REACTION TIME PERFORMANCE IN HEALTHY ADULTS AS AN EFFECT OF AGE AND HAND PREFERENCE USING THE CRTT

by

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Background: The Computerized Revised Token Test (CRTT) is a standardized assessment of language processing abilities. The test requires perceptual, motor, and cognitive skills that may impact patient performance. A battery of reaction time tasks (CRTT-RT) was developed to assess these skills on a more basic, nonlinguistic level in order to assess a patient's perceptual-motor-cognitive skills' contribution to their CRTT language performance. Normative data on the CRTT-RT Battery do not currently exist across age and for right and left hands. The purpose of this study was to investigate the effect of age and hand preference on the simple and choice reaction time (RT) tasks included in the CRTT-RT Battery.

Procedures: Sixty-four healthy, normal adults completed the CRTT-RT tasks and the CRTT-R-$_{WF}$ version of the CRTT with both their right and left hands. Participants included 32 younger adults (20-32 years; 16 male, 16 female) and 32 older adults (65-78 years; 16 male, 16 female). For this study, the CRTT-RT data were analyzed to evaluate the effects of age and hand preference on speed and accuracy of responses.

Results: Statistically significant main effects were determined for both age and hand preference on all RT tasks combined. Age effects were additionally observed on individual RT tasks, where the older group performed slower (increased RT) than the younger group. Hand preference effects were observed on 4 of the 6 RT tasks, those that required motor movement control and response mapping, with the left hand performing significantly slower. A significant interaction between age and hand was observed for CRTT-RT Task 3 (Movement), where the older group demonstrated an over-additive slowing with the left hand. Accuracy of responses on the choice RT tasks demonstrated non-substantive differences between age and hand.

Conclusions: Slowing in reaction time performance on the CRTT-RT Battery is evident with increased age as well as non-preferred hand use with a computer mouse. Theories of generalized slowing with age, increased task complexity, cognitive load, and automaticity are explored as potential explanations for the obtained results.

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PREFACE

The information presented in this thesis represents the hard work and dedication of the many individuals who volunteered their time from December of 2015 to May of 2017. The following individuals and groups deserve recognition for their guidance and support.

The supervision of the thesis committee members, Dr. Malcolm McNeil, Dr. Sheila Pratt, and Dr. J. Scott Yaruss, guided the success of this research project. Fellow graduate student, Ashley Byrne, dedicated her time and energy to serving as a co-investigator in this research to collect and analyze the participant data on language performance measured by the CRTT. Neil Szuminsky provided technological support with the programming of the study's assessment, the CRTT-RT Battery. A special thank you is reserved for family, classmates, undergraduate volunteers, and faculty in the University of Pittsburgh School of Health and Rehabilitation Sciences who have provided endless support through all stages of this process.

1.0 INTRODUCTION

The *Computerized Revised Token Test* (CRTT) was developed to describe and quantify language-processing abilities in people with language and cognitive impairments. Test performance requires motor and perceptual skills in addition to other linguistic and cognitive abilities. To investigate the relationships among language performance and these more fundamental perceptual-motor and cognitive abilities, a battery of reaction time (RT) tasks was developed by the test's author that were hypothesized to underlie the task demands of the CRTT. These RT tasks systematically vary in difficulty from simple finger tapping (a measure of isolated motor speed) to choice reaction time (measures of decision making and stimulus-response mapping). Performance on these tasks may be impacted by age and hand preference. As such, the purpose of this study was to assess the effects of age and hand preference in healthy, normal adults on this battery of RT tasks. The eventual goal of this research is to determine if and/or to what extent the perceptual-motor and cognitive abilities that underlie these tasks contribute to performance on the CRTT. A parallel study was conducted to explore the impact of age and hand preference on CRTT performance. Together, the two studies will contribute to a better understanding and accounting of individual patient performance on the CRTT.

1.1 BACKGROUND

1.1.1 Revised Token Test (RTT)

Aphasia is an acquired neurological impairment that affects language. It is characterized by an inefficiency in the ability to decode and encode linguistic information across multiple modalities (Darley, 1982; McNeil 1988; McNeil & Pratt, 2001). Communication impairments in aphasia cross language domains and modalities and include deficits in reading and listening comprehension, as well as spoken and written production. Test batteries, thus, should assess an individual's strengths and weaknesses in communication across modalities and language domains (i.e. semantics, syntax, and phonology). Use of multimodality assessments is essential to identify deficits, differentially diagnose, and guide intervention (McNeil et al., 2015b).

The *Revised Token Test* (RTT) (McNeil & Prescott, 1978) is a diagnostic tool that was developed to evaluate the auditory processing and comprehension abilities in people with aphasia (PWA). Adapted from the concept of a token test published by DeRenzi and Vignolo (1962), the RTT provides a standardized means of administration for presenting stimuli and scoring responses to assess an individual's processing of linguistic information. The RTT offers relevant information about an individual's auditory attention, memory, and temporal processing abilities (McNeil & Prescott, 1978).

The complex administration and scoring of the RTT requires extensive training and has led to the use of simplified assessments and scoring systems in the clinical setting (McNeil et al., 2015b). To combat the use of simplified and un-standardized versions of the RTT, a computerized version of the test was developed. The *Computerized Revised Token Test* (CRTT) provides consistent, automated presentations of digital forms of the stimuli used in the RTT.

Furthermore, the CRTT provides an online, multidimensional scoring system for each of the subtests. The computerization of the RTT reduces discrepancies in training, administration, and scoring that otherwise compromise the psychometric data of the RTT. In addition, the CRTT has well-established construct and concurrent validity, high test-retest reliability, and scoring accuracy (McNeil et al., 2015a).

The CRTT includes a listening (CRTT-L) version, which is comparable to the original RTT, as well as three reading versions (CRTT-R): CRTT-Reading-Full Sentence (CRTT-R-FS), CRTT-Reading-Word Constant (CRTT-R-WC), and CRTT-Reading-Word Fade (CRTT-R-WF). The reading versions of the CRTT are reliable, valid, and consistent with the CRTT-L performance in people with aphasia (McNeil et al., 2015b). However, the different versions of the CRTT have not been examined systematically for aging and hand preference effects. In an unpublished work, Jorgensen et al. (2016) found an age effect for the CRTT-L, however the effect proved minimal once audibility of stimuli was corrected.

A recent addition to the CRTT is a series of tasks measuring basic motor speed and motor control, simple and choice reaction time, response inhibition, and stimulus/response mapping (CRTT-RT). The tasks were designed, in part, to be completed in conjunction with the CRTT to examine deficits in these domains relative to language processing deficits. Normative data for the CRTT-RT across age and hand preference currently do not exist.

1.1.2 Reaction Time as an Effect of Aging

A general slowing in the processing of information is well established as an effect of aging (Verhaeghen & Cerella, 2008). Older adults’ increases in reaction times and response times have been shown in a variety of cognitive tasks ranging from visual memory search to lexical decision-making (Salthouse, 1991). Age-related slowing is apparent at basic sensorimotor processing levels as evidenced by delays in reaction time tasks (Fozard, Vercryssen, Reynolds, Hancock, & Quilter, 1994). It is unclear whether the age-related slowing across cognitive domains is associated with slowed perceptual skills, movement control, response inhibition, cognitive decision-making, or stimulus/response mapping. Many researchers have sought to identify the sources that may account for slower processing times on test performance with increased age.

1.1.2.1 Aging Theories on Movement Control

Walker, Philbin, and Spruell (1996) identified four existing theories explaining slowed movement control in older adults: (1) error-aversion, (2) increased motor noise, (3) increased perceptual noise, and (4) generalized slowing of the perceptual-motor system.

The theory of error-aversion speculates that individuals become more conservative as they age. This suggests older adults are more averse to making errors. In most reaction time tasks, an individual must decide to optimize their performance in terms of speed or accuracy (i.e. to have a faster reaction time with less accuracy or to have a slower reaction time with greater accuracy). This speed-accuracy tradeoff is generally dependent on the individual's motivation given the nature of the task. Some studies suggest that older adults show preference for higher accuracy levels as opposed to younger adults when given the same task (Goggin & Stelmach, 1990).

The theory of increased motor and perceptual noise in older adults is based on the prior assumptions that a) there is noise in the neuromotor system (Gregory, 1959), and b) neural noise increases with age (Layton, 1975). Fitts' law is a performance principle signifying a linear relationship between task difficulty and movement time. Fitts' law can be applied to this perceptual-motor-noise theory. The amount of noise in the neuromotor system increases as greater force is required for the movement (Fitts, 1954; Welford et al., 1969). This noise-to-force relationship assumes that adults must slow their movement rate to compensate for the increase in neural noise and to achieve the same level of accuracy as the younger population. Similarly, an increase in perceptual noise, such as interference in the visual processing system (Cremer & Zeef, 1987), would slow the performance rate in older adults consistent with the above principle.

The final theory of age-related declines in movement control includes a generalized slowing hypothesis across cognitive, motor, and perceptual domains. Salthouse (1991; 1996) describes age-related slowing as a function of processing speed (Processing-Speed Theory). This theory hypothesizes that the rate at which older adults process information is less than that of younger adults (Verhaeghen & Cerella, 2002). With less efficient processing abilities, older adults are slower to perform movement tasks. Cerella (1980; 1985) further discussed the general slowing mechanism as it applies to task domain and task difficulty. This theory predicts older adults will present with slower reaction times across tasks that are proportional to those of young adults, signifying a natural aging process.

Few researchers adhere to only one of these theories to explain the age-related differences in reaction time. Many believe that most, if not all, of these hypothesized factors can lead to slowed performance as a function of aging. The general slowing mechanism described above can be measured by the amount of time an individual spends to complete a task. The Processing-Speed Theory can then be measured by the amount of information correctly processed within the allotted time. Both theories, and their associated methods, provide measures for evaluating the presence and extent of age-related slowing.

