230	R Hand	R Hand	0.5-1
231	R Hand	R Hand	<1
232	R Hand	R Hand	1
233	R Hand	R Hand	1
234	R Hand	R Hand	<1
302	R Hand	R Hand	4-5

Table 14: Younger Group CELF-5 Scores

CELF-5 - Younger			
Subject #	Raw Score 1	Raw Score 2	Combined Score
101	10	9	19
105	10	9	19
108	8	9	17
109	10	9	19
110	10	9	19
111	10	9	19
112	10	9	19
113	10	9	19
114	10	9	19
115	9	9	18
116	10	9	19
117	10	9	19
118	10	8	18
121	9	9	18
122	10	9	19
203	10	9	19
204	10	9	19
205	9	9	18
206	9	9	18
207	10	9	19
208	10	9	19
209	10	9	19
210	10	9	19
211	10	9	19
212	10	9	19
218	10	9	19
224	10	9	19
225	10	9	19
229	10	9	19
301	10	9	19
401	9	9	18
501	10	9	19

Table 15: Older Group CELF-5 Scores

CELF-5 - Older			
Subject #	Raw Score 1	Raw Score 2	Combined Score
103	10	9	19
104	10	9	19
119	9	8	17
120	9	9	18
123	9	8	18
124	10	7	17
125	9	9	18
126	10	9	19
127	10	9	19
128	9	10	19
129	10	9	19
130	9	9	18
131	10	8	18
213	9	9	18
214	10	9	19
215	10	9	19
216	9	8	17
217	9	8	17
219	10	7	17
220	10	9	19
221	9	9	18
222	9	9	18
223	10	9	19
226	10	8	18
227	10	9	19
228	10	8	18
230	10	9	19
231	9	9	18
232	10	9	19
233	10	9	19
234	10	9	19
302	9	9	18

Table 16: Younger Group ABCD Story Retell Scores

ABCD Story Retell - Younger			
Subject #	Immediate	Delayed	Ratio
101	17	17	1.00
105	12	12	1.00
108	17	15	0.88
109	12	12	1.00
110	13	12	0.92
111	16	13	0.81
112	15	15	1.00
113	14	14	1.00
114	14	13	0.93
115	15	14	0.93
116	16	15	0.94
117	14	15	1.07
118	17	14	0.82
121	13	13	1.00
122	17	16	0.94
203	12	13	1.08
204	16	15	0.94
205	15	15	1.00
206	12	12	1.00
207	12	9	0.75
208	14	13	0.93
209	12	12	1.00
210	14	16	1.14
211	17	17	1.00
212	16	15	0.94
218	13	13	1.00
224	15	15	1.00
225	14	15	1.07
229	15	15	1.00
301	14	14	1.00
401	16	14	0.88
501	15	16	1.07

Table 17: Older Group ABCD Story Retell Scores

ABCD Story Retell - Older			
Subject #	Immediate	Delayed	Ratio
103	13	12	0.92
104	15	13	0.87
119	15	14	0.93
120	15	15	1.00
123	12	12	1.00
124	15	15	1.00
125	14	14	1.00
126	14	14	1.00
127	15	15	1.00
128	16	15	1.07
129	15	17	1.13
130	15	14	0.93
131	15	15	1.00
213	14	13	0.93
214	13	15	1.15
215	12	12	1.00
216	11	12	1.09
217	11	11	1.00
219	14	14	1.00
220	12	14	1.17
221	17	16	0.94
222	15	15	1.00
223	12	12	1.00
226	13	11	0.85
227	15	15	1.00
228	13	13	1.00
230	14	15	1.07
231	12	13	1.08
232	16	14	0.88
233	16	16	1.00
234	13	13	1.00
302	13	13	1.00

