EFFECTS OF AGING AND HAND USE ON LANGUAGE COMPREHENSION USING THE COMPUTERIZED REVISED TOKEN TEST- READING-WORD FADE AND SPEED OF PROCESSING BATTERY

by

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Background: The Computerized Revised Token Test (CRTT) (McNeil et al., 2015) is a standardized assessment of language processing abilities. The CRTT-Reading-Word-Fade (CRTT-R-$_{WF}$) is a self-paced reading version of the CRTT that places demands on perceptual-motor, cognitive and working memory skills that can adversely influence the fidelity of the test as a measure of language processing. To account for these demands, a speed of processing battery (CRTT-SOP) also was created. The purpose of this study was to collect age-related normative data for the CRTT-R-$_{WF}$ and CRTT-SOP and to investigate aging and the hand used to respond as two potential variables that could influence performance on the test.

Methods: Thirty-four healthy adults completed this study. Group 1 consisted of 15 adults (35-49 years) and Group 2 consisted of 19 older adults (50-64 years). Every participant completed both tests twice, once with each hand. The CRTT-R-$_{WF}$ scores were used to evaluate the effects of age and hand on participant responses. Speed of processing and perceptual-motor control were evaluated with the CRTT-SOP response times. Performance by these groups also were compared to older and young participants from Byrne (2017) and Hendricks (2017) who used the same tasks and methods.

Results: Group 1 and Group 2 did not exhibit significantly different CRTT-R-$_{WF}$ scores, but there was a significant effect for hand used on the CRTT-R-$_{WF}$ with significantly higher scores with the right hand. There were no significant group differences on the CRTT-SOP tasks, although there were significant differences on the SOP tasks by the hand used. When combined with the data from the previous studies, complex interactions and main effects for group and hand were observed for both the CRTT-R-$_{WF}$ and the CRTT-SOP tasks.

Discussion: The results suggested limited group sizes and large variability, rather than a lack of slowing across groups, may account for the stabilization of performance across Groups 1 and 2. The group differences observed when the data were combined with the previous two studies suggested that age is a factor with the CRTT-SOP, along with the hand used to complete the tasks. The right-hand advantage was generally consistent across tasks.

Table of Contents

List of Tables

List of Figures

Preface

This project reflects the hard work and support of numerous individuals who dedicated their time and expertise towards our common goal. I would like to recognize the continuous support of my thesis advisor, Dr. Sheila Pratt, who helped guide my passions, share her wealth of knowledge, and always assured me with her catch phrase that, “everything will work out just fine.” To Dr. Malcolm McNeil, thank you for answering all of my frantic emails with thoughtful advice, kind encouragement, and trips to Forbes Tower. I would also like to thank Neil Szuminsky, our programmer, for his help downloading the program and fixing its glitches along the way. Leslie Zhen deserves recognition for lending a hand with all of the statistical analyses necessary to interpret the data; I couldn’t have run a single ANOVA without you. To my kind and patient research assistants Jala Bell, Joseph Engelmeier and Andrea Smith, a special thanks for the dedication of your time running participants, without you we would not have been able to accommodate such a wide range of schedules and include as many participants as we did. I would also like to acknowledge my committee members, Dr. Richard Peach, Dr. William Evans, Dr. Elaine Mormer, and my moderator Dr. Janice Vance for agreeing to serve on my committee and help guide my project towards success. Finally, I would like to thank my family and friends for always being there to proofread my drafts and buy me a cup of coffee when I looked particularly tired. I will never forget each and every contribution made on this project’s behalf- we did it!

1.0 INTRODUCTION

Speech-language pathologists diagnose and treat populations that vary by impairment type and severity. These populations also vary by age, with many communication disorders becoming more prevalent with increased age. For this reason, it is important that the diagnostic tests used to assess these disorders represent the lifespan and include relevant normative data and account for age–related effects. Age-based test norms are common with tests administered to infants and children but less so with tests administered to adults. Yet test norms are useful for differentiating normal variability from impairment, identifying and accounting for age-related differences, and documenting significant treatment outcomes. Accounting for age-related performance differences (e.g., motor slowing with aging) is not common with most tests of communication disorders but is important for test purity and accurate interpretation of test results.

This study investigated whether aging and the hand used to respond impacted response-time and language comprehension performance on the Computerized Revised Token Test (CRTT) (McNeil et al., 2015). The CRTT is an assessment tool adapted from the Revised Token Test (McNeil & Prescott, 1978; RTT) and designed to evaluate language processing inefficiencies and disorders secondary to brain damage (e.g., aphasia and other language and learning disabilities). Although sensitive to aphasia and other language-processing impairments, the RTT was insensitive to aging (McNeil & Prescott, 1978). Thus, age-based norms were not needed. It also should be noted that the test did not include measurement of subtle differences in response times, making it difficult to account for age-related slowing of responses. In contrast, preliminary data collected with the CRTT have shown substantive age effects that likely are due to increased sensitivity afforded by computer-based administration and scoring (Byrne, 2017; Hendricks, 2017). Reaction times and tracking of response timing also are included in the CRTT but lack norms. Therefore, to insure test purity and interpretability, age-based norms for the response-time and reading versions of the CRTT need to be established.

1.1 BACKGROUND

In 2016, the National Aphasia Association (NAA) conducted a nation-wide survey to determine the level of familiarity and understanding of aphasia in the United States (2016 Aphasia Awareness Survey (n.d.)). With nearly 180,000 people acquiring aphasia each year, which is more common than widely known Parkinson's Disease or cerebral palsy, one would assume the general public would have a firm grasp of aphasia and what such a diagnosis means. In reality, most Americans have never heard of aphasia. Anecdotal evidence was confirmed through the NAA's survey of 1,142 respondents with a strikingly low aphasia awareness – only 8.8% of respondents had heard of the term aphasia and correctly identified it as a language-related disorder. What does this mean for the thousands of people affected by aphasia each year? It's a confusing, frightening diagnosis to receive.

Aphasia is a complex language disorder caused by damage to cortical and/or subcortical structures of the hemisphere(s) dominant for verbal symbolic manipulations (i.e., association, storage, retrieval, and rule implementation) (McNeil & Pratt, 2001). It is most often the result of neurological damage from a stroke affecting the left hemisphere of the brain, which is dominant for speech and language functions. However, areas of the brain rarely operate in isolation, so it is not surprising that language-dominate areas are reliant on other brain regions to carrying out other cognitive and executive functions. Furthermore, the severity of a person's aphasia depends on the functionality of multiple, intertwined structures of the brain working together (McNeil & Pratt, 2001).

For a disorder that potentially impacts a range of communication-based skills, it is essential to assess individual strengths and weaknesses in all forms of communication using a battery of tests. The Computerized Revised Token Test (CRTT) was designed to evaluate the auditory language, reading, language-related executive functions, syntactic challenges and nonlinguistic speed of processing skills of people with aphasia, several factors among many important components of communicating. Therefore, the CRTT battery could be a beneficial addition to the available tests designed to aid in differential diagnosis and planning interventions so as to best serve patient needs.

1.1.1 Byrne and Hendricks Studies

Byrne (2017) and Hendricks, (2017) investigated the need for age-based norms and the impact of age and the hand used to respond when taking the CRTT-R-WF and the CRTT Speed of Processing battery (CRTT-SOP). Their participants were healthy, neuro-typical adults aged 20-34 and 65+ years. They found that the older adult group scored lower on the CRTT-R-WF and had slower response times on the CRTT-SOP, especially with their left hand (left hand non-dominant in nearly all cases). Their data suggested that aging and reduced response times might contribute to inferior performance on the CRTT, absent of brain injury and language impairment. Furthermore, their results showed that the CRTT does not have absolute task purity (testing only exactly that which it claims to) and that corrections will be required to compare across age groups and the hand used during testing.

This study aimed to extend the Byrne and Hendricks studies by enrolling 35-49 and 50-64 year-old adults to fill the age-gap between their more extreme age groups. It specifically aimed to determine the normal growth/declination curves and age-related variability for the test for neuro-typical adults and document any discontinuities in the performance across the entire age range (i.e., 20 to 65+ years).

By establishing norms by age and hand, and collecting speed of processing data, appropriate norms can be established that account for age and might eventually be corrected for slowing and use of the non-dominant hand (i.e., for use with patients with no or limited use of their dominant hand). The development of corrected norms that will improve test purity (improving confidence that test performance can be attributed to language-specific processing impairments) and allow comparisons across the adult age-range and patient populations.

1.1.2 Revised Token Test

The Revised Token Test (RTT) (McNeil & Prescott, 1978) is a diagnostic tool used to evaluate the auditory processing and comprehension abilities in people with aphasia (PWA). The RTT's original target population, PWA, has since been expanded to other populations with language processing difficulties across the lifespan. The RTT is an adaptation of a token test published by DeRenzi and Vignolo (1962) and designed to determine the extent of a person's ability to process language while using simple word-level (single morpheme) content and nominal syntactic forms. By limiting the word-level and syntactic forms, the impact of certain language processing skills (e.g., attention, working memory, and temporal processing mechanisms) can be examined employing basic stimulus manipulations. During administration, patients are asked to identify plastic objects (circles and squares of different colors) by touching or manipulating them in response to orally presented commands from a trained test administrator, who scores each response on a 1 – 15 scale using multidimensional scoring system (McNeil & Prescott, 1978). Both the test administration and scoring system entail extensive training and periodic rehearsal.

In clinical settings, many SLP's have resorted to using simplified, and therefore unstandardized, versions of the RTT to avoid the complex preparatory training procedures, as well as the timely scoring mechanics that the RTT requires. The CRTT was developed to alleviate the complex, manual scoring and administration by providing reliable, automated presentations and scoring of auditory stimuli. The plastic stimuli were converted to digital forms compliant with computerized administration. The CRTT presents sentence-level commands and the digital tokens, and allows the patient to respond using either a touch screen or computer mouse. The patient's responses are recorded and scored by the CRTT's online, using the multidimensional scoring system. By default, the consistent automated administration and scoring increases inter- and intra-judge reliability and reduces training, administration, and scoring challenges that otherwise threatened the quality of the psychometric properties of the RTT. As a result, there is less complex preparatory training procedures and therefore a smaller risk of clinicians neglecting to follow the standardized procedures.

1.1.3 Versions of the CRTT

Unlike the RTT, the CRTT has both auditory and reading versions. The auditory, or listening, version of the CRTT (CRTT-L) is nearly identical to the original RTT. Three reading versions of the CRTT (CRTT-R) were developed: CRTT-Reading-Full Sentence (CRTT-R_{FS}), CRTT-Reading-Word Constant (CRTT-R_{WC}), and CRTT-Reading-Word Fade (CRTT-R_{WF}). McNeil et. al., (2015) reported that each reading version was reliable, valid, and consistent with the CRTT-L performance in people with aphasia. All versions of the CRTT have well-established construct and concurrent validity, high test-retest reliability and scoring accuracy (McNeil et. al., 2015). Age and the hand used in testing still required systematic examination to determine their effects on task performance, absent of neurological damage. Additionally, the contributions of motoric and cognitive control contribution to test performance also needed additional examination.