1.1.2.2 Previous Findings

A study on dual-task performance, by Vaportzis, Georgiou-Karistianis, and Stout (2013), investigated the theory of generalized slowing in simple choice and complex choice reaction time tasks as a function of normal aging. Performance of both speed and accuracy across tasks, were analyzed, with emphasis provided to participants on the importance of both speed and accuracy on performance. The findings of this study were twofold: (1) age-related differences in speed of performance were present in simple choice reaction time tasks, whereas (2) age-related differences in accuracy of performance were present in complex choice reaction time tasks.

In an attempt to explain the aging effect on speed in simple choice reaction time tasks, Vaportzis et al. (2013) considered both the error-aversion theory (Goggin & Stelmach, 1990) and the Processing Speed Theory (Salthouse, 1996). They proposed that either (1) the older adults decided to be more cautious by favoring accuracy over speed in simple tasks; or (2) the older adults were unable to process and perform the task as quickly as the young adults due to generalized slowing with age. The results of their study demonstrated that on tasks requiring greater cognitive demand, the age effect on speed of performance was eliminated. This finding discounts the Processing Speed Theory's claim for generalized slowing. Yet, the accuracy level under more complex conditions significantly decreased as a function of age. The authors thereby hypothesized an age-related difference in performance strategy for more cognitively demanding tasks. One proposed explanation for these results draws upon the findings of Davidson et al. (2003). The authors suggested the young adults slowed their speed for more complex tasks to account for the higher attentional demand and to perform at their desired accuracy level.

In the Baltimore Longitudinal Study of Aging, Fozard et al. (1994) applied cross-sectional and longitudinal analyses to simple and complex reaction time data from 1,265 participants. The authors investigated task performance in individuals between the ages of 17 and 96 years and found an overall increase in both reaction time and error rate with age. Similar to previous findings, this study determined that slowing of performance is continuous across the adult life span. Slowing, too, is a function of task complexity. The researchers acknowledged neural mediation as the rationale for the heightened amount of errors in older adults. Thus, this hypothesis is consistent with the aging theory of increased perceptual-motor noise as a function of age.

1.1.3 Reaction Time as an Effect of Hand Preference

Hand preference, the favored use of one hand over the other in various activities, is an inherent human asymmetry (Peters, 1981; Triggs et al., 2000). Most individuals display a preference for hand use when applied to activities of both simplistic and skilled performance. Cerebral lateralization is an important central concept to studies of hand preference. Paul Broca's research on hemispheric dominance first founded the idea of left-hemisphere language dominance in right-handed individuals (Broca, 1861). Following Broca's discovery, research in the field of neuropsychology has continually confirmed that certain functions are lateralized to one of the two cerebral hemispheres. Functions such as speech, language, and visuospatial attention are associated with contralateral hand preference and skill (Gazzaniga, 1995; Gotts et al., 2013).

Patients with upper motor neuron damage that can accompany aphasia can present with weakness (paresis) or paralysis of their arms, hands, fingers, or legs on the side of their body contralateral to the site of lesion. Right-handed individuals who suffer from brain damage to their left cerebral hemisphere may experience paresis of their right/dominant hand. Limited capabilities of their dominant hand may then force the individual to perform motor tasks with their non-dominant hand. Several researchers have sought to investigate the reason(s) for, and extent to which, testing with the non-dominant hand impacts performance.

Some studies have proposed a close relationship between hand preference and the allocation of attention (Song & Bédard, 2013), suggesting that greater attentional resources are devoted to the dominant hand in fine motor activities. Kourtis and Vingerhoets (2016) identified both dominance and extent of hand preference (the “consistency with which a person uses his/her dominant hand”; 2015, p. 1) as integral factors in dictating where and to what extent attention is allocated to hand movement. The authors determined that the consistency of hand preference plays an important role in movement control. As such, hand movements rely more on an individual’s amount of use as opposed to their inherent hand-dominance.

To investigate this hypothesis, Peters and Ivanoff (1999) measured reaction time performance across novel, computer mouse tasks. The study included both right and left-handed individuals with right-handed mouse experience, in addition to left-handed individuals with left-handed mouse experience. Participants were challenged with a variety of simple reaction time and movement tasks. Results overall demonstrated faster reaction times with the preferred hand, noting that asymmetries in data were determined by hand experience and consistency as discussed above. However, the preferred-hand advantage in performance was so small (<0.2 ms) that the authors concluded hand preference to be trivial to task performance. Furthermore, a study involving only right-handed individuals found that reaction time performance between right and left hands was not affected by task difficulty (Bryden, 2002).

Gignac and Vernon (2004) also investigated reaction time performance as a function of hand-dominance in healthy adults. Four tasks were administered: (1) simple reaction time; (2) synonyms/antonyms; (3) sentence verification; and (4) category matching. The language content embedded in these tasks led the authors to apply the concept of cerebral dominance in their hypothesis on reaction time. Gignac and Vernon predicted slower reaction times with the left hand because the task would be processed in the left cerebral hemisphere. Processing in the language-dominant hemisphere would then force the information to be transmitted to the right hemisphere before the left hand would be able to respond.

The results of this study found no statistically significant difference in response time between dominant and non-dominant hands on the simple RT task or the synonym/antonym task. Statistically significant differences were determined for the other two tasks, however mean differences were <65ms and the findings were inconsistent with one another (i.e. dominant hand outperformed non-dominant hand on category matching, with the reverse effect on sentence verification). The study was therefore unable to find a consistent difference in hand dominance on simple and choice RT tasks.

Beyond main effects, one of the primary findings of this study was the high correlation (r = .96) between dominant and non-dominant hands in reaction time performance. The strong correlation led the authors to infer that they were able to measure the same construct across tasks: "general speed of information processing" (2004, p. 737). The study proposed that this finding is clinically significant for patients with limited use of their dominant and/or preferred hand. Clinicians, the authors advocated, could feel confident in administering reaction time measures to patients using the non-preferred hand whilst considering the patient's performance to be uncompromised by hand use.

1.2 EXPERIMENTAL QUESTIONS AND HYPOTHESES

The purpose of this study was to explore the effects of age and hand preference on reaction time and accuracy performance in healthy adults. Specifically, the following questions were investigated:

1. Is there a significant ($p \leq .05$) difference in reaction time tasks as an effect of age?
2. Is there a significant ($p \leq .05$) difference in reaction time tasks as an effect of hand preference?
3. Are there significant ($p \leq .05$) interactions among reaction time tasks as an effect of age?
4. Are there significant ($p \leq .05$) interactions among reaction time tasks as an effect of hand preference?

Secondary questions explored the accuracy of performance on the three choice RT tasks requiring response inhibition (Go-No-Go), decision making, and response mapping. The coherence of slowing across age, hands, and tasks also were explored as revealed through regression line comparisons using Brinley plots.

This study sought to assess the replicability of the age-related findings of Fozard et al. (1994) and Vaportzis et al. (2013) using the reaction time battery of the CRTT-RT. It was hypothesized that an age effect would be present for the simple reaction time CRTT-RT Tasks (1-3). It also was predicted that there would be no age effect in speed of response for choice reaction time CRTT-RT Tasks (4-6). Conversely, it was predicted that accuracy on the three more complex reaction time tasks would decrease with age.

The findings from CRTT-RT Tasks 1-6 also were considered relative to those of Peters and Ivanoff (1999) and Gignac and Vernon (2004). Both studies found that hand preference produced minimal impact on RT performance. For the purposes of this study, however, the null hypotheses were not assumed. It was hypothesized that using the non-automatized hand to complete a task would require more cognitive resources and slow processing and performance than the preferred hand. It was therefore predicted that there would be a significant effect of hand preference on reaction time performance on each of the CRTT-RT Tasks.

2.0 METHODS

2.1 PARTICIPANTS

This study included 64 healthy adults divided into two groups: (1) male and female young adults between the ages of 20-32 years (*mean* = 23.8 years); (2) male and female older adults between the ages of 65-78 years (*mean* = 71.8 years). The participants in each group were selected to include both males and females to account for sex differences in reaction time performance (Dykiert, Der, Starr & Deary, 2012; Fozard et al., 1994; Lahtela, Niemi, & Kuusela, 1985).

The majority of participants self-identified as Caucasian. One participant in Group 1 identified as African-American; one participant in Group 2 identified as Latino American (see Appendix A, Tables 1 and 2). All participants reported English as their native language, and a single participant also identified as bilingual. See Appendix A for additional demographic data on individual participants.

This study was approved by the University of Pittsburgh Institutional Review Board, in combination with the parallel study investigating the effects age and hand preference on language comprehension performance as assessed by the CRTT. All participants provided verbal and written informed consent prior to participation and each received $15.00 in remuneration upon study completion. Participant recruitment was facilitated by University of Pittsburgh approved flyers and communication among interested volunteers.

2.1.1 Inclusion and Preliminary Procedures

Research in cognitive aging has proposed a general regression in various cognitive functions as an effect of aging. Behavioral methods have suggested age-related declines in processing speed, attention, perception, and working memory (Craik & Salthouse, 2008). The definition of a "healthy, normal adult" for the purposes of this study assumed these age-related differences; therefore, criterion measures with normative data across the lifespan were selected as screening tools to account for healthy, normal age-related declines.

