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Palm Form Recognition Task on the Quick Neurological Screening Test-II: Revisiting Issues of Clinical Sensitivity

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PALM FORM RECOGNITION TASK ON THE QUICK NEUROLOGICAL SCREENING TEST-II: REVISITING ISSUES OF CLINICAL SENSITIVITY

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The present study investigated the effects of number presentation format on imperception rates on a modified version of the Palm Form Recognition (PFR) Task of the Quick Neurological Screening Test-II. The moderator variables of preferred number writing style, age, and sex were explored.

The sample consisted of parent volunteered eight to twelve year old students from the second, third, fourth, and fifth grades in two rural school districts in Pennsylvania. Ninety total participants were recruited for participation, forty-six of which were administered the modified version of the PFR Task under the one-stroke number presentation format and forty-four of which were administered the modified version of the PFR Task under the two-stroke number presentation format. Analyses for this study involved use of independent t-tests, Pearson correlation, Chi Square, and linear regression to examine differences in imperception rates based upon the independent and moderator variables.

Results of the data analyses revealed no significant differences between the number of errors on the modified PFR task as a result of treatment condition. Age effects were confirmed statistically, indicating that errors decreased as age increased, regardless of treatment condition. No significant correlation was found to exist between sex and total errors on the modified PFR task. When assessing

the moderating role of the match between preferred- and presented-number writing style for the numbers 4, 5, 8, and 9, no significant relationship was found collectively. However, further analyses of individual numbers 4, 5, 8, and 9 revealed a significant difference between variables that exceeded the probability of chance for total errors on 4 as a result of the match or mismatch between preferred- and presented- number writing style on 4.

Finally, with regard to the multi-variable relationships of age/error rate/presentation format and age/error rate/match between preferred- and presented- number writing style, linear regression analyses revealed statistically significant, but clinically non-meaningful predictions between 1.) age and total errors under the one-stroke treatment condition, 2.) age, total errors, and match between preferred- and presented number writing style on 5, and 3.) age, total errors, and no match between preferred- and presented number writing style on 8.

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CHAPTER I

AN INTRODUCTION

From the moment of birth, infants experience the excitement and wonder of the world through the five sensory functions: sight, sound, smell, taste, and touch. These sensory experiences lay the foundation for life-long learning and cognitive development. While the biological intricacies of the senses are seldom reflected upon during a typical day, certainly the senses themselves enter into conscious thought on a frequent basis. Consider, for example, the strong aroma of coffee in the morning or the peaceful view of the sun as it settles for the night.

The senses are often taken for granted; except, that is, when a sensory malfunction arises. For example, difficulties with vision and hearing are common and typically easily remediated with a visit to the local optometrist or audiologist. Disruptions to the senses of smell and taste are also typical and often accompany the common cold. Having had greater opportunity to experience temporary losses of these senses seems to have resulted in the assignment of these senses with greater value in life experience.

This is in contrast to the sense of touch, which generally functions effortlessly and without fail allowing one to perhaps minimize the value of this sense. However, disruptions to the sense of touch can have dramatic consequences, as one may experience briefly when a leg or arm “falls asleep” or after having received a local anesthetic prior to a medical procedure. The loss of the sense of touch would perhaps be the most devastating with regard to the effect it would have on one’s ability to actively explore surroundings with one’s hands.

The hand has been referred to as the “man’s outer brain”, “the intelligent hand”, and as “the unitary sense organ” (Katz, 1925/1989, pp. 4-5). Through a series of complex neuroanatomical substrates, the hand, in all of its infinite wisdom, enables its master to perceive and discriminate among sensations. For the purposes of communication, these sensations are commonly assigned descriptive labels that give tactual encounters meaning. Whether these encounters are positive (e.g. the soft caress of a loved-one’s hand), negative (e.g. the painful sensation of being burned), or neutral (e.g. the ability to sense vibration), one cannot deny that tactile input is a critical component of life experience as a whole (Katz, 1925/1989).

The Problem

The importance of the touch modality has been espoused by the medical, psychological, and neuropsychological communities for many years (Reitan & Wolfson, 1992). However, the knowledge and research base surrounding the sense of touch has been relatively sparse in comparison to the other somatosensory systems such as vision and audition (Casey & Rourke, 1992; Katz, 1925/1989).

One reason for this dearth which has been identified is the historical lack of appropriate presentation and assessment techniques that would allow for the systematic and comprehensive evaluation of the brain/behavior relationships accompanying the tactile sensory experience (Katz, 1925/1989). For example, early investigations of the perception of number through touch conducted by Messenger (1903) utilized crude apparatus, non-standardized procedures, and relatively subjective interpretation of outcomes. Given the primary intention of neuro-psychological assessments to “produce a reliable and valid ‘picture’ of the relationships between brain and behavior” (as cited in Casey & Rourke, 1992, p. 477), the failure of early studies to engage in sound methodological procedures for data collection limit their utility.

Due to historical limitations in the knowledge and research base involving the sense of touch, the emergence of the Reitan-Klove Sensory-Perceptual Examination within the Halstead-Reitan Neuropsychological Test Battery in the 1950’s was well-received across disciplines. In general, the Halstead-Reitan Neuropsychological Test Battery was developed in order to infer the presence, extent, and localization of brain damage based upon task performance. The Halstead- Reitan Neuropsychological Test Battery consists of eleven test domains designed to assess aspects of memory, language, abstract thinking, sensory perception, lateral dominance, and motor functioning. The Reitan-Klove Sensory-Perceptual Examination of the Halstead-Reitan Neuropsychological Test Battery focuses specifically on the perception of unilateral and bilateral sensations in the form of auditory, visual, and tactile input. Despite the relative lack of reliability and validity data to accompany its unveiling, the Reitan-Klove represented one of the first systematic attempts to evaluate sensory-perceptual abilities and has persisted to this day as a standard technique utilized in current neuropsychological assessment batteries.

As indicated above, the Reitan-Klove Sensory Perceptual Examination includes visual, auditory, and tactile subtests including Tests for Perception of Bilateral Sensory Stimulation, the Tactile Finger Recognition task, and the Finger Tip Number Writing Perception task. Of particular interest to the present research, however, is the Finger Tip Number Writing task. This is a graphesthesia assessment, meaning that it measures the ability to perceive, or recognize, writing on the skin. In this task, numbers are traced on the fingertips in a standard order over the course of four trials. After each number is traced, the examinee is asked to report which number was traced without the aid of vision. Errors, or imperceptions, in number identification are examined to identify lateral differences and to make inferences regarding potential brain dysfunction, specifically in the parietal lobe.

All of the tasks comprising the Reitan-Klove Sensory-Perceptual Examination have been evaluated both directly and indirectly in the research literature. See Casey and Rourke(1992)and Reitan and Wolfson (1992) for a comprehensive review of the research literature pertinent to issues of reliability and validity of these various measurement techniques. Although these studies will be reviewed more thoroughly in Chapter 2, globally speaking, results of reliability and validity research are ambiguous at best. For example, with regard to the Finger Tip Number-Writing task, concerns have been raised regarding the clinical sensitivity of this assessment as a function of age and the impact of inconsistencies in number presentation formats (i.e. numeral drawing strategy). More specifically, researchers have suggested that error rates decrease as students get older and that error rates decrease when numbers are traced using two strokes rather than just one stroke. See Figure 1. (Casey & Rourke, 1992; Santa Maria, Pinkston, Browndyke, & Gouvier, 1997).

In addition to ambiguous results of reliability and validity studies, researchers have failed to examine other factors which may influence performance results. For example, on the Finger Tip Number-Writing task, test authors indicate that, “in some instances, it is worthwhile to have the subject write the numbers…on paper…so that the numbers can be made in the way most familiar to the subject” (Reitan & Wolfson, 1992, p. 404). Although this procedure is certainly not indicated as mandatory practice, it may have significant implications for test performance. As such, a valid research question that has been ignored, to date, is whether performance is enhanced when examinees are presented with their preferred number writing style versus the examiner's method for number writing.

Despite known limitations, many of the measures comprising the Reitan-Klove Sensory Perceptual Examination have been incorporated, in whole or part, into other neuro-psychological assessment tools, including the Quick Neurological Screening Test (QNST). The QNST was first published in 1974 as a way to screen individuals in those areas of neurological functioning most related to learning (Mutti, Sterling, Martin, & Spalding, 1998). Currently in its second revised edition, the QNST-II consists of 15 subtests targeting areas of neurological integration ranging from fine- and gross-motor coordination (i.e. Hand Skill task, Skipping task, etc.) to tactile-spatial perception (i.e. Palm Form Recognition task). The test manual provides educational and medical implications to aid interpretation of task performance. The test authors acknowledge that the majority of tasks on the QNST-II have been adapted from pre-existing exams and instruments frequently utilized in the medical, early childhood development, and neuropsychological fields.

Although the QNST-II claims to offer an efficient way to accurately identify the presence of neurological soft signs commonly seen in people diagnosed with learning disabilities, there is some room for debate regarding the accuracy of test results (Mutti, Sterling, Martin, & Spalding, 1998). For example, the Palm Form Recognition task was included without incorporating the modifications 1.) recommended by researchers to support reliability and validity and 2.) necessary to overcome known limitations on a similar measure(i.e. Halstead-Reitan Finger Tip Number Writing Task).

Upon review of the administration manual for the QNST-II Palm Form Recognition task, it becomes apparent that the lack of standardization in certain portions of test administration protocol could potentially impact number of imperceptions, or errors, made by the examinee. For example, in the directions for subtest administration, examinees eight years of age or younger, and those individuals suspected of having a disability, are asked to write the numbers one through nine on paper. The examiner is then directed to identify any "idiosyncratic numeral formation" (e.g. one-stroke versus two-stroke formation) on the test numbers (i.e. 2, 3, 4, 5, 6, 7, 8, and 9) and incorporate them when tracing the numbers on the palm (Mutti, Sterling, Martin, & Spalding, 1998, p.18). Although the numbers 2, 3, 6, and 7 can only be traced using one-stroke, the numbers 4, 5, 8, and 9 could potentially be traced using either one- or two-strokes. See Figure 1. Failure of test developers and researchers to acknowledge and incorporate current research data during the development, standardization, and revision phases of the QNST-II in order to increase accuracy of data speaks to the importance and need for additional systematic research with the QNST-II Palm Form Recognition Task.

Problem Significance

In the field of psychological assessment, standardization of test procedures is a key component in the process of test development. The aim of standardization is to create explicit guidelines for test administration, scoring, and interpretation procedures. By doing so, test developers attempt to minimize or eliminate the effects of extraneous variables on test performance. The standardization process is particularly critical when norms are being utilized as a basis for interpretation of performance. In this case, standardization enables examiners to make valid comparisons between the performances of individually obtained test scores and those of the norm group (Murphy & Davidshofer, 1994).

The importance of standardized test administration procedures has been heralded both directly and indirectly by national educational and psychological organizations. The American Educational Research Association, American Psychological Association, and National Council on Measurement in Education (1999) have developed the Standards for Educational and Psychological Testing. Included in these standards is the expectation that examiners will strictly adhere to standardized procedures for test administration and scoring. While these standards go on to outline allowable provisions for special populations, they continue to state that any modification, regardless of intent, must be accompanied by evidence to justify the validity of such modifications and subsequent interpretation of test scores. Additionally, in the National Association of School Psychologist's Professional Conduct Manual: Principles for Professional Ethics Guidelines for the Provision of School Psychological Services, similar standards are espoused, albeit in a more indirect manner. For example, these principles outline that School Psychologists should maintain the highest standards in assessment and use instruments or techniques that are reliable, valid, and have "up-to-date standardization data" (National Association of School Psychologists, 2000, p. 27).

Lee, Reynolds, and Willson (2003) conducted an extensive literature review targeting the effects of modified test administration procedures on task performance. Specifically, these authors reviewed modifications noted in the cognitive/neuropsychological, achievement/educational, and personality/emotional testing domains. Their findings suggested that any alteration in standardized test administration procedures, large or small, could have a significant impact on test performance. In the cognitive/neuropsychological domain, alterations to standardized administration procedures including task instructions, voice inflection, presentation rate, delay periods, presentation modalities (visual versus auditory; standard versus computerized), response formats (spontaneous versus multiple choice), administration order, presence of observers, and provision of reinforcements all yielded significant affects on test performance. With regard to achievement/educational assessments, several factors have also been found to significantly impact test performance including test setting factors, mode of administration, pacing of administration, time restrictions, and mode of response. Finally, modifications to administration practices of personality/emotion testing such as test instructions, mode of administration (paper and pencil versus computerized), and interviewer effects also yielded clinically significant differences in test performance (Lee, Reynolds & Willson, 2003).

Although there is considerable evidence to suggest that even minor modifications to standardized testing formats can significantly alter outcomes, this impact was not noted unilaterally across studies in the review by Lee, Reynolds and Wilson (2003). For example, on intelligence tests changes to some task directions yielded no significant findings. In addition, modifications to task performance for the purposes of process analysis did not result in significant differences in test performance. Based upon the comprehensive literature review conducted, Lee, Reynolds and Wilson (2003) recommended that any modification to standardization procedures should be empirically validated prior to use to establish the effects on test performance and psychometric properties.

Currently, there is considerable research that has been conducted using the Reitan-Klove Finger Tip Number Writing Task. These studies have focused primarily on the effects of brain damage on subsequent performance on graphesthesia assessments, typically in attempt to establish the validity of the task itself (Casey & Rourke, 1992). The literature base is lacking, however, when it comes to robust evaluations of psychometric properties. This is particularly intriguing given the considerable flexibility afforded in test administration procedures, and the subsequent potential effects on reliability and validity of test results.

For example, in a study conducted by Santa Maria, Pinkston, Browndyke, and Gouvier (1997), the effects of the variability in test administration practices on the Finger-Tip Number Writing Task were questioned. These researchers compared performance outcomes on this task when numerals were traced with one-stroke versus two-stroke presentations. Based upon the data collected, the researchers found that participants made significantly more errors when numbers were presented in one-stroke versus two-strokes. The authors argued that two-stroke presentations provided additional tactile cues and generally made the test easier. It was therefore concluded, that “the clinical sensitivity of the [Finger Tip Number Writing Task] can be increased by the administration of all numerals in the one-stroke format” (Santa Maria, Pinkston, Browndyke, & Gouvier, 1997, p. 129).

Despite these empirically derived recommendations, the QNST-II continues to espouse a flexible administration format in the Palm Form Recognition task, a modified version of the Reitan-Klove Finger-Tip Number Writing Task in which examinees are asked to identify, by touch alone, numbers traced onto the palm of the hand. In the administrative manual compiled by Mutti, Sterling, Martin and Spalding (1998), examiners are instructed to have students ages eight and younger write the numbers one through nine prior to test administration and to note any "idiosyncratic numeral formation" that should be employed during the examination (p. 18).

If, indeed, the goal of neuro-psychological assessments is to capture a snapshot of brain-behavior relationships, and yet current measures do not incorporate empirically-derived recommendations to enhance such psychometric properties, it would seem as if the interpretive significance of data collected is severely compromised (Casey & Rourke, 1992). Although performance on individual tasks should always be interpreted within the larger context of the neuropsychological profile, one may argue that 'the whole is only as good as the sum of its parts'. Therefore, in order to obtain a valid and reliable holistic profile, it is vitally important that individual subtests are conducted in the most psychometrically responsible manner. In support of the neuropsychological model of assessment, Gaddes and Edgell (1994) suggested that better knowledge leads to better remedial treatment. As such, the current research is critical in order to determine whether the professional field is currently using practices that would produce a valid and reliable assessment which can be linked to an appropriate program for intervention and remediation (Reitan & Wolfson, 1992, p. 129).

Research Questions

The current study investigated the following research questions: 1) Do children perform better on the modified QNST-II Palm Form Recognition task when numbers are presented in a one-stroke versus a two-stroke format?, 2) Do error rates vary as a function of age?, 3) Do error rates vary as a function of sex (male and female)?, 4) Do error rates vary as a function of the correspondence between preferred number

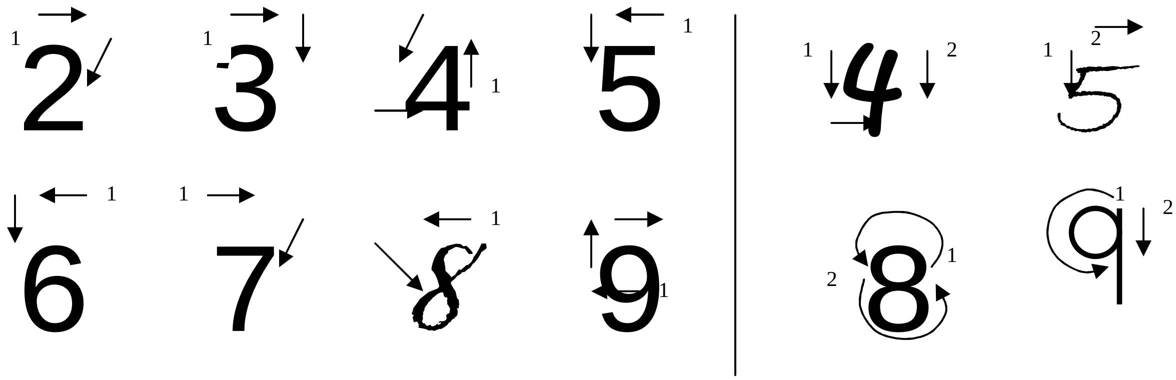

Figure 1: Examples of one-stroke and two-stroke number formations.

writing style and number presentation format, 5) Do error rates vary as a function of the interaction between age and presentation format, and 6) Do error rates vary as a function of the interaction between preferred vs. presented number writing style and age?