1.1.4 Aging Theories on Cognition, Language Processing and Comprehension

For the purposes of this study, it is important to understand the effects of aging on cognition. Cognition often is defined as "the mental action or process of acquiring knowledge and understanding through thought, experience, and the senses." (Cognition (n.d.)). Cognitive functions such as attention, learning, long-term and working memory, as well as judgment and evaluation all work together to enable processes such as the comprehension and production of language. Healthy aging is accompanied by many different cognitive changes, but current research fails to provide indisputable evidence as to when age-related cognitive declines begin in healthy adults, and to what extent such declines play a role in language processing and/or comprehension.

Evidence shows that a normal, healthy brain undergoes a reduction in volume, as well as regional activation as one ages (Morrison & Hof, 1997). With such evidence in mind, Burke and Graham (2012) evaluated research on aging-related changes in the brain and why aging affects certain behavioral components of language processing and not others. They examined the aging literature for evidence of structural differences and changes in activation patterns in brain regions associated with language. They investigated whether an observed pattern of neural change could explain aging-related declines in phonological retrieval in production and preservation of semantic retrieval in comprehension. Given a node structure theory perspective, they claimed that the literature supported the theory that language comprehension is largely based on the semantic system, and that comprehension processes acting on semantic knowledge were well maintained into old age. They also argued that language comprehension was independent of age-linked declines in visual and auditory acuity and working memory. This may suggest that the structural and neural activation changes seen in aging adults reflects changes in working memory/cognitive functioning rather than semantic knowledge or comprehension.

Working memory theories propose that working-memory storage capacity in adults decreases with age, thus making it more difficult for older adults to understand and produce complex linguistic information. In this way, a person's language processing or comprehension is thought to rely on working memory, in conjunction with our semantic knowledge, to receive and encode new information, retrieve previous information, and manipulate the collective information in order to perform a desired action, such as processing language. The reading tasks within the CRTT-R-WF (discussed in detail in later sections) prevents participants from re-reading previously presented stimuli, thus increasing the cognitive demands of working memory and likely accounts for lower scores from older adults with seemingly decreased working memory capacity (Byrne, 2017). The current study intends to extend this previous work, based on Byrne's hypotheses that normal aging related neural changes and limitations of working memory capacities are reflected in reduced scores on the CRTT-R-WF.

1.1.5 Cognitive Aging, Motor Performance and Hand Preference and Use for CRTT-R-WF and CRTT-SOP Battery

All language comprehension measures, including the CRTT, require both the processing of auditory or visual stimuli as discussed previously, and a motor response. During administration of the CRTT participants use either a touch screen or computer mouse to respond regardless of the mode of stimulus presentation. The nature of the measure thus requires consideration of cognitive aging effects on sensorimotor performance. Many of the previously mentioned cognitive processes, such as attention and working memory, required for language comprehension and production also require high levels of motor performance. Moreover, a reduction in attention as an effect of aging has been hypothesized as a possible link between cognitive aging and motor performance (Ren et al., 2013). For the purposes of this study, "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" (Byrne 2017). Ren et al. (2013) showed the amount of attention a person is able to devote to a task declines with age. It also is important to note that response speed in tasks with specific targets, like the CRTT-R-WF, has been shown to be slower in older adults (Hommel, Li & Li, 2004,; Salthouse, 1993).

The generalized slowing discussed in the aging theories of cognition has been hypothesized to hold true for the perceptual motor system as well. The generalized slowing theory suggests that the rate at which older adults, as part of natural aging, process information is slower than that of younger adults (Verhaeghen & Cerella 2002) and predicts slower reaction times across tasks with age.

Motor requirements related to the hand used during responses is another consideration. When studying hand preference or dominance, it is important to consider the concept of cerebral lateralization and functional specialization of the brain. Paul Broca is credited with the idea of left-hemisphere language dominance in right-handed individuals. Past centuries of continued research in neuropsychology has continually confirmed the concept of cerebral lateralization in functions such as speech, language and visuospatial attention and shown that such functions are associated with hand preference and skill (Gazzaniga, 1995; Gotts et al., 2013). Hand preference has been shown to be an inherent human asymmetry (Hendricks 2017; Triggs et al., 2000). These findings are important for our study because the CRTT is designed to assess individuals with neurological damage. As such, some individuals could have limb-motor impairments to their preferred hand as a result. Therefore, it is important that hand preference effects on performance be evaluated.

The impact of hand preference's influence on attention allocation and motor performance. Song and Bedard (2013) proposed that greater attentional resources are devoted to the dominant hand in fine motor activities. Similarly, Kourtis and Vingerhoets (2016) suggested that the consistency of hand preference plays a role in movement control. These findings may have consequences for individuals who identify their left hand as their preferred/dominant hand but habitually use their right hand when using a computer mouse. This may be a forced condition because most computers are designed for right-hand dominant individuals.

The impact of hand experience and consistency has been assessed relative to task difficulty. Peters and Ivanoff (1999) challenged both right- and left-handed individuals with a variety of simple reaction time and movement tasks. They found that the preferred hand advantage was so small that hand preference on task performance was trivial for the use of a computer mouse. Bryden (2002) came a similar conclusion when he compared right- and left-hand performance on tasks of varied difficulty. With patients in mind, these insignificant differences in preferred vs. non-preferred hand suggested that the hand used to respond when completing the CRTT would not substantively impact results. However, Hendricks (2017) found significantly faster responses with the right than left hand on CRTT-SOP performance.

1.2 EXPERIMENTAL QUESTIONS AND HYPOTHESIS

The unfortunate truth of all language assessments is that they will never achieve absolute task purity. The complex nature of language and its entanglement with other cognitive functions and motor performance ensures some impurity. In addition to test impurity, environmental conditions impact results and the motor and speech production limitations of people with strokes, traumatic brain injuries and degenerative diseases can limit the tests that can be used and accurately administered. Because neurological disorders affecting language and motor activities increase with age, examination of the hand used when taking the CRTT is a critical issue.

The primary goal of the current study was therefore to investigate the effects of aging and the hand used when responding on the CRTT-R-$_{WF}$ and CRTT-SOP battery by healthy, neuro-typical middle-aged adults. The study also intended to extend the Byrne (2017) Hendricks (2017) findings. As such, the following questions were investigated:

1. Is there a significant ($p \leq .05$) difference in CRTT-R-$_{WF}$ mean scores between middle-aged and older middle-aged adults?
2. Is there a significant ($p \leq .05$) difference in CRTT-R-$_{WF}$ mean scores when participants respond with their left hand as opposed to their right hand?
3. Is there a significant ($p \leq .05$) difference in CRTT-R-$_{WF}$ efficiency scores between middle-aged and older middle-aged adults?

4. Is there a significant ($p \leq .05$) difference in CRTT-R-$_{WF}$ efficiency scores when participants respond with their left hand as opposed to their right hand?
5. When compared to the Byrne (2017) and Hendricks (2017) data, do the middle-aged adults in the current study demonstrate an aging effect across the adult lifespan effect on the CRTT-R-$_{WF}$?
6. Is there a significant ($p \leq .05$) difference in SOP task performance between middle-aged and older middle-aged adults?
7. Is there a significant ($p \leq .05$) difference in SOP tasks performance when participants respond with their left hand as opposed to their right hand?
8. When compared to the Byrne (2017) and Hendricks (2017) data, do the middle-aged adults in the current study demonstrate an aging effect across the adult lifespan on the CRTT-SOP tasks?

From the background information discussed regarding aging effects associated with cognitive slowing and working memory demands, as well as the results of Byrne (2017), it was predicted that the older middle-aged participants would evidence significantly lower mean and efficiency scores on the CRTT-R-$_{WF}$ and significantly slower response times on the CRTT-SOP tasks than the younger-middle-aged participants. From the evidence discussed regarding the effects of the hand used to respond re: Hendricks (2017) and Byrne (2017), it was expected that participants would produce lower CRTT efficiency scores on the CRTT-R-$_{WF}$ and slower response times on the CRTT-SOP when responding with their left hand than their right hand because most people use their right hand when using a computer mouse and more people are right-hand dominant than left-hand dominant. That is, using their non-practiced hand, especially if it is the non-dominant hand, would produce slowed responses. The participant's motorically unpracticed hand would require a greater amount of attention directed toward the motor components needed to accurately move the mouse, thus slowing performance. Slower performance and longer response times would not significantly negatively influence the CRTT mean score but would negatively impact the efficiency score because it accounts for response time. Again, it was predicted that the age groups would respectively replicate the results of the Byrne (2017) study and the non-practiced hand would result in longer response times, negatively influencing a participant's efficiency score, but not their mean score.

2.0 METHODS

2.1 PARTICIPANTS

Thirty-four healthy adults completed this study. The participants were divided into two groups: middle-aged adults (Group 1, 35-49 years) and older middle-aged adults (Group 2, 50-64 years). Group 1 consisted of 15 participants, 7 males and 8 females, with an average age of 43.2 years. Group 2 consisted of 19 participants, 6 males and 13 females, with an average age of 60.6 years.

The majority of participants self-identified as Caucasian. One participant in Group 1 identified as Asian, 3 identified as African American, and one identified as African American and Indian. One participant from Group 2 identified as African American (See Appendix A, Table 4 for demographic information). All but one participant reported English as their native language. One participant from Group 1 reported that her home language during early childhood was Thai, but that she used English as a native level of proficiency and identified as trilingual. Five participants were excluded from the study. Two participants were excluded because they were not interested in completing the data collection of the study and chose to leave before completing all four CRTT measures. Three other participants were excluded because of computer program malfunctions that deleted or failed to record a portion of the participant's data. It should be noted that the computer programmer was contacted, and the computer programming malfunctions were resolved upon consultation before any other participant's data was collected.

The University of Pittsburgh Institutional Review Board approved this study (PRO16030419). Verbal and written consent were obtained from all participants prior to initiating the study protocol and each received $15.00 as compensation upon study completion. Participant recruitment was facilitated by University of Pittsburgh's online participant recruitment forum, Pitt+Me, as well as communication among interested volunteers.