Six criterion measures were used to qualify participants in this study. (1) Participants completed a self-reported questionnaire (Adapted from Heilman, 2008; Appendix B) providing qualitative information including native language, education level, and occupational history (Appendix A, Tables 1 and 2). The participants also provided information about hand preference in computer-related activities, as well as approximate hours of daily computer usage (Appendix A, Tables 3 and 4). Participants were excluded from the study if they indicated medical, psychological, or other cognitive conditions that could influence performance (such as stroke, alcohol abuse, depression, Parkinson's disease, and Alzheimer's disease) and/or any physical impairments hindering use of hands or wrists for the purposes of this study. (2) All participants completed a vision screening to assess for corrected or uncorrected vision using the Reduced Snellen Chart (Snellen, 1862). The participants were required to have binocular visual acuity of 20/40 or better with no presence of color blindness for inclusion. (3) Reading comprehension skills were assessed using the reading subtest for ages 13-21 years from the *Clinical Evaluation of Language Fundamentals 5th Edition* (CELF-5; Wiig, Semel, & Secord, 2014). The screening measure required participants to read two passages and accurately respond to comprehension questions with a combined raw score of 17 or greater. (See Appendix A, Tables 5 and 6 for participant scores). (4) Intermediate-term memory capabilities were screened using the immediate/delayed story retell task from the *Assessment Battery of Communication in Dementia* (ABCD; Bayles & Tomoeda, 1993). A ratio (delayed recall / immediate recall) of 0.70 or greater was required to qualify for participation in this study (Appendix A, Tables 7 and 8). (5) Short-term and working memory skills also were assessed using the Digit Span Forward and Backward subtests from the *Wechsler Adult Intelligence Scale – Fourth Edition* (WAIS-IV; Wechsler, 2008). All participants were required to achieve a scaled score of eight or greater as compared to age-matched normative data (Appendix A, Tables 9 and 10). (6) The final inclusionary criterion required participants to demonstrate their ability to differentiate between "big/little," "circle/square," and "red/green/blue/black/white" colors using the Fade Reading Pretest of the CRTT-R-WF.

Two additional preliminary procedures were administered to each participant. (1) The Language Experience and Proficiency Questionnaire (LEAP-Q; Marian, Blumenfield, & Kaushanskaya, 2003) was included to obtain subjective reports of each participant's language experiences. This questionnaire provided information regarding participants' percentage of current exposure to each language they reported to know, as well as the percentages of time they would choose to read and speak in each language (Appendix A, Tables 11 and 12). (2) The Edinburgh Handedness Inventory (Oldfield, 1971; Appendix C) also was administered to identify participant hand dominance on various activities (Appendix A, Tables 13 and 14).

2.2 PROCEDURES

All participants completed the six reaction time tasks included in the RT Battery in the CRTT program, as well as the word-fade reading version of the CRTT (CRTT-R-WF). The participants completed each task twice – once with their right hand and once with their left hand – totaling four tasks per participant (RT Right Hand, RT Left Hand, CRTT-R-WF Right Hand, and CRTT-R-WF Left Hand). The order of the four tasks was randomized for each participant to reduce the possibility of an order effect (Appendix A, Table 15). The CRTT-RT Tasks are described in the following sections.

2.2.1 Reaction Time (RT) Tasks

The participants completed tap, simple RT (one stimulus), choice RT (multiple stimuli), and movement tasks with their preferred and non-preferred hands. These tasks were designed to assess nonlinguistic, perceptual-motor, and cognitive skills at various levels of processing (e.g., simple motor speed, simple reaction time, reaction time + movement speed, response inhibition, and response selection/mapping).

CRTT-RT Task 1 required participants to tap a computer-mouse as rapidly as possible for a 10-second period. They executed this task over three consecutive trials and the average interval between taps was determined. Response times less than or greater than three standard deviations from each participant's own mean were removed and the average interval time was recalculated and used in the final analysis (See Table 1 at the end of this section). Data from Task 1 were used to estimate basic motor-related speed across ages and across hands.

The CRTT-RT Task 2 measured the response time required for detecting and responding to a visual stimulus. Thirty different tokens (squares and circles of five colors) were presented randomly at the same location on the center of the screen, one at a time. The participants were instructed to tap the mouse as quickly as possible after a token appeared. The time interval between token presentations varied from 0 to 50 ms to reduce anticipatory responses. The average response time across trials was determined, values less than or greater than three standard deviations from the individual participant's mean time were removed (Table 1), and the average was recalculated and used as a measure of simple reaction time[1].

The CRTT-RT Task 3 added a simple skilled movement to the previous task in order to measure movement time plus reaction time. It evaluated the speed at which participants detected and then motorically responded to the stimuli. The participants were instructed to move the cursor from the bottom of the screen to the token at the center of the screen and click the mouse as quickly as possible after a token appeared. The time for each stimulus/response was recorded and the average and standard deviation across the 30 trials were recorded. Response times less than or greater than three standard deviations from the mean were removed from the average (Table 1), and the mean was recalculated and used in analysis.

The CRTT-RT Task 4 was the first of the three choice reaction time tasks that required the participant to cognitively map stimulus items to multiple response types. Task 4 was a "Go-No-Go" task in which one token (circle or square) was randomly presented on the screen at a time. The participants were instructed to click the left mouse button as quickly as possible if a

[1] In instances where a "0" appeared in the data, the trial was considered to be a program error and the value was thereby removed from the trial count and averages. In instances where the response time was less than 100 ms for CRTT-RT Tasks 2-6, the trial was considered to be an anticipatory response and the value was removed from the trial count and averages (Table 1).

circle appeared, but to withhold a response if a square appeared. The percentage and average response times of correct responses were calculated. Response times less than or greater than three standard deviations from the mean were removed (Table 1), and the average was recalculated and used to measure the speed and accuracy of this inhibitory choice reaction time task.

As in Task 4, CRTT-RT Task 5 randomly presented one token on the screen at a time. Participants were instructed to press the predetermined button on the mouse that corresponded to the shape of the token presented. The left mouse button corresponded to the circle and the right button to the square. As compared to Task 4, the participant responded to every stimulus while maintaining the predetermined shape-to-button mapping. The accuracy percentage was calculated in addition to the average response times for correct responses. Values outside of three standard deviations from the mean were removed (Table 1) and the average was recalculated and used in the analyses.

The CRTT-RT Task 6 involved a more complex, two stimuli-two response mapping task. Two tokens were presented on the screen at a time and the participants were instructed to sequentially respond to both stimuli using the same stimulus-response map used in the former task (circle: left mouse button; square: right mouse button). The participants were required to respond to the token that appeared on the left side of the screen before responding to the token positioned on the right. Circles and squares were randomly presented in the left and right positions. Trials of two circles and two squares additionally appeared at random to reduce the opportunity for second stimulus responses to be linked to the first stimulus/response decision. Percentages and average response times for correct responses were calculated for both the first and second stimuli. Response times greater or less than three standard deviations from the mean were removed from the data (Table 1) and averages were recalculated to be used in analysis.

Table 1. Number and Percent of Removed Responses per Task (Combined Right and Left Hands)

Total Number and Percent of Removed Response Times							
	Task 1	Task 2	Task 3	Task 4	Task 5	Task 6 (1)	Task 6 (2)
+/- 3 SD from Mean	2 0.52%	95 2.47%	45 1.17%	3 0.08%	5 0.13%	46 0.80%	57 0.99%
Removed from Trial Count and Averages	3 0.78%	9 0.23%	0	25 0.67%	4 0.10%	4 0.07%	46 0.80%
Incorrect Responses				118 3.18%	94 2.45%	157 2.73%	138 2.40%

2.2.2 Computerized Revised Token Test (CRTT)

As indicated previously, the participants also completed the CRTT-R-WF reading version of the CRTT with their preferred and non-preferred hands. As adapted from the original RTT, the CRTT included 10 or 20 tokens (squares and circles of five colors; see Figure 1) depending on the subtest. Participants were required to manipulate the tokens presented on the screen in response to imperative commands. In the CRTT-R-WF, the commands were presented as text at the bottom of the computer screen in a word-by-word, participant-paced moving window (i.e., the previous word disappeared with the onset of each new word). By inhibiting the participants' ability to reread the previous word, the CRTT-R-WF increased the participants' demand on short-term/working memory and provided additional timing information on the processing of commands per word. Commands were comprised of combinations of two actions (touch, put), two shapes (circle, square), two sizes (big, little), five colors (red, green, blue, black, white,) ten prepositions (above, before, behind, below, beside, by, in front of, on, next, under), and five adverbial clauses (McNeil & Prescott, 1978; McNeil et al., 2015a).

Like the Revised Token Test, the CRTT was designed to assess language processing and comprehension abilities (McNeil et al., 2015b). The CRTT subtests varied in complexity and length thereby increasing the participants' demands on attention and short-term/working memory. In the parallel study, Byrne determined the mean subtest and overall CRTT scores and efficiency scores for each participant (Appendix A, Tables 16 and 17).