Hypotheses

The available relevant literature throughout the 20th century to present day has been reviewed. Based upon this review, the following hypotheses were proposed, corresponding to the research questions posed above: 1.) Participants will perform significantly better (i.e. demonstrate fewer errors) on two- stroke administration format of the modified Palm Form Recognition task versus the one-stroke administration format, 2.) Error rates will vary as a function of age, such that as age increases, a trend toward decreased errors will emerge, 3.) There will be no difference in error rates as a function of sex (male and female), 4.) Participants will demonstrate fewer errors when presentation format matches preferred number writing style, 5.) Trends toward decreased errors as a function of age will be less significant in the two-stroke presentation format condition versus the one-stroke presentation format condition, and 6.) Trends toward decreased errors when presentation format matches

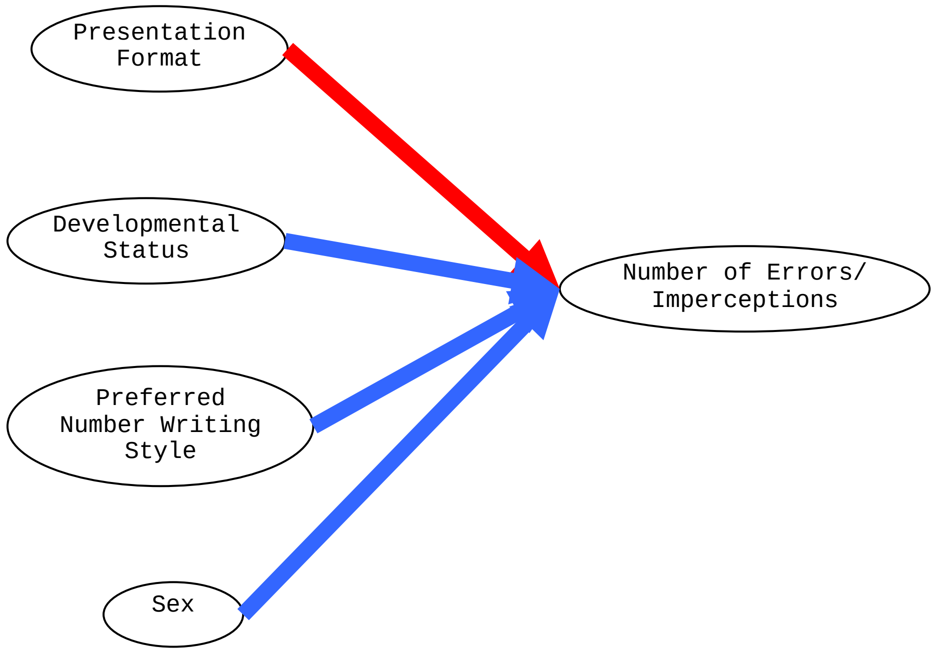

Figure 2: The hypothesized relationships among the variables.

preferred number writing style will be more evident in younger participants (e.g. 8- and 9- year olds) than in older participants (i.e. 10-, 11-, and 12-year olds). See Figure 2 above for an illustration of the hypothesized relationships among the variables.

Definitions

For the purposes of this paper, *neuropsychological assessment* is defined as a series of investigative procedures used to gain "detailed information about the biological and pathological condition of the brain, …the individual's behavioral and psychological functions, …and for establishing relationships between these two aspects" (Reitan & Wolfson, 1992, p. 20-21). This definition is grounded in the Reitan-Wolfson Theory of brain-behavior relationships. Forming the basis of this theory is the belief that incoming information must initially travel to the cerebral cortex through the various sensory pathways to allow for central processing. In accordance with this belief, multiple assessment procedures were incorporated into the Halstead Reitan Neuropsychological test battery in order to examine sensory-perceptual functions.

Sensory-perceptual functions are those processes whereby one receives and is aware of conditions within or without the body resulting from the stimulation of sensory receptors (e.g. tactile, auditory, visual, etc.) (Thomas, 1985). Of primary importance for the purposes of this paper is *tactile perception*, or the awareness of the stimulation of receptors sensitive to touch. Tactile perception encompasses *graphesthesia,* which is defined as the ability by which outlines, numbers, words, or symbols traced or written upon the skin are recognized. It is this ability that is the focus of most assessments of fine tactile discrimination such as Halstead-Reitan's Finger Tip Number Writing task and the QNST-II Palm Form Recognition Test. The QNST-II Palm Form Recognition Task involves tracing numbers on the palm of the hand and asking examinees to identify those numbers by touch alone (Mutti, Sterling, Martin, & Spalding, 1998).

The focus of the current study of research will be on the effects of alternate number presentation formats on children's performance on a fine tactile discrimination test. *Number presentation writing styles* are the method by which the examiner traces each number onto the palm of the participant. Presentation writing styles will be defined as *one-stroke* (i.e. the point of the writing stylus remains in contact with the participant's skin from beginning to ending of numeral drawing) or *two-stroke* (i.e. the point of the writing stylus is lifted from the skin one time and relocated to another part of the skin to complete the numeral drawing). *Preferred number writing style* is indicated by how the child typically writes the numbers one through nine. Performance will be measured based upon number of *imperceptions*, or errors, in numeral identification made by the participants. More specifically, *error rates*, or number of errors made by each participant, will be examined in the present study.

Assumptions

The primary assumption of this study was that all research participants were non-disabled students according to Federal and State special education law. A participant was considered non-disabled if, according to parent and/or school reports, they were not currently receiving, nor under review for consideration for the receipt of, any special education services including Life Skills Support (i.e. part-time or full-time placement for students diagnosed with Mental Retardation or Multiple Disabilities), Speech/Language Support (i.e. part-time or full-time placement for students identified with a Speech/Language Impairment, Listening Comprehension Learning Disability, or Oral Expression Learning Disability), Learning Support (part-time or full-time support for students identified with one or more areas of Learning Disability), Emotional Support (i.e. part-time or full-time support for students identified with an Emotional Disturbance), or Autism Support (i.e. part-time or full-time support for students identified with Autism Spectrum Disorders). In addition, participants in this study were not reportedly receiving any special education related services such as Occupational Therapy, Physical Therapy, Vision Therapy, Deaf and Hard of Hearing Services, etc.) as defined in the Individuals with Disabilities Education Act of 1997. Finally, participants in this study were not under pharmacological treatment for identified psychiatric or psychological disorders according the Diagnostic and Statistical Manual of Psychiatric Disorders- Fourth Edition and International Classification of Disorders- Ninth Edition.

Examiners utilized in this study were certified school psychologists. Given these credentials, it was assumed that examiners administering the modified QNST-II Palm Form Recognition Task had been properly trained in best practices of test administration including building rapport, conducting testing in a quiet, distraction-free location, following standardized test procedures, accurate scoring procedures, etc.

Limitations

As indicated in Santa Maria, Pinkston, Browndyke and Gouvier (1997), clinical neuropsychology measures may require adaptation for use in neuropsychological research studies. The current study required modifications to the standardized test administration of the QNST-II, as detailed in the Method’s Section. When modifications are made to standardized test procedures, standard scores or categorical descriptions may be less valid. In order to compensate for the aforementioned limitations, raw scores were used to compare differences between the imperception rates of control versus experimental participants and categorical descriptions were not used.

A second limitation of the current study is the generalizability of the results. Due to the need to use a sample of convenience and to limit the scope of the current study for practicality purposes, the resulting outcomes are applicable to only a small portion of the population (i.e. 8- to 12- year old students in rural school districts of South Central Pennsylvania). Given this limitation, future researchers with greater availability of time, staff, and funds would need to address the current problem with a larger and less specific sample in order to increase generalizability.

Summary

The research base regarding the sense of touch is lacking in comparison to the other sensory functions, primarily due to the lack of appropriate assessment procedures and techniques. Those assessments that have been developed, such as the Reitan-Klove Sensory Perceptual Examination tasks of the Halstead-Reitan Neuropsychological Test Battery, have demonstrated questionable psychometric properties. For example, the Finger Tip Number Writing task, a graphesthesia assessment, has been found to produce variable outcomes as a function of age and whether numbers are traced using two strokes rather than just one stroke. In addition, specific to the Finger Tip Number Writing task, studies have failed to address whether performance is enhanced when examinees are presented with their preferred number writing style versus the examiner's method for number writing.

Despite these flaws, authors of the Quick Neurological Screening Test have incorporated a similar graphesthesia assessment, the Palm Form Recognition task, into its original and subsequent revised editions. While the test authors claim that this instrument is intended to screen for dysfunction in a wide range of neurological integration skills, it is evident that the lack of standardization in components of the test protocol could result in variable error rates. Standardization enables examiners to make valid comparisons between the performances of individually obtained test scores and those of the norm group and is espoused by national educational and psychological associations. It is imperative in the field of school psychology and neuropsychology that standardization procedures are strictly adhered to in order to obtain a valid picture of individual functioning, accurate interpretation of data, and valid recommendations for remediation.

This study investigated the effects of alternate number presentation formats on children's performance on a modified version of the QNST-II Palm Form Recognition task. Specifically, this study examined differences in error rates when considering the independent variable of number presentation format and the moderator variables of preferred number writing style, developmental status (age), and sex (male and female).

CHAPTER II

A REVIEW OF THE LITERATURE

Tasks such as the Palm Form Recognition subtest on the Quick Neurological Screening Test –II and the Halstead-Reitan Finger Tip Number Writing test are used primarily to detect disorders of sensory-perceptual functions. However, deficits in such functions are commonly associated with more global educational and adaptive impairments. Given the potential interpretative significance of such data, accuracy of obtained scores becomes vital. The present chapter reviews selected portions of the literature related to neuropsychological functioning including its historical trends and theoretical significance as well as

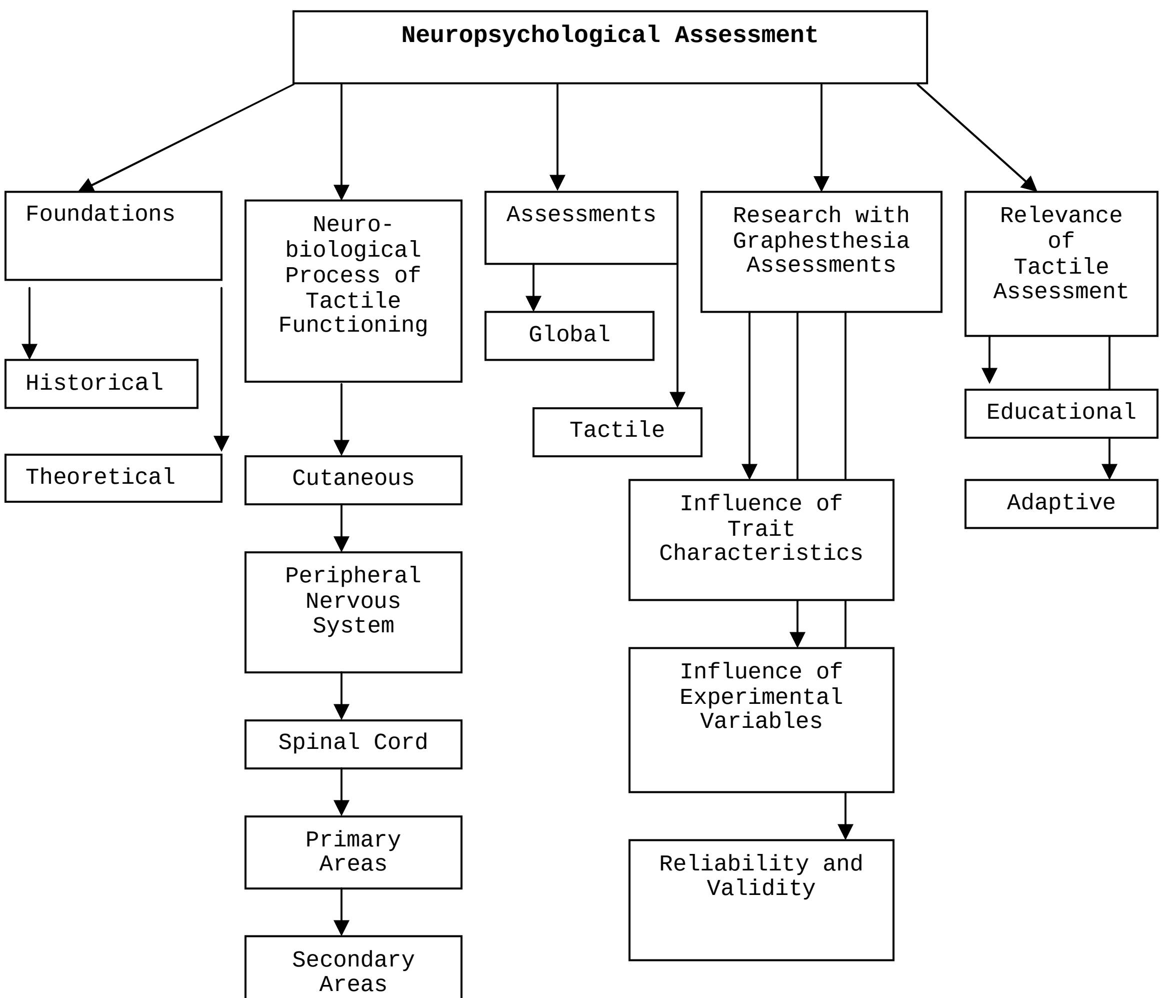

Figure 3: The logical structure of the review of the literature.

the neurobiological framework for tactile sensation and somatosensory perception more specifically. The present author intends to guide the reader through a review of historical and current graphesthesia evaluation tools and procedures, an overview of research examining the effects of trait variables upon tactile performances (i.e. developmental status, handedness, and sex), and an introduction to relevant experimental studies conducted to assess potential confounding variables to current assessments of tactile perception (i.e. practice effects, presentation format, and tactile cues.) The literature review will be concluded with an overview the literature base that lends credibility to the importance of accurate evaluations in this domain. The reader is referred to Figure 3 to examine the logical structure of the review of literature.

Foundations: Historical

Historical accounts related to the earliest developments in the neurosciences date back to approximately 3500BC-2500BC with the *Edwin Smith Surgical Papyrus*. These ancient Egyptian documents, translated by Breasted in 1930, provided the first mention of the word ‘brain’ as well as some of the first descriptions and case studies related to head injuries and resulting behavioral manifestations such as language impairments. Following these accounts, historians note the works of Greek physicians such as Alcmaeon of Croton in 500 B.C., Hippocrates in 400 B.C., and Hierophilus in the 3rd Century as some of the first to posit hypotheses about the structure and functions of the brain (Beaumont, 1983; Fitzhugh-Bell, 1997; Selnes, 2001).

During the 2nd Century A.D., a Roman physician by the name of Claudius Galen began to generate theories of human anatomy based upon the study of animal dissection and the deficits that accompanied various wounds. His work reportedly became the leading work in the field of anatomy for over 1000 years until the findings of Vesalius, a Belgian Anatomist, were published in a textbook entitled *On the Structure of the Human Body.* Through anatomical dissection and study with the human body, Vesalius was able to correct many of the errors noted in Galen's work and was eventually credited as 'the father of modern anatomy' (Beaumont, 1983; Cannon, 2001; Fitzhugh-Bell,1997; Long, n.d.; Selnes, 2001; Smith, 2005).

The studies of many great physicians, philosophers, and physiologists emerged during the late 17th and early 18th Century focusing on the relationships among the structural anatomy of the brain, the functions of the mind, and the concept of the soul. A physician by the name of Thomas Willis documented his postulations about brain functions and locations in an illustrated book entitled *Cerebri Anatome*. He has also been credited with coining the terms hemispheres, lobes, and neurology (Finger, 1994; Fitzhugh-Bell, 1997; Selnes, 2001). Additionally, case studies documenting curious behavior resulting from various defects (e.g. acquired alexia, motor aphasia, etc.) began to emerge with greater frequency.

In the 19th century, Franz Joseph Gall, an Austrian physician, put forth the basic premises of phrenology, in which relationships between behavior and features of the skull were postulated (Kalat, 1995). Miller (1996) provides a review of the basic principles of phrenology, including the notions of plurality and localization of functioning and notes that these principles remain central ideas of neuropsychology to date. At present, the field of phrenology is considered pseudoscience. However, some researchers believe that this field, as originally presented by Gall and later expanded upon by Spurzheim in the 1880's, represented one of the first documented underpinnings of neuropsychology in that it posited the notion that "different parts of the brain do control different aspects of behavior” (Kalat, 1995, p. 128; Beaumont, 1983).

The phrenology-based theories regarding the notion of localization of functioning as posited by Gall and Spurzheim came under scrutiny during the late 1800’s as the focus shifted to theory based upon anatomical scientific research. French anatomist Marie-Jean-Pierre Flourens was one of the first scientists to publicly refute the ideas of Gall based upon scientific studies involving brain functioning. Through the infliction of lesions and ablations on animals, Flourens founded the idea of equi-potentiality, in which he observed that there was a relationship between functional impairment and the degree of brain damage (Fitzhugh-Bell,1997; Long, n.d.).

The work of Flourens was followed by Paul Broca in 1861. Broca is credited as writing “one of the top ten most influential scientific reports of that century, describing the autopsy of a brain tumour” (Smith, 2005, Neuroscience 1861-1926 section, ¶ 2). Broca’s study represented the first scientific research to demonstrate a clear connection between a complex mental function (expressive language) and representation of that function in a distinct area of the brain (posterior third of the left inferior frontal gyrus – “Broca’s Area”) (Cannon, 2001; Fitzhugh-Bell,1997; Long, n.d.; Selnes, 2001; Smith, 2005).

Broca’s research was followed by the findings of Carl Wernicke, a German physician, who studied patients experiencing receptive language deficits. Wernicke discovered this complex language function to be associated with a specific left hemisphere lesion in the brain. The scientific, anatomical basis of brain functioning put forth by Broca, Wernicke, and many other physicians, anatomists, and neurologists during the late 19th Century parlayed into a strong emphasis on localization of functioning in what had, by now, become known as the field of ‘neuropsychology’.

It is interesting to note that there is some debate regarding the originator of the term, neuropsychology. One source indicates that the term was first utilized by Unzer in 1771 in a German textbook, which was translated into English almost a century later (Cannon, 2001, History of Neuropsychology section, ¶ 8). Other sources suggest the term may have been coined by William Osler, an internist at Johns Hopkins University Medical School. Still others, however, credit Donald Hebb, a neuroscientist, with the first use of the term in his book entitled *The organization of behavior: A neuropsychological theory* (Cannon, 2001; Selnes, 2001; Woodruff-Pak, 1997). Regardless, the emphasis on localization in this now named field met with some resistance and led to the early division of scientific researchers into various theoretical camps.

Foundations: Theoretical

The initial work of strict localists like Broca and Wernicke was based in the theory that complex mental functions such as speech and language could be localized to specific cerebral areas (Beaumont, 1983). Attempts for localization of functioning quickly extended to other mental functions including sensory-motor abilities. In this vein, localists, later known as Mosicists, began to narrowly localize functions and engage in brain mapping and diagramming activities. However, according to Graves (1997), the localist views failed as a relevant model of brain functioning because it lacked description of an information exchange system.

In the early 20th Century, likely related to social and political influences of the time, many researchers began to embrace a holistic view. Within this framework, the idea of equipotentiality, which was first posited by Flourens, began to re-emerge(Beaumont, 1983). The hypothetical underpinnings of the Holists are best summarized in Karl Lashley's 1929 book entitled *Brain Mechanisms and Intelligence.* In this book, Lashley put forth his 'theory of mass action', which disregarded the notion of localized functioning for the idea of generalized neural functioning in the brain. Under this theory, holists endorsed diffuse representation of mental functions in the brain and the idea that many, if not all, cerebral functions required total brain involvement. The belief was that in order to obtain full understanding of mental functions, one must view the brain as a system. Although research emerged to support the holistic view, much of the lesion and ablation research from previous years could not be refuted (Beaumont, 1983; Cannon, 2001; Fitzhugh-Bell, 1997; Long, n.d.; Selnes, 2001; Smith, 2005). As such, the connectionist, or interactionist, movement emerged, which allowed for a combined view that encompassed both localist and holist traditions (Beaumont, 1983).