2.1.1 Inclusion Criterion and Preliminary Procedures

For the purposes of this study, the definition of a "healthy adult" accepted age-related differences that research suggests accompanies healthy aging. Participants passed the following six criterion measures in order to qualify for this study. (1) A self-reported questionnaire (Adapted from Heilman, 2008 Appendix B) providing qualitative information including native language, education level, and occupational history (Appendix A, Table 4). Additionally, participants indicated the hand used in computer-related activities including approximate hours of daily usage. The participants were excluded from the study if they self-reported medical, psychological, or other cognitive conditions that could influence performance (e.g., stroke, alcohol abuse, Parkinson's Disease, Alzheimer's disease, depression) and/or physical impairments that would limit range of mobility, use of their hands, wrists, or arms for the purposes of this study's protocol. (2) A vision screening using the Reduced Snellen Chart (Snellen, 1862) to assess corrected or uncorrected vision. For inclusion, a participant was required to demonstrate a visual acuity of 20/40 or better and no presence of color blindness. (3) To assess reading comprehension, participants read two passages and were required to accurately respond to comprehension questions with a combined raw score of 17 or greater on the Clinical Evaluation of Language Fundamentals 5th Edition (CELF-5; Appendix A, Table 5) (Wiig, Semel, &Secord, 2014), a reading subtest for ages 13-21 years. (4) Using the Arizona Battery of Communication Disorders of Dementia (ABCD) (Bayles & Tomoeda, 1933), participants completed a story retell task to screen immediate and delayed memory capabilities. A delayed /immediate recall ratio of 0.70 or greater was required to pass (see Appendix A, Table 6). (5) Another memory-based screener, the Digit Span Forward and Backward subtests from the Wechsler Adult Intelligence Scale-4th Edition (WAIS-IV) (Wechsler, 2008), assessed short-term and working memory skills. The participants repeated a string of numbers, up to 8 digits, both forwards and backwards. A scaled score of eight or greater as compared to age-matched normative data was required to pass (Appendix A, Table 7). (6) The last screening measure required for inclusion was the Fade Reading Pretest of the CRTT-R-$_{WF}$. The pretest ensured the participant's ability to select stimuli with the mouse, to differentiate between "big/little," "circle/square," and "red/green/blue/black/white" colors. The pretest also served to briefly familiarize the subject with the CRTT's general format.

Participants completed two additional preliminary procedures serving as descriptive measures: (1) The Language Experience and Proficiency Questionnaire (LEAP-Q) (Marian, Blumenfeld, & Kaushanskaya, 2007), and (2) The Edinburgh Handedness Inventory (Oldfield, 1971). The LEAP-Q provided subjective information about the participants' language experiences including current exposure to each language they reported knowing, both orally and written. The Edinburgh Handedness Inventory provided a laterality quotient identifying participant hand dominance on various activities (Appendix A, Table 8).

2.2 PROTOCOL

All participants completed the CRTT-R-$_{WF}$ and the six tasks from the CRTT-SOP battery. Every participant completed these tests twice, once with their left hand and once with their right hand, totaling four task conditions per participant: CRTT-R-$_{WF}$ Right Hand, CRTT-R-$_{WF}$ Left

Hand, CRTT-SOP Right Hand, and CRTT-SOP Left Hand. To minimize possible order effects, the order of completion of these four tasks was randomized for each participant. To adhere to the original CRTT design, subtests within each task were not randomized. The CRTT-R-$_{WF}$ and CRTT-SOP battery tasks and data collection are discussed in greater detail in the following sections. All participants used the same laptop and standard, wired mouse during administration of all procedures. All data was collected in a quiet laboratory or otherwise unoccupied classroom within Forbes Tower.

2.2.1 Computerized Revised Token Test- Reading-Word Fade

The participants completed the 10-subtest, 100-item word-fade reading comprehension version of the CRTT (CRTT-R-$_{WF}$). Each subtest consists of 10 imperative sentences (commands) from which the participants were required to respond by clicking or moving one or more tokens out of an array of 10 or 20 tokens (alternated between subtests) on the computer screen (Figures 1 and 2). Prompted by a 'green light' indicating when the participant was to begin clicking the mouse in order to initiate the first printed word, each command appeared in a word-by-word, self-paced moving window in text at the bottom of the computer screen. Each time the participant clicked the mouse, a new word in the sentence appeared, and the previous word disappeared with the onset of each new word. The fleeting nature of the word-fade task required the participant to hold each part of speech in their short-term memory as they continued clicking to complete the sentence and comprehend the command to ultimately formulate their response. Once the participant reached the final word in the sentence, a period appeared, and the digital token array appeared on the screen for the response. This presentation method lends to better identification of the point of increased processing demands within each sentence because the stimuli disappear with the onset of the following word. That is, the CRTT-R-$_{WF}$ enables the identification of reading times for each particular word in the sentence because the participants are prevented from re-reading previously presented stimuli. These measured reading times can be analyzed and used to detect the points of increased processing demands within each sentence (e.g., when the participant takes a longer time to process one part of speech as compared to another), but that analysis was not included in this study except as reflected in efficiency. The commands included two shape word (circle, square), two size word (big, small), two actions (touch, put), five colors (white, black, red, green, blue), 5 adverbial clauses (unless, instead of, either, if there is, if you have not), and 10 prepositions/prepositional phrases (above, before, behind, below, beside, by, in front of, on, next to, under) as well as left and right within Subtest VII and VIII (McNeil et al., 2015b; McNeil & Prescott, 1978.). These combinations create commands for manipulating the tokens pictured in Figures 1 and 2.

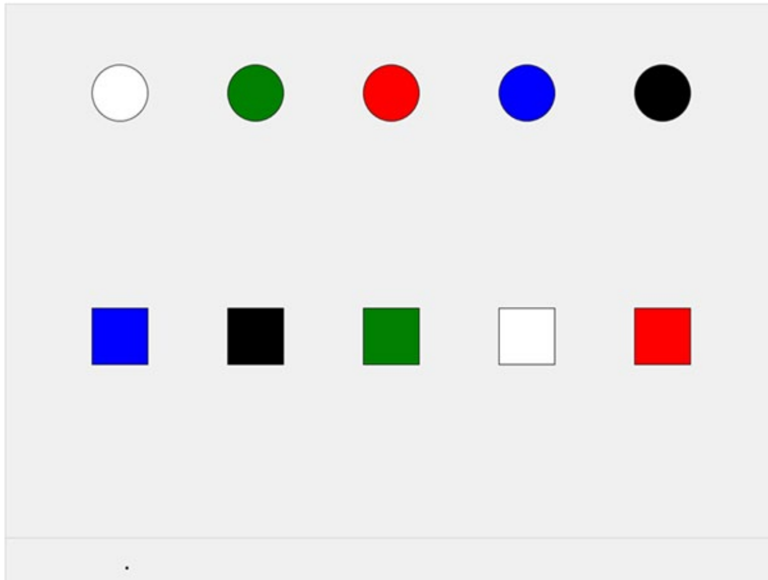

Figure 1: The Computerized Screen of the 10 Big CRTT Tokens (McNeil et al., 2015a)

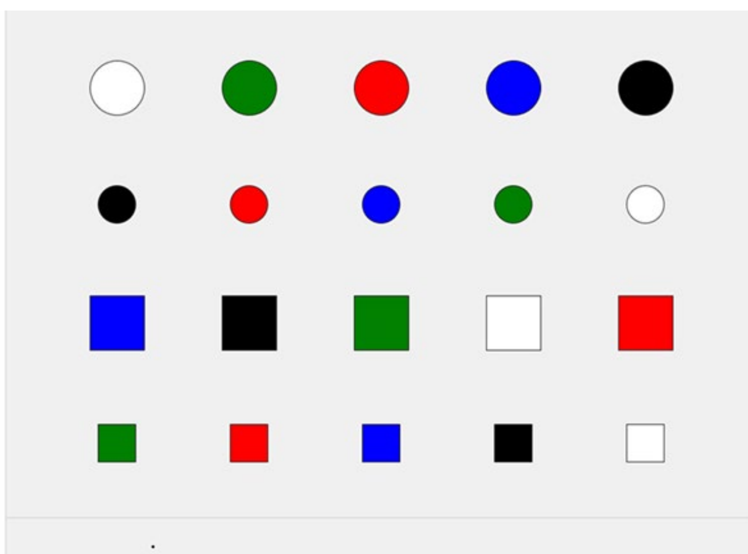

Figure 2: The Computerized Screen of the 20 CRTT Tokens (McNeil et al., 2015a)

Subtests I, III, V, VII, and IX use only the 10 big tokens seen in Figure 1. The remaining five subtests use all 20, big and small tokens, as seen in Figure 2. The subtests vary in sentence length and systematically increased in syntactic complexity, thereby increasing the demands on attention and short-term/working memory. Additionally, the commands differ between simple one-part commands (e.g. "touch the black square" or "touch the little black square") compared to compound two-part commands such as "touch the green circle and the white square" or "touch the little green circle and the big white square". Each word except the articles were assigned different scores based on five measures of the multidimensional scoring procedures: responsiveness, accuracy, promptness, efficiency and completeness.

The efficiency score (ES) generated by the CRTT 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/mt*)). It should be noted that the default *mt* value is set at 30 seconds (McNeil et al., 2015a). The ES equation can be used to reflect the accuracy and time of the participant's responses for individual commands, subtests, and the entire test. For the purposes of this study, only the ES for each overall subtest and the entire test were considered.

2.2.2 Computerized Revised Token Test – Speed of Processing Tasks

The participants completed each of the 6 SOP tasks designed to assess speed of processing, with their left and right hands. The SOP Task 1 (Tapping) required participants to tap a computer-mouse as rapidly as possible for three 10-second time periods. The average interval between taps was determined and used to estimate basic motor-related speed across both age and hand.

The SOP Task 2 (Simple Reaction Time) instructed the participants to click the mouse as quickly as possible after a token appeared on the center of the screen. For this task, participants did not have to click on the token itself, they were only required to click the mouse, regardless of where the cursor was located on the screen. A mix of thirty tokens (squares and circles of 5 colors) were presented one at a time with time intervals varying by 50 ms between stimuli. The varied time intervals between presentations served to reduce anticipatory responses. From this task, the average response time across tasks was determined and identified the participants' response time for detecting and responding to a visual stimulus, namely their simple reaction time.

The SOP Task 3 (Simple Reaction Time Plus Movement) evaluated the speed at which participants detected and then motorically responded to the stimuli by adding a simple skilled movement to SOP Task 2. Instead of clicking the mouse, independent of the cursor's location, participants were instructed to click on the stimuli presented at the center of the screen. This task required the participants to move the cursor from the bottom of the screen to the token that appeared in the center of the screen and click mouse as quickly as possible. This added movement component provided a measure of movement time plus reaction time across 30 trials.

The final three tasks offered different motor responses options and could be judged for correctness and speed, although only speed was considered in the current study. These tasks are considered choice reaction time tasks and test the participants' inhibitory control (SOP Task 4) and cognitive mapping skills (SOP Task 5 & 6). In the SOP Task 4 (Go-No-Go) required participants to cognitively inhibit the response when a square appeared. One token (circle or square) was randomly presented on the screen one at a time. The participants were instructed to click the left mouse button as quickly as possible if a circle appeared on the screen, but to withhold a response if the shape that appeared was a square. The percentage and average response times of the correct responses were calculated and used to measure the participants' speed and accuracy for an inhibitory choice RT task.

The SOP Task 5 (One Stimulus, Two Response RT Mapping) required participants to click the left mouse button as quickly as possible if a circle appeared, or the right mouse button if a square appeared. As within SOP Task 4, only one shape (circle or square) appeared on the screen at a time. The accuracy percentage and average response times were calculated. The predetermined shape-to-button mapping also was used in Task 6.