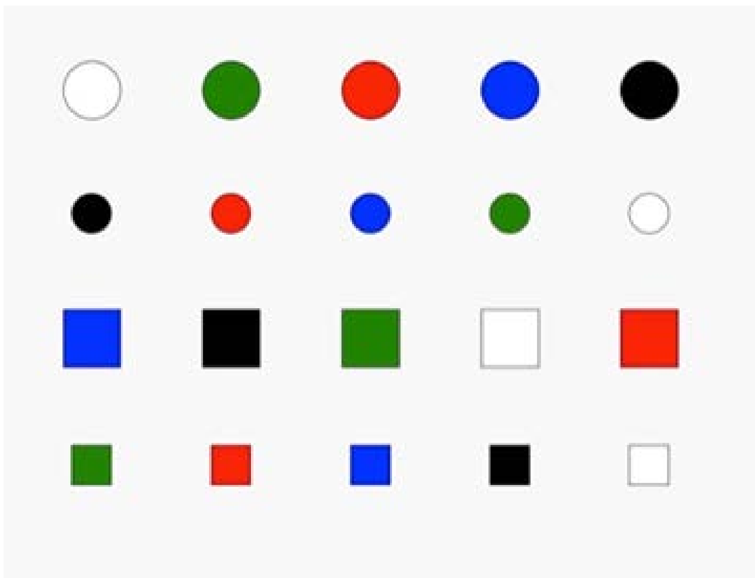


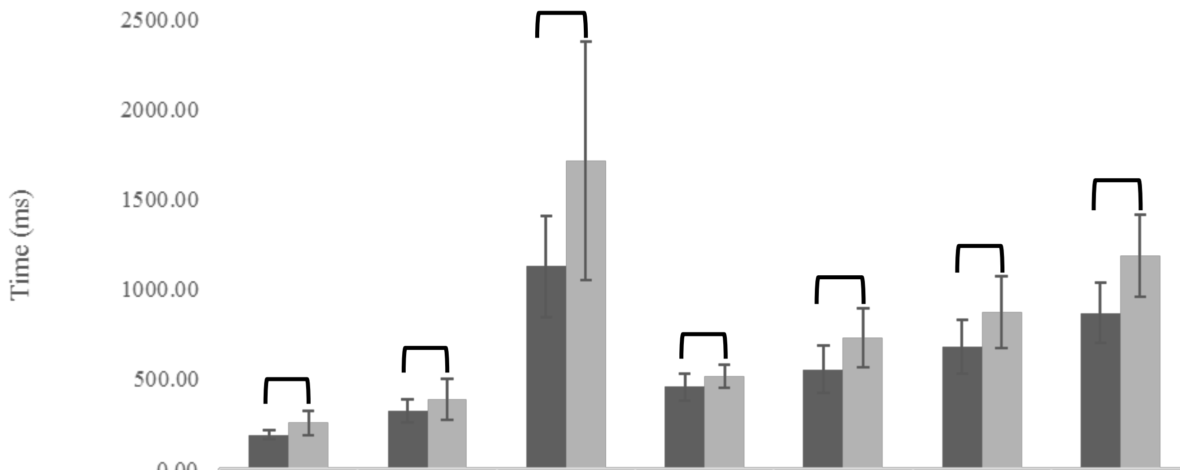
Figure 1. CRTT Token Stimuli

3.0 RESULTS

The CRTT-RT data were analyzed using a three-way ANOVA, with repeated measures on hand: 6 (RT Tasks) x 2 (age groups) x 2 (hands). Post-hoc analyses were completed and an alpha level .05 was set for each comparison. Equal variance could not be assumed therefore degrees of freedom were corrected using Huynh-Feldt estimates of sphericity.

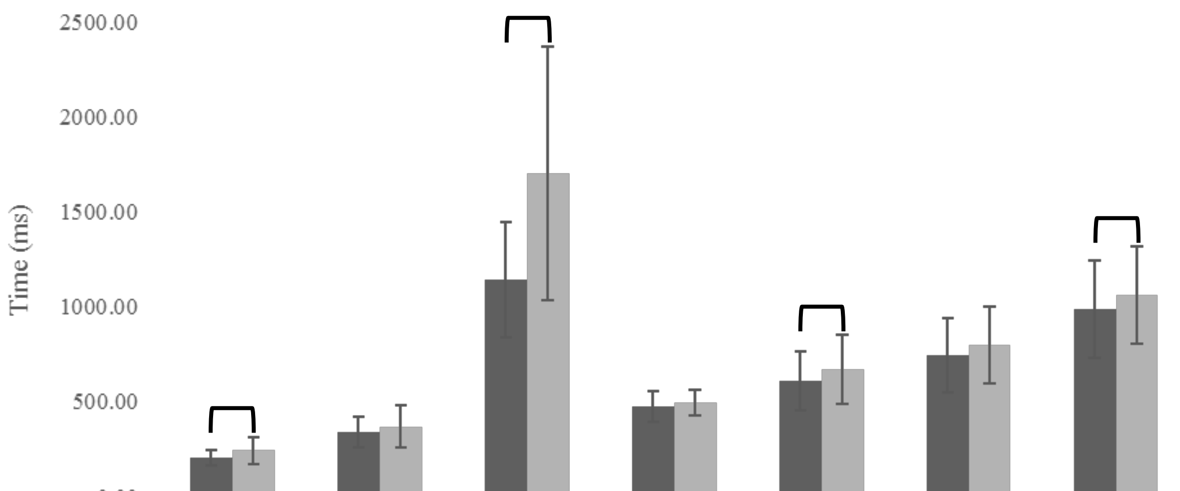
Within-subjects analyses determined a statistically significant three-way interaction between task, age, and hand ($F(1.53, 189.91) = 4.516$, $p = .020$, partial $\eta^2 = .035$). Statistically significant two-way interactions between task and age ($F(1.53, 189.91) = 45.252$, $p < .000$, partial $\eta^2 = .267$) and task and hand ($F(1.53, 189.91) = 45.368$, $p < .000$, partial $\eta^2 = .268$) also were found. The interactions occurred with the older group demonstrating an over-additive slowing for the left hand on Task 3 (Movement).

There was no significant interaction between age and hand. Statistically significant main effects were observed for age on RT Tasks, $F(1, 124) = 76.671$, $p < .000$, partial $\eta^2 = .382$, and hand on RT Tasks, $F(1, 124) = 34.370$, $p < .000$, partial $\eta^2 = .217$. All pairwise comparisons were performed for statistically significant main effects confirming that the older group performed significantly slower (increased RT) than the younger group and the left hand performed slower (increased RT) than the right hand across all tasks. Figures 2 and 3 below show the average and standard deviation response times for significant main effects of age and hand (significant effects per task are indicated with bracket above bars).



	Task 1	Task 2	Task 3	Task 4	Task 5	Task 6 (1)	Task 6 (2)
Younger Average	191.26	323.77	1128.25	458.28	553.61	678.83	866.47
Older Average	257.89	389.48	1715.51	515.24	727.91	871.43	1187.89

Figure 3. Average Response Times per Task by Age Group



	Task 1	Task 2	Task 3	Task 4	Task 5	Task 6 (1)	Task 6 (2)
Right Hand	205.28	341.24	1141.38	475.36	608.24	745.03	987.27
Left Hand	244.60	368.43	1703.63	496.48	669.64	800.77	1064.30

Figure 2. Average Response Times per Task by Hand

3.1 POST-HOC ANOVA ANALYSES

Post-hoc ANOVAs were applied and controlled at the .05 level to assess the effects of age and hand on individual RT Tasks.

3.1.1 CRTT-RT Task 1: Tap

Statistically significant effects were observed for age, $F(1, 124) = 65.249$, $p < .000$, partial $\eta^2 = .345$, with the older group demonstrating slower performance than the younger group, as well as hand, $F(1, 124) = 22.630$, $p < .000$, partial $\eta^2 = .154$, with the left hand showing slower performance than the right hand. There was no significant interaction between group and hand (Figure 4).

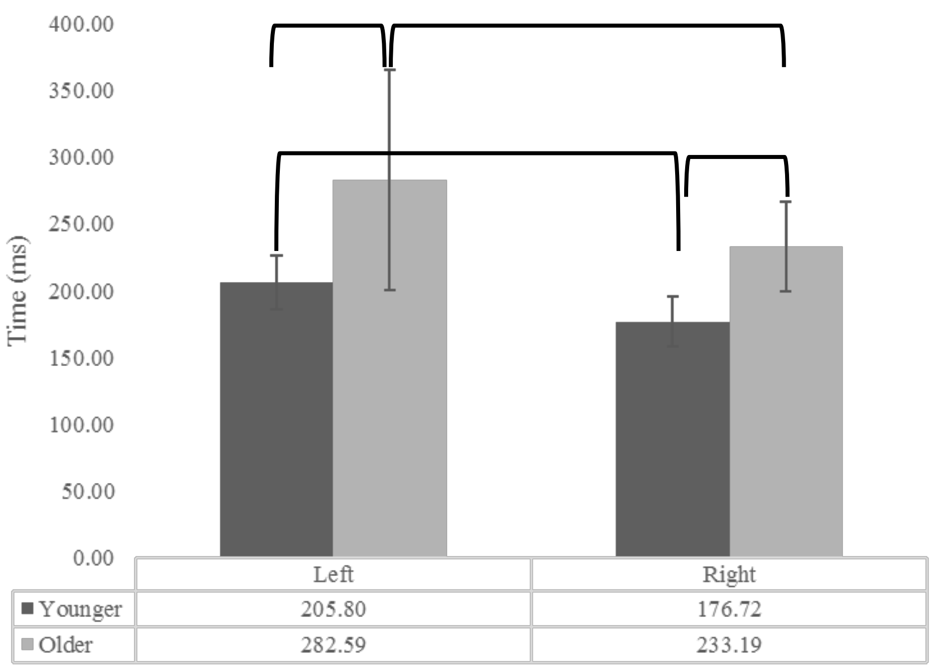
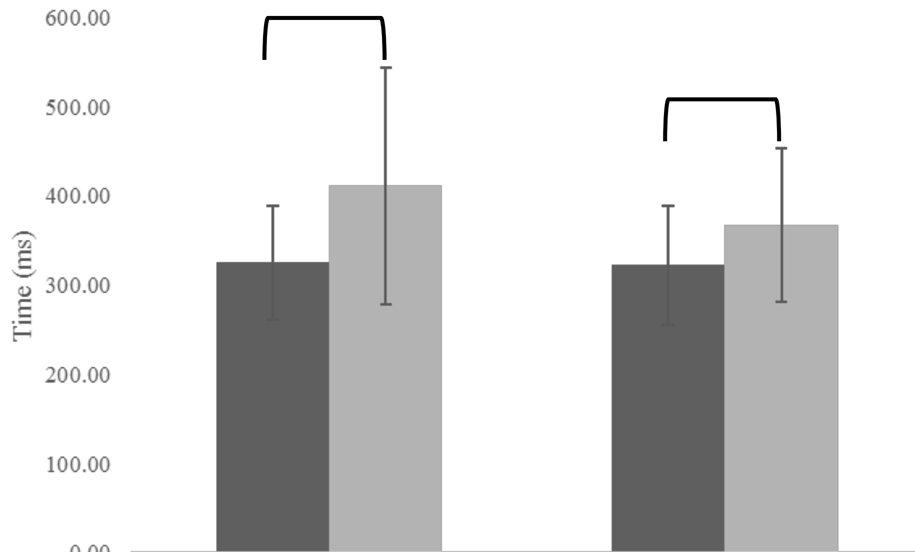


Figure 4. Task 1 Average Response Times by Age and Hand

3.1.2 CRTT-RT Task 2: Simple

There was a statistically significant effect for age, $F(1, 124) = 16.408$, $p < .000$, partial $\eta^2 = .117$, with the older group performing slower than the younger group. However, there was no effect of hand and no significant interaction between group and hand (Figure 5).