Under this theory, the connectionists argued that although strict localization applied to some brain functions, there were other functions that required the interaction among several cerebral areas (Long, n.d.). Beaumont (1983) notes that this theoretical camp was initially seen in the works of John Hughlings Jackson in the field of epilepsy. In his studies, Jackson proposed that "localization of a deficit after brain injury is not the same as localization of higher cerebral functions in an intact brain" (Prigatano, 1999). According to Graves (1997), the later works of Wernicke also shifted to a connectionist perspective. In 1874, Wernicke put forth a model in which he posited that only rudimentary sensory and motor processes appeared to be strictly localized, while all other functions involved interconnections throughout the brain (as cited in Graves, 1997).

Approximately a decade later, Lichtheim simplified Wernicke’s theory as originally proposed and provided supplemental diagrams designed to highlight the theoretical principles. This resulted in the Wernicke-Lichtheim Model, which has formed the cornerstone of modern neuropsychological theory (Graves, 1997). Despite the growing acceptance of the works of Wernicke and Lichtheim, various branches broke off from strict adherence to this model.

One of the more influential divisions was led by Alexander Luria, a Russian neuropsychologist. Under the strong influence of his colleague Lev Semionovich Vygotsky, Luria’s theory of neuropsychology posited three basic concepts. The first concept as outlined in Plaisted, Gustavson, Wilkening and Golden (1983) involved the idea that “no one area of the brain is responsible for any particular overt behavior, however, neither do all of the areas of the brain contribute equally to all behaviors” (p. 14). The second foundation of Luria’s theory involved the idea of functional systems. Under this notion, Luria asserted that there were many cerebral systems which could potentially carry out any given behavior and it is the existence or non-existence of these systems which predicts the consequence of brain injuries. Finally, Luria posited the notion of ‘pluripotentiality’, in which he proposed that any given area of the brain may be involved in carrying out a multitude of functions (Plaisted, Gustavson, Wilkening & Golden, 1983).

Although many of the theories noted above focus on a more global explanation of brain functions as related to anatomical representation, the Reitan-Wolfson Theory represents a developmental theory which focuses on more specialized functions of the left and right hemispheres as well as the processes that occur “between stimulus and response” (Reitan & Wolfson, 1992, p. 48). The seeds for this theory were planted in Reitan while he was training under Ward Halstead in the first laboratory of neuropsychology. Historically, the development of this laboratory, as well as the research of A.A. Strauss and H. Werner at the Wayne State Hospital and Training School in Michigan, is said to mark the beginnings of the ‘modern era’ of both adult and child neuropsychology around 1935 (Reitan & Wolfson, 1992).

Through the collaborative efforts of these and other researchers, a growing body of literature emerged which attempted to correlate brain damage largely with soft neurological signs and behavioral manifestations. The emergence of the work of Reitan at the Indiana University Medical Center helped to focus the field of neuropsychology, particularly child neuropsychology, back toward a neurological basis for behavior (Reitan & Wolfson, 1992).

Reitan’s experiences at the Indiana University Medical Center resulted in his increased knowledge about, and appreciation for, the biological aspects of neuropsychology. His research, which validated inferences made on neuropsychological tests through neurological information, helped to eradicate many of the misconceptions in the field of child neuropsychology. Additionally, this research ultimately led to the development of standardized testing procedures. Such formal clinical tests were not available until the Halstead Reitan Neuropsychological Test Batteries were developed (Davison, 1974; Reitan & Wolfson, 1992; Selnes, 2001).

The tests selected for inclusion in the Halstead-Reitan battery were designed to directly assess their theoretical conceptualization of brain functions. As proposed in Reitan and Wolfson (1992) the core principles of this theory include:

> 1.)an initial registration of incoming material and integration of this material with the individual’s past experience,

> 2.)a second level of processing dependent largely upon content of incoming material and organized according to the lateralized functioning of the cerebral hemispheres, and
>
> 3.)a third stage of central processing especially directed to more complex and difficult tasks, and thereby representing perhaps the highest features of human brain functioning, consisting of concept formation, reasoning, and logical analysis (p.70).

Although the developmental model proposed deviates from the typical anatomical models presented above, Reitan and Wolfson (1992) do commit to both an 'equipotenitality' hypothesis (represented in the first and third stages of central processing as outlined above) and a 'regional-localization' hypothesis (represented in the second stage of central processing as outlined above) within their model (Reitan & Wolfson, 1992). As such, this model could be categorized under the connectionist camp, as it subsumes portions of both the holistic and localist models.

Neurobiological Process of Sensory-Perceptual Functioning

According to Brown in Hunter, Mackin, and Callahan (1995), "the Greeks were among the first to tell us that there is no distinct demarcation between the body and the mind"(p. 9). Under normal conditions, there is constant and coordinated communication between the hand and the somatosensory region of the brain. In light of the sheer complexity of the communication loop between the hand and the brain, Brown (1995) writes of the hand as an extension of the brain. David Katz, an influential researcher in the field of the psychology of perception, would have also likely agreed with the concept of 'the intelligent hand' put forth by Klatzky and Lederman (1987) (as cited in Katz, 1925/1989). The hand has been identified as the principal organ of touch. Katz (1925/1989) noted that while humans are in their earliest periods of development, the brain educates the hand. However, as the hand becomes trained in childhood, it then becomes a tool of knowledge for the brain.

Research generally supports, at minimum, five types of cutaneous hand experiences including, “fine (discriminative) touch, vibration, light touch, temperature, and pain” (Casey & Rourke, 1992, p. 478). Casey and Rourke (1992) indicate that while pain and temperature are believed to be mediated by the spinothalamic, or protopathic, system, discriminative touch and vibration is believed to be experienced via the epicritic, or dorsal funiculus, system. Given the focus of the present paper on discriminative and light touch involving the hand, an abbreviated review of only the epicritic system follows. It should be noted, however, that the sensory receptors and pathways vary as a function of the cutaneous modality and location of stimulation (Casey & Rourke, 1992).

When the skin or hairs on the skin are stimulated by physical contact, specialized receptors called Meissner’s corpuscles (discriminative touch) transform this contact into neural impulses. Casey and Rourke (1992) note that in the case of discriminative touch, Meissner’s corpuscles are noted to occur in greater quantity in the tips of the fingers than in the palm of the hands. Once touch is transformed into a neural impulse, it travels very quickly through the heavily myelinated Class A axon fibers of the epicritic pathways of the peripheral nervous system (Casey & Rourke, 1992; Cholewiak & Collins, 1991; Long, n.d.) These impulses innervate the spinal cord posteriorally and “ascend the cord and brainstem to the thalamus and somaesthetic cortical strip…in the contralateral hemisphere” (Gaddes & Edgell, 1994, p. 72).

Once reaching this dense group of cells posterior to the fissure of Rolando in the parietal lobe of the brain, these impulses are interpreted as sensations at a conscious level of awareness. While sensation is described as simple awareness of experience, perception involves the ability to understand this awareness (Gaddes & Edgell, 1994). For perception to occur, neural impulses project along fibers from the somaesthetic strip to the association cortex of the parietal lobe. By means of interconnections throughout the brain (i.e. in the postcentral gyrus and various portions of the thalamus), the association areas of the parietal lobe enable the integration of sensory input with some degree of understanding of such input (Casey & Rourke, 1992; Cholewiak & Collins, 1991; Gaddes & Edgell, 1994).

While Reitan and Wolfson (1992) indicate that the Finger Tip Number Writing Task of the Halstead-Reitan is primarily a measure of fine-tactile discrimination, they acknowledge that the factors of attention and alertness are embedded into the task as well. Given the role of focused attention on this task, researchers have cited the involvement of not only parietal lobe functioning but also the secondary area of the pre-frontal cortex of the frontal lobe, as well as noted neural pathways connecting the frontal lobe with the midbrain (Kalat, 1995; Languis & Miller, 1992; Yeudall, Reddon, Gill, & Stefanyk, 1987). The notion of having primary, secondary, and even tertiary areas of the brain involved in such a neurological task suits the theoretical model posited by Reitan and Wolfson (1992). Specific to the Finger Tip Number Writing task, tactile information is transmitted from the hand to the brain by means of the somatosensory system as described above. Once reaching the brain, there is an initial detection of incoming tactile information in the somaesthetic strip. The degree of this registration is dependent upon one’s level of attention and alertness, as monitored by the pre-frontal cortex of the frontal lobe and associated neural pathways. This tactile input is then sent on to the post-central gyrus in order to give the input meaning (i.e. organizing the tactile input traced on the finger tip into a meaningful numeric symbol). Given the visual-spatial nature of this task, the right hemispheric post-central gyrus is implicated at this stage of processing. However, given the language production demands of the task in which the examinee must then assign a language label to the numeric symbol perceived in order to produce a response, involvement of the speech areas of the left hemisphere is assumed.

Assessments: Global

Gaddes and Edgell (1994) have identified three types of investigative techniques that contribute to the knowledge base currently espoused by the professional community within the field of neuropsychology. The first level of investigation involves direct observation of the brain during neurosurgery, autopsy, or through the use of advanced medical technology. The most accurate scientific information can be gained when direct observations are correlated with pre-existing assessment data and reports. Obviously, opportunities for observation during brain surgery and autopsy are somewhat limited. However, it should be noted that it was the latter method that allowed Broca and other researchers to posit theories of brain-behavior relationships in the late 19th century. Additionally, well into the 19th century, reports regarding the sequelea of brain damage had been prevalent (Reitan & Wolfson, 1992).

In addition to the limited opportunity for direct observational methods, in the early stages of support for the neuropsychological approach, the medical field had not yet developed many of the scanning techniques currently relied upon to date for the observation of brain functions (e.g. Computerized Axial Tomography, Magnetic Resonance Imaging, Positron Emission Tomography, etc.). Although the use of techniques such as radiological brain scanning, cerebral ablations, cortical electrostimulation or electrode implantation, and the use of drugs and chemicals are referenced during the inception of the neuropsychological approach, such techniques were commonly considered too primitive and/or too invasive to warrant consideration. For these reasons, investigation into neuropsychology via direct observation was less common than the practice coined by Penfield in 1977 as ‘presumptive diagnosis’ (Gaddes & Edgell, 1994).

Presumptive diagnosis refers to predictions and speculations made by trained medical professionals about brain functioning based upon behavioral observations, or soft neurological signs. This is considered by Gaddes and Edgell (1994) to represent the second level of neuropsychological investigation. Diagnoses in this vein are hallmarks of the medical model and are far more practical and common than direct observation. Unfortunately, this practice results in “…reliable statement only about behavior and speculation about brain function” (p. 17).

The third, and final, level of investigation identified by Gaddes and Edgell (1994) involves the use of direct assessment techniques. When such assessments 1.)are carried out by trained individuals, 2.) involve comprehensive techniques used in a manner consistent with their development, and 3.) incorporate the evaluation of both behavioral observation and test performance, they can lead to meaningful and reliable statements about probable brain function or dysfunction. It was within this very level of investigation that “the systematic examination of the somatosensory system” was rooted (Casey & Rourke, 1992).

Assessments: Tactile

Specific assessments of tactile functioning have been developed throughout the years to measure disorders of tactile sensation, inattention, recognition, and discrimination (Lezak, 1995). Of particular interest to the current topic of study is the development of the Reitan-Klove Sensory Perceptual Examination of the Halstead-Reitan Battery, which focuses primarily on measurement of tactile sensitivity (Casey & Rourke, 1992). The Sensory-Perceptual Examination consists of three subtests including 1.) Bilateral Simultaneous Sensory Perception Tests, 2.) Tactile Finger Recognition Test, and 3.) Finger-tip Number Writing Perception Test. In addition to these subtests, the final portion of the Halstead-Reitan Battery designed to measure sensory-perceptual functioning is the Tactile Form Recognition Test. Each test was developed to measure a specific aspect of sensory-functioning. The tests of bilateral stimulation were specifically designed to identify lateralized deficits in the various sensory modalities. The Tactile Finger Recognition test was developed as a broad measure of the initial registration of incoming tactile information. The Tactile Form Recognition Tests focuses specifically on tactile form discrimination, or stereognosis. Finally, the Finger-tip number writing tests, the primary focus of the current study, was intended to measure the participant’s fine tactile discrimination.

Since it is believed that tactile input is processed in the contralateral hemisphere of the brain, the Halstead-Reitan tests of sensory perceptual functions were developed in a manner that would allow for identification of lateralized brain deficits by observations of performance under bilateral and/or unilateral conditions of tactile stimulation with both the preferred and non-preferred side/hand. Additionally, according to Reitan and Wolfson (1992), each sensory-perceptual test on the Halstead-Reitan Battery was intentionally designed to incorporate some degree of decision making at the cerebral level in order to demonstrate the battery's focus on neuropsychology over physiology. Despite some acknowledged shortcomings of this battery, the Halstead-Reitan has been said to represent the "…best and most complete comprehensive evaluation of cognitive, sensory-perceptual, psychomotor, and motor functions available in clinical neuropsychology" (MacNeill-Horton, p. 251).

On the Halstead-Reitan Finger-Tip Number Writing test more specifically, numbers are written with a stylus on the fingertips of the patient's hand in a prescribed fashion. Analyses of the patterns of performance evidenced by patients on this symbol identification task are often helpful in lateralizing the site of brain damage (Lezak, 1995).

According to Lezak (1995), the skin writing technique involving tracing numbers or letters onto the palmar surface of the hands was initiated into practice by Rey in 1964. Rey reportedly developed a series of assessments in which examinees were presented with numbers and letters traced on their 1.) nondominant hand, 2.) dominant hand, 3.) both hands together, and 4.) forearms. Patterns of errors on these trials reportedly suggested the presence of lesions or, more generally, disorders of tactile functioning (Lezak, 1995).

There are a multitude of other test batteries that incorporate assessments of tactile perception. Many of these assessments are compilations, or variations, of the Halstead-Reitan Battery. For example, consider the Victoria Test Battery, which is a cross-battery assessment in which a variety of subtests from fixed batteries such as the Halstead-Reitan Battery are utilized in a flexible, problem-solving approach. The Victoria Test Battery, which is used in the University of Victoria Neuropsychology laboratory, includes “five tactile, tactile-visual, and tactile-motor tests” (Gaddes & Edgell, 1994, p. 485). Lezak (1995) also references the Wisconsin Test Battery, the SAINT (System for Analysis and Interpretation of Neuropsychological Tests), the Repeatable Cognitive-Perceptual-Motor Battery, and the Halstead Russell Neuropsychological Evaluation System, as additional examples of batteries that have incorporated, in whole or part, the Halstead-Reitan Battery.

The Quick Neurological Screening Test (QNST) is another example of an instrument that was designed by test authors to incorporate and modify various subtests from the Halstead-Reitan Battery. The QNST originally emerged in 1974 and was later revised in 1978. A 1998 Edition was also released and incorporates literature reviews in the manual, more thorough directions for administration, and a revised protocol. The QNST is intended to be a screening instrument for use with children and adults in order to identify neurological indicators often seen in people diagnosed with learning disabilities (Mutti, Sterling, Martin, & Spalding, 1998). This screening consists of 15 subtests adapted and modified from other medical, developmental, or neuropsychological assessments. According to a factor analytical study conducted by Finlayson and Obrzut(1993), the authors described the QNST as a measure of primarily sensory perception or sensory processing. The following subtests of the QNST involve haptic perception: 1.) Palm Form Recognition and 2.) Double Simultaneous Stimulation of Hand and Cheek. Of primary interest for the current study is the Palm Form Recognition test, which represents a modified version of the Halstead-Reitan Finger Tip Number Writing Test. The authors of QNST indicate that the Palm Form Recognition test is a measure of both tactile functioning and spatial perception.

Additional tactile screening assessments have been developed and incorporated into routine mental status exams (MSE) "…for use in areas such as neuropsychology, neurology, clinical psychology, psychiatry, and general medicine" (Berg, Franzen & Wedding, 1987, p. 64). Berg, Franzen and Wedding (1987) review tests for finger agnosia (e.g. In-between test, Two-Point test, and Match Box test), stereognosis (e.g. object recognition), and dysgraphesthesia (e.g. skin writing). These screening measures are intended to be easily administered and to require no cumbersome equipment. Excess errors on any of these tasks may suggest tactile perceptual dysfunction.

The Luria-Nebraska Neuropsychological Battery (LNNB) was initially introduced in 1979 as Luria's Neuropsychological Investigation. The LNNB represents a collection of Luria's assessment techniques, materials, theory, and methodological approach to neuropsychological investigation. Although, as Lezak (1995) points out, Luria borrowed content from other psychological tests, cognitive assessments, speech tasks, and neurological examinations, many of the tasks comprising this battery were self-developed techniques. The Luria-Nebraska Battery provides evaluation data in the following domains: 1.) Motor, 2.) Rhythm, 3.) Tactile, 4.) Visual, 5.) Receptive Speech, 6.) Expressive Language, 7.) Writing, 8.) Reading, 9.) Arithmetic, 10.) Memory, and 11.) Intellectual Processes. Within the Tactile domain, tactile perception is assessed through "…localization of stimuli, 2-point discrimination, pin prick and pressure sensation, movement detection, graphesthesia, and stereognostic skills in both the right and left hands and arms" (Plaisted, Gustavson, Wilkening & Golden, 1983, p. 16). According to Purisch (2001), the introduction of the LNNB to the field met with controversy and subsequent decline in use due to theoretical and methodological criticisms. However, more recent research suggests the utility of the LNNB in diagnosis and treatment (Purisch, 2001). According to Moses (1997), when interpreted via a functional systems approach, the Luria-Nebraska assessment is a valuable tool that can add unique information about presenting symptomatology.

Research with Graphesthesia Assessments

Graphesthesia refers to one's ability to identify, by touch alone, numbers or symbols written on the skin. According to Casey and Rourke (1992), the only standardized graphesthesia assessments are those presented in the Reitan-Klove Sensory-Perceptual Examination of the Halstead-Reitan Test Battery. More specifically, on the Finger Tip Number Writing tasks of the Halstead-Reitan, the examinee is presented with the numbers three through six in a series of predetermined randomized trials for a total of 20 trials per hand (Lezak, 1995). Extensive reviews of the literature were conducted to explore the specific field of graphesthesia assessment. In general, there is a noted dearth in formal studies with these measures in the past two decades. The available research is highlighted below.