The SOP Task 6 (Two Stimuli, Two Response Mapping) presented participants with two tokens in the center of the screen at the same time and required a more complicated response-mapping task. They were instructed to respond sequentially, left to right, to both stimuli using the predetermined shape-to-button response map used in SOP Task 5 (left mouse click for circle, right mouse click for square). That is, if a circle appeared on the left followed by a square on the right, a participant was to click the left mouse button first, and then the right mouse button as quickly as possible. Trials included circles and squares in both positions as well as each shape in the left and right positions. The randomization of shape position reduced the possibility that a second stimulus-response was linked to the first stimulus-response decision. Both percentages and average response times were collected for correct response times, including percentages and averages for both the first and second stimuli.

3.0 RESULTS

3.1 STATISTICAL ANALYSIS CRTT-R-$_{WF}$

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

An alpha level of .05 was set for all statistical analyses with false discovery corrections for multiple comparisons.

A 2x2 (group x hand) mixed design ANOVA was conducted to test whether Group 1 and Group 2 participants differed in mean overall scores for the CRTT-R-$_{WF}$ as a function of the hand used to respond. The interaction between group x hand was not statistically significant, $F(1,32) = 0.042$, $p = .839$, $\eta^2 = .001$, and there were no significant main effects of group for the right hand, $F(1,32) = 3.28$, $p = .080$, $\eta^2 = .093$, or the left hand, $F(1,32) = 2.04$, $p = .163$, $\eta^2 = .060$. Moreover, Group 1 and Group 2 did not differ on CRTT-R-$_{WF}$ mean scores with hands combined. However, there were significant main effects of hand for Group 1, $F(1\text{-}14) = 8.217$, $p = .012$, $\eta^2 = .370$, and Group 2, $F(1\text{-}18) = 4.712$, $p = .044$, $\eta^2 = .207$. Group 1 scored significantly higher when using the right hand ($M = 14.22$, $SD = 0.68$) than the left hand ($M = 13.97$, $SD = 0.86$), as did Group 2 – right hand $M = 14.52$, $SD = 0.22$, left hand $M = 14.30$, $SD = 0.46$. Figure 3 and Table 3 show the overall mean scores by group and hand. It should be noted that the assumption of normality was not met given that the Box's M test for equality of covariance matrices was statistically significant, $F(3, 182410.16) = 6.54$, $p < .001$. The Mauchly's test of sphericity was assumed to be met because hand used had only two levels. As such, compound symmetry was not assumed. Removal of one significant outlier (participant 133, WF_MN_R) improved Box's M test and allowed compound symmetry to be met but did not change results, so the outlier was retained in all analyses.

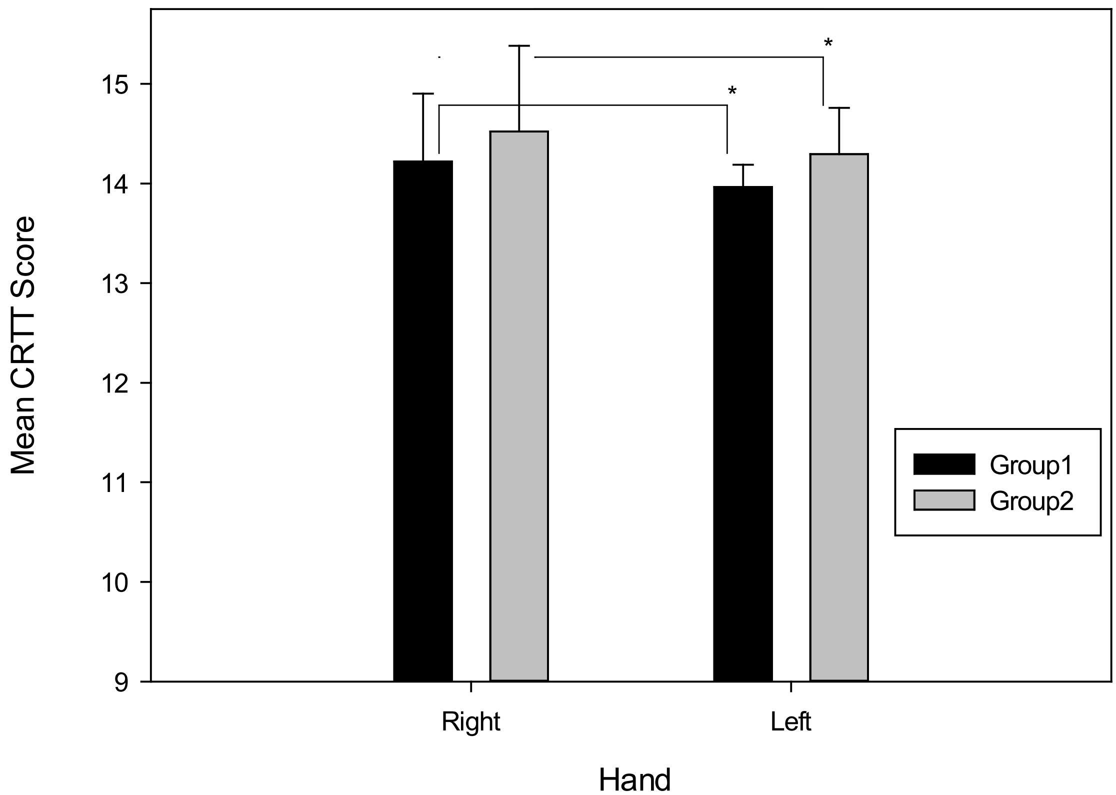

Figure 3: Overall Mean CRTT-R-WF Scores by Age and Hand

Table 1: Descriptive Statistics of Mean Scores by Group and Hand

	Group	Mean	Standard Deviation	*N*
CRTT-R-$_{WF}$_M_R	1	14.2213	.68158	15
CRTT-R-$_{WF}$_M_R	2	14.5218	.22276	19
CRTT-R-$_{WF}$_M_L	1	13.9657	.86166	15
CRTT-R-$_{WF}$_M_L	2	14.2952	.46464	19

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

A 2x2 (group x hand) mixed design ANOVA was conducted to test whether Group 1 and Group 2 differed in efficiency score for the CRTT-R-$_{WF}$ as a function of the hand used to respond. The interaction between group x hand was not statistically significant, F (1,32) = 0.011, p = .915, η^2 <.001. There also were no significant main effects of group for the right hand, F (1,32) = 1.77, p = .192, η^2 = .052, or the left hand, F (1,32) = 1.47, p = .234, η^2 = .044, for CRTT-R-$_{WF}$ efficiency. In addition, Group 1 and Group 2 did not differ on CRTT-R-$_{WF}$ efficiency score.

There were significant main effects of hand for Group 1, F (1,14) = 17.69, p = .001, η^2 = .558, and Group 2, F (1,18) = 33.87, p < .001, η^2 = .653. Group 1 had higher efficiency when using the right hand (M = 12.73, SD = 1.02) than the left hand (M = 12.18, SD = 1.19). Group 2 also had higher efficiency scores when using the right hand (M = 13.07, SD = 0.43) than the left hand (M = 12.54, SD = 0.46). Figure 4 depicts the overall mean efficiency scores by group and hand. The data used to create the graph can also be found in Table 4. It should be noted that assumption of normality was not met. Box's M test for equality of covariance matrices was not statistically significant, F (3,182410.16) = 4.70, p = .003. The Mauchly's test of sphericity was assumed to be met since hand has only two levels. Compound symmetry was not assumed.

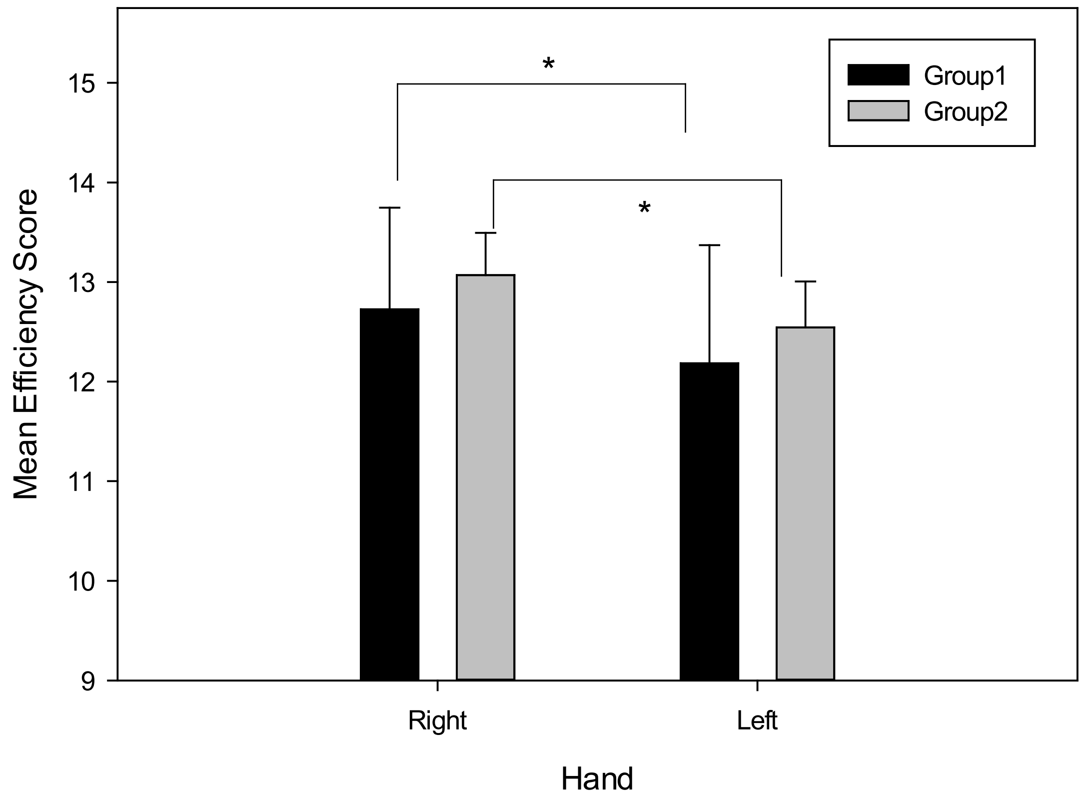

Figure 4: Overall Mean Efficiency Scores for Group and Hand

Table 2: Descriptive Statistics of Mean Efficiency Scores by Go

	Group	Mean	Standard Deviation	Number
CRTT-R-$_{WF}$_EF_R	1	12.7263	1.02092	15
CRTT-R-$_{WF}$_EF_L	1	12.1837	1.18709	15
CRTT-R-$_{WF}$_EF_R	2	13.0697	0.42549	19
CRTT-R-$_{WF}$_EF_L	2	12.5436	0.46205	19

3.2 STATISICAL ANALYSIS CRTT-SOP BATTERY

3.2.1 Group and Hand Differences across the CRTT-SOP Tasks

An omnibus MANOVA comparing response time differences on the CRTT-SOP tasks as a function of group and hand was not significant. However, difference by hand were examined below given the pattern observed in Figure 5 below.