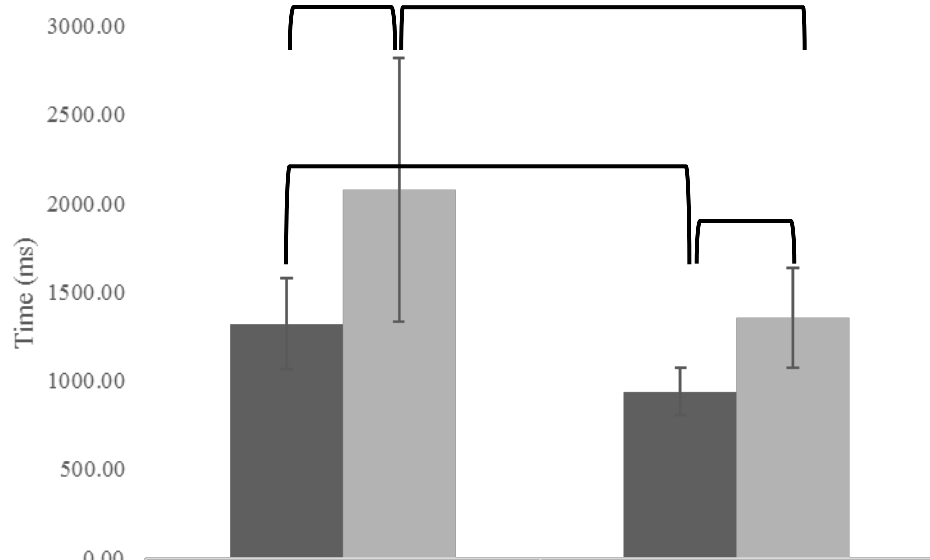


	Left	Right
Younger	325.21	322.32
Older	411.49	367.47

Figure 5. Task 2 Average Response Times by Age and Hand

3.1.3 CRTT-RT Task 3: Movement

Statistically significant effects were found for age, $F(1, 124) = 62.080$, $p < .000$, partial $\eta^2 = .334$, with the older group performing slower than the younger group, and hand, $F(1, 124) = 54.847$, $p < .000$, partial $\eta^2 = .307$, with the left hand performing slower than the right hand. There was a significant age by hand interaction, $F(1, 124) = 5.094$, $p = .026$, partial $\eta^2 = .039$, with the left hand performing significantly slower than the right hand for the older group relative to the right/left hand difference for the younger group (Figure 6).

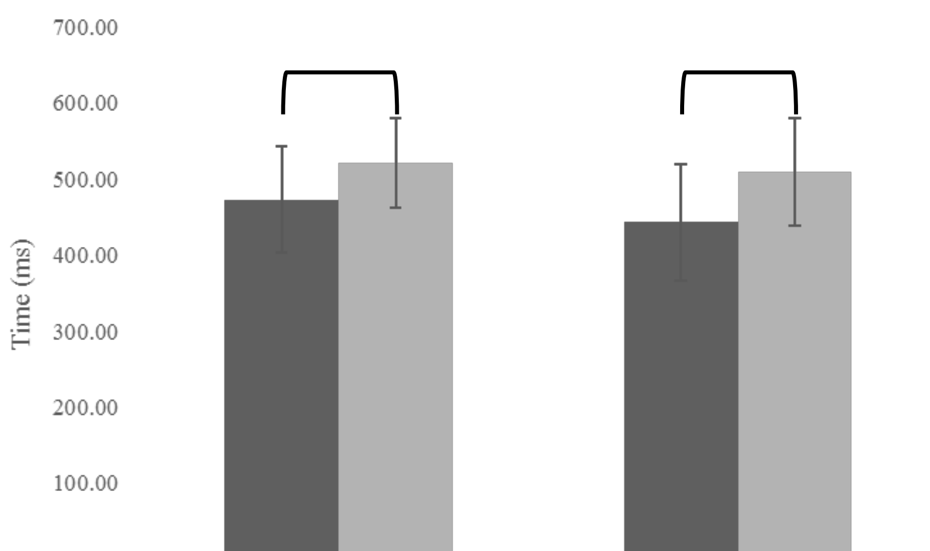


	Left	Right
■ Younger	1320.16	936.34
■ Older	2075.64	1355.38

Figure 6. Task 3 Average Response Times by Age and Hand

3.1.4 CRTT-RT Task 4: Go-No-Go

There was a statistically significant main effect for age, $F(1, 124) = 21.722$, $p < .000$, partial $\eta^2 =$



	Left	Right
■ Younger	473.17	443.39
■ Older	521.14	509.33

Figure 7. Task 4 Average Response Times by Age and Hand

.149, with the older group performing slower than the younger group. No significant main effect for hand was found, $F(1, 124) = 2.895$, $p = .091$, partial $\eta^2 = .023$. There also was no significant interaction between group and hand (Figure 7).

No significant differences were observed on accuracy of performance in CRTT-RT Task 4 between age and hand (Figure 8).

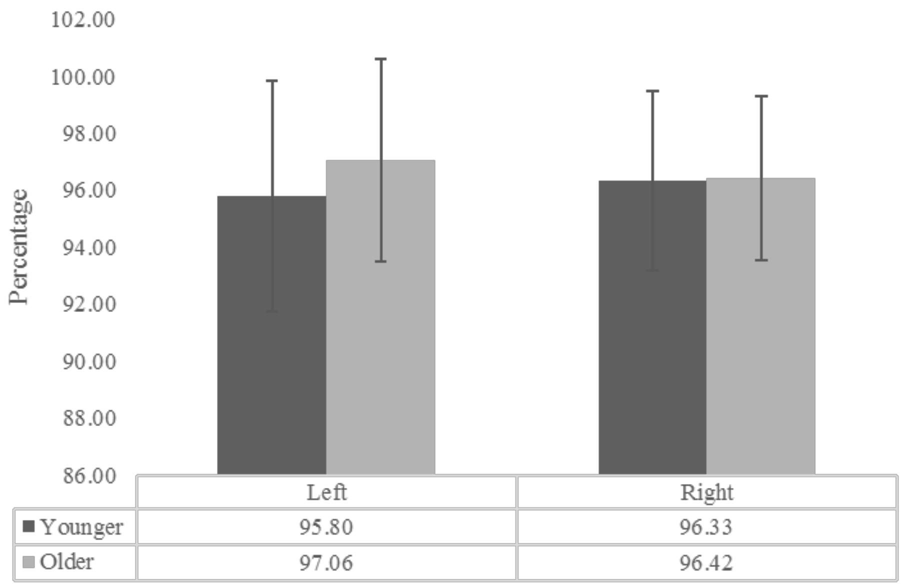


Figure 8. Task 4 Average Accuracy by Age and Hand

3.1.5 CRTT-RT Task 5: Map 1

Statistically significant effects were observed for age, $F(1, 124) = 42.284$, $p < .000$, partial $\eta^2 = .268$, and hand, $F(1, 124) = 4.899$, $p = .029$, partial $\eta^2 = .038$, such that the older group was slower than the younger group and the left hand was slower than the right hand for both groups. There was no significant interaction between group and hand (Figure 9).

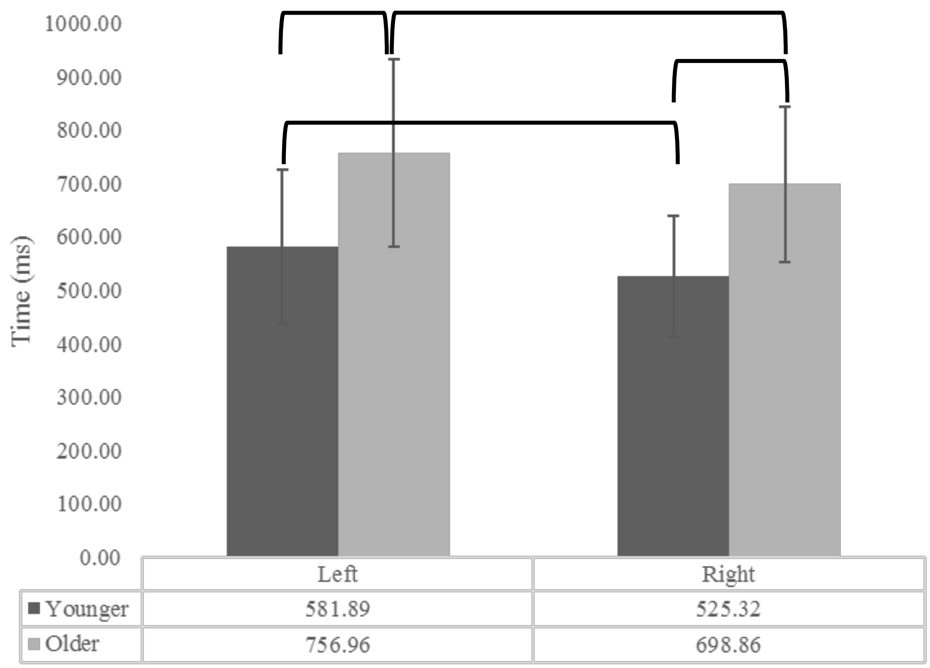


Figure 9. Task 5 Average Response Times by Age by Hand

No significant differences were observed on accuracy of performance for Task 5 between age groups or hands (Figure 10).