Influence of Trait Characteristics and Experimental Variables

Historically, research has been conducted on the Finger Tip Number Writing tasks using normal participants, psychiatric patients, and patients having suffered neurological insult. One topic of such research is hand superiority. According to research reported by Harley and Grafman (1983), nonneurological participants demonstrated significantly fewer imperceptions for numbers written on the left hand than for those written on the right hand. Additionally, Harley and Grafman (1983) noted that the fewest errors were made on the three middle fingers (i.e. pointer, middle, and ring fingers). The left hand advantage has also been documented in psychiatric patients. Maxwell, et al. (1984) reviewed the records of 495 psychiatric patients and found a statistically significant left-hand advantage in right-handed patients and a trend for a left-hand advantage in left-handers.

Those professionals who have researched the apparent left-hand advantage for numbers written on the fingertips have identified two principle explanations for this advantage. The first explanation posits that the tendency for participants to demonstrate fewer imperceptions for numbers drawn on the left hand results from a right hemispheric superiority for tactile-spatial processing (Harley & Grafman, 1983; Maxwell, et al., 1984). That is, some researchers have concluded that performances on sensorimotor tasks such as the Finger Tip Number Writing task will be more deficient in patients with right hemispheric cerebral damage than left hemispheric cerebral damage (Maxwell & Niemann, 1984). Upon initial inception, this explanation seemed plausible as it arose during a time when researchers were consistently demonstrating "…that the right hemisphere plays a distinctively important role in the mediation of spatial perception in the tactile… modalities…", particularly on tasks assessing tactile perception of line-direction (Benton, Levin, & Varney, 1973; Fontenot & Benton, 1970, p. 88; Maxwell & Niemann, 1984). However, this hypothesis, as applied directly to the Finger Tip Number Writing task, met with some criticism and, subsequently, additional research. Out of this research grew a new hypothesis.

The second hypothesis espoused by researchers regarding the left-hand advantage on the Finger Tip Number Writing Task was that the so-called left-hand advantage emerged simply due to practice effects. That is, since the administration directions for this task indicate that the numbers should first be written on the examinees' right hand and then on the left hand, it is possible that examinees acclimate to the task, therefore showing a distinct left-hand advantage (Maxwell & Niemann, 1984; Maxwell, et al., 1984).

In 1984, Maxwell and Niemann conducted a study to look at practice effects versus lateral asymmetry. In this study, they questioned the legitimacy of the claimed right hemispheric superiority for the Finger Tip Number Writing Task based upon previous studies of tactile asymmetry as well as the influence of the verbal demands of the task itself. By counterbalancing hand-order on the Finger Tip Number Writing Task, these researchers found a significant practice effect but no lateral asymmetry (i.e. right hemispheric superiority). This trend toward enhanced performance with the administration of additional tactile probes had also been demonstrated a decade earlier when Fontenot and Benton (1971) looked at tactile perception of line orientation using a variable number of probes.

When Maxwell and Niemann (1984) further examined the Finger Tip Number Writing practice effect, they determined that the primary explanation for the practice effect was not practice with numbers drawn on the skin, but rather recognition that only four numbers (i.e. 3, 4, 5, 6) were being used in the test. When modified task directions were given at the start of the task, no practice effects were in evidence.

In summarizing lateralizing research on graphesthesia assessments such as the Finger Tip Number Writing Tasks, Casey and Rourke (1992) highlight the importance of interpreting dysgraphesthesia errors within the context of a complete neuropsychological evaluation, as errors may be indicative of either left or right hemispheric impairment. That is, left hemispheric dysfunction may arise due to 1.) the “symbolic requirements of the task” (Casey & Rourke, 1992, p. 484) or 2.) the transfer of spatial information to the left hemisphere for the purposes of assigning language labels to perceived numbers (Maxwell, et al., 1984). To the contrary, right hemispheric dysfunction may be suspected due to the spatial nature of the task (Casey & Rourke, 1992; Harley & Grafman, 1983).

In addition to multiple research studies aimed at delineating practice effects versus hemispheric dominance, several studies have been conducted to examine age effects on tactile performance. According to Casey and Rourke (1992), simple tactile perception appears to develop at a fairly early age. More specifically, these authors conducted a thorough review of the literature and concluded that 1.) children demonstrate minimal changes in simple tactile perception from ages 3-14 and 2.) by age 8, more complex tactual-perceptual skills appear fully developed (e.g. bilateral asymetrical stimulation; tactile form recognition, etc.). In a review of relevant studies assessing age effects on performance on the Halstead Reitan Finger Tip Number Writing tasks, Casey and Rourke (1992) note a sharp increase in performance from ages 6 to 7 and a trend toward decreased imperceptions from ages 9 to 14. This notion was also confirmed in a finger localization study by Benton, as reviewed in Casey and Rourke (1992). According to these authors, "…finger localizing skills are already in the process of development before the age of 6 years and are not yet completely developed in the 9-year-old, as their performance was below that of the average adults" (Casey & Rourke, 1992, p. 486).

In summarizing the review of the literature regarding developmental considerations in somatosensory perception, Casey and Rourke (1992) conclude that the process of finger differentiation appears to be one of the first to develop by age five. The process of simple finger recognition appears to continue in development until approximately age 9 or 10. Finger recognition tasks involving a component of symbolic thinking (e.g. fingers are identified by numbers and the examinee has to name the number or point to the corresponding number on a picture chart) are believed to emerge roughly between the ages of 12 and into adulthood (Casey & Rourke, 1992).

Age effects have not only been studied in the developmental research field, but have also been a topic of study for the field of aging. Lezak (1995) indicates that the research generally supports an overall decline in tactile sensitivity in approximately one quarter of all older persons ages 50-65. Although likely influenced by normal cognitive effects associated with aging such as a reduction in brain volume, biochemical alterations, changes in cerebral blood flow, and changes in brain wave frequencies, the notable decline in tactile functions is more commonly linked with skin changes (Lezak, 1995). More specifically, Woodruff-Pak (1997) documents a series of research studies conducted from the 1940’s through the 1980’s which suggests that individuals experience significant changes in the number of Meissner’s corpuscles, nerve endings located in the upper areas of the skin, throughout life. The density of these receptors are noted to decrease from birth through age 20 due to growth patterns. Additionally, other researchers have noted a decrease in the number of these receptors in older adulthood, particularly those located in the fingers. It is the loss of these receptors which is often linked to the overall decline in tactile sensitivity noted in the normal aging process (Woodruff-Pak, 1997).

Whether specifically designed for such purposes, or simply included in data analysis, several studies have examined the differences in performance that emerge based upon sex. Given the spatial nature of the Finger-Tip Number Writing task, one may anticipate male superiority on such task. That is if one aligns himself with author Beaumont (1983), who writes “the evidence in general psychology about sex differences…has pointed to a superiority among males for spatial and mechanical skills, and a superiority among females for verbal skills" (p. 249). While Beaumont (1983) notes that these findings have not been unequivocally supported, a study by Gordon and O'Dell (1983) serves to highlight the extent of the sex debate. In a study of 72 university students administered tactile-motor subtests from the Halstead-Reitan, significant sex differences emerged. This study was designed to replicate, with a larger sample size, a former study by Gordon, O'Dell, and Bozeman (1981) in which significant sex differences were demonstrated on neuropsychological assessments. The results of the Gordon and O'Dell (1983) study, demonstrated female superiority on left-hand fingertip number writing, left-hand finger agnosia, and the Tactual Performance Test (memory and localization). Male superiority was noted on both hands on the grip strength and finger tapping tasks. Further analysis of the degree of discrepancy on all measures, however, suggested that only the latter two differences (i.e. grip strength and finger tapping) were clinically meaningful sex differences.

Gaddes and Edgell (1994) reviewed a series of studies conducted from the 1940's through the 1970's and concluded that researchers tend to agree that there is indeed a sex-related difference in hemispheric proficiency. That is, males tend to evidence a right-hemispheric (i.e. spatial) superiority, and females a left-hemispheric (i.e. verbal) superiority. However, Gaddes and Edgell (1994) go on to explain that utilization of lateralized hemispheric processing may be task-dependent and that sex differences seem to be more apparent on tasks that are not easily completed using a verbal-only strategy. These authors cite a study conducted by Gaddes and Crockett (1975) in which 353 boys and girls from the ages of 6 years to 13 years were administered the

Spreen-Benton Aphasia Battery. The results of this study demonstrated that "no sex differences were found in 11 of the 20 subtests and these included… stereognosis in both hands…" (p. 236). The apparent conclusion is that normal functioning boys and girls, although perhaps using different strategies (i.e. verbal versus nonverbal/spatial), are able to perform equally as well on neuropsychological assessments.

In more recent texts, Kalat (1995) suggests that, globally, while sex differences related to hemispheric dominance and lateralization may exist, in part due to the effects of early testosterone in brain development, these differences are not significant. Additionally, specific to tactile functioning, upon review of the available literature, Casey and Rourke (1992) concluded that on finger localization and recognition tasks, no significant differences in level of performance emerge based upon sex. In this review, specific studies are cited that support this notion, including a study by Benton (1955) of 158 5.5 through 9.5 year olds in which there was no statistical difference between males and females (as cited in Casey & Rourke, 1992).

There is only one known study to date that has been conducted to examine the effects of variations in administration procedures on the Halstead-Reitan Finger-Tip Number Writing Task. This study was designed to examine the relative effects of the lack of standardization in certain portions of test administration protocol on number of imperceptions made by the examinee. Santa Maria, Pinkston, Browndyke, and Gouvier (1997) compared performance outcomes on this task when numerals were traced with one-stroke versus two-stroke presentations. Based upon the data collected, the researchers found that participants made significantly more errors when numbers were presented in one-stroke versus two-strokes. The authors argued that two-stroke presentations provided additional tactile cues and generally made the test easier. It was therefore concluded that “the clinical sensitivity of the [Finger Tip Number Writing Task] can be increased by the administration of all numerals in the one-stroke format” (Santa Maria, Pinkston, Browndyke, & Gouvier, 1997, p. 129).

Reliability and Validity

According to Gaddes and Edgell (1994), comparisons between participants with and without brain-damage are critical in order to determine the extent and type of presenting dysfunction. In this vein, the utility of a neuropsychological assessment should be based upon its ability to discriminate brain-damaged from normal participants. According to research conducted to evaluate the ability of the graphesthesia assessment to function in this manner, results are ambiguous at best. In a review of the reliability research presented in Casey and Rourke (1992), it is concluded that graphesthesia assessments alone are not particularly sensitive in discriminating brain-damaged from normal populations. However, they do cite several studies in which younger brain damaged children (ages 5-8) demonstrated significantly more errors on graphesthesia assessments than their same-aged normal counterparts. This trend was noted to be more evident with performances on the left hand than on the right hand. This is likely due, in part or whole, to the enhanced ability of the normals to learn from the presumed practice effects, as discussed above. Finally, research suggests that the discriminative capabilities of graphesthesia assessments is more pronounced in children with actual brain-damage than in those with suspected brain impairment (e.g. learning disabilities, minimal brain dysfunction, etc.) (Casey & Rourke, 1992).

Educational and Adaptive Implications

According to Heller (1991), tactile functioning has not been a primary area of interest for researchers. A more current review of the literature through 2008, conducted for the purposes of the present study, confirms this finding. This trend emerges despite human dependence upon the sense of touch in directing and perceiving activities throughout life. The importance of this sense is routed in the developmental course of tactile perception. Gaddes and Edgell (1994) indicate that in response to the development of the somoesthetic strip of the parietal lobes, the sense of touch is the first of the five sensory functions to develop prenatally. In infancy, the sense of touch enables the integration of the other senses and supports multi-dimensional perception of the world. This process of integration has been identified by Swiss psychologist, Jean Piaget, as representing the first stage of cognitive development. This stage has been termed as the stage of sensorimotor development and represents birth through age two in which there is a "…progression in the infant's ability to organize and coordinate sensations with physical movements and actions" (Santrock, 1995, p. 191). Piaget describes six substages that emerge during the sensorimotor stage. It is during the fourth substage, termed *coordination of secondary circular reactions*, in which purposeful tactile exploration is said to emerge (Santrock, 1995). This exploration allows the child the tactile feedback necessary for the development and refinement of sensorimotor skills.

Many studies have been conducted that suggest not only educational implications related to tactile perception, but also serious adaptive implications. With regard to the latter, the adaptive role of touch is perhaps best illustrated in the blind and deaf-blind populations. Blind people are reliant upon tactile input for navigational, information-gathering, and for spatial orientation purposes in general. Through the use of active touch, which Heller (1991) considers any touch that involves invoked movement for the intent of gaining information about the environment, blind people are able to read and write Braille. Additionally, through the use of passive touch, which Heller (1991) considers any touch that does not involve intentional movement, deaf-blind people are able to engage in information gathering through 'print-on-palm' techniques, involving the presentation of word spellings or number tracings on the palm of the hand.

Given the importance of the tactile sense in these specific instances, deficits in tactile functioning have grave adaptive implications. For instance, Gaddes and Edgell (1994) report that a lesion in the somoesthetic and tactile pathways may result in inability to perceive two-dimensional surface touch, such as Braille. Additionally, variations in tactile sensitivity of 'reading fingers' have consequences such as impaired rate of Braille reading (Foulke, 1991). Deficits in tactile functioning may also influence 'print-on-palm' perception. The adaptive implication of such impairments is perhaps best highlighted through the life story of Helen Keller. "If Annie Sullivan had failed to reach Helen Keller's mind through touch, by circumventing her blindness and deafness, then Helen would almost certainly have remained intellectually starved and mediocre, instead of developing in the superior way that she did" (Gaddes & Edgell, 1994, p. 67-68).

As alluded to earlier, educational implications have also been documented in studies of tactile functioning. Reitan and Wolfson (1992) indicate that, while the influence of sensory-perceptual deficits on global brain functioning had been well-documented in the adult population during the late 1950's and early 1960's, more robust examination of these influences in childhood did not emerge until the 1970's and 1980's. When similar research questions were geared toward a younger population, however, similar trends emerged. In early studies, researchers merely suggested that certain tactile-perceptual measures were sensitive enough to discriminate children with brain damage from normal children. As reported in Reitan and Wolfson (1992), a study conducted by Boll and Reitan in 1972 revealed that the Finger-tip Number Writing and Tactile Finger Localization tests, in particular, showed a significant discrepancy between children with brain-damage and children without brain damage.

Once this relationship was established, researchers began to examine the relationship between sensorimotor functions and general cognitive ability. As reported in Reitan and Wolfson (1992), research generally supported the notion that individuals with deficits in sensorimotor functions tended to show weaker performance on measures of cognitive functioning including, but not limited to, the Wechsler scales, Category Test, and Trail Making tests.

According to research reported in Boll, Berent, and Richards (1977) several studies have also documented a strong correlation between performance on tasks of tactile perception and reading achievement, problem solving, linguistic learning, memory, emotional development, and motor development. This relationship is noted in not only the brain-impaired population, but also in the control groups. Given the documented influence of tactile functioning on global psychological functions such as intelligence, and in light of the well-documented predictive relationship between intelligence and academic functions, it was only logical for examiners to explore the potential relationship between tactile functioning and academic achievement. Past research that has posited such a relationship is outlined in Boll, Richards, and Berent (1978) and consistently suggests associations between tactile functioning on measures of arithmetic ability as well as reading ability. The experimental study conducted by Boll, Richards, and Berent (1978) further supported the positive correlation between tactile functioning and achievement. Based upon the results of their study, these authors concluded that tactile perceptual abilities are a predictor of academic testing outcomes in both the brain injured and non-brain-injured participants (Boll, Richards, & Berent, 1978).

In a study conducted by Finlayson and Reitan (1976), a significant relationship between number of errors on tasks assessing tactile functioning and performance on other measures of cognitive and academic functioning was also noted. However, these authors found that this relationship was stronger in older participants (ages 12-14) than in younger participants (ages 6-8). In participants ages 9-14, the positive correlation between tactile perceptual abilities and reading performance has also been documented in more recent research conducted by Havey (1990).

Blondis, Snow, and Accardo (1990) conducted a longitudinal study designed to determine the presence and progression of soft neurological signs including sensory, motor, and perceptual abilities, in students academically functioning at-grade level and those functioning below grade level (i.e. receiving special education or other remedial services). Over the course of one year, the indicators which were found to have the best discriminative power were measures of motor coordination, graphesthesia, and observations of associated movements during hand skill testing. This finding further supports the plausible relationship between sensory functions, such as fine tactile discrimination, and academic proficiency.

Over the past several decades, increasing research has emerged to support the notion of subtyping in the learning disability population according to classical learning disabilities versus nonverbal learning disabilities. Whereas the child with a classical learning disability would typically evidence generally adequate nonverbal abilities, delayed language-based problem solving, and subsequent academic gaps in language arts areas, the child with a nonverbal learning disability would evidence generally adequate verbal abilities, delayed visually-based problem solving, and subsequent academic gaps in the mathematical and mechanical areas. According to Harnadek and Rourke (1994), research has highlighted nine principal characteristics of children diagnosed with nonverbal learning disabilities and tactile-perceptual deficits top the list. More specifically, these authors indicate that deficits in tactile perception, tactile attention, and tactile memory are key contributors to academic problems in the nonverbal learning disabled population. Given this finding, one can surmise a correlation between tactile functioning and academic achievement, particularly in those areas requiring mathematical and mechanical skills.

Summary

The present chapter has provided an overview of selected portions of the literature related to neuropsychological functioning including its historical trends and theoretical significance as well as the neurobiological framework for tactile sensation and somatosensory perception more specifically. A review of historical and current graphesthesia evaluation tools and procedures, an overview of research examining the effects of trait variables upon tactile performances (i.e. developmental status, handedness, and sex), and an introduction to relevant experimental studies conducted to assess potential confounding variables to current assessments of tactile perception (i.e. practice effects, presentation format, and tactile cues) has been presented. The literature review has been concluded with an overview the literature base that lends credibility to the importance of accurate evaluations in this domain, with particular emphasis on the educational and adaptive implications of tactile functioning.

CHAPTER III

RESEARCH METHODS AND PROCEDURES

The purpose of this study was to gain information regarding the effects of modifying administration procedures on test performance. Specifically, the goal of this research was to determine if significant differences emerge on a modified version of the Palm Form Recognition Task of the Quick Neurological Screening Test-II when numbers are presented in a one-stroke format versus a two-stroke format. The effects of additional moderator variables including preferred number writing style, age, and sex were also examined. Research site approval for this study was granted through the Superintendents of two rural school districts in South-Central Pennsylvania. This study was further approved by the Department Review Board and Institutional Review Board at Indiana University of Pennsylvania. A total of ninety parent-volunteered students ages eight through twelve from the 2nd, 3rd, 4th, and 5th grades participated in the study.