Table 18: Younger Group WAIS-5 Digit Span Scores

WAIS-4 Digit Span- Younger				
Subject #	DS Forward	DS Backward	Total	Scaled Score
101	11	10	21	12
105	14	6	20	12
108	12	7	19	11
109	12	9	21	12
110	14	12	26	16
111	14	8	22	13
112	14	8	22	13
113	11	10	21	12
114	14	7	21	13
115	10	7	17	10
116	9	8	17	10
117	11	10	21	12
118	9	6	15	8
121	13	10	23	14
122	9	10	19	11
203	13	9	22	13
204	15	8	23	14
205	15	12	27	17
206	13	6	19	11
207	12	9	21	10
208	7	8	15	8
209	16	12	28	18
210	10	12	22	13
211	11	10	21	12
212	10	6	16	9
218	13	12	25	15
224	14	5	19	11
225	12	9	21	12
229	12	8	20	12
301	12	11	23	14
401	14	9	23	14
501	13	11	24	15

Table 19: Older Group WAIS-5 Digit Span Scores

WAIS-4 – Digit Span – Older				
Subject #	DS Forward	DS Backward	Total	Scaled Score
103	8	7	15	10
104	13	8	21	15
119	9	5	14	9
120	14	6	20	14
123	9	5	14	9
124	13	7	20	14
125	9	9	18	12
126	7	6	13	8
127	12	7	19	13
128	13	11	24	17
129	11	7	18	12
130	10	6	16	11
131	13	8	21	15
213	8	5	13	8
214	9	4	13	8
215	12	8	20	13
216	12	4	16	11
217	7	5	12	8
219	7	6	13	8
220	8	7	15	10
221	8	6	14	9
222	11	7	18	12
223	15	10	25	18
226	8	10	18	12
227	14	7	21	14
228	11	7	18	12
230	12	7	19	13
231	12	5	17	12
232	9	7	16	11
233	11	8	19	12
234	13	5	18	12
302	10	6	16	10

Table 20: Younger Group LEAP-Q Responses

LEAP-Q - Younger				
Subject #	Formal Years of Education	% Exposure	% Reading	% Speaking
101	15	100	100	100
105	16	100	100	100
108	18	100	100	100
109	18	100	100	100
110	17	100	100	100
111	17	100	100	100
112	18	100	100	100
113	18	100	100	100
114	20	100	100	100
115	18	100	100	100
116	18	100	100	100
117	16	100	100	100
118	16	100	100	100
121	18	100	100	100
122	19	100	100	100
203	16	100	100	100
204	18	100	100	100
205	20	100	100	100
206	18	100	100	100
207	16	100	100	100
208	19	100	100	100
209	18	80	100	60
210	18	100	100	100
211	19	100	100	100
212	18	100	100	100
218	17	100	100	100
224	16	100	100	100
225	19	100	100	100
229	18	100	100	100
301	15	100	100	100
401	16	100	100	100
501	15	100	100	100

Table 21: Older Group LEAP-Q Responses

Leap Q - Older				
Subject #	Formal Years of Education	% Exposure	% Reading	% Speaking
103	13	100	100	100
104	12	100	100	100
119	18	100	100	100
120	20	100	100	100
123	20	100	100	100
124	12	100	100	100
125	12	100	100	100
126	19	100	100	100
127	20	100	100	100
128	18	100	100	100
129	12	100	100	100
130	16	100	100	100
131	14	100	100	100
213	14	100	100	100
214	23	100	100	100
215	18	100	100	100
216	15	100	100	100
217	16	95	100	95
219	13	100	100	100
220	19	100	100	100
221	16	100	100	100
222	18	100	100	100
223	16	100	100	100
226	15	100	100	100
227	12	100	100	100
228	14	100	100	100
230	19	100	100	100
231	14	100	100	100
232	22	100	100	100
233	23	100	100	100
234	19	100	100	100
302	18	100	100	100