3.2.1 Mean Group Differences for CRTT-SOP Performed with the Right Hand

A two-way MANOVA (group x SOP task) was used to assess the mean differences between the two groups on CRTT-SOP tasks when performed with the right hand. Four extreme outliers from Group 1 were removed for this analysis. The test was not significant with the two groups not differing overall or at the level of any of the SOP tasks.

3.2.2 Mean Group Differences for CRTT-SOP Performed with the Left Hand

A two-way MANOVA (group x SOP task) was used to assess the overall mean difference between two groups on CRTT-SOP tasks when performed with the left hand. Two extreme outliers were removed for the analysis, one from each group. The two groups differed on the Simple SOP task, $F(1,30) = 7.491$, $p=.01$. The group means and standard deviations for each SOP task for each hand are listed below in Tables 3 - 6.

3.2.3 Relationship between the Right and Left Hand across CRTT-SOP Tasks

Figure 5 below illustrates is the relationship between Group 1 and 2 across the CRTT-SOP tasks for both hands. The functions are similar and the task means overlap but there is some spread between the right and left hand regression lines suggestive of a hand effect, especially for the more complex tasks. There was a hand by group interaction on the Simple task, $F(1,29) = 4.787$, $p=.037$. Further examination of the results showed this effect was due to a significantly shorter time for Group 1 for the right hand on the SOP Tap task, $F(1,32) = 7.712$, $p=.009$ and a significantly longer time on the left hand on the Simple RT SOP task 2, $F\ (1,30) = 20,684$, $p<.0001$.

3.2.4 CRTT-SOP Task 1: Tapping

Table 3: Group Means and Standard Deviations for CRTT-SOP Tap Task

Group	Hand			
	Right		Left	
	Mean	*SD*	*Mean*	*SD*
1	184.76	38.22	231.52	54.60
2	214.05	48.00	233.78	49.05

3.2.5 CRTT-SOP Task 2: Simple RT

Table 4: Group Means and Standard Deviations for CRTT-SOP Simple RT Task

Group	Hand			
	Right		Left	
	Mean	*SD*	*Mean*	*SD*
1	352.31	69.10	406.44	101.00
2	349.20	90.04	323.99	113.12

3.2.6 CRTT-SOP Task 3: Simple RT Plus Movement

Table 5: Group Means and Standard Deviations for CRTT-SOP Movement Task

Group	Hand			
	Right		Left	
	Mean	*SD*	*Mean*	*SD*
1	1127.25	324.20	1587.82	597.72
2	1185.00	215.92	1402.41	382.79

3.2.7 CRTT-SOP Task 4: Go-No-Go

Table 6: Group Means and Standard Deviations for CRTT-SOP Go-No-Go Task

Group	Hand			
	Right		Left	
	Mean	*SD*	*Mean*	*SD*
1	417.38	61.00	435.78	64.04
2	439.29	69.37	442.81	55.08

3.2.8 CRTT-SOP Task 5: One Stimuli, Two Response RT Mapping

Table 7: Group Means and Standard Deviations for CRTT-SOP Map 1 Task

Group	Hand			
	Right		Left	
	Mean	*SD*	*Mean*	*SD*
1	522.25	73.32	579.56	142.79
2	588.23	119.75	578.25	103.56

3.2.9 CRTT-SOP Task 6: Two Stimuli, Two Response RT Mapping

Table 8: Group Means and Standard Deviations for CRTT-SOP Map 2 Task

Group	Hand							
	Right				Left			
	Mean 1	*SD 1*	*Mean 2*	*SD 2*	*Mean 1*	*SD 1*	*Mean 2*	*SD 2*
1	809.06	249.12	987.98	255.91	798.05	144.72	1051.08	184.73
2	717.18	153.08	1103.50	237.02	798.09	188.76	1158.61	452.82

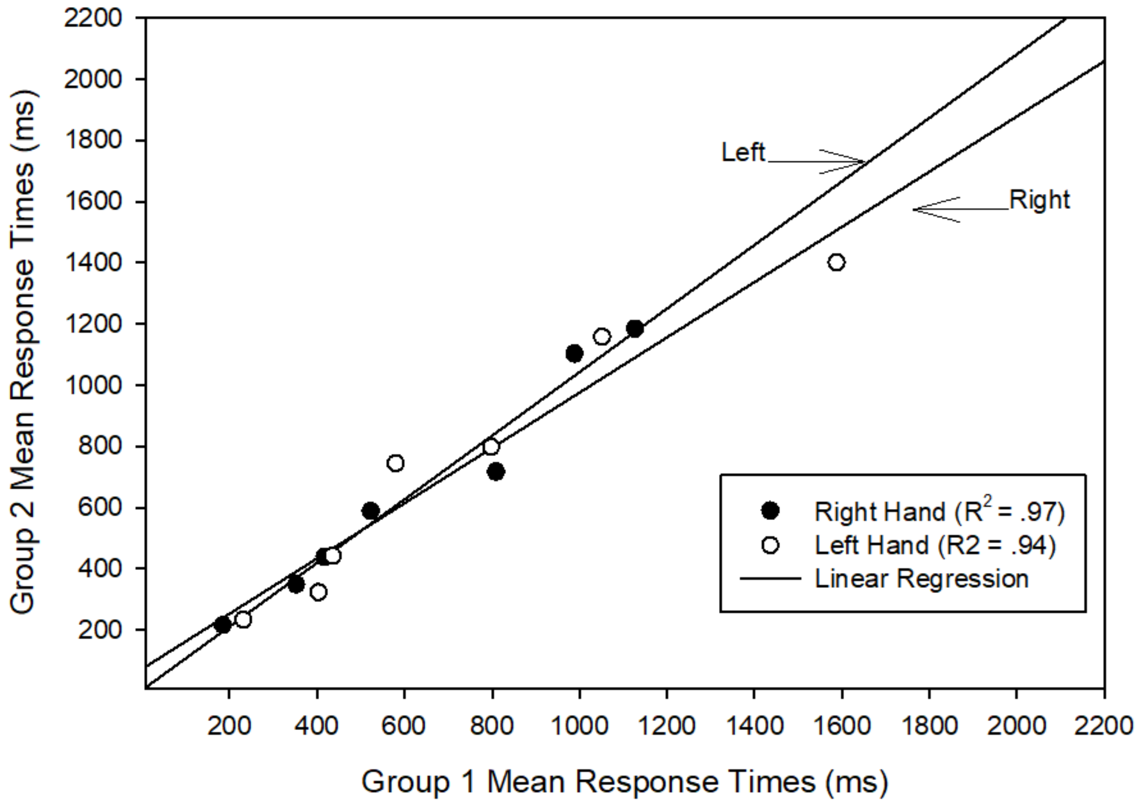

Figure 5: Group 1 vs. Group 2 Mean Response Times across SOP Tasks for Right and Left Hands

4.0 COMPARISON WITH BYRNE AND HENDRICKS STUDIES

The current study aimed to extend the Byrne (2017) and Hendricks (2017) (B & H) study results by including 35-49 and 50-64 year-old adults to fill the age-gap between the more extreme age ranges that they tested. The current study specifically aimed to determine the normal age-related changes on the CRTT for neuro-typical, healthy adults and document any discontinuities in the performance across the adult age range from 20 to 65+ years. It was hypothesized that the two middle age groups would show similar age and hand effects as observed in the B & H studies.

4.1 CRTT-R-WF Mean Scores across the Four Groups

A 4x2 (group x hand) mixed design ANOVA was conducted to test whether the four age groups differed in mean scores for the CRTT-R-$_{WF}$ when performed using their left and right hands. The interaction between group x hand was statistically significant, F (3,94) = 3.302, p = .024, partial $\eta 2$ = .095. and there were significant main effects of hand for the B & H young group, F(1,31) = 27.111, p < .001, partial $\eta 2$ = .467, Group 1, F(1,14) = 8.22, p = .012, partial $\eta 2$ = .370, Group 2, F(1,18) = 4.712, p =.044, partial $\eta 2$ = .207, and the B & H old group, F(1,31) = 49.37, p < .001, partial $\eta 2$ = .614. All groups scored higher when using their right hand than their left hand. There were significant main effects of group for the right hand, F (3,94) = 10.34, p < .001, partial $\eta 2$ = .248, and the left hand, F (3,94) = 14.280, p < .001, partial $\eta 2$ = .313. For both the right and left hands, the B & H young group scored higher than Group 1 and the B & H old group. Group

2 also scored higher than the B & H old group. Figure 5 and Table 3 show the overall CRTT mean scores by age and hand.

It should be noted the assumption of normality was not met. Box's M test for equality of covariance matrices was statistically significant, F (9,30455.34) = 8.17, $p < .001$. The Mauchly's test of sphericity was assumed to be met since hand only had two levels. Compound symmetry was not assumed.

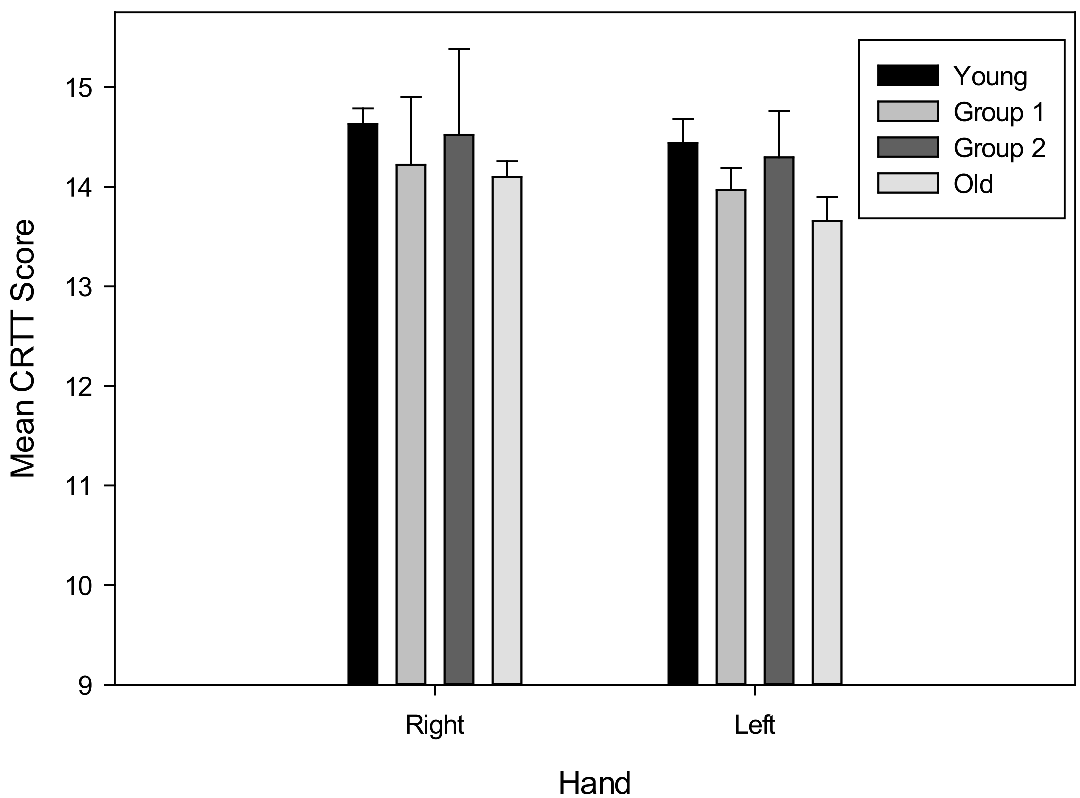

Figure 6: Overall Mean CRTT Scores by Group and Hand

Table 9: Descriptive Statistics of Mean Scores by Group and Hand

Comparison (Right Hand)	*p*-value	Comparison (Left Hand)	*p*-value
B & H young > Group 1	.013	B & H young > Group 1	.021
B & H young > B & H old	<.001	B & H young > B & H old	<.001
Group 1 > B & H old	.004	Group 1 > B & H old	<.001