Design

A post-test only true experimental design was utilized in this study. The dependent variable in this study was the number of errors made on the modified QNST-II Palm Form Recognition Task. The independent variable was the number presentation format (i.e. one-stroke or two-stroke). Participants were randomly assigned into one of two number presentation conditions (i.e. one-stroke or two-stroke condition). Moderator variables that were examined include preferred number writing style (one-stroke or two-stroke), developmental status (age), and sex (male and female). See Figure 4 and Figure 5 for an examination of the study’s design.

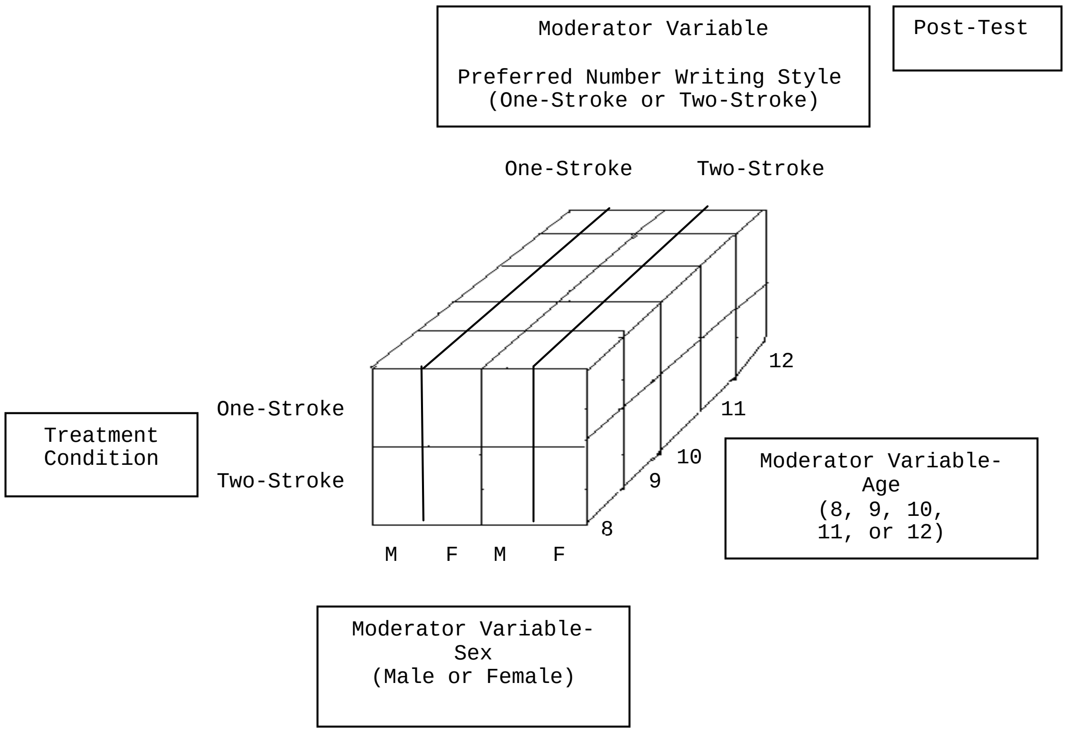

Figure 4: Structure of the post-test only true experimental design.

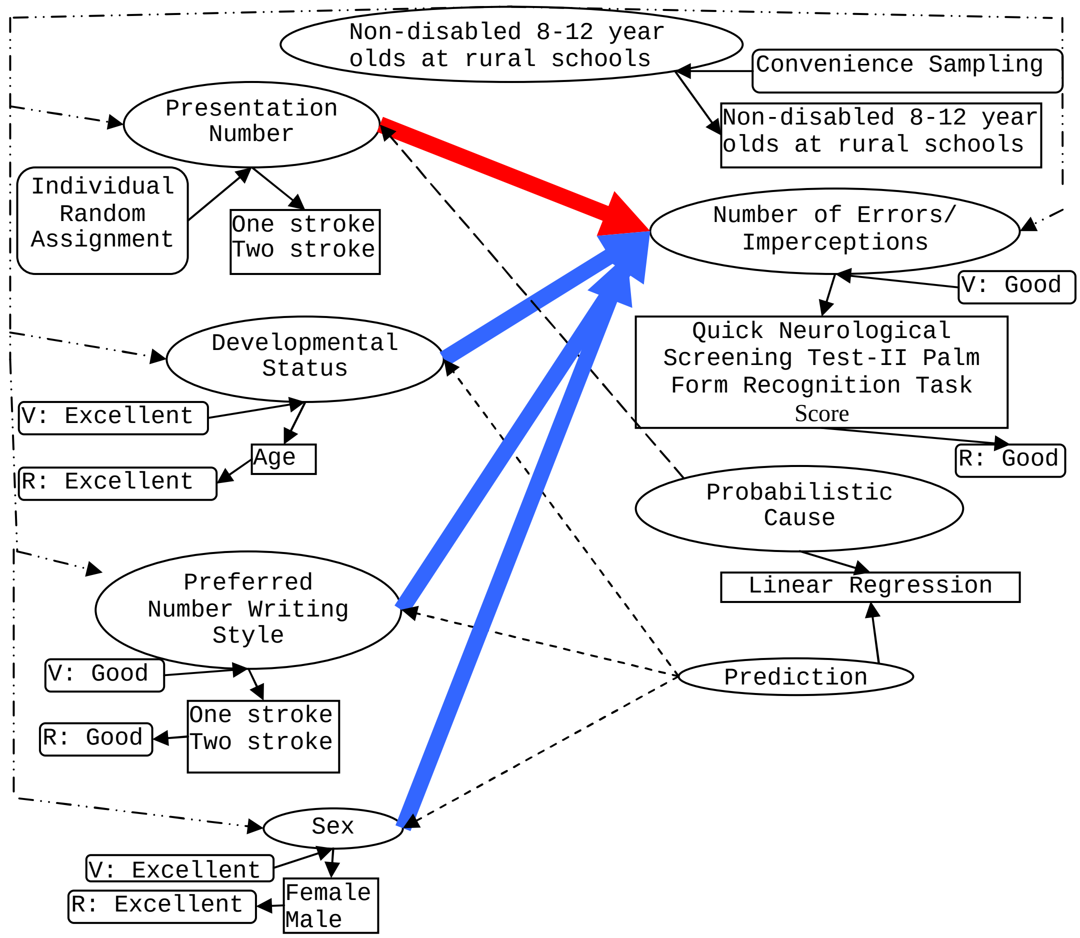

Figure 5: Path diagram of the study.

Population

Students from two rural school districts in South Central Pennsylvania were utilized in this study. The focus of this study was on students ages 8- to 12-years in grades 2, 3, 4, and 5 who were not presently identified with any type of disability according to the Individuals with Disabilities Education Act of 1997 and who were not currently under pharmacological treatment for identified psychiatric or psychological disorders according the Diagnostic and Statistical Manual of Psychiatric Disorders- Fourth Edition or International Classification of Disorders- Ninth Edition.

Sample

A total of approximately 1,200 students in the 2nd, 3rd, 4th, and 5th grades of the selected elementary schools in the identified school districts were given written Informed Consent letters and subsequent Permission to Participate in Research forms to take home from school with them (see Appendixes A and B for sample letters and forms). Of these 1,200 forms, a total of 155 parent-completed Permission to Participate in Research forms were returned to school, representing a return rate of approximately 13%.

Forty-six of the students volunteered for participation in the study were excluded for being out-of-age (16 students were under the age of 8), having DSM-IV diagnoses (11 were diagnosed with ADHD, 1 was diagnosed with an Anxiety Disorder, and 2 had multiple diagnoses), or for having been diagnosed under IDEA and/or currently receiving special education services (2 receiving Occupational Therapy services, 1 receiving Physical Therapy services, 4 receiving Learning Support services, 5 receiving speech services, and 4 receiving multiple services). Additional participant attrition occurred due to absence on the date of assessment (8), inability to establish parent contact to schedule testing session (5), and inability of parents to provide transportation on the date of assessment (6).

The remaining 90 participants met eligibility criteria to be included in the study. Uneven distribution of ages resulted, with higher numbers surfacing at ages 8 and 9, than at ages 10, 11, and 12. There were equal numbers of male and female participants. The reader is referred to Table 1 for a description of the sample.

Table 1

Description of the Sample

	Age 8	Age 9	Age 10	Age 11	Age 12	Total
Total *(n)*	30	26	19	14	1	90
Males *(n)*	13	9	13	9	1	45
Females *(n)*	17	17	6	5	0	45

Assignment

Stratified random assignment by age was utilized in the present study. Upon verification of eligibility for participation in the study, volunteered students were grouped by age (8, 9, 10, 11, or 12). The participants in the individual age groups were then randomly assigned to one of two treatment conditions (i.e. one- stroke number presentation format or two-stroke number presentation format), through the use of a Random Numbers Chart (Gay, 1996, p. 602-605). The reader is referred to Table 2 for an analysis of assignment to treatment condition by age.

Table 2

Analysis of Assignment to Treatment Condition by Age

	Age 8	Age 9	Age 10	Age 11	Age 12	Total
Total *(n)*	30	26	19	14	1	90
One-Stroke *(n)*	15	13	10	8	0	46
Two-Stroke *(n)*	15	13	9	6	1	44

Instrumentation

In order to collect information regarding errors made on a graphesthesia assessment, the current study utilized a variation of the Palm Form Recognition subtest from the Quick Neurological Screening Test-Second Revised Edition (Mutti, Sterling, Martin & Spalding, 1998). The Quick Neurological Screening Test was first released in 1974 and later revised in 1978. A test manual change only predicated the release of the Quick Neurological Screening Test-Second Revised Edition (QNST-II) in 1998. The QNST was originally developed as a "…quick and accurate way for educational specialists, school nurses, pediatricians, psychologists, and rehabilitation therapists to detect soft neurological signs…" (Mutti, et.al, 1998, p. 9). Soft neurological signs are defined as minor behavioral deviations such as poor motor coordination, oral-motor overflow, hypokinesis, and spatial-perceptual difficulties that are suggestive of neurological dysfunction in absence or conjunction with hard signs, or medical evidence, of such dysfunction (Gaddes & Edgell, 1994). In the test manual, the authors clearly differentiate among developmental (or age-expected) soft signs versus soft signs that are indicative of abnormal functioning. While assessing both, the evaluator administering the QNST-II is advised by test authors to consider soft signs of abnormality to be more serious than developmental soft signs.

In order to fully assess the presence of all soft neurological signs, the QNST-II is comprised of 15 subtests designed to 1.) identify children whose learning difficulties are unlikely to be due to neurophysiological difficulties, 2.) target children who are in need of more in depth psycho-educational assessment for the purposes of developing remedial programs, and 3.) target children who are in need of more in depth medical assessment for the purposes of diagnosis (Mutti, et.al, 1998). The tasks upon which the subtests are based have been derived and adapted from various other neurological, neuropsychological, and developmental batteries. The test authors have included evidence in the form of a review of the medical and educational literature, to support inclusion of each of the 15 subtests. For example, when discussing the inclusion of the Palm Form

Recognition task, Mutti, et al. (1998) cite studies in which a high correlation has been found between graphesthesia assessments and factors such as tactile deficits, verbal intelligence quotients, reading proficiency, spatial perception, and numerical operations skills.

The test authors report that the entire QNST-II can be administered in as little as 20-30 minutes. A total score is obtained through the summation of the individual scores on the 15 subtests. Each subtest consists of a series of tasks or behavioral observations which are assigned scores of 1 or 3, if erroneous performance or behavioral manifestations are observed. Scores of 1 indicate developmental soft signs while scores of 3 represent abnormal soft signs. For each subtest, scores are summed and assigned a categorical descriptor indicating whether performance is Severely Discrepant from expectations for functioning(SD), Moderately Discrepant (MD), or within the Normal Range (NR). Finally, all subtest scores are summed and an overall categorical descriptor is assigned.

Directions for individual subtest administration and scoring are contained within the manual. For the Palm Form Recognition Task, the examinee is to present palms face up, resting on their knees, while eyes are closed. For examinees 8 years of age and younger, they would first be asked to write the numbers 1 through 9 on a piece of paper to verify number identification skills and for the test administrator to note how they form the numbers so that preferred number writing style can be used in test administration. The examiner is to then trace the numbers 3, 9, 5, 7 on the examinees' right hand and then the numbers 2, 8, 4, 6 on the left hand using the forefinger or a pencil's eraser. Scores of 1 are assigned if the examinee asks for the number to be presented more than once, if the answer given is a letter instead of a number, or if the number cannot be identified. Unlike many of the other subtests on the QNST-II, there is not an option to assign scores of 3 on the Palm Form Recognition Task.

Normative data for the QNST were obtained through administration of all subtests to approximately 2,300 children in Northern California from ages ‘under 6’ to ‘over 17’. Approximately half of this sample was receiving special education services and half was not receiving special educational support. During the QNST-II test development study, the authors found that “the QNST tasks are mastered at consistently lower ages in the undifferentiated group than in the LD group” (Mutti, et al., 1998, p. 67). According to data reported regarding “the percentages of children successfully completing each task at various ages”, 25% of the undifferentiated participants were successful with the Palm Form Recognition task at age 5 years, 9 months, 50% at age 7 years, 7 months, and 75% at age 9 years, 0 months (Mutti, et al., 1998, p. 67-68). In the group with Learning Disabilities, 25% were successful at under 7 years of age, 50% at 10 years of age, and 75% at 11 years of age. Difficulty specifically on the Palm Form Recognition task was not found to be more characteristic in the population with Learning Disabilities than in the Undifferentiated population. This suggests that performance on the Palm Form Recognition task may not independently be a reliable way to discriminate special education students from non-special education students.

The test authors conducted an additional pilot study using fewer participants (approximately 180) in order to determine differences in overall QNST performance in various age groups. Although significant differences among age groups were reported, the nature of these differences was not reported.

Additional studies have been conducted with the QNST and are reported in the test manual. These studies have examined the discriminative validity (e.g. ability to discriminate students with Learning Disabilities (LD) from students without Learning Disabilities (non-LD) based upon overall and subtest scores) and predictive validity (e.g. ability of QNST scores to predict reading ability). Based upon these studies, researchers have concluded that the QNST can successfully be used to predict reading ability in children over 6 years of age, that the QNST total score successfully discriminates LD from non-LD students, and that certain subtests do appear to discriminate non-LD from LD students better than other subtests (e.g. Finger to Nose, Figure Recognition, Rapidly Reversing Hand Movements, and Thumb and Finger Circle).

As reported by the authors in the test manual, the QNST has been reported to demonstrate test-retest reliabilities of 0.81 and inter-rater reliabilities ranging from of 0.69 to 0.71.

The original version of the QNST was reviewed by Rattan and Dean (1985). According to these reviewers, the scoring instructions for the QNST were generally adequate and the sample size seemed appropriate. However, significant concerns were noted with regard to subjective and theoretically flawed scoring criteria, insufficient information regarding the standardization sample, uneven sample distributions, and limited reliability and validity research. In another review by Adams (1985), strengths for the QNST were noted with regard to clear instructions for administration, availability of a videotape for training purposes, large norming sample, and for the mere idea of trying to standardize an examination commonly used in childhood neurological exams. However, Adams (1985) notes significant flaws with regard to subjective scoring criteria, failure of test authors to define Learning Disability, the possibility of excessive false positive findings, and failure to include measures of cognitive and academic skills. According to the reviews of the QNST-II reported in the Fourteenth Mental Measurements Yearbook (Gotts, 2001), "empirical shortcomings" continued to be noted (p. 979). In addition to acknowledging continuation of similar concerns as presented in previous reviews of the original QNST, current critiques highlight the lack of empirical validation for the weighting of subtest scores as 1 or 3, the selection of test items, determination of cutoff scores (e.g. distinguishing between moderate discrepancy and severe discrepancy), and variations among administration procedures presented using task materials. Despite these recognized weaknesses, the QNST-II continued to be considered a "promising instrument" (Gotts, 2001, pg. 981).

A factor analytic study was conducted by Finlayson and Obrzut (1993) to examine the factorial structure of the QNST-R. Five factors were found to represent 57% of the total variance. More specifically, the Palm Form Recognition task (factor loading .592), in addition to four other subtests of the QNST-R (factor loadings ranging from .514 to .678), loaded on a "tactile-kinesthetic-motor" and left-right difference" dimension (p. 7). These authors concluded that "the QNST-R demonstrates construct validity for a subtest of neuropsychological functions as originally proposed by the test authors" (p. 8-9).

Parush, Rilsky, Goldstand, Mazor-Karsnenty, and Yochman (2002) recently conducted a study to look at the reliability and validity of the QNST-II. Results of investigations into reliability found high internal consistency (α= 0.85), interrater reliability (r = 0.89), and test-retest reliabilities (r = 0.63). Discriminative validity was also found to be significant in differentiating children with and without perceptual-motor disabilities. More specifically, the QNST-II accurately identified 97% of the students with diagnosed perceptual-motor disabilities as at-risk. A factor analytic study conducted found five factors corresponding to form recognition, kinesthetic functioning, motor planning, visual and visual-motor functions, and tactile functions (Parush, Rilsky, Goldstand, Mazor-Karsnenty, and Yochman, 2002).

As indicated above, the current study utilized a variation of the Palm Form Recognition subtest from the Quick Neurological Screening Test-Second Revised Edition (Mutti, Sterling, Martin & Spalding, 1998). Whereas the QNST-II utilizes tracings of the numbers 3, 9, 5, and 7 on the right hand and the numbers 2, 8, 4, and 6 on the left hand, the current study utilized tracings of all of the numbers 2 through 9 on both hands. Additionally, on the QNST-II while the examinee is asked to present their palms face up resting on their knees, the current study required the participants to present their palms face up resting on a table. The original QNST-II directions further require that the examinee close their eyes during task administration. The current study utilized a shield to block the participants' lines of vision. Further differences exist in how the numbers are presented. For example, while the QNST-II administration requires numbers to be traced utilizing the forefinger or a pencil's eraser, the current study required all examiners to trace the numbers onto the participants' palms utilizing a stylus. While the QNST-II does suggest that examinees 8 and younger be asked to write the numbers prior to task administration so that the examiner can note any preferred number writing style, the current study required all participants to write the numbers 1 through 10 on a sheet of paper prior to task administration in order to note preferred writing style. Additionally, the variation of the Palm Form task utilized in the current study presented a modified initial introduction to the task in order to make the directions more suitable for the extraction of just one subtest from the lengthy QNST-II battery. Finally, whereas the scoring of the QNST-II involves coding errors as 1 and interpreting the sum of scores under broader categorical descriptors, the current task required examiners to code errors as – or 0, so that the raw data could be analyzed in order to answer the posited research questions.