Table 22: Younger Group Edinburgh Handedness Inventory

Edinburgh Handedness Inventory - Younger		
Subject #	Laterality Quotient	Decile
101	84.62	R
105	66.67	R
108	100.00	R
109	84.62	R
110	69.23	R
111	-85.71	L
112	88.24	R
113	84.62	R
114	90.00	R
115	80.00	R
116	-84.62	L
117	55.56	R
118	73.33	R
121	-100.00	L
122	80.00	R
203	100.00	R
204	84.62	R
205	-80.00	L
206	73.33	R
207	76.47	R
208	80.00	R
209	-100.00	L
210	-40.00	A
211	81.82	R
212	100.00	R
218	76.46	R
224	-88.89	L
225	80.00	R
229	60.00	R
301	75.00	R
401	88.89	R
501	100.00	R

Table 23: Older Group Edinburgh Handedness Inventory

Edinburgh Handedness Inventory- Older		
Subject #	Laterality Quotient	Decile
103	60.00	R
104	100.00	R
119	66.67	R
120	-73.33	L
123	100.00	R
124	100.00	R
125	100.00	R
126	100.00	R
127	85.71	R
128	81.82	R
129	84.62	R
130	100.00	R
131	53.85	R
213	81.82	R
214	73.33	R
215	44.44	R
216	100.00	R
217	81.81	R
219	100.00	R
220	80.00	R
221	100.00	R
222	85.71	R
223	100.00	R
226	75.00	R
227	-60.00	L
228	85.71	R
230	88.89	R
231	100.00	R
232	87.50	R
233	84.61	R
234	100.00	R
302	100.00	R

Table 24: Subject Test Order

Test Order				
Subject #	CRTT-R	CRTT-L	RT-R	RT-L
101	2	4	1	3
103	1	4	2	3
104	3	2	1	4
105	4	3	1	2
108	2	4	1	3
109	1	4	4	3
110	1	4	2	3
111	3	2	1	4
112	2	1	4	3
113	2	3	1	4
114	2	1	4	3
115	3	1	2	4
116	4	3	1	2
117	2	1	3	4
118	1	3	4	2
119	2	3	4	1
120	2	3	1	4
121	2	4	1	3
122	2	4	1	3
123	3	2	1	4
124	1	2	3	4
125	4	1	3	2
126	1	4	2	3
127	4	2	3	1
128	3	1	2	4
129	3	4	1	2
130	1	2	4	3
131	1	2	4	3
203	2	3	1	4
204	2	1	3	4
205	2	1	4	3
206	4	2	3	1
207	1	2	3	4
208	3	4	1	2
209	4	1	2	3
210	1	3	2	4
211	1	3	4	2
212	2	3	4	1
213	1	3	2	4

214	1	2	4	3
215	4	3	1	2
216	2	4	3	1
217	1	3	2	4
218	4	2	3	1
219	3	4	2	1
220	4	3	1	2
221	2	4	1	3
222	2	3	1	4
223	2	4	1	3
224	1	2	4	3
225	4	1	3	2
226	4	3	1	2
227	2	1	3	4
228	1	4	3	2
229	2	3	4	1
230	1	3	4	2
231	1	3	2	4
232	4	1	2	3
233	4	3	1	2
234	1	3	4	2
301	4	1	3	2
302	4	1	3	2
401	2	1	3	4
501	3	2	4	1

APPENDIX B: CRTT-RT Battery Task Descriptions and Data

Of the six RT tasks, Task: 1: Tapping; Task 2: Simple reaction time; and Task 3: Simple reaction time plus movement are considered simple reaction time tasks. These tasks only require one motor response to a given stimulus. CRTT-RT Task 1 required participants to tap a computer-mouse as quickly as possible for a 10-second time period across 3 trials. The average interval between taps was determined. This data was used to estimate basic motor-related speed across ages and across hands. CRTT-RT Task 2 required participants to click the mouse as quickly as possible after a token appeared in the center of the screen. A mix of thirty different tokens (squares and circles of all 5 colors) were randomly presented, one at a time. measured the response time required for detecting and responding to a visual stimulus. The time interval between token presentations varied from 0 to 50ms to reduce the possibility of anticipatory responses. The average response time across trials was determined. This data was used as a measure of simple reaction time. CRTT-RT Task 3 added a simple movement to Task 2 in order to measure movement time plus reaction time. Participants were required to move the cursor from the bottom of the screen to the token that appeared in the center of the screen, then click the mouse as quickly as possible. Participants performed this task across 30 trials. The time for each stimulus/response was recorded. The average time for each stimulus/response was recorded. This data was used to evaluate the speed at which a participant detected and then motorically responded to a stimulus.