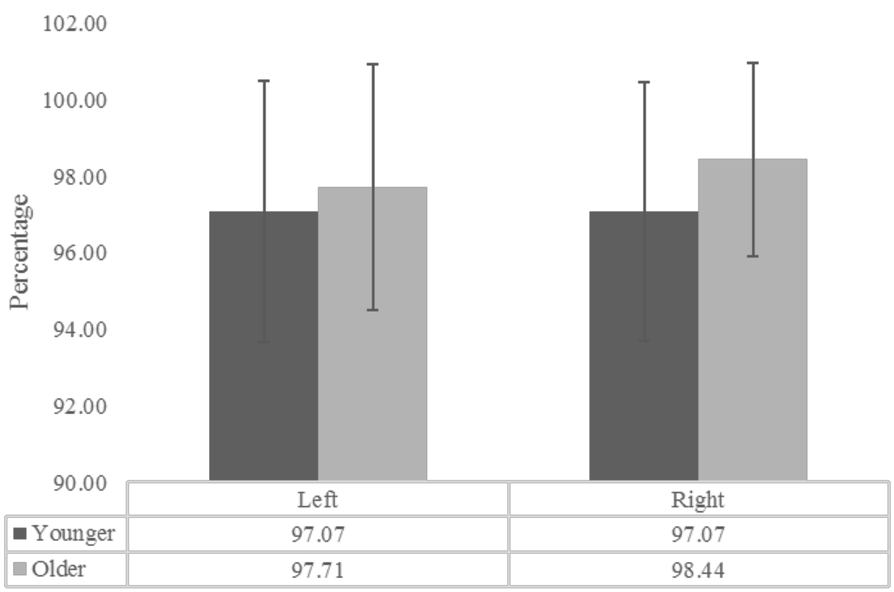
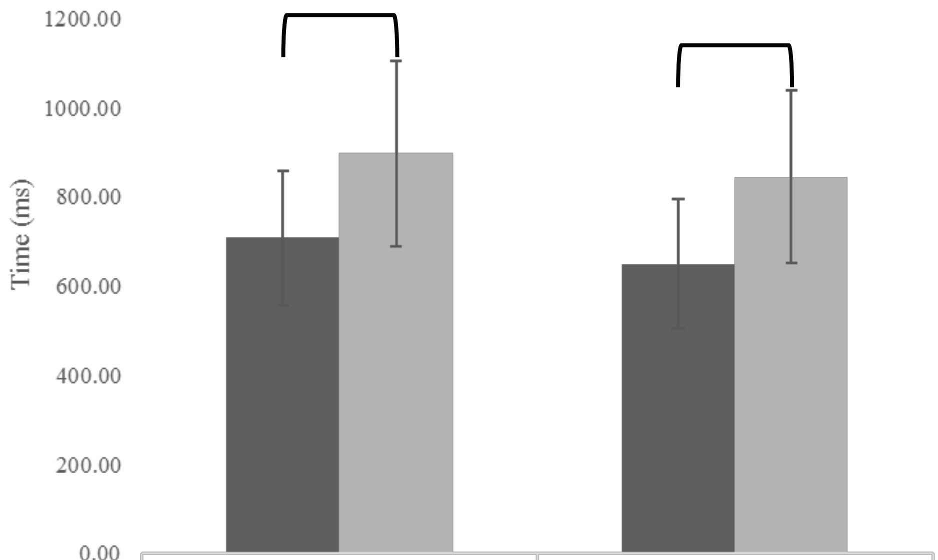


Figure 10. Task 5 Average Accuracy by Age by Hand

3.1.6 CRTT-RT Task 6: Map 2

3.1.6.1 Response 1

As two sequential responses were required for CRTT-RT Task 6, the times and accuracies for each were analyzed separately. A statistically significant effect of age was found, $F(1, 124) = 38.318$, $p < .000$, partial $\eta^2 = .236$, with the older group performing slower than the younger group. There was no significant effect for hand and no significant interaction between group and hand (Figure 11).



	Left	Right
Younger	708.09	649.57
Older	897.51	845.34

Figure 11. Task 6 Response 1: Average Response Times by Age and Hand

A statistically significant difference in accuracy of performance was observed for age on Task 6 Response 1, $F(1, 124) = 5.802$, $p = .017$, partial $\eta^2 = .045$, with the older group achieving a significant, but small (<2%), higher accuracy for both hands. There was no significant difference between hands and no significant interaction between age and hand (Figure 12).

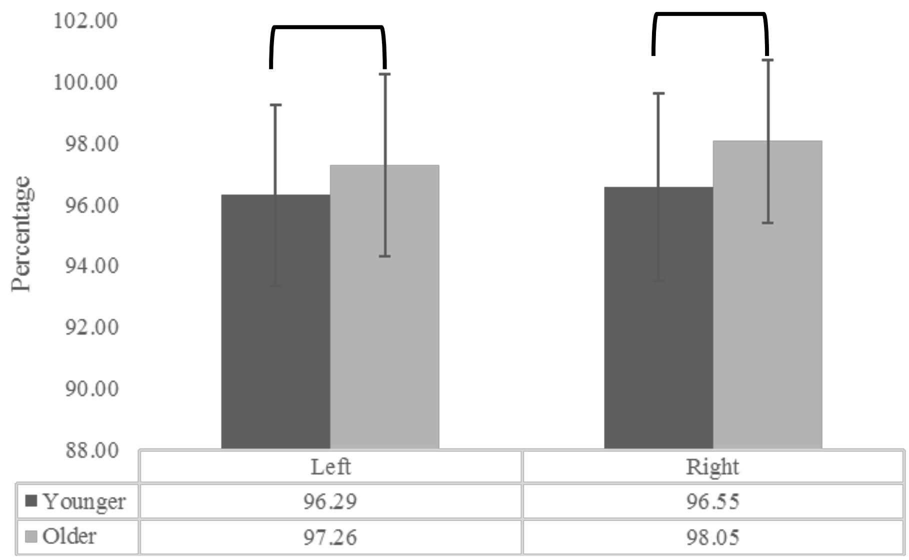


Figure 12. Task 6 Response 1: Average Accuracy by Age and Hand

3.1.6.2 Response 2

Statistically significant effects were observed for age, $F(1, 124) = 83.992$, $p < .000$, partial $\eta^2 = .404$, and hand, $F(1, 124) = 4.814$, $p = .030$, partial $\eta^2 = .037$, with the older group demonstrating slower performance than the younger group and the left hand demonstrating slower RTs than the right hand. There was no significant interaction between group and hand (Figure 13).

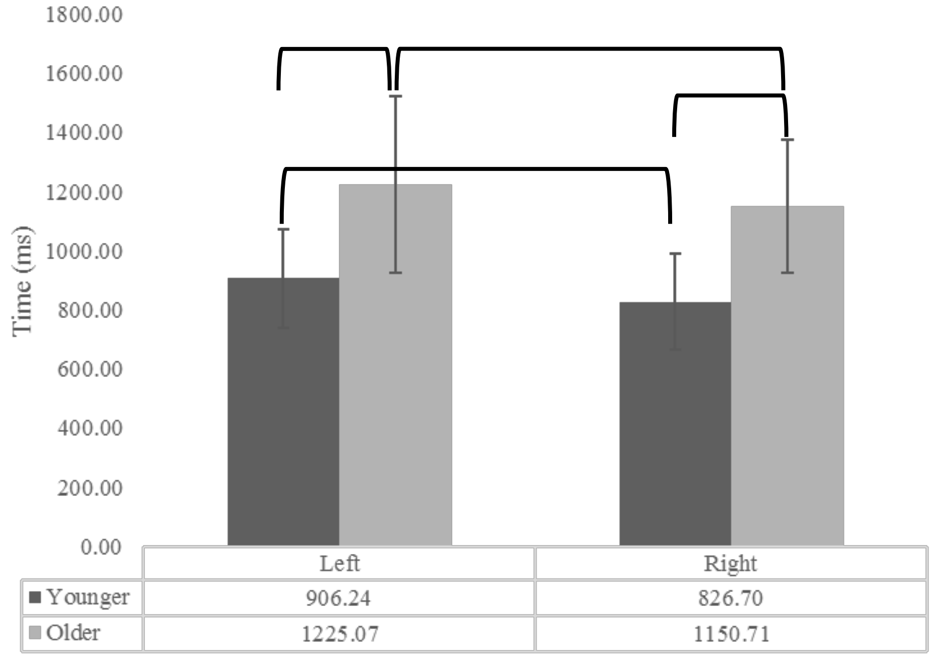


Figure 13. Task 6 Response 2: Average Response Times by Age and Hand

There was a statistically significant difference in accuracy on Response 2 for age, $F(1, 124) = 5.981$, $p = .016$, partial $\eta^2 = .046$, with the older group demonstrating a significant, but small (<2%), higher accuracy for both hands. There was no significant difference between hands and no significant interaction between age and hand (Figure 14).

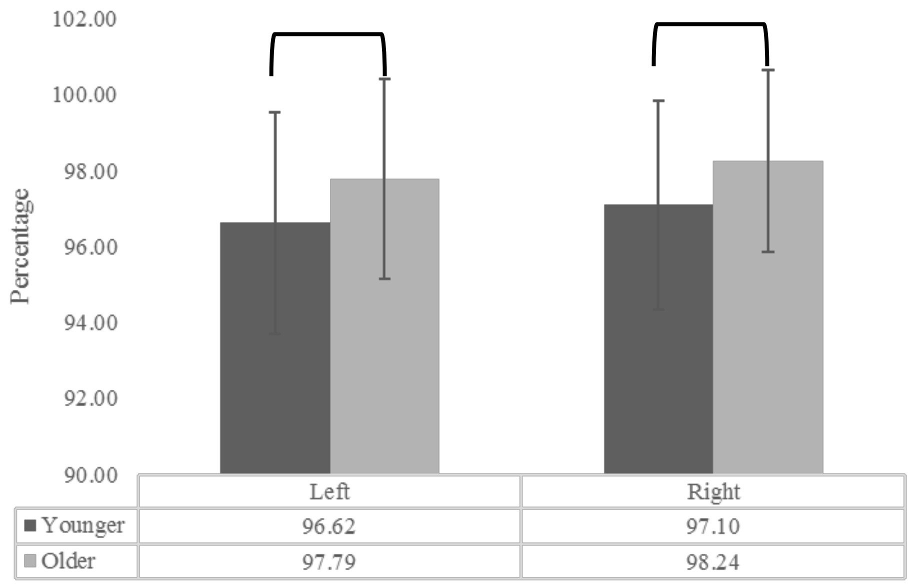


Figure 14. Task 6 Response 2: Average Accuracy by Age and Hand

3.2 BRINLEY PLOT

A Brinley plot was created to show the relationship between average response times of younger and older adults across tasks, with both right and left hands. Linear regression lines were plotted for each hand and slope values were determined. Figure 15 illustrates the close relationship of hand performance across tasks with near perfect correlations for both hands, a high linearity coefficient for both hands, and a clear slowing for both hands and all tasks for the older group.