Note: B & H = Byrne (2017) and Hendricks (2017)

4.2 RTT-R-WF Efficiency Scores across the Four Groups

A 4x2 (group x hand) mixed design ANOVA was conducted to test whether the four different age groups differed significantly in their CRTT efficiency score for the CRTT-R-WF across hands. The interaction between group x hand was statistically significant, F (3,94) = 16.89, p <.001, partial $\eta2$ = .350. There were significant main effects of hand for the B & H young group, F(1,31) = 773.33, p < .001, partial $\eta2$ = .961; Group 1, F(1,14) = 105.72, p < .001, partial $\eta2$ = .883; Group 2, F(1,18) = 486.10, p < .001, partial η2 = .964, and the B & H old group (2017), F(1,31) = 562.09, p < .001, partial η2 = .948. As with the CRTT mean score, all groups were more efficient when using the right hand than the left hand. There were significant main effects of group for the right hand, F (3,94) = 10.34, p < .001, partial $\eta2$ = .248, and the left hand, F (3,94) = 22.03, p < .001, partial $\eta2$ = .413. Results from pairwise comparisons using false discovery corrections are summarized in the table below. The B & H young group was significantly more efficient than Group 1 and the B & H old group for both the right and left hands. For the left hand, the B & H old group had a significantly lower efficiency scores compared to all other groups.

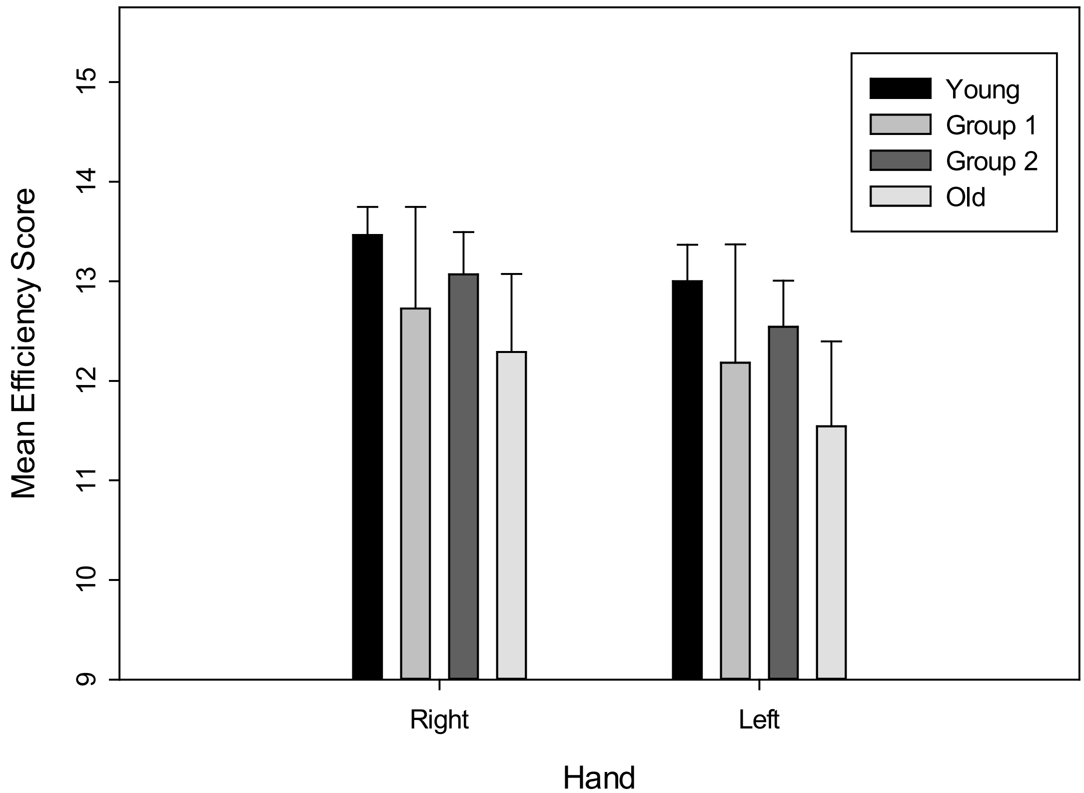

Figure 7: Mean Efficiency Score by Group and Hand

4.3 CRTT-SOP across the Four Groups

A generalized estimating equations was run using Proc Glimmix in SAS to address whether the four different age-groups differed on the CRTT-SOP tasks as a function of hand. Significant outliers were removed for all analyses. The interaction between group x hand x SOP task was statistically significant, $F(45,1303) = 3.40$, $p < .001$, as were two-way interactions for group and SOP task, $F(18,1321) = 4.11$, $p<.0001$), and hand and SOP task, $F(6,1321) = 10.24$, $p<.0001$).

There also were main effects for group, $F(3,1348)=97.85$, $p<.0001$, hand, $F(1,1348)=72.83$, $p<.0001$, and SOP task, $F(6,1348)=1614.09$, $p<.0001$.

Post-hoc comparisons using the false discovery correction was conducted to compare groups by hand by subtest. Results are presented in Table 4 below.

Table 10: Post-hoc Comparisons Comparing Groups by Hand by Subtest

Task	Hand	Interpretation
Tapping	R x L	All groups were faster with right hand than the left hand.
	Both	The B & H Young group was faster than all other groups.
		Groups 1 and 2 were faster than the B & H Old group.
	Right	Group 1 was faster than Group 2.
	Left	Group 1 was slower than Group 2.
Simple RT	R x L	All groups except Group 2 were faster with right than left hand.
	Right	The B & H Young group was faster than all other groups.
		The B & H Old group was slower than Groups 1 and 2.
		Group 1 was slower than Group 2.
	Left	The B & H Young group was faster than Group 1 and the B & H Old group, but not Group 2.
		Group 2 was faster than the B & H Old group.
		Group 1 was slower than Group 2 and the B & H Old group.
Simple RT Plus Movement	R x L	All groups were faster with right than left hands.
	Both	The B & H Young group was faster than all other groups.
		Groups 1 and 2 were faster than the B & H Old group.
	Right	Group 1 was faster than Group 2.
	Left	Group 2 was faster than Group 1.
Go-No-Go	R x L	All groups were faster on the right than left hands.
	Both	Group 1 and Group 2 were faster than the B & H Young and Old groups.
	Right	Group 1 was faster than Group 2.
		The B & H Young group was faster than the B & H Old group.
	Left	The B & H Young group was faster than B & H Old group.
		Group 2 was faster than Group 1.
One Stimuli, Two Response RT	R x L	All groups except Group 2 were faster with right hand than left hand.
	Right	The B & H Young group was faster than all other groups.
		Group 1 was faster than Group 2 and the B & H Old group.
		Group 2 was faster than the B & H Old group.
	Left	The B & H Young group was faster than all groups except Group 2.
		Groups 1 and 2 were faster than the B & H Old group.
		Goup 2 was faster than Group 1.
Two Stimuli, Two Response RT Mapping	R x L	All groups except Group 1 were faster with the right hand.
	Both	The B & H Young group was faster than all other groups.
		Groups 1 and 2 were faster than the B & H Old group.
	Right	Group 1 was faster than Group 2
	Left	Group 2 was faster than Group 1.
Two Stimuli, Two Response RT Mapping	R x L	All groups were faster with the right hand than left hand.
	Both	The B & H Young group was faster than all other groups.
		Group 1 was faster than Group 2 and the B & H Old group.
		Group 2 was faster than the B & H Old group.

Brinley plots for the three older groups relative to the young group illustrated the age-related response time patterns across the SOP tasks for each hand (Figures 8 and 9). The plots suggest a general slowing effect with age that was most pronounced between the two extreme age groups, especially for the left hand.

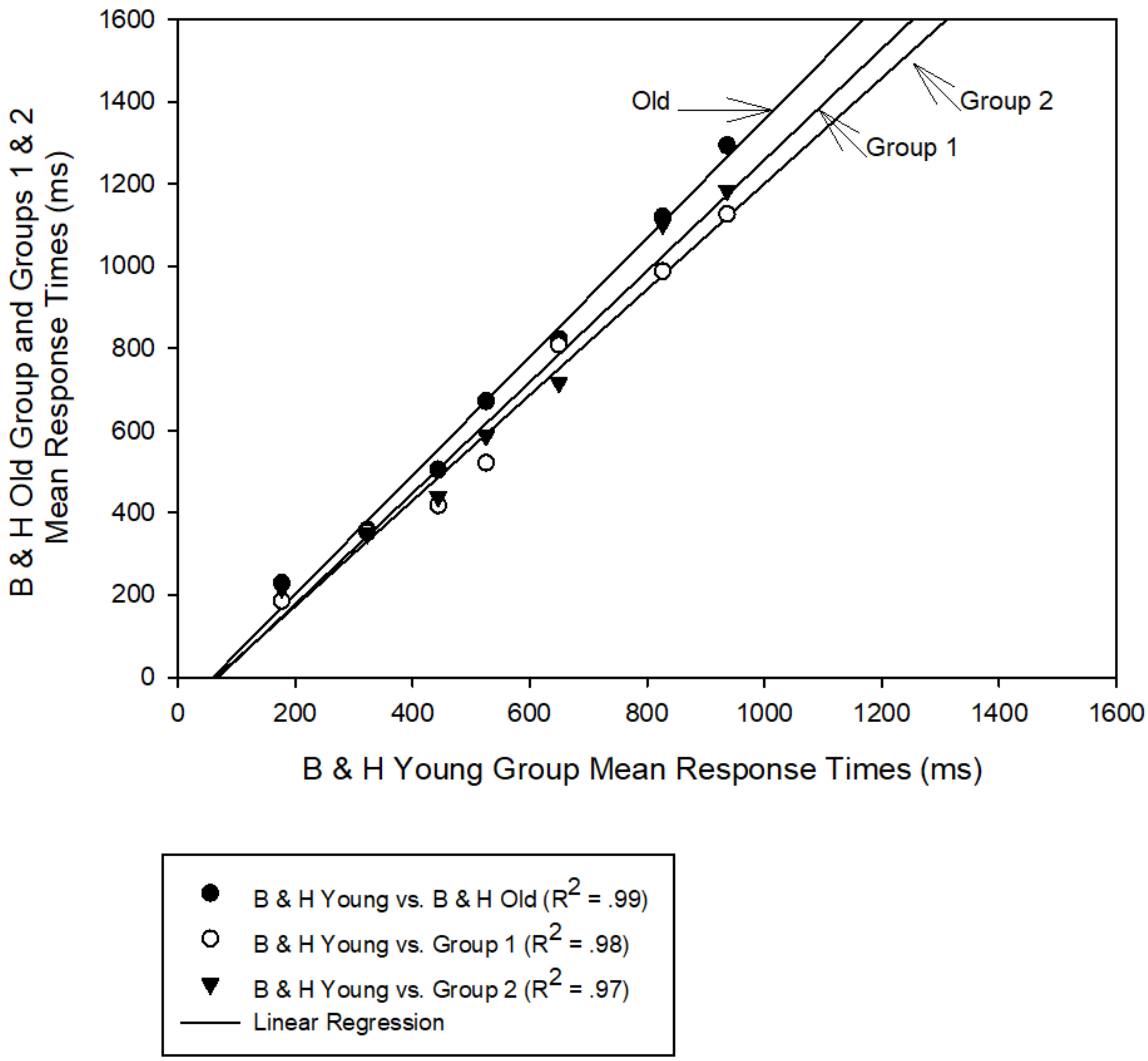

Figure 8: B & H Young Group Mean Response Times vs. Other Three Group Means across SOP Tasks for the Right Hand