The remaining three tasks, CRTT-RT Task 4: Go-No-Go; CRTT-RT Task 5: One stimulus, two response RT mapping; and CRTT-RT Task 6: Two stimuli, two response RT mapping, are considered choice reaction time tasks. During these three tasks, participants have different options of motor responses to choose from, and must respond correctly according to the given stimulus. This concept is referred to as “cognitive mapping.” During Task 4, one token (circle or square) was randomly presented at the center of the screen, one at a time. Participants were required to click the left mouse button as quickly as possible if a circle appeared, and to refrain from responding if a square appeared. The percentage and average response times of correct responses were calculated. This data was used to measure the speed and accuracy of this inhibitory choice RT task. During CRTT-RT Task 5, one token (circle of square) was randomly presented at the center of the screen, one at a time. Participants were required to click the left mouse button as quickly as possible if a circle appeared, or the right mouse button if a square appeared. Task 5 required a response for all 30 trials. The percentage and average response times of correct responses were again calculated. in addition to the average response times for correct responses. During CRTT-RT Task 6, two tokens appeared at the center of screen at the same time. Participants were required to sequentially respond to both tokens (i.e. two total mouse clicks) using the same stimulus-response mapping as in Task 4 (circle: left mouse button; square: right mouse button). Participants were instructed to respond to the token on the left before responding to the token on the right. Circles and squares appeared randomly in the left and right positions. Trials of two circles and two squares were also included in order to reduce the possibility that second stimulus responses linked to the first stimulus/response decision. Percentages and average response times for correct responses were calculated for both the first and second stimuli across 45 trials.

Table 25: Reaction Time Combined Data

Combined RT R-Hand											
	Tap	Simple	Movement	Go-No-Go		Decision Map 1		Decision Map 2			
	Avg Interval	Avg RT	Avg RT	Avg RT (Correct)	% Correct	Avg RT (Correct)	% Correct	Avg RT (Correct) 1	% Correct 1	Avg RT (Correct) 2	% Correct 2
Older Average	**233.19**	**367.47**	**1355.38**	**509.33**	**96.42**	**698.86**	**98.44**	**845.34**	**98.05**	**1150.71**	**98.24**
Younger Average	**176.72**	**322.32**	**936.34**	**443.39**	**96.33**	**525.32**	**97.07**	**649.57**	**96.55**	**826.7**	**97.1**
Difference	56.47	45.15	419.04	65.94	0.09	173.54	1.37	195.77	1.5	324.01	1.14
Combined RT L-Hand											
	Tap	Simple	Movement	Go-No-Go		Decision Map 1		Decision Map 2			
	Avg Interval	Avg RT	Avg RT	Avg RT (Correct)	% Correct	Avg RT (Correct)	% Correct	Avg RT (Correct) 1	% Correct 1	Avg RT (Correct) 2	% Correct 2
Older Average	**282.59**	**411.49**	**2075.64**	**521.14**	**97.06**	**756.96**	**97.71**	**897.51**	**97.26**	**1225.07**	**97.79**
Younger Average	**205.8**	**325.21**	**1320.16**	**473.17**	**95.8**	**581.89**	**97.07**	**708.09**	**96.29**	**906.24**	**96.62**
Difference	76.79	86.28	755.48	47.97	1.26	175.07	0.64	189.42	0.97	318.83	1.17
Older RT R-Hand v L-Hand											
	Tap	Simple	Movement	Go-No-Go		Decision Map 1		Decision Map 2			
	Avg Interval	Avg RT	Avg RT	Avg RT (Correct)	% Correct	Avg RT (Correct)	% Correct	Avg RT (Correct) 1	% Correct 1	Avg RT (Correct) 2	% Correct 2
R-Hand Average	**233.19**	**367.47**	**1355.38**	**509.33**	**96.42**	**698.86**	**98.44**	**845.34**	**98.05**	**1150.71**	**98.24**
L-Hand Average	**282.59**	**411.49**	**2075.64**	**521.14**	**97.06**	**756.96**	**97.71**	**897.51**	**97.26**	**1225.07**	**97.79**
Difference	-49.4	-44.02	-720.26	-11.81	-0.64	-58.1	-0.73	-52.17	0.79	-74.36	0.45
Younger RT R-Hand v L-Hand											
	Tap	Simple	Movement	Go-No-Go		Decision Map 1		Decision Map 2			
	Avg Interval	Avg RT	Avg RT	Avg RT (Correct)	% Correct	Avg RT (Correct)	% Correct	Avg RT (Correct) 1	% Correct 1	Avg RT (Correct) 2	% Correct 2
R-Hand Average	**176.72**	**322.32**	**963.34**	**443.39**	**96.33**	**525.32**	**97.07**	**649.57**	**96.55**	**826.70**	**97.10**
L-Hand Average	**205.8**	**325.21**	**1320.16**	**473.17**	**95.8**	**581.89**	**97.07**	**708.09**	**96.29**	**906.24**	**96.62**
Difference	-29.08	-2.89	-356.82	-29.78	0.53	-56.57	0	-58.52	0.26	-79.54	0.48