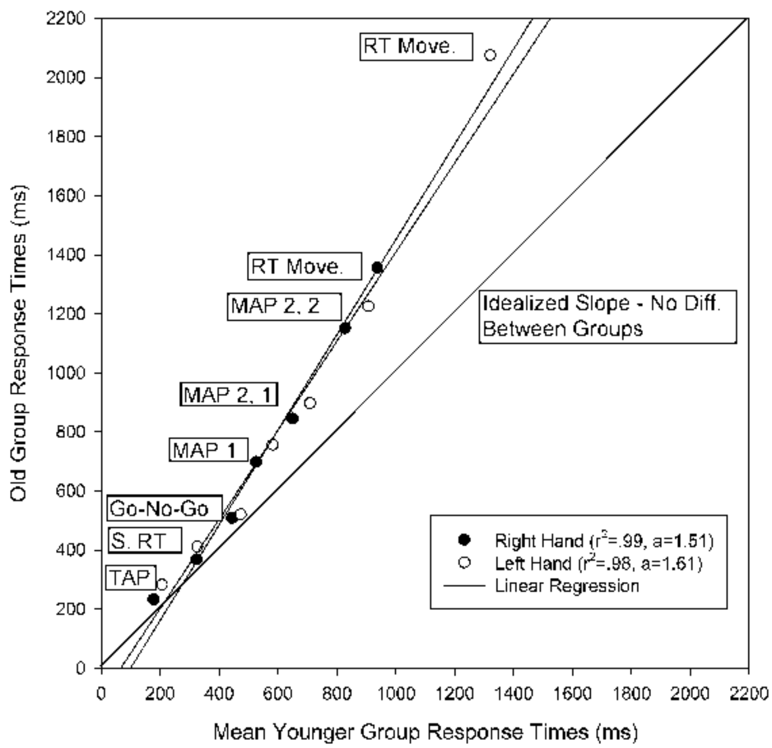


Figure 15. Brinley Plot of Average Response Times of Younger Adults by Older Adults

4.0 DISCUSSION

This study investigated the effects of age and hand preference on reaction time and movement time performance using the CRTT-RT test battery. The CRTT-RT tasks included measures of basic motor speed, simple motor control, and simple and choice reaction time. The findings from like studies, in addition to theories of cognitive aging and preference for hand use, were considered to make predictions about reaction time, movement control, and accuracy performance for each task, age group, and hand. The hypotheses and results of the age effects on RT performance are discussed below, followed by hand preference.

4.1 AGING

The first experimental question sought to determine significant differences across tasks as an effect of age. It was hypothesized that there would be a significant age effect in speed of performance on simple RT/movement control tasks (CRTT-RT Tasks 1-3) and no significant age effect on the choice RT tasks (CRTT-RT Tasks 4-6). However, it was hypothesized that there would be a significant decrease in accuracy with age on the more complex CRTT-RT Tasks 4-6.

The hypotheses for age effects were partially confirmed. Statistically significant main effects were found for age across all tasks combined and for each individual task. Therefore, the first hypothesis predicting an age effect on speed of the simpler perceptual-motor tasks was correct. However, an age effect also was present on all choice RT tasks, rejecting the hypothesis that an age effect on speed of performance is eliminated with increased task complexity. A significant main effect of age on all tasks, despite complexity, is consistent with the Processing-Speed Theory for increased response time with age at its basic level (Salthouse, 1991, 1996). Simply stated, older adults showed a generalized slowing in response time. That is, they evidenced less efficiency in reacting to, processing, and responding to tasks.

The Processing-Speed Theory further suggests that age-related slowing should be more pronounced with increased complexity, as task demands require greater cognitive resources. To evaluate this theory in the current study, we then asked if the age effect varied by task. The Brinley plot (Figure 15) demonstrates a near-linear relationship of age-related slowing of response times with increased task complexity (with the exclusion of Task 3, discussed below). The plot shows a ~1.5 slope, signifying that the older group is approximately 0.5 times slower than the younger group. In comparing the linear regression lines of the RT data and that of the idealized slope (1.0; representative of no difference in performance between age groups), it is evident that the more complex choice RT tasks exhibit a greater gap from the idealized slope than the response times of CRTT-RT Tasks 1 and 2. This is consistent with the Salthouse theory of a greater age-effect with task complexity.

Within-group analyses further showed a statistically significant interaction between age and task. This interaction occurred from the task demonstrating the largest difference in average response time between groups: CRTT-RT Task 3 (Movement). Average differences in response times varied from 400 to 800 ms between the younger and older groups. The large discrepancy in average difference of response time in this task, compared to the more complex choice RT tasks, is likely due to the fine motor control required of Task 3. Informal observation of participant performance, in conjunction with the significant increase in response times, support the notion that older adults have poorer movement control with the computer mouse than the younger adults.

Beyond speed of performance, accuracy was considered to further test theories of cognitive aging on RT performance. The results of this study are inconsistent with the hypothesis that accuracy decreases on choice reaction time tasks with increased age. In fact, older adults were collectively just as accurate on CRTT-RT Tasks 4 and 5, and even more accurate (though within a 2% difference) on CRTT-RT Task 6. A possible rationale for the minimal difference in accuracy between groups may be due to the true level of complexity in the CRTT-RT choice RT tasks. The task with the greatest level of cognitive difficulty (Task 6) required participants to map two stimuli to two responses. The complexity of this task may be deemed a “simple” choice RT task when compared to like studies. The findings by Vaportzis, Georgiou-Karistianis, and Stout (2013) demonstrated a significant decrease in accuracy of performance on *complex* choice RT tasks. Yet, the older adults performed slower but just as accurately on the *simple* choice RT tasks, consistent with the findings in the present study. For the simple choice RT tasks, Vaportzis et al. required participants to respond to specific stimuli (2 to 4 designated letters) when shown a series of letters of the alphabet. Though a different task in nature, this simple choice RT task may be comparable to the level of complexity of CRTT-RT Task 5, which required the participant to respond to a shape with the correct stimulus-responses mapping. The choice RT tasks in the CRTT-RT battery may not be complex enough to show discrepancies in accuracy of performance as a function of age. Although this may be an accurate explanation for the findings of this study relative to others’ findings, it should be remembered that the original design of the CRTT-RT tasks was to assess the contributions of underlying perceptual-motor-cognitive demands on CRTT performance in persons with language and cognitive pathologies, thus optimally using relatively simpler tasks for assessment.

The significant difference present on CRTT-RT Task 6, in which the older adults performed significantly better, is not a clinically substantive difference as there was a <2% difference in performance between groups. The high level of accuracy rates for both age groups suggests that accuracy was a strong motivational factor in task completion in general.

4.2 HAND PREFERENCE

The presented results demonstrated the significant effect of hand, both right and left, on CRTT-RT performance. To evaluate true hand *preference*, an ANOVA was used to include all individuals who indicated right-hand preference for a computer mouse via self-report (n = 62; Appendix A, Tables 3 and 4) in addition to an analysis of covariance (ANCOVA) with preferred hand as a covariate. A single participant in each age group identified left-hand preference for a computer mouse whereby variability in hand preference was too limited to conduct right-hand preference vs. left-hand preference analyses. Both the revised ANOVA and the ANCOVA with right-hand preference as a covariate showed no significant difference in results compared to the original ANOVA comparing only right and left hands. Based on this study's findings, the following discussion of the effect of the hand used (right vs. left) also represents the effect of the preferred hand vs. non-preferred hand on CRTT-RT performance.

It was hypothesized that a hand effect would be present across all CRTT-RT tasks due to the increased cognitive demand required to use the non-automatized hand. A statistically significant main effect was determined for hand on all RT tasks combined, where the left hand, on average, performed slower than the right hand. With the overwhelming majority of participants indicating right-hand preference for computer mouse, the hypothesis for slowed RT performance on the non-preferred hand was confirmed. However, single task analyses demonstrated a significant hand effect on only four RT tasks: Task 1 (Tap), Task 3 (Movement), Task 5 (Map 1), and Task 6-Response 2.

The CRTT-RT Tasks 1 (Tap) and 3 (Movement) measure basic motor speed and movement control. Both tasks incorporate fine motor movements that are subject to the individual's skill of hand use. The ongoing use and practice with one hand over the other provokes a level of automaticity which dictates the skill and control of these fine motor movements. The preferred use of the right hand for a computer mouse among most participants suggests that the right-hand is better rehearsed to perform more controlled, efficient movements. CRTT-RT Tasks 1 and 3 are simple, nonlinguistic tasks that should be minimally impacted by cognitive variables; these tasks thereby represent the importance that automaticity plays on these basic motor tasks. Thus, the significant hand effect present on CRTT-RT Tasks 1 and 3, where the right hand is consistently faster in tap interval and response time, is consistent with the hypothesis that lower (faster) reaction times are present with the more automatized hand.