Procedures

The researcher obtained permission from two rural school districts in South-Central Pennsylvania to allow students in 2nd, 3rd, 4th, and 5th grades to participate in the current study. Upon receiving confirmation of institutional approval, a written Informed Consent letter and subsequent Permission to Participate in Research form was sent home with all students in the 2nd, 3rd, 4th, and 5th grades of the selected elementary schools in the identified school districts (a total of approximately 1,200 students). This letter outlined the goals of the study, reviewed the methods that would be utilized, highlighted that participation was on a voluntary basis, indicated that there were no known potential negative effects of said participation, and specified that for a student to be considered for participation, all forms must be submitted to the main office of the respective school.

Upon receipt of returned permission forms, parents were contacted to participate in a brief phone interview in order to assure that their children met eligibility criteria for participation in the study. Upon verification of eligibility, each child was then randomly assigned to one of the two treatment conditions. Although participants were not excluded from the present study as a result, parents were asked to note on the Parent Permission Form if their child had ever experienced any damage to their hands directly, or to other parts of the body that may influence their hands (e.g. burns, peripheral nerve damage, prolonged exposure to cold or heat, accidents resulting in serious cuts or bruises to the hands, etc.). Parents were asked to check YES or NO. If responding YES, parents were asked to provide a brief description of the nature of such damage. This information was utilized during data analysis to determine if the performance of those children whose parents had indicated YES differed in any significant way from those children whose parents had indicated NO to this question.

During the time when the examiners were awaiting return of permission forms, all examiners were given training with the test procedures, materials, and protocol. Although it was assumed that all examiners (as practicing school psychologists) had been trained in best practices of test administration, the primary investigator reviewed with each administrator the methods and procedures for data collection as outlined herein. The examiners were trained on the standardized administration procedures for the modified Quick Neurological Screening Test-II Palm Form Recognition Task utilized in the present study (e.g. pressure to be applied when tracing numbers, speed of numeral-tracing, how to address sweaty palms/curled palms, etc.). For the purposes of verifying treatment integrity, each examiner was video-taped during five different testing sessions. The video camera was focused only on the examiners' and participants' hands. Recordings were coded alphabetically by examiner, and contained no identifying information regarding the participants. Upon completion of the study, these video recordings were reviewed by the Primary Investigator and a checklist containing critical features of standardized administration procedures was completed. See Appendix F. All videotapes were erased upon completion of the study.

With an adequate sample size having been obtained (90 total participants), the data collection phase was initiated. Testing sessions were scheduled during one, eight-hour day in one of the school districts and during four, two-hour after-school sessions in the other school district. Two examiners were present during each testing session to conduct the 5-7 minute assessments. The reader is referred to Appendix C for a sample testing schedule.

Examiners were randomly assigned to participants. Upon meeting with the participant, the examiner read and reviewed the Student Assent Form with the participant and obtained the signature of the child prior to beginning the assessment (See Appendix D). When student consent was obtained, all examiners, regardless of testing condition, placed a pencil and piece of paper in front of the child at their midline. Each testing session began with the examiner asking the participant to write the numbers one through ten on the piece of paper. As this task was completed by the participant, each examiner made note of the child's hand dominance for writing and preferred number-writing style. In accordance with the administration directions of the QNST-II, participants were given an introduction to the task to follow. This introduction was an adapted version of the suggested introduction for children under the age of 11 as presented in the QNST-II manual as follows: "I'm going to take a look at how you use your hands. This will tell me something about how you read, write, and do numbers. This won't take us long, and when we're finished, you can ask as many questions as you like. Even if what I ask you to do is hard, just try to do your very best". After this introduction, participants were then asked to extend their right arm onto the table with the palm facing up. A shield was put in place to block the child's line of vision to their extended hand. Examiner's then stated: "I'm going to write some numbers on the palm of your hand. This is the top part [touch part closest to wrist] and this is the bottom part [touch part closest to fingers]. See if you can tell me what number I'm writing. What number is this?". The question, "What number is this" was repeated with each new numeral presented. Requests for repetitions were considered as errors and the reply was, "Let's try the next one". For participants in the one-stroke format, the numbers 2-9 were traced on the palm of the hand in a predetermined randomized fashion, with all digits presented in the one-stroke format. Imperceptions were recorded as they occurred. For participants in the two-stroke format, the numbers 2-9 were traced on the palm of the hand in a predetermined randomized fashion, with the numerals 2, 3, 6, and 7 presented in the one-stroke format, and the numerals 4, 5, 8, and 9 presented in the two-stroke format. Imperceptions were recorded as they occurred. These procedures were then repeated with the left hand, with the numbers 2-9 again traced according to the participants group assignment. Following completion of evaluation, all participants were praised for their participation and were given a chance to ask as many questions as they would like. The purpose of the research procedures was simply stated to them as, "helping to figure out if kids can do better when tests are given in different ways". See Table 3 for a project Task Table. See Appendix E for a sample assessment protocol.

Table 3

Graphesthesia Assessment Research Task Table

#	Name	Description	Begin	End	Person
1	Project Idea	Examine Neuropsychology literature base and formulate research idea. Review idea with Dissertation	10-05	01-06	Doctoral Candidate, Dissertation Chairperson, Dissertation

Table 3 Continued

		Chairperson and Committee.			Committee
2	Refine Study Topic and Design	Review literature base relevant to graphesthesia assessments.	01-06	02-06	Doctoral Candidate
3	Select and Obtain Materials	Review, select, and obtain the instrument(s) to be used to measure effects of alternate number presentation formats on imperception rates.	02-06	03-06	Doctoral Candidate
4	Chapters 1, 2, and 3	Conduct an extensive literature review and draft first three chapters of dissertation using *Dissertation Guidelines* as reference.	03-06	05-06	Doctoral Candidate
5	Topic Approval Form	Draft Topic Approval Form and accompanying 20-page outline of research study to be submitted to and reviewed by Dissertation Committee; upon review and approval, submit Form to Graduate School with 2-page brief abstract of study.	05-06	7-06	Doctoral Candidate, Dissertation Committee, Graduate School
6	Institutional Review Board	Draft IRB Protocol and submit to Department Review Board; upon review and approval, submit IRB Protocol to IRB Committee for review and final approval	7-06	5-07	Doctoral Candidate, Department Review Board, Institutional Review Board
7	Research Site Approval	Meet with Superintendents, School Counselors, and Directors of Special Education (as appropriate) in order to obtain permission from two rural school districts in South-Central Pennsylvania to utilize district students in present research; obtain	1-07	4-07	Doctoral Candidate, representatives of the two rural school districts, Institutional Review Board

Table 3 Continued

Table 3 Continued

		written Research Site Approval and submit to IRB			
8	Chapter 1, 2, and 3 Dissertation Proposal Defense	Submit drafted dissertation Chapters to Dissertation Committee Chairperson for review. Complete revisions as necessary. Submit drafted dissertation Chapters to entire Committee. Complete revisions as necessary. Schedule and Complete Dissertation Proposal Defense.	5-07	3-08	Doctoral Candidate, Dissertation Committee Chairperson, Dissertation Committee
9	Participant Recruitment	With the assistance of District representatives, send out Informed Consent Letter and Permission to Participate Forms to all students in the 2nd through 5th grades of the selected elementary school in the	4-08	5-08	Doctoral Candidate, District Representative s

Table 3 Continued

		identified school districts. Conduct second mailing if necessary.			
10	Verification of Eligiblity	Parents will be interviewed via phone to determine their child's eligibility to participate in the study.	4-08	5-08	Doctoral Candidate, District Representative s
12	Staff Training	All research assistants (3) will be given training with the test procedures, materials, protocols and specific methods and procedures for data collection.	4-08	4-08	Doctoral Candidate, Research Assistants (3)
13	Scheduling and Random Assignment	Parents of eligible students will be contacted and each student will be assigned to a testing date. Student will be randomly assigned to testing condition. Parents will be	4-08	5-08	Doctoral Candidate, District Parents

Table 3 Continued

		informed of testing location and that they will be responsible for providing after-school transportation.			
13	Data Collection	Four examiners will be present to conduct the 5-7 administration of the modified QNST-II Palm Form Recognition Task; Testing sessions will be held 2 times a week for 5 weeks for a period of one-hour after school.	5-08	6-08	Doctoral Candidate, Research Assistants (3), Research Participants
14	Scoring, Data Entry, and Statistical Analysis	Score the modified QNST-II Palm Form Recognition Task protocols. Code qualitative data. Enter data into SPSS software program. Examine data to see if it meets the assumptions for analysis to be used. Run the analysis.	6-08	9-08	Doctoral Candidate
15	Chapters 4 and 5	Draft Chapters 4 and 5 of dissertation using *Dissertation Guidelines* as reference. Submit drafted Chapters to Dissertation Chairperson for review. Revise as necessary. Submit revised Chapters 4 and 5 to Dissertation Committee for review. Revise as necessary.	9-08	10-08	Doctoral Candidate, Dissertation Chairperson, Dissertation Committee
16	Dissertation Defense	Schedule with and meet with Dissertation Committee to Defend dissertation. Revise as necessary.	10-08	10-08	Doctoral Candidate, Dissertation Committee
17	Final Dissertation	Submit final Dissertation	10-08	11-08	Doctoral Candidate

Table 3 Continued

Power and Sample Size

According to Green (1991), various rules-of-thumb have been reported for defining an appropriate sample size. In a comparison of results of previous rule-of-thumb studies with power analysis, Green (1991) concluded that “some support was obtained for a rule-of-thumb that N greater than or equal to 50 + 8m for the multiple correlation and N greater than or equal to 104 + m for the partial correlation (where m is the number of predictors)” (p. 499). The current study utilized a total of 90 students. As such, it is believed that the design of the study had sufficient power (i.e. it was highly probable that the null hypothesis would be rejected, if it was false) for the multiple correlation, but not for the interpretation of the beta weights.

Statistical Analyses

Research data obtained through the administration of the modified Palm Form Recognition task of the Quick Neurological Screening Test-II was analyzed using the *Statistical Package for the Social Sciences 16.0* (SPSS 16.0). The reader is referred to Table 4 for an overview of research questions, hypotheses, variables, statistical analyses, and statistical assumptions for the current study.

Research Question 1: Do children perform better on the modified QNST-II Palm Form Recognition task when numbers are presented in a one-stroke versus a two-stroke format? It was hypothesized that participants would perform significantly better (i.e. demonstrate fewer errors) on two-stroke administration format of the modified Palm Form Recognition task versus the one-stroke administration format. Number of errors made on the modified Palm Form Recognition task was the dependent variable that will be utilized to test the hypothesis. With all statistical assumptions verified, an independent samples t-test was the statistical method utilized to evaluate differences in means between the one-stroke treatment group and the two-stroke treatment group.

Research Question 2: Do error rates vary as a function of age? It was hypothesized that error rates would vary as a function of age, such that as age increased, a trend toward decreased errors would emerge. In order to answer this question and test the hypothesis, the moderator variable of age and the dependent variable of number of errors on the modified Palm Form Recognition task were utilized. With all statistical assumptions verified, simple linear correlation (Pearson r) and nonparametric statistics (Kendall's Tau-b) were used to determine the extent to which these two variables were associated to each other.

Research Question 3: Do error rates vary as a function of sex (male and female)? It was hypothesized that there would be no difference in error rates as a function of sex (male and female). The moderator variable of sex and the dependent variable of number of errors on the modified Palm Form Recognition task were used in order to verify this hypothesis. With all statistical assumptions verified, simple linear correlation (Pearson r) and nonparametric statistics (Kendall's Tau-b, Mann-Whitney U) were used to determine the extent to which these two variables were associated to each other.

Research Question 4: Do error rates vary as a function of the correspondence between preferred number writing style and number presentation format? It was hypothesized that participants would demonstrate fewer errors when presentation format matched with preferred number writing style. Preferred Number Writing Style (one-stroke or two-stroke), as noted via observations by the examiners, and number of errors on the modified Palm Form Recognition task were the variables of interest in answering this research question. With statistical assumptions verified, Chi Square analyses was conducted to determine the presence of a relationship between these two variables

Research Question 5: Do error rates vary as a function of the interaction between age and presentation format? It was hypothesized that trends toward decreased errors as a function of age would be less significant in the two-stroke presentation format condition versus the one-stroke presentation format condition. Variables used to answer this question and test the hypothesis included age, presentation format, and errors on the modified Palm Form Recognition task. With statistical assumptions verified, multiple linear regression was the statistical procedure that was utilized to support or reject the hypothesis.

Research Question 6: Do error rates vary as a function of the interaction between preferred vs. presented number writing style and age? It was hypothesized that trends toward decreased errors when presentation format matches preferred number writing style would be more evident in younger participants (e.g. 8- and 9- year olds) than in older participants (i.e. 10-, 11-, and 12-year olds). The variables of interest for this research question and subsequent hypothesis were age, Preferred Number Writing Style, Presentation Format, and errors on the modified Palm Form Recognition task. With statistical assumptiosn verified, multiple linear regression was the statistical procedure that was utilized to support or reject the hypothesis.

Table 4

Research Questions, Hypotheses, Variables, Statistical Analyses, and Statistical Assumptions for the Graphesthesia Assessment Project

Research Questions	Hypotheses	Variables	Statistic	Assumptions	Assumptions Appropriateness
1. Is there a difference in performance on the modified QNST-II Palm Form Recognition task when numbers are presented in a one-stroke versus a two-stroke format?	Participants will perform significantly better (i.e. demonstrate fewer errors) on two-stroke administration format of the modified Palm Form Recognition task versus the one-stroke administration format	Presentation Format; Errors on the modified QNST-II Palm Form Recognition Task	t-test for independent samples	1. Interval or Ratio data, 2. Normality for each group 3. Equal variances for groups 4. Sample size	1. Examine the instrument 2. Histogram with a normal curve 3. Descriptive Statistics 4. ”Rules of Thumb”
2. Do error rates vary as a function of age?	Error rates will vary as a function of age, such that as age increases, a trend toward decreased errors will emerge	Age and Errors on the modified QNST-II Palm Form Recognition Task	Pearson correlation; Kendall’s Tau-b	1. Interval or Ratio data 2. Residual normality for each X value 3. Residuals equal variance for each X value 4. Linearity	1. Examine the instrument 2. Examine a plot of the residuals 3. Visual inspection of a scattergram 4. Visual inspection of a scattergram
3. Do error rates vary as a	There will be no difference in	Sex (male and female) and	Pearson correlation;	1. Interval or Ratio data	1. Examine the instrument

Table 4 Continued

function of sex (male and female)?	error rates as a function of sex (male and female)	Errors on the modified QNST-II Palm Form Recognition Task	Kendall's Tau-b; Mann Whitney U	2. Residual normality for each X value 3. Residuals equal variance for each X value 4. Linearity	2. Examine a plot of the residuals 3. Visual inspection of a scattergram 4. Visual inspection of a scattergram
4. Do error rates vary as a function of the correspondence between preferred number writing style and number presentation format	Participants will demonstrate fewer errors when presentation format matches with preferred number writing style	Preferred Number Writing Style; Presentation Format and Errors on the modified QNST-II Palm Form Recognition Task	Chi Square	1. Independently sampled scores 2. Reasonably large N 3. Represent-ativeness of the population 4. Contribution of each participant to one cell only	1. Examine the instrument 2. Examiner the sample 3. Visual Inspection of cell frequencies
5. Do error rates vary as a function of the interaction between age and presentation format	Trends toward decreased errors as a function of age will be less significant in the two-stroke presentation format condition versus the one-stroke presentation	Age, Presentation Format, and Errors on the modified QNST-II Palm Form Recognition Task	Multiple Linear Regression	1. Interval or Ratio data 2. Residual normality for each X value 3. Residuals equal variance for each X value 4. Linearity 5. Non-multi-	1. Examine the instrument 2. Examine a plot of the residuals 3. Visual inspection of a scattergram 4. Visual inspection of a scattergram

Table 4 Continued

	format condition			collinearity	5. Examine Variance Inflation Factor (SPSS) or run cor-relations among variables and look for high bivariate correlations
6. Do error rates vary as a function of the interaction between preferred vs. presented number writing style and age?	Trends toward decreased errors when presentation format matches preferred number writing style will be more evident in younger participants	Age, Preferred Number Writing Style, Presentation Format, and Errors on the modified QNST-II Palm Form Recognition Task	Multiple Linear Regression	1. Interval or Ratio data 2. Residual normality for each X value 3. Residuals equal variance for each X value 4. Linearity 5. Non-multi-collinearity	1. Examine the instrument 2. Examine a plot of the residuals 3. Visual inspection of a scattergram 4. Visual inspection of a scattergram 5. Examine Variance Inflation Factor (SPSS) or run cor-relations among variables and look for high bivariate correlations

Summary

The sample for the current study consisted of 90 students, ages 8 through 12 from the 2nd, 3rd, 4th, and 5th grades of two rural school districts in South Central Pennsylvania. Parent-volunteered students meeting eligibility criteria for inclusion in this study were administered a modified version of the Palm Form Recognition task of the Quick Neurological Screening Test-II by trained examiners. Students were randomly assigned to a treatment condition, whereby they either received the numbers presented in a one-stroke format or a two-stroke format. The dependent variable was the number of errors made on the task.

The data obtained from task administration were analyzed to examine the overall effects of altered presentation formats, as well as the influence of moderating variables including preferred number writing style, age, and sex.

CHAPTER IV

RESULTS OF THE STUDY

This chapter presents the results obtained from the experimental research in which the effects of alternate number presentation formats on children's performance on a modified version of the QNST-II Palm Form Recognition task were measured. Specifically, outcomes related to differences in error rates when considering the independent variable of the number presentation format and the moderator variables of preferred number writing style, developmental status (age), and sex (male and female) will be discussed. Additional qualitative analyses addressing the issues of treatment integrity are reviewed.

Data Analyses of the Research Questions

In order to analyze the data, the *Statistical Package for the Social Sciences 16.0* (SPSS 16.0) was utilized. This statistical analysis software program is frequently used in educational psychology research, provides numerical and visual displays of data, is easily accessible by the researcher, and allows for a range of analyses to be run on the same data.

Hand Damage and Error Rates

Although participants were not excluded from the present study as a result, parents were asked to note on the Parent Permission Form if their child had ever experienced any damage to their hands directly, or to other parts of the body that may influence their hands (e.g. burns, peripheral nerve damage, prolonged exposure to cold or heat, accidents resulting in serious cuts or bruises to the hands, etc.). Parents were asked to check YES or NO. If responding YES, parents were asked to provide a brief description of the nature of such damage. This information was utilized during data analysis to determine if the performance of those children whose parents had indicated YES differed in any significant way from those children whose parents had indicated NO to this question.

Out of 90 total participants in the study, two participants were identified as having hand damage. One of these participants had reportedly experienced a burn to their right hand; the other child had reportedly experienced a left elbow laceration with resultant nerve damage. Error patterns were inspected in order to detect significant deviation in the performance of participants identified as having experienced hand damage and the performance of participants identified as having not experienced hand damage. These results are reported in Table 5 and Table 6. There does not appear to be reason to exclude participants having experienced hand damage from subsequent data analyses, because their error rates do not deviate significantly from the error rates of the participants who have not experienced hand damage.