APPENDIX C: Subject History Form

Subject #______________

Birth date: ______________ Age: _______________

Is English your native language? Yes No

Sex: M F

If no, what is the primary language spoken in your home? _________________

Do you wear glasses? Yes No

Do you have difficulty hearing? Yes No

If yes, do you wear a hearing aid? Bilateral/ Right / Left / NA

Have you ever had any kind of speech, language or learning problem? Yes No

If yes, explain:

Did you ever have speech or language treatment? Yes No

If yes, explain:

Have you had any medical, psychological, or other conditions that might affect your ability to communicate or participate in the study (e.g., Stroke, Parkinson's disease, Alzheimer's disease, alcoholism, depression, etc.)? Yes No

If yes, explain:

Race: Caucasian African-American Asian Native-American Other

What is the highest level of education you completed? ____________________________

What is your occupation? (If retired, etc., indicate last occupation): _________________

Which is your dominant hand? Left Right

Which hand do you use a mouse with? Left Right

Which hand do you use a touchscreen with? Left Right

How many hours a day do you use a computer mouse? _____________________

How many hours a day do you use a touch screen? ________________________

Do you have any problems with your hand or wrist (e.g., carpal tunnel syndrome, arthritis)? Yes No

If yes, what is the problem? ____

(Adapted from Heilman, 2008)

APPENDIX D: Edinburgh Handedness Inventory

Subject #______________

Birth date: ______________ Age: _______________

Please indicate your preferences in the use of hands in the following activities by *putting* **+** *in the appropriate column*. Where the Preference is so strong that you would never try to use the other hand unless absolute forced to, *put* **++**. If in any case you are really indifferent, *put* **+** *in both columns*.

Some of the activities require both hands. In these cases, the part of the task, or object, for which hand preference is wanted is indicated in brackets.

Please try to answer all questions, and only leave a blank if you have no experience at all of the object or tasks.

		Left	Right
1.	Writing		
2.	Drawing		
3.	Throwing		
4.	Scissors		
5.	Toothbrush		
6.	Knife (without fork)		
7.	Spoon		
8.	Broom (upper hand)		
9.	Striking Match (match)		

10.	Opening box (lid)		
i.	Which foot do you prefer to kick with?		
ii.	Which eye do you use when using only one?		

L.Q.		Leave these spaces blank	Decile	

(Adapted from Oldfield, 1971)

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