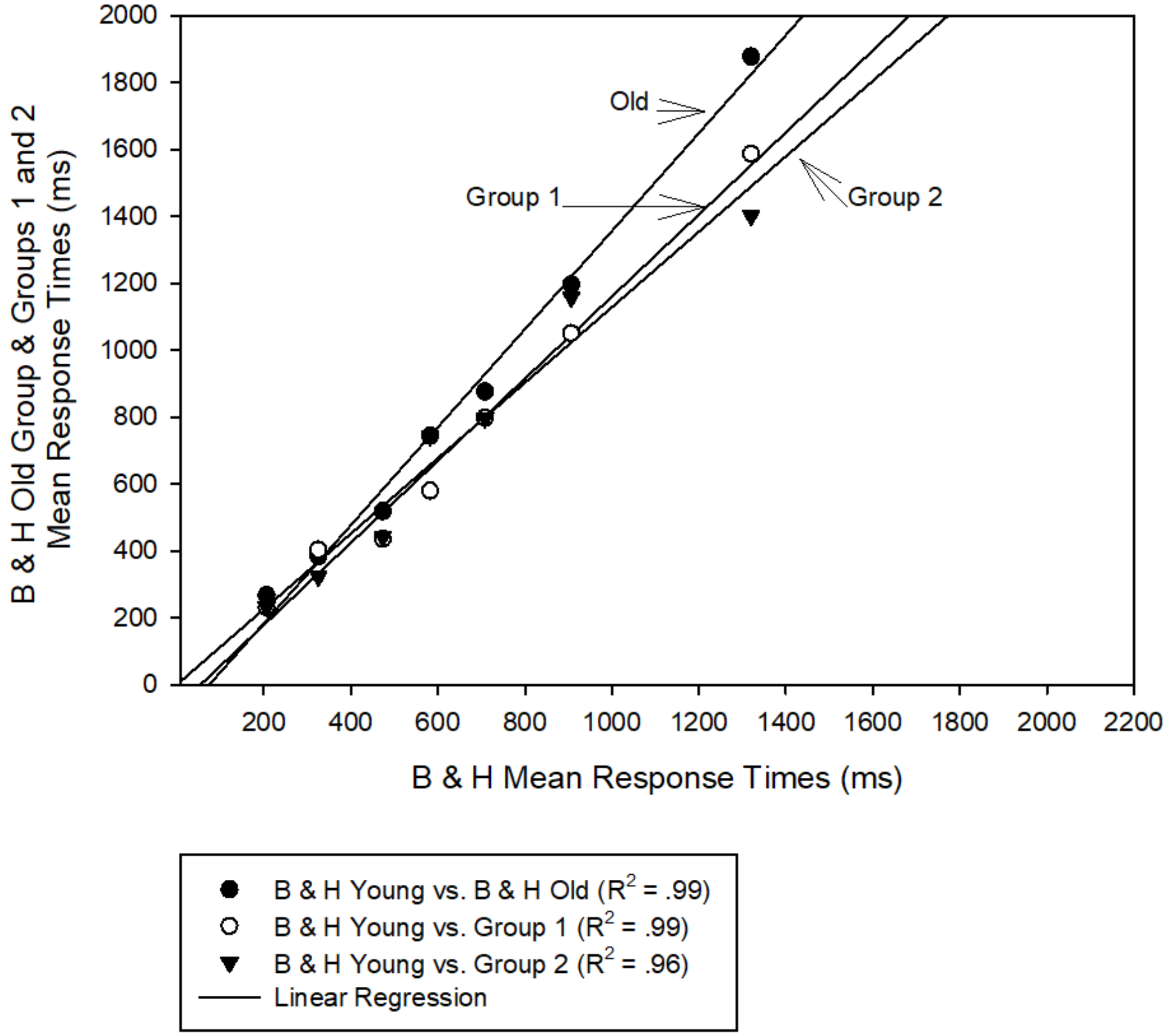

Figure 9: B & H Young Group Mean Response Times vs. Other Three Group Means across SOP Conditions for the Left Hand

5.0 DISCUSSION

This study investigated the effects of age and the hand used on English reading comprehension and response time performance on the CRTT-R-$_{WF}$ and CRTT-SOP battery respectively. The CRTT was designed to limit the demands of vocabulary, discourse variables, complex syntax, working memory and attention to asses language comprehension and processing as exclusively as possible. The self-paced word-by-word presentation format of the CRTT-R-$_{WF}$ however, may increase the motoric and working memory demands on test performance. The CRTT-SOP Battery measured basic motor speed, simple motor control, simple and choice reaction/reaction times and response inhibition. Research from previous studies were considered to hypothesize how the CRTT-R-$_{WF}$ mean and efficiency scores, as well as the CRTT-SOP Battery performance time and accuracy would change across age groups and the hand used to perform the tasks. The hypotheses and results of the age and hand effects on the CRTT-R-$_{WF}$ and CRTT-SOP Battery performance are discussed below.

5.1 AGING

Several experimental questions, in regard to both the CRTT-R-$_{WF}$ and the CRTT-SOP, asked if scores would differ significantly as an effect of age. For the CRTT-R-$_{WF}$, it was hypothesized that both mean, and efficiency scores would show a significant reduction as an effect of age. For the CRTT-SOP Battery, it was hypothesized that participants would exhibit significantly slower response times across tasks as an effect of age.

5.1.1 Aging Effects on CRTT-R-$_{WF}$

Experimental questions 1 and 3 asked whether CRTT-R-$_{WF}$ mean and efficiency scores would differ significantly as an effect of age. It was hypothesized that both scores would show a significant age effect. Group 1 and Group 2 did not exhibit significant differences on CRTT-R-$_{WF}$ mean or efficiency scores. These findings support the rejection of the original hypothesis. It is, however, important to note the small sample size as well as outliers within the small data set. Three participants within Group 1 exhibited mean and efficiency scores greater than 3SD below the group's average mean score. Because that data from this study will contribute to a normative sample, excluding participants who passed all the screening measures even if they scored much lower than other participants in their age range could not be justified. Personal factors including attention to detail, willingness to follow directions, and overall interest in the task could not be measured but may have played a role in the poor scores of these participants. With such a small sample size, individuals that were less engaged and focused on the task could have created high variability within the group and may have reduced the group's average mean and efficiency scores considerably, which may account for the unforeseen lack of significance between Group 1 and Group 2. An examination of these participants' individual trial-by-trial scores suggested extreme variability that was atypical for their neuro-typical peers and resembled the intermittent variability that characterizes pathological populations such as that of persons with aphasia (McNeil, 1983; McNeil, Odell & Campbell, 1982).

Comparing Group 1 and Group 2 mean and efficiency scores with the Byrne (2017) and Hendrick (2017) participants revealed more evidence that the performance of some individuals within Group 1 was inconsistent with the majority of the group. Group 2's means and efficiency scores were closer than Group 1's data in comparison to the young Byrne (2017) and Hendricks (2017) group. Group 2 scored significantly higher on the CRTT-R-$_{WF}$ than their old group.

Results of Group 2 in comparison to both Byrne (2017) and Hendricks (2017) data are consistent with both the generalized slowing and working memories theories and suggest that aging effects on language processing tasks are not significant until sometime after age 64. The significant interaction between age and hand could also support the working memory theory as Group 2 exhibited lower efficiency scores with their left hand, hypothesizing that lack of motor ability due to use and practice more with the left hand slowed response and lowered efficiency scores. Group 2's results are also consistent with Byrne's hypotheses of normal aging related neural changes and limitations of working memory capacities.

5.1.2 Aging Effects on CRTT-SOP Battery

Experimental question 6 asked whether CRTT-SOP performance would be affected by age. It was hypothesized that Group 2 would evidence significantly slower response times on the CRTT-SOP tasks than the younger-middle-aged participants as an effect of age. The groups did not differ overall on the CRTT-SOP tasks. These findings led to a rejection of the original hypothesis. A closer analysis of group x hand x subtest interactions across B & H groups and Group 1 and Group 2 suggested a general slowing effect with age that was most pronounced between the two extreme age groups, especially for the left hand (discussed in detail in later section). The B & H Young group was faster on all tasks, except Task 4, with both hands. Several outliers were observed again in Group 1 suggesting personal factors including attention to detail, willingness to follow directions, and overall interest in the task may have played a role in the poor scores of these participants. With such a small sample size, individuals who were less engaged and focused on the task could have created high variability within the group and may have reduced the group's overall mean scores considerably, which may account for the unforeseen lack of significance between Group 1 and Group 2 as an effect of age.

5.2 HAND USED TO RESPOND

5.2.1 Effects of Hand Used to Respond on CRTT-R-$_{WF}$

Several experimental questions asked whether there would be significant ($p < .05$) effects on the CRTT mean score and efficiency score on the CRTT-R-$_{WF}$ as a function of the hand used to respond. It was hypothesized that the participants' motorically unpracticed hand would require a greater amount of attention directed toward the motor components needed to accurately move the mouse, thus slowing performance. Slower performance/longer response times would not significantly negatively influence a participant's CRTT mean score but would negatively impact their efficiency score. Again, it was predicted the age groups would respectively replicate the results of the Byrne (2017) study and the non-practiced hand would result in longer response times, negatively influencing a participant's efficiency score, but not their mean score. All groups CRTT mean scores and efficiency scores were significantly higher when using the right hand than the left hand. These findings reject the notion that the hand used to respond would not affect mean scores.