The CRTT-RT Tasks 5 (Map 1) and Task 6-Response 2 also observed significant effects of hand use. Both tasks are complex choice RT tasks requiring mapping of one or two responses. It was predicted that both increased cognitive demand and automaticity of hand use contribute to the speed of performance on both tasks. Tasks 5 and 6 required participants to use their index finger and/or their middle finger to respond to the single token or pair of tokens presented on the screen. The stimulus-finger mapping, however, is reversed between the right and left hands – i.e. the "circle" maps to the index finger on the right hand but the middle finger on the left hand (though both are the “left” mouse button). The CRTT-RT Tasks 5 and 6 measure the time required to process the stimuli and then decide the appropriate response(s) that is specific to the hand being used. For the non-automatized hand, the demand of cognitive processing in combination with a less-practiced/poorer controlled motor response yields a slower response time. Of note, Task 6-Response 1 did not show a significant hand effect. It is unclear why the second response, and not the first, demonstrated a significant hand effect on performance. The increased cognitive demand for sequencing the second response may be greater than the demand required of the first response.

It also is noteworthy that two tasks (Task 2: Simple RT; Task 4: Go-No-Go) did not show a significant hand difference. It is speculated that the reduced demand for motor control on these tasks – that is, they only require a one-button response – is less affected by level of automaticity or motor control when compared to the other, more motorically complex, tasks that require multiple taps, movement, and two-button responses.

Though a hypothesis was not created for accuracy of response as an effect of hand, this variable may influence the speed of response times seen in these tasks. There was no effect of hand on accuracy of performance on choice RT tasks; but, as discussed with aging, accuracy of response appeared to be a valued motivator for task completion. Accuracy serves as an added cognitive demand that is separate from the perceptual-motor processes investigated through these tasks. The responsibility of mapping a stimulus for the tested hand and deciding the correct response represent a need for additional cognitive resources to be allocated to the task beyond the motor response. Collectively, this is consistent with the results of increased (slower) response times on the non-automatized hand.

5.0 LIMITATIONS AND OBSERVATIONS FOR FUTURE RESEARCH

5.1 STUDY LIMITATIONS

Though this study demonstrated strong and consistent results for CRTT-RT performance across age and hand preference, several limitations in study design and data collection should be considered. The following differences in external and internal testing conditions were observed: (1) this study was conducted using two computers, of different brand and size; (2) most data were collected outside of a university lab space and in participants' homes whereby environmental differences in factors such as lighting and occasional outdoor sounds were present; (3) the time of day for testing varied considerably (any time between 8am and 9pm); and (4) personal factors such as tiredness, hunger, and distractibility may have been present, especially dependent upon time of testing. In an attempt to control for external and internal uncontrolled variables, a reasonably large sample size (*n* of 64) and randomized task presentations should have limited these variables' impact on overall performance. Furthermore, consistency in protocol, computer brightness/sound/mouse, and testing locations free of most distractions was established.

As participants in this study completed reaction time tasks in addition to language processing tasks with their right and left hands, factors such as fatigue and familiarity with tasks were apparent. Again, the four test measures were randomized to reduce an order effect and to account for these potential factors on performance.

5.2 OBSERVATIONS FOR FUTURE RESEARCH

This study investigated reaction time performance in healthy younger (20-32 years) and older (65-78 years) adults. The results of this study demonstrated a significant age effect between groups, yet the age(s) by which performance shows the greatest decline in speed of response remains unknown. In order to discern where in the lifespan the breakdown occurs, or to better understand to what extent slowing on the CRTT-RT Tasks increases with age, this study should be replicated to include participants in the middle age range (35-64 years) using smaller age intervals, such as 2-5 years as opposed to the 15-year interval used in the present study.

The extent by which true hand preference affects performance also should be explored. It was hypothesized that hand preference/extent of use is a strong indicator of basic motor speed and control. To further investigate this hypothesis beyond the current study, participants who prefer using their left hand for a computer mouse should be tested. If this theory holds true, left-hand-preferred individuals should show decreased (faster) reaction times on both CRTT-RT Tasks 1 and 3. This would indicate that level of automaticity and extent of use is the contributing factor to the hand effect shown on these motor control tasks. Realistically, however, it is important to note that the right-handed computer mouse is the societal norm. As such, there are few individuals who strictly prefer using their left hand for a computer mouse, including most left-hand dominant individuals. If this test were to be performed in a clinical setting representative of the general population, it is expected that most individuals would prefer to use their right-hand and speed of performance would be significantly lower (faster) compared to their left, non-automatized hand on these two tasks.

6.0 SUMMARY AND CONCLUSION

The current study was designed to investigate the effects of age and hand preference on reaction time performance using the CRTT-RT Battery. There were statistically significant main effects for both age and hand preference on all RT tasks combined.

Statistically significant effects of age were determined on individual RT tasks, where the older population performed slower on all tasks. The age effect was more pronounced on the more complex choice RT tasks (Tasks 4-6) and those requiring motor movement control (Task 3). There were minimal differences in accuracy of performance on choice RT tasks between the younger and older groups (<2%). Salthouse's Processing-Speed Theory, as it applies to age-related slowing and task complexity, was discussed for the rationale behind these results.

Statistically significant effects of hand preference were observed on CRTT-RT Tasks 1, 3, 5, and 6 (Response 2), where the left hand performed slower (increased RT) than the right hand. It is hypothesized that level of automaticity, motor control, and increased cognitive demand for response mapping tasks contributed to the effect of hand preference on performance.

Prior to this study, a patient's performance on the CRTT-RT Tasks yielded relatively arbitrary results as scores could not be compared to healthy normal controls. This study therefore provided preliminary, normative data for the RT tasks. The findings of this study further unveiled patterns in how performance on these simple and choice reaction time tasks are affected by age and hand preference. Aphasia and other language and cognitive impairments for which the CRTT was developed can impact patients of any age. The age effect present on the CRTT-RT Tasks guides researchers and clinicians to identify how much patient performance differs from their age-matched population. Likewise, the effect of hand preference present on the CRTT-RT Battery suggests that a patient's use of a preferred or non-preferred hand on the assessment will produce different results. This is particularly relevant for patients forced to use their non-preferred hand secondary to paresis, paralysis, or other hand or limb-restricting conditions. Eventually, this research should support discovery of the extent to which perceptual-motor-cognitive skills measured by the RT tasks affect participant performance on language processing abilities as measured by the CRTT.

APPENDIX A

Appendix A, Table 2: Younger 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

Appendix A, Table 3: Older 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)

Appendix A, Table 4: Younger Hand Preferences (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

Appendix A, Table 5: Older Hand Preferences (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

Appendix A, Table 6: Younger 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

Appendix A, Table 7: Older 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

Appendix A, Table 8: Younger 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

Appendix A, Table 9: Older 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

Appendix A, Table 10: Younger Digit Span Scores

WAIS-4 - 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

Appendix A, Table 11: Older Digit Span Scores

WAIS-4 - 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

Appendix A, Table 12: Younger Leap Q

Leap Q - Younger				
Subject #	Formal Years of	% Exposure	% Reading	% Speaking

	Education			
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

Appendix A, Table 13: Older Leap Q

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

Appendix A, Table 14: Younger 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

Appendix A, Table 15: Older 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

Appendix A, Table 16: 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 A, Table 17: CRTT Mean and Efficiency Scores

Group-Hand-Measure	Value	Subtest I	Subtest II	Subtest III	Subtest IV	Subtest V	Subtest VI
Old-Right-Score	AVG:	13.99	14.44	13.98	13.77	13.83	13.96

	SD:	0.52	0.54	0.71	0.87	0.77	0.78
Old-Right-Efficiency	AVG:	13.06	14.44	13.98	13.77	13.83	13.96
	SD:	0.66	0.75	0.93	1.11	1.28	1.19
Old-Left-Score	AVG:	13.19	13.73	13.36	13.47	13.22	13.45
	SD:	0.49	0.64	0.94	0.76	0.78	0.97
Old-Left-Efficiency	AVG:	11.85	12.41	11.22	11.05	10.57	10.50
	SD:	0.74	0.89	1.09	1.17	1.16	1.32
Young-Right-Score	AVG:	14.91	14.93	14.76	14.74	14.28	14.32
	SD:	0.15	0.12	0.43	0.48	0.37	0.51
Young-Right-Efficiency	AVG:	14.29	14.22	13.67	13.56	12.68	12.62
	SD:	0.20	0.19	0.49	0.50	0.57	0.76
Young-Left-Score	AVG:	14.39	14.80	14.38	14.61	14.00	14.14
	SD:	0.47	0.22	0.45	0.43	0.73	0.63
Young-Left-Efficiency	AVG:	13.59	13.91	12.98	13.04	12.17	12.04
	SD:	0.54	0.28	0.51	0.47	0.79	0.79

Appendix A, Table 18: CRTT Mean and Efficiency Scores Continued

Group-Hand-Measure	Value	Subtest VII	Subtest VIII	Subtest IX	Subtest X	Overall
Old-Right-Score	AVG:	14.11	13.79	14.48	14.64	14.12
	SD:	0.53	0.71	1.09	0.44	0.45
Old-Right-Efficiency	AVG:	14.11	13.79	14.48	14.64	14.12
	SD:	0.88	1.20	1.32	0.70	0.76
Old-Left-Score	AVG:	13.58	13.40	13.80	14.64	13.65
	SD:	0.67	0.93	0.51	0.39	0.49
Old-Left-Efficiency	AVG:	10.94	10.51	13.09	13.28	11.54
	SD:	1.16	1.36	0.81	0.69	0.84
Young-Right-Score	AVG:	14.46	14.31	14.73	14.87	14.63
	SD:	0.36	0.37	0.32	0.24	0.16
Young-Right-Efficiency	AVG:	12.99	12.62	13.89	14.12	13.47
	SD:	0.50	0.52	0.51	0.36	0.28
Young-Left-Score	AVG:	14.14	14.26	14.79	14.87	14.44
	SD:	0.53	0.39	0.22	0.26	0.23
Young-Left-Efficiency	AVG:	12.33	12.27	13.79	13.90	12.99
	SD:	0.61	0.57	0.37	0.37	0.36

APPENDIX B

SUBJECT HISTORY

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 INVENTORY OF HANDEDNESS

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?		

(Adapted from Oldfield, 1971)

(Leave Blank)

L.Q.	
Decile	

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