Table 5

Left-Handed Total Errors of Participants With and Without Hand Damage

	Total Errors with Numbers Presented to Left Hand							
	0	1	2	3	4	5	6	Total
No Hand Damage	10	26	21	6	9	11	5	88
Hand Damage	0	0	0	0	1	0	1	2

Table 6

Right-Handed Total Errors of Participants With and Without Hand Damage

	Total Errors with Numbers Presented to Right Hand								
	0	1	2	3	4	5	6	7	Total
No Hand Damage	5	14	21	17	13	11	6	1	88
Hand Damage	0	0	0	1	1	0	0	0	2

Error Rates and Number Presentation Format

The primary intent of the current study was to determine if children perform better when numbers are presented in a one-stroke versus a two-stroke format. It was hypothesized that participants would perform significantly better (i.e. demonstrate fewer errors) on the two-stroke administration format of the modified Palm Form Recognition task versus the one-stroke administration format. In order to answer this research question, normality of the data was confirmed utilizing visual inspection of the distribution of the data via histograms with a normal curve. There were no significant deviations from normality. Descriptive statistics and Levene's test were used in order to check for equal variances for the groups. For the Levene's test, F= <.001, p=.989. Since the p-value is greater than alpha (0.05), the variances are assumed equal. These results are reported in Tables 7 and 8.

With all statistical assumptions verified and sample size deemed appropriate according to Borg and Gall (1989) rule-of-thumb research, differences between the mean errors of the one-stroke and two-stroke treatment groups were analyzed utilizing an independent samples t-test. No significant differences in total errors were noted between the one-stroke treatment group and the two-stroke treatment group (t(178) = -

.880, p = .380). Table 9 illustrates the results of the independent samples t-test.

Table 7

Means, Standard Deviations, and Standard Error of the Means for Total Errors in the One-Stroke versus Two-Stroke Treatment Condition

	n	Mean	S.D.	Std. Error Mean
Total Errors One-Stroke Condition	90	2.56	1.730	.182
Total Errors Two-Stroke Condition	90	2.79	1.827	.193

Table 8

Levene's Test for Equality of Variances

	F	Sig.
Total Errors	<.001	.989

Table 9

Independent Samples t-Test for Total Errors in the One-Stroke versus Two-Stroke Treatment Condition

	t	df	Sig (2-tailed)	Mean Difference	Standard Error Difference
Total Errors	-.880	178	.380	-.233	.265

Additional analyses were conducted to see if any differences between treatment groups emerged when total errors were split into right hand errors and left hand errors. Again, normality of the data was confirmed utilizing visual inspection of the distribution of the data via histograms with a normal curve. There were no significant deviations from normality. Descriptive statistics and Levene's test were used in order to check for equal variances for the groups. For the Levene's test, F=.620, p=.432 on the right hand and F=.261, p=.610 on the left hand. Since the p-value is greater than alpha (0.05), the variances are assumed equal. These results are reported in Tables 10 and 11.

Having verified all statistical assumptions, differences between the mean errors of the one-stroke and two-stroke treatment groups were analyzed by running separate independent samples t-tests. No significant differences in errors were noted for numbers presented to the right hand in one- versus two-strokes (t(178) = -1.181, p= .239) or for numbers presented to the left hand in one- versus two-strokes (t(178) = -.352, p= .725). Table 12 highlights the results of the independent samples t-tests.

Table 10

Means, Standard Deviations, Standard Error of the Means, and Range for Total Errors on the Right and Left Hands using One- or Two-Stroke Number Presentation Formats

	n	Mean	S.D.	Std. Error Mean	Range
Right Hand					
One-Stroke	90	1.38	.978	.103	0-3
Two-Stroke	90	1.56	1.040	.110	0-4
Left Hand					
One-Stroke	90	1.18	1.097	.116	0-4
Two-Stroke	90	1.23	1.017	.107	0-3

Table 11

Levene's Test for Equality of Variances

	F	Sig.
Right-Hand	.620	.432
Left-Hand	.261	.610

Table 12

Independent Samples T-Tests for One-Stroke versus Two-Stroke Number Presentation Formats on the Right and Left Hands

	t	df	Sig (2-tailed)	Mean Difference	Standard Error Difference
Right Hand One-Stroke vs. Two-Stroke	-1.181	178	.239	-1.78	.150
Left Hand One-Stroke vs. Two-Stroke	-.352	178	.725	-.056	.158

Error Rates and Age

The second research question was "Do error rates vary as a function of age?" It was hypothesized that error rates would vary as a function of age, such that as age increases, a trend toward decreased errors would emerge. Statistical assumptions of normality, equal variances of residuals, and linearity were verified through examination of plots and scattergrams. The data were analyzed with Pearson correlation. A significant negative correlation was found to exist between age and total errors, such that as age increased errors decreased. These findings are reported in Figure 6 and Table 13.

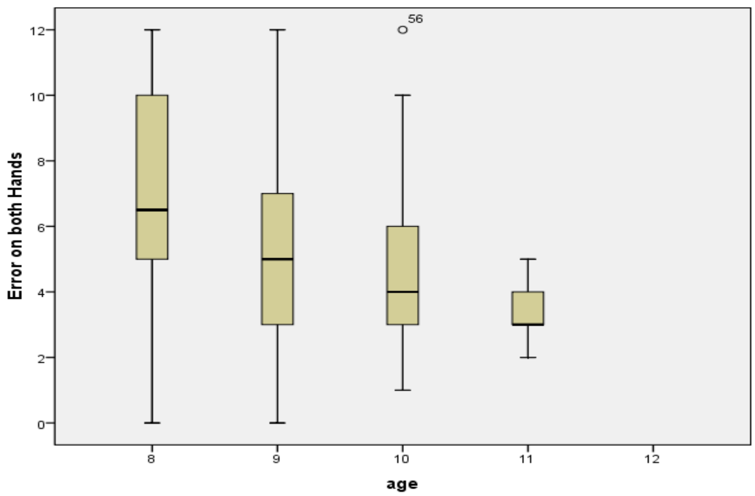

Figure 6: Analysis of total errors by age.

Table 13

Pearson Correlation for Age and Total Errors

		Age	Total Errors
Age	Pearson Correlation	1.000	-.286***
	Sig. (2-tailed)		.006
	N	90	90
Total Errors	Pearson Correlation	-.286***	1.000
	Sig. (2-tailed)	.006	
	N	90	90

***Correlation is significant at the 0.01 level (2-tailed)

Additional analyses were conducted to see if performance varied by age when total errors were split into right hand errors and left hand errors. In order to verify the assumptions necessary to run the correlational analyses, residuals for age and errors were inspected for normality using the Kolmogorov-Smirnov and Shapiro-Wilk tests of normality. Results of these tests are reported in Table 14. In general, the residuals for Total Errors with the Right Hand were found to be normally distributed at all age-groups, but the Total Errors with the Left Hand were not found to be normally distributed at any age group.

The residuals for age and errors on the modified Palm Form Recognition Task were further examined in order to verify the assumption of equal variances. The data were fit to detrended probability plots and inspected for patterns. Visual inspection suggested relatively equal variance. Further analysis of assumptions led to investigation of scattergrams to determine linearity, which did not appear to exist for either the right hand or the left hand.

Table 14

Tests of Normality for Age and Errors on the Modified Palm Form Recognition Task

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Age	Statistic	df	Sig.	Statistic	df	Sig.
Total Errors with the Right Hand	8	.142	30	.125	.961	30	.335
	9	.149	26	.145	.935	26	.099
	10	.177	19	.120	.944	19	.305
	11	.214	14	.081	.934	14	.346
Total Errors with the Left Hand	8	.231	30	.000	.880	30	.003
	9	.218	26	.003	.905	26	.020
	10	.289	19	.000	.798	19	.001
	11	.245	14	.023	.870	14	.042

a. Lilliefors Significance Correction
b. Total Errors with the Right Hand is constant when age = 12. It has been omitted.
c. Total Errors with the Left Hand is constant when age = 12. It has been omitted.

Since the assumptions of linearity and normality had been rejected, Pearson correlations could not be run. Kendall’s Tau-b, a nonparametric statistic, was used to measure the degree and significance of the correspondence between age and errors, when total errors were split into right hand errors and left hand errors. With age and right-handed error, the correlation was not significant since the p-value = 0.084, which is greater than alpha level 0.05. With age and left-handed error, the correlation was found to be significant since the p-value = 0.006, which is less than the alpha level of 0.05. The correlation coefficient is r = -0.237. These findings are highlighted in Tables 15 and 16.

Table 15

Kendall's Tau-b Correlation for Age and Total Errors on the Right Hand

		Age	Total Errors on the Right Hand
Age	Correlation Coefficient	1.000	-.148
	Sig. (2-tailed)	.	.084
	N	90	90
Total Errors on the Right Hand	Correlation Coefficient	-.148	1.000
	Sig. (2-tailed)	.084	.
	N	90	90

Table 16

Kendall's Tau-b Correlation for Age and Total Errors on the Left Hand

		Age	Total Errors on the Left Hand
Age	Correlation Coefficient	1.000	-.237**
	Sig. (2-tailed)	.	.006
	N	90	90
Total Errors on the Left Hand	Correlation Coefficient	-.237**	1.000
	Sig. (2-tailed)	.006	.
	N	90	90

**. Correlation is significant at the 0.01 level (2-tailed).

Error Rates and Sex

The third research question was "Do error rates vary as a function of sex?" It was hypothesized that there would be no difference in error rates as a function of sex. Statistical assumptions of normality, equal variances of residuals, and linearity were verified through examination of plots and scattergrams. The data were analyzed with Pearson correlation. No significant correlation was found to exist between sex and total errors, since the p-value is greater than alpha (0.05). These findings are reported in Figure 7 and Table 17.

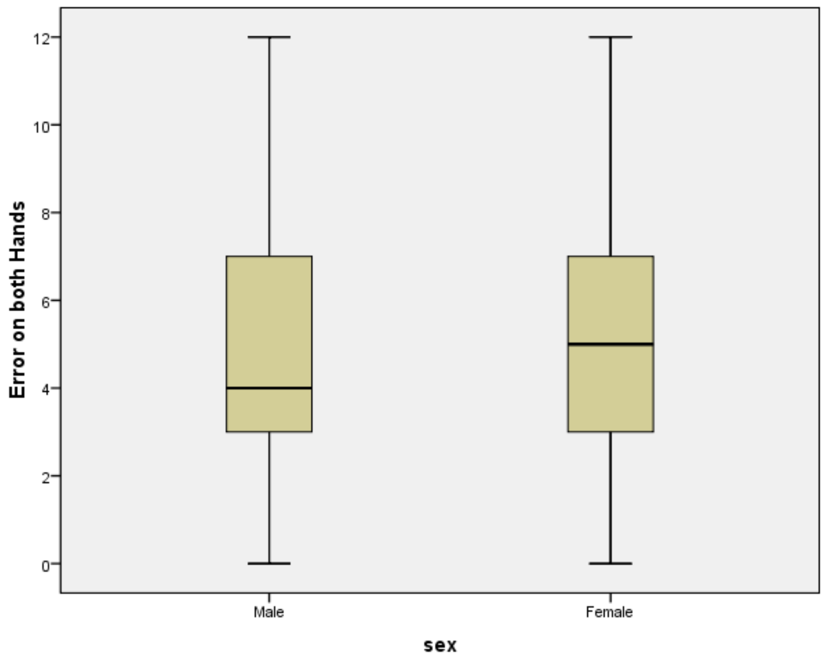

Figure 7: Analysis of total errors by sex.

Table 17

Pearson Correlation for Sex and Total Errors

		Sex	Total Errors
Sex	Pearson Correlation	1.000	.004
	Sig. (2-tailed)		.973
	N	90	90
Total Errors	Pearson Correlation	.004	1.000
	Sig. (2-tailed)	.973	
	N	90	90

Additional analyses were conducted to see if performance varied by sex when total errors were split into right hand errors and left hand errors. Residuals for sex and errors were inspected for normality using the Kolmogorov-Smirnov and Shapiro-Wilk tests of normality. Results of these tests are reported in Table 18. In general, normality was found to not exist for all four groups (Right-Handed Error Male/Female and Left-Handed Error Male/Female).

Table 18

Tests of Normality for Sex and Errors on the Modified Palm Form Recognition Task

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Sex	Statistic	df	Sig.	Statistic	df	Sig.
Total Errors with the Right Hand	Male	.183	45	.001	.943	45	.029
	Female	.150	45	.013	.941	45	.024
Total Errors with the Left Hand	Male	.261	45	.000	.850	45	.000
	Female	.252	45	.000	.904	45	.001

a. Lilliefors Significance Correction

The residuals for sex and errors on the modified Palm Form Recognition task were further examined in order to verify the assumption of equal variances. The data were fit to detrended probability plots and inspected for patterns. No discernable pattern was noted. Visual inspection suggested that the variances for the residuals were not equal. Further analysis of assumptions led to investigation of scattergrams to determine linearity, which did not appear to exist.

With the assumptions of normality, equal variance of residuals, and linearity violated, Pearson correlation calculations were not calculated. Kendall’s Tau-b, a nonparametric statistic, was used to measure the degree and significance of the correspondence between sex and errors, when total errors were split into right hand errors and left hand errors. With sex and right-handed error, the correlation was not significant since the p-value = 0.233, which is greater than alpha level 0.05. With sex and left-handed error, the correlation was not significant since the p-value = 0.078, which is greater than alpha level 0.05. These results are highlighted in Tables 19 and 20.

Table 19

Kendall's Tau-b Correlation for Sex and Total Errors on the Right Hand

		Sex	Total Errors on the Right Hand
Sex	Correlation Coefficient	1.000	-.111
	Sig. (2-tailed)	.	.233
	N	90	90
Total Errors on the Right Hand	Correlation Coefficient	-.111	1.000
	Sig. (2-tailed)	.233	.
	N	90	90

Table 20

Kendall's Tau-b Correlation for Sex and Total Errors on the Left Hand

		Sex	Total Errors on the Left Hand
Sex	Correlation Coefficient	1.000	.166
	Sig. (2-tailed)	.	.078
	N	90	90
Total Errors on the Left Hand	Correlation Coefficient	.166	1.000
	Sig. (2-tailed)	.078	.
	N	90	90

These findings were further confirmed when data were analyzed using the Mann-Whitney U Test. With sex as the grouping variable, no significant difference was found between males and females with respect to right-handed error since the p-value = 0.233, which is greater than alpha level 0.05. With sex as the grouping variable, no significant difference was found between males and females with respect to left-handed error since the p-value = 0.078. See Tables 21, 22, and 23.

Table 21

Descriptive Statistics for Mann-Whitney U Test

	N	Mean	Std. Deviation	Minimum	Maximum
Total Errors with the Right Hand	90	2.93	1.675	0	7
Total Errors with the Left Hand	90	2.41	1.811	0	6
Sex	90				

Table 22

Ranks for Mann-Whitney U Test

	Sex	N	Mean Rank	Sum of Ranks
Total Errors with the Right Hand	Male	45	48.73	2193.00
	Female	45	42.27	1902.00
	Total	90		
Total Errors with the Left Hand	Male	45	40.74	1833.50
	Female	45	50.26	2261.50
	Total	90		

Table 23

Test Statistics[a] for Mann-Whitney U Test

	Total Errors with the Right Hand	Total Errors with the Left Hand
Mann-Whitney U	867.000	798.500
Wilcoxon W	1902.000	1833.500
Z	-1.192	-1.764
Asymp. Sig. (2-tailed)	.233	.078

a. Grouping Variable: Sex

Error Rates and Match Between Preferred- and Presented- Number Writing Style

The fourth research question was "Do error rates vary as a function of the correspondence between preferred number writing style and number presentation format". It was hypothesized that participants would demonstrate fewer errors when presentation format matched with preferred number writing style. The frequency distribution of the relevant data is reported in Table 24. In order to utilize Chi-Square analyses to determine the presence of a relationship between error rates and match between preferred- and presented- number writing style, data were combined into groups representing range of errors for the numbers 4, 5, 8, and 9 (0-2, 3-4, or 5-7) and range of matches for 4, 5, 8, and 9 (0-2 or 3-4). Based upon the results of the analyses, no significant relationship was found (p-value = .983, which is greater than alpha level 0.05). See Table 25.

Table 24

Frequency Distribution for Total Errors on 4, 5, 8, and 9 by Number of Matches between Presented- and Preferred- Number Writing Style on 4, 5, 8, and 9

		Total Errors on the Numbers 4, 5, 8 and 9								
		0	1	2	3	4	5	6	7	Total
Total Matches on the Numbers 4, 5, 8 and 9	0	0	1	0	0	0	0	0	0	1
	1	1	2	5	6	5	2	2	0	23
	2	5	6	9	9	2	2	5	1	39
	3	5	3	5	4	3	2	3	0	25
	4	0	0	0	2	0	0	0	0	2
	Total	11	12	19	21	10	6	10	1	90

Table 25

Chi Square Test for Range of Errors on 4, 5, 8, and 9 by Range of Matches between Presented- and Preferred- Number Writing Style on 4, 5, 8, and 9

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	.035[a]	2	.983
Likelihood Ratio	.035	2	.983
Linear-by-Linear Association	.023	1	.880
N of Valid Cases	90		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 5.10.

Further analyses were conducted to determine if total errors on the individual numbers of 4, 5, 8, and 9 were related to the match between preferred- and presented- number writing style. Chi Square analyses were run for the individual numbers 4, 5, 8, and 9. In order to meet the minimum cell count requirement to run Chi Square analyses, data were combined on the individual number 8 into range of errors (0 or 1-2). Results of these analyses are presented in Tables 26, 27, 28, and 29. Although no significant relationship was noted between errors and the match between preferred- and presented- number writing style on the numbers 5 (p-value = 0.136, which is greater than alpha level 0.05), 8 (p-value = 0.454, which is greater than alpha level 0.05), and 9 (p-value = 0.545, which is greater than alpha level 0.05), there was a significant difference between variables that exceeded the probability of chance for total errors on 4 as a result of the match or mismatch between preferred- and presented- number writing styles.

Table 26

Chi Square Test for Total Errors on 4 by Match Between Preferred- and Presented-Number Writing Style on 4

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	9.239[a]	2	.010
Likelihood Ratio	9.468	2	.009
Linear-by-Linear Association	.017	1	.897
N of Valid Cases	90		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 10.73.

Table 27

Chi Square Test for Total Errors on 5 by Match Between Preferred- and Presented-Number Writing Style on 5

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	3.991[a]	2	.136
Likelihood Ratio	4.034	2	.133
Linear-by-Linear Association	3.126	1	.077
N of Valid Cases	90		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 14.00.

Table 28

Chi Square Test for Total Errors on 8 by Match Between Preferred- and Presented-Number Writing Style on 8

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.560[a]	1	.454		
Continuity Correction	.223	1	.637		
Likelihood Ratio	.560	1	.454		
Fisher's Exact Test				.583	.583
Linear-by-Linear Association	.554	1	.457		
N of Valid Cases	90				

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 7.64.

Table 29

Chi Square Test for Total Errors on 9 by Match Between Preferred- and Presented-Number Writing Style on 9

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	1.214[a]	2	.545
Likelihood Ratio	1.208	2	.546
Linear-by-Linear Association	.061	1	.805
N of Valid Cases	90		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 6.67.

Error Rates, Age, and Presentation Format

The fifth research question was “Do error rates vary as a function of the interaction between age and presentation format?”. It was hypothesized that trends toward decreased errors as a function of age would be less significant in the two-stroke presentation format condition versus the one-stroke presentation format condition. Since the stated question involved only one dependent variable, linear regression was utilized to conduct the analyses. The dependent variable, total errors, was combined into three groups: 0-3 errors, 4-6 errors, and 7-12 errors. For the purposes of these analyses, age groups of 11-years old and 12-years old were combined, since there was only one participant 12-years of age. The data were separated into One-Stroke Presentation Format versus Two-Stroke Presentation Format. The assumptions of normality, equal variances, and linearity were confirmed.

With the analyses run on the One-Stroke Presentation Format, the correlation between age and total errors was -0.338. The coefficient of determination was 0.094. The p-value was 0.022, which is less than alpha (0.05), so the regression model was found to be significant. Please refer to Tables 30, 31, 32, 33, and 34.

Table 30

Means and Standard Deviations for Error Rates and Age on One-Stroke Presentation Format

	n	Mean	S.D.
Total Errors on PFR	46	1.9	0.8
Age	46	2.2	1.1

Table 31

Correlation Matrix for Error Rates and Age on One-Stroke Presentation Format

		Total Errors on PFR	Age
Pearson Correlation	Total Errors on PFR	1.000	-.338
	Age	-.338	1.000
Sig. (1-tailed)	Total Errors on PFR		.011
	Age	.011	
N	Total Errors on PFR	46	46
	Age	46	46

Table 32

Linear Regression Fit of Model for Error Rates and Age on One-Stroke Presentation Format

R	R Square	Adjusted R Square	Std. Error of the Estimate
.338	.114	.094	.72990

Table 33

Analysis of Variance for Error Rates and Age on One-Stroke Presentation Format

	Sum of Squares	df	Mean Square	F	Sig.
Regression	3.015	1	3.015	5.660	.022
Residual	23.441	44	.533		
Total	26.457	45			

Table 34

Variables in the Equation for Error Rates and Age on One-Stroke Presentation Format

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	2.419	.246		9.816	.000
	Age	-.236	.099	-.338	-2.379	.022

With the analyses run on the Two-Stroke Presentation Format, the correlation between age and total errors was -0.257. The coefficient of determination was 0.044. The p-value was 0.092 which is greater than alpha (0.05), so the regression model was found not to be significant. Please refer to Tables 35, 36, 37, 38, and 39.

Table 35

Means and Standard Deviations for Error Rates and Age on Two-Stroke Presentation Format

	n	Mean	S.D.
Total Errors on PFR	44	2.0227	.84876
Age	44	2.1818	1.08419

Table 36

Correlation Matrix for Error Rates and Age on Two-Stroke Presentation Format

		Total Errors on PFR	Age
Pearson Correlation	Total Errors on PFR	1.000	-.257
	Age	-.257	1.000
Sig. (1-tailed)	Total Errors on PFR		.046
	Age	.046	
N	Total Errors on PFR	44	44
	Age	44	44

Table 37

Linear Regression Fit of Model for Error Rates and Age on Two-Stroke Presentation Format

R	R Square	Adjusted R Square	Std. Error of the Estimate
.257	.066	.044	.82989

Table 38

Analysis of Variance for Error Rates and Age on Two-Stroke Presentation Format

	Sum of Squares	df	Mean Square	F	Sig.
Regression	2.051	1	2.051	2.978	.092
Residual	28.926	42	.689		
Total	30.977	43			

Table 39

Variables in the Equation for Error Rates and Age on Two-Stroke Presentation Format

		Unstandardized Coefficients		Standardized Coefficients		
Model		B	Std. Error	Beta	t	Sig.
1	(Constant)	2.462	.284		8.677	.000
	Age	-.201	.117	-.257	-1.726	.092

Error Rates, Age, and Match Between Preferred- and Presented- Number Writing Style

The sixth research question was “Do error rates vary as a function of the interaction between preferred vs. presented number writing style and age?”. It was hypothesized that trends toward decreased errors when presentation format matches preferred number writing style would be more evident in younger participants (e.g. 8-

and 9- year olds) than in older participants (i.e. 10-, 11-, and 12-year olds). Since the stated question involved only one dependent variable, linear regression was utilized to conduct the analyses. The dependent variable, total errors, was combined into three groups: 0-3 errors, 4-6 errors, and 7-12 errors. For the purposes of these analyses, age groups of 11-years old and 12-years old were combined, since there was only one participant 12-years of age. The data were separated into Match between Preferred- and Presented-Number Writing Style for each individual number 4, 5, 8, and 9 and No Match between Preferred- and Presented-Number Writing Style for each individual number 4, 5, 8, and 9. The assumptions of normality, equal variances, and linearity were confirmed.

With the analyses run on the individual number 4, the regression model was found to be non-significant under both the Match condition (p-value = .060, which is greater than alpha 0.05) and No Match condition (p-value = .208, which is greater than alpha 0.05). With the analyses run on the individual number 5, the regression model was found to be significant under the Match condition (p-value = .003, which is less than alpha 0.05), but insignificant under the No Match condition (p-value = .955, which is greater than alpha 0.05). The regression model found to be significant under the Match condition for the individual number 5 is reported in Tables 40, 41, 42, 43, and 44.

Table 40

Means and Standard Deviations for Error Rates and Age in the Match Condition for the Individual Number 5

	n	Mean	S.D.
Total Errors on PFR	45	2.0	0.8
Age	45	1.3	0.5

Table 41

Correlation Matrix for Error Rates and Age in the Match Condition for Individual Number 5

		Total Errors on PFR	Age
Pearson Correlation	Total Errors on PFR	1.000	-.439
	Age	-.439	1.000
Sig. (1-tailed)	Total Errors on PFR		.046
	Age	.001	
N	Total Errors on PFR	45	45
	Age	45	45

Table 42

Linear Regression Fit of Model for Error Rates and Age in the Match Condition for Individual Number 5

R	R Square	Adjusted R Square	Std. Error of the Estimate
.439	.193	.174	.72390

Table 43

Analysis of Variance for Error Rates and Age in the Match Condition for Individual Number 5

	Sum of Squares	df	Mean Square	F	Sig.
Regression	5.378	1	5.378	10.262	.003
Residual	22.533	43	.524		
Total	27.911	44			

Table 44

Variables in the Equation for Error Rates and Age in the Match Condition for Individual Number 5

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	2.933	.324		9.061	.000
	Age	-.733	.229	-.439	-3.203	.003

For the individual number 8, the slope for the linear regression run for the Match condition was insignificant (p-value = .473, which is greater than alpha 0.05), while the slope for the linear regression run for the No Match condition was significant (p-value = .037, which is less than alpha 0.05). The regression model found to be significant for the No Match condition for the individual number 8 is reported in Tables 45, 46, 47, 48, and 49.

Table 45

Means and Standard Deviations for Error Rates and Age in the No Match Condition for the Individual Number 8

	n	Mean	S.D.
Total Errors on PFR	43	2.0	0.9
Age	43	1.4	0.5

Table 46

Correlation Matrix for Error Rates and Age in the No Match Condition for Individual Number 8

		Total Errors on PFR	Age
Pearson Correlation	Total Errors on PFR	1.000	-.319
	Age	-.319	1.000
Sig. (1-tailed)	Total Errors on PFR		.019
	Age	.019	
N	Total Errors on PFR	43	43
	Age	43	43

Table 47

Linear Regression Fit of Model for Error Rates and Age in the No Match Condition for Individual Number 8

R	R Square	Adjusted R Square	Std. Error of the Estimate
.319	.102	.080	.82379

Table 48

Analysis of Variance for Error Rates and Age in the No Match Condition for Individual Number 8

	Sum of Squares	df	Mean Square	F	Sig.
Regression	3.153	1	3.153	4.646	.037
Residual	27.824	41	.679		
Total	30.977	42			

Table 49

Variables in the Equation for Error Rates and Age in the No Match Condition for Individual Number 8

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	2.745	.378		7.261	.000
	Age	-.560	.260	-.319	-2.155	.037

Finally, for the analyses run on the individual number 9, the regression model was found to be non-significant under both the Match condition (p-value = 0.51, which is greater than alpha 0.05) and the No Match condition (p-value = .393, which is greater than alpha 0.05).

Treatment Integrity

For the purposes of verifying treatment integrity, each examiner was video-taped during five different test administrations. The video camera was focused only on the examiner’s and participant’s hands. Recordings were coded alphabetically by examiner (A, B, C, and D), and contained no identifying information regarding the participants. Upon completion of the study, these video recordings were reviewed by the Primary Investigator and a checklist containing critical features of standardized administration procedures was completed. See Appendix F.

Qualitative analyses of the completed checklists indicate that the examiners carried out the research task with a mean accuracy rate of 93.13%. The percentage of accuracy of each recorded test administration is outlined by examiner in Table 50. The random sampling of examiner performance suggested that the examiners carried out the majority of administration requirements without error. Further analysis revealed errors only on checklist items 4, 6, 9, 13, 14, and 16, as detailed in Table 51.

Table 50

Percentage of Accuracy of Recorded Test Administrations by Examiner

	Administration					
	1	2	3	4	5	Mean
Examiner A	87.50	93.75	75.00	87.50	87.50	86.25
Examiner B	93.75	93.75	100.00	100.00	100.00	97.50
Examiner C	100.00	100.00	100.00	93.75	100.00	98.75
Examiner D	75.00	93.75	87.50	93.75	100.00	90.00

Table 51

Frequency Distribution of Examiner Error by Item Number

Item Number	Examiner A	Examiner B	Examiner C	Examiner D	Total
1	0	0	0	0	0
2	0	0	0	0	0
3	0	0	0	0	0
4	2	0	1	1	4
5	0	0	0	0	0
6	0	0	0	3	3
7	0	0	0	0	0
8	0	0	0	0	0
9	1	1	0	1	3
10	0	0	0	0	0
11	0	0	0	0	0
12	0	0	0	0	0
13	3	0	0	0	3
14	1	0	0	0	1
15	0	1	0	3	4
16	4	0	0	0	4
Total	11	2	1	8	22

Summary

This chapter has presented the data obtained from the experimental research in which the effects of alternate number presentation formats on children’s performance on a modified version of the QNST-II Palm Form Recognition task were measured. The complications of this study were discussed, including test administration variations due to uncontrollable factors such as student characteristics and environmental circumstances, examiner difficulty navigating the protocol, parent response to exclusionary criteria, and logistical complications of scheduling testing sessions.

Results of statistical analyses revealed no significant differences between the number of errors on the modified Palm Form Recognition task as a result of treatment condition (one-stroke vs. two-stroke). Age effects were confirmed statistically, indicating that errors decreased as age increased, regardless of treatment condition. Confirming previous research, no significant correlation was found to exist between sex and total errors on the modified Palm Form Recognition task. When assessing the moderating role of the match between preferred- and presented- number writing style for the numbers 4, 5, 8, and 9, no significant relationship was found collectively. However, further analyses of individual numbers 4, 5, 8, and 9 revealed a significant difference between variables that exceeded the probability of chance for total errors on 4 as a result of the match or mismatch between preferred- and presented- number writing style on 4.

Finally, with regard to the multi-variable relationships of age/error rate/presentation format and age/error rate/match between preferred- and presented- number writing style, linear regression analyses revealed statistically significant, but clinically non-meaningful predictions between 1.) age and total errors under the one-stroke treatment condition, 2.) age, total errors, and match between preferred- and presented number writing style on 5, and 3.) age, total errors, and no match between preferred- and presented number writing style on 8.

The chapter concluded with a qualitative analysis of the treatment integrity checklist completed by the Primary Investigator.

CHAPTER V

A DISCUSSION OF THE STUDY

The chapter to follow presents a discussion of the results. This discussion is structured according to individual research questions, hypotheses, and findings. Results are interpreted in the context of previous research findings. Practical implications and limitations of the present study, as well as directions for future research, are presented.

The knowledge base regarding the sense of touch is limited in comparison to that of the other sensory functions, primarily due to a historical lack of appropriate assessment procedures and techniques. Tactile assessments that have been developed have demonstrated questionable psychometric properties. For example, the Finger Tip Number Writing task from the Halstead-Reitan Reitan-Klove Sensory Perceptual Examination has been found to produce variable outcomes as a function of age and whether numbers are traced using two strokes rather than just one stroke (Casey & Rourke, 1992; Santa Maria, Pinkston, Browndyke, & Gouvier, 1997). In addition, researchers have failed to address whether performance on this measure is enhanced when examinees are presented with their preferred number writing style versus the examiner’s method for number writing.

Despite these flaws, authors of the Quick Neurological Screening Test have incorporated a similar graphesthesia assessment, the Palm Form Recognition task, into the original and subsequent revised editions. While the test authors claim that this instrument is an efficient and reliable way to screen for neurological dysfunction, it is evident that the lack of standardization in components of the test protocol could result in variable error rates.

Standardization enables examiners to make valid comparisons between the performances of individually obtained test scores and those of the norm group and is espoused by national educational and psychological associations. In the fields of school psychology and neuropsychology, it is imperative that standardization procedures are strictly adhered to in order to obtain a valid picture of individual functioning, accurate interpretation of data, and valid recommendations for remediation.

This study investigated the effects of alternate number presentation formats on children's performance on a modified version of the QNST-II Palm Form Recognition task. Specifically, differences in error rates were examined when considering the independent variable of number presentation format and the moderator variables of preferred number writing style, developmental status (age), and sex (male and female).

Error Rates and Number Presentation Format

The primary intention of the current study was to determine the effects of alternate number presentation on children's performance on a modified version of the QNST-II Palm Form Recognition task. The following research question was presented: Do children perform better on the QNST-II Palm Form Recognition task when numbers are presented in a one-stroke versus a two-stroke format? In order to answer this question, an independent samples t-test was utilized to compare differences in mean errors obtained by participants in the one-stroke treatment condition and participants in the two-stroke treatment condition.

Research reviewed by Lee, Reynolds, and Willson (2003) suggested that changes to standardized test procedures, large or small, could have a significant impact on test performance. Specifically, within the cognitive/neuropsychological domain, these authors found that alterations to standardized administration procedures including task instructions, voice inflection, presentation rate, delay periods, presentation modalities (visual versus auditory; standard versus computerized), response formats (spontaneous versus multiple choice), administration order, presence of observers, and provision of reinforcements all yielded significant affects on test performance.

Specific to graphesthesia assessments, only one study emerged in the literature relevant to the effects of variations in administration procedures. Santa Maria, Pinkston, Browndyke, and Gouvier (1997) compared performance outcomes of adults on the Halstead-Reitan Finger-Tip Number Writing task when numerals were traced with one-stroke versus two-stroke presentations. These researchers found that participants made significantly more errors when numbers were presented in one-stroke versus two-strokes. The authors argued that two-stroke presentations provided additional tactile cues and generally made the test easier. It was concluded that “the clinical sensitivity of the [Finger Tip Number Writing Task] can be increased by the administration of all numerals in the one-stroke format” (Santa Maria, Pinkston, Browndyke, & Gouvier, 1997, p. 129).

Based upon the review of relevant literature, it was hypothesized that participants in the current study would perform significantly better (i.e. demonstrate fewer errors) on two-stroke administration format of the modified QNST-II Palm Form Recognition task than on the one-stroke administration format. However, results of statistical analyses revealed no significant differences between the number of errors obtained by participants in the one-stroke treatment condition and those obtained by participants in the two-stroke treatment condition. This finding did not differ for numbers presented to the right hand or the left hand.

Failure of the current study to demonstrate findings consistent with the Santa Maria, Pinkston, Browndyke and Gouvier (1997) study may be related to the differences in the mean age of participants. While the previous study utilized individuals with a mean age ranging from 24.8 to 25.5, the current study focused on children ages eight through 12. Santa Maria, Pinkston, Browndyke and Gouvier (1997) suggested that in adults, the two-stroke presentations provided additional tactile cues and generally made the test easier. Due to significant variations in children's and adults' attention, information processing, strategy use, and overall learning styles, the children in the present study may have been less aware of the provision of additional tactile cues, and therefore benefited less from such cues (Santrock, 1995; Sullivan, Kantack, & Burtner, 2008). Additionally, there is a significant decline in the density of Meissner corpuscles, or specialized touch receptors, on the fingertips noted between the ages of 12 and 50 ("Meissner's corpuscle," 2008). With the mean age of participants in the Santa Maria, Pinkston, Browndyke, and Gouvier (1997) anchored in the middle of this age range, it is plausible that additional tactile cues would be of greater benefit than in the current study, which utilized participants ranging in age from eight to twelve years.

Differences between past and present research studying this specific alteration to administration procedures may have also resulted due to differences in the very nature of the presented tasks. Santa Maria, Pinkston, Browndyke and Gouvier (1997) utilized the Finger Tip Number Writing (FTNW) Task from the Halstead-Reitan, as opposed to the current study that utilized a modified version of the Palm Form Recognition (PFR) task from the QNST-II. These tasks vary in a multitude of ways. One of the most obvious is the presentation of traced numbers to the fingertips on the FTNW task and to the palm on the PFR task. As cited previously, Casey and Rourke (1992) note that in the case of discriminative touch, specialized touch receptors called Meissner's corpuscles are noted to occur in greater quantity in the tips of the fingers than in the palm of the hands. Given this neurobiological difference, it is plausible that the fingertips, which are heavily populated with touch receptors, would show greater benefit from the provision of additional tactile cues than the palmar surface, which consists of fewer tactile receptors and consequently weaker overall discriminative capabilities. Additionally, given the greater surface area of the palm, it is not unreasonable to expect fewer errors than would occur on the fingertips.

A second difference between the FTNW task and the PFR task that may have contributed to the differences between past and present research findings involves the frequency of number presentation. Whereas the FTNW task utilized only four numbers, each presented a total of five times to each hand, the current PFR task utilized eight numbers, each presented a total of one time to each hand. Participants in the Santa