5.2.2 Effects of Hand Used to Respond on CRTT-SOP Tasks

Experiment question 7 asked whether significant effects would be observed as a result of the hand used on the CRTT-SOP tasks. It was hypothesized the participants would perform slower with their left hand than their right hand as a result of less motoric practice with the left hand. There was no significant overall mean difference between Group 1 and Group 2 for tasks performed with the right hand. There was also no significant overall mean difference between Group 1 and Group 2 for tasks performed with the left hand, however the two groups did differ on the Simple response task. Further examination of the results also showed group differences by hand on the other simpler tasks such as the Tap task and the Movement task. There also was a hand by group interaction on the Simple task.

Figures 8 & 9 from above show performance comparisons across all age groups, addressing the question: when compared to the Byrne (2017) and Hendricks (2017) data, and address the question of whether the middle-aged adults in the current study demonstrated an aging effect across the adult lifespan on the CRTT-SOP tasks? The data revealed a general slowing effect with age that was most pronounced between the two extreme age groups, especially for the left hand. These findings support the hypothesis that the hand used to respond would show significant slowing effects on CRTT-SOP performance when examined across the entire age range.

6.0 STUDY LIMITATIONS AND OBSERVATION FOR FUTURE RESERACH

6.1 Study Limitations

When determining the overall interpretability, generalizability and importance of this study, a number of limitations in study design and data collection should be taken into consideration. The following differences in external and internal testing conditions were observed: (1) data was collected in three different rooms within Forbes Tower based on scheduling conflicts and room availability whereby environmental differences in factors such as seating accommodations and lighting were present; (2) testing appointment times varied considerably (any time between 8am- 6pm) and personal factors (fatigue, hunger, boredom, distractibility, overall interest in participating) could have impacted participant performance respective to what time of day their testing took place; (3) the sample size per group was relatively low which could have affected the reliability of the test results as small sample size often leads to a higher variability, which may lead to experimental error. Although the CRTT is a computer-administered and scored test, inter and intra-judge reliability between the primary investigator and research assistants should be considered regarding the administration of the screening procedures. Lastly, participants were observed to become more familiar with expectations the second time they completed the CRTT-R-$_{WF}$ and CRTT-SOP Battery. Randomization of test sequence was used to reduce possible order effects from these potential factors.

6.2 Observations for Future Research

This study aimed to replicate the Byrne and Hendricks studies with 35-49 and 50-64 year-old adults to fill the age-gap in their studies. It specifically aimed to determine the normal age-related variability for the test for neuro-typical adults, and document any discontinuities in the performance across the entire age range (i.e., 20 to 65+ years). Unfortunately, the results for the younger middle-aged group (34-49 years) yielded group effects that are difficult to explain within any coherent theory of aging. Indeed, several individuals within this age group were identified that performed outside of the range of the other participants. For this reason, another replication study, with a larger sample size is required to find conclusive results in order to best evaluate possible age differences in CRTT performance across the lifespan. It is imperative that clinicians, as well as researchers, gain a better understanding of how normal, age-related changes impact scores on diagnostic measures and performance on treatment protocols (Byrne, 2017), including those of tests designed to minimize aging and other contributions to test performance such at the CRTT-R-$_{WF}$ and CRTT-SOP.

The results of this study revealed no significant age effect between the two groups of participants examined in this study [a younger group (34-49 years) and an older group (50-64 years)]. A larger middle age range sample size could allow for a better understanding of the rate at which CRTT-R-$_{WF}$ mean and efficiency scores change with age. Increases and decreasing the age intervals for groups of participants could also lead to a more accurate point of optimal age-related performance as well as any declination point from optimal performance.

This study found a significant difference in CRTT-R-$_{WF}$ mean scores, efficiency scores, as a function of the hand used to take the test. Further studies would benefit from examining both the frequency with which an individual uses a computer mouse, and whether that hand is preferred or dominant. It is important to remember that using the right hand with a computer mouse has become the norm. Therefore, many left-hand dominant individuals may still be more motorically practiced using a computer mouse with their right hand. It also could be true in the future that many individuals no longer use a computer mouse. The prevalence of laptop computers with mouse pads and computers and smart phones with touch screens could negatively influence the amount of time individuals use a traditional computer mouse. Normative data should continue to be collected both for age and hand, at least for healthy individuals, based on the statistically significant main effects and interactions found between age and hand for the CRTT-R-$_{WF}$ mean and efficiency scores across all ages considered from this study, and the two parallel studies it sought to extend. Future research could investigate whether these effects will be replicated with pathological populations. Different versions of the CRTT also need to be examined to determine if the observed age and hand effects are evident in these test versions as well.

7.0 SUMMARY AND CONCLUSIONS

This study investigated whether aging and the hand used to respond impacted response-time and language processing performance on the CRTT. All group CRTT-R-$_{WF}$ mean scores and efficiency scores were significantly higher when using the right hand than the left hand. The results of this study revealed no significant age effect between Group 1 (34- 49 years) and Group 2 (50-64 years) participants examined in this study. Group 1 and Group 2 also did not reveal significant age or hand use effects for overall mean scores on the CRTT-SOP battery; however, significant hand effects were observed between different subtests across the entire adult age range. Further research should include larger sample sizes for these age range to allow for a better understanding of the rate at which CRTT-R-$_{WF}$ mean and efficiency scores as well as CRTT-SOP scores change with age.

Appendix A : Demographics

Table 11: Participant Demographics Based on Subject Hisotry Questionairre

Participant Demographics						
Subject #	Gender	Age	Race	Native Language	Highest Level of education	Occupation
101	M	37	African American	english	some college	unemployed
103	F	45	Caucasian	english	bachelors	secretary
104	M	59	African American	english	trade school	chef
105	F	44	Asian	thai	PhD	homemaker
106	M	47	African American	english	professional degree	driver
107	F	64	Caucasian	english	bachelors	headstart teacher
108	M	60	Caucasian	english	bachelors	retired/part time
109	F	49	Caucasian	english	masters	retail
110	F	60	Caucasian	english	bachelors	teacher
111	M	54	Caucasian	english	1 year of college	unemployed
113	M	64	Caucasian	english	masters	retired
114	F	39	African American	english	bachelors	CNA
115	F	62	Caucasian	english	bachelors	flight attendant
116	F	60	Caucasian	english	associates	retired
117	F	60	Caucasian	english	bachelors	administrator
119	F	63	Caucasian	english	bachelors	administrator
120	M	37	Caucasian	english	masters	grad student
121	F	39	Caucasian	english	bachelors	NRR
124	F	61	Caucasian	english	bachelors	homemaker
126	M	63	Caucasian	english	bachelors	service representative
127	F	60	Caucasian	english	masters	guidance councelor
128	M	60	Caucasian	english	bachelors	actor
129	F	49	Caucasian	english	bachelors	clinical consultant
130	M	58	Caucasian	english	highschool grad	retired
131	F	62	Caucasian	english	some college	executive assisstant
132	M	54	Caucasian	english	bachelors	programmer
133	M	64	Caucasian	english	bachelors	consultant
134	M	63	Caucasian	english	some college	retired
135	F	34	Caucasian	english	masters	youth counselor
136	M	42	Caucasian	english	masters	career consultant
137	M	41	Caucasian	english	masters	higher education
138	F	49	Caucasian	english	bachelors	underwriter
139	M	47	Caucasian	english	some college	remodeling work
140	M	49	African American	english	bachelors	production worker

Table 12: CELF -5 Scores

CELF-5			
Subject #	Raw Score 1	Raw Score 2	Combined Score
101	10	9	19
103	10	9	19
104	10	9	19
105	10	9	19
106	10	9	19
107	10	9	19
108	10	9	19
109	10	9	19
110	10	9	19
111	10	9	19
113	10	9	19
114	10	9	19
115	10	9	19
116	10	9	19
117	10	9	19
119	10	9	19
120	10	9	19
121	10	9	19
124	10	9	19
126	10	9	19
127	10	9	19
128	10	9	19
129	10	9	19
130	10	9	19
131	10	9	19
132	10	9	19
133	10	9	19
134	10	9	19
135	10	9	19
136	10	9	19
137	10	9	19
138	10	9	19
139	9	9	18
140	10	9	19

Table 13: ABCD Story Retell Scores

ABCD Story Retell			
Subject #	Immediate	Delayed	Ratio
101	16	16	1.00
103	16	16	1.00
104	14	12	0.85
105	16	16	1.00
106	13	11	0.85
107	13	13	1.00
109	16	16	1.00
110	17	16	0.94
111	2	2	2.00
113	15	14	0.93
114	17	16	0.94
115	17	16	0.94
116	14	141	1.00
117	17	17	1.00
119	17	17	1.00
120	17	16	0.94
121	15	16	0.94
124	13	13	1.00
126	16	15	0.94
127	16	14	0.88
128	17	17	1.00
129	16	16	1.00
130	14	12	0.86
131	17	17	1.00
132	17	16	0.94
133	17	17	1.00
134	16	15	0.94
135	15	15	1.00
136	17	17	1.00
137	16	16	1.00
138	17	17	1.00
139	17	17	1.00
140	16	15	0.94

Table 14: WAIS-4 Digit Span Scores

WAIS-4				
Subject #	DS Forward	DS Backward	Total	Scaled Score
101	13	11	24	15
103	14	8	22	14
104	10	6	16	10
105	15	8	23	14
106	13	5	17	10
107	16	5	21	13
109	16	8	24	13
110	13	6	19	11
111	12	5	17	11
113	16	4	20	12
114	16	12	28	18
115	14	8	22	14
116	15	11	26	17
117	12	5	17	11
119	16	14	30	19
120	16	9	25	16
121	15	8	23	14
124	16	8	24	15
126	11	8	19	12
127	15	4	19	12
128	16	14	30	19
129	14	5	19	11
130	12	10	22	14
131	16	12	28	19
132	15	8	23	14
133	14	6	20	13
134	16	10	26	17
135	14	9	23	14
136	16	12	28	18
137	16	13	29	19
138	16	12	28	18
139	12	4	18	11
140	16	4	20	12

Table 15: Edinburgh Handedness Laterality Quotient

Edinburgh Handedness		
Subject #	Laterality Quotient	Decile
101	-17.64	L
103	84.61	R
104	-42.86	L
105	-33.34	L
106	50.00	R
107	60.00	R
108	100.00	R
109	-66.67	L
110	-100.00	L
111	0.71	R
113	100.00	R
114	100.00	R
115	100.00	R
116	-83.34	L
117	100.00	R
119	16.67	R
120	0.85	R
121	100.00	R
124	0.83	R
126	-0.83	L
127	100.00	R
128	0.55	R
129	100.00	R
130	0.83	R
131	0.33	R
132	0.60	R
133	0.57	R
134	0.92	R
135	-0.07	L
136	0.60	R
137	100.00	R
138	100.00	R
139	100.00	R
140	0.71	R

Appendix B: Subject History Form

Subject #______________

Birth date: ______________ Age: _______________

Sex: M F

Is English your native language? Yes No

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 C: Edinburgh Handedness Inventory

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 absolutely 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?		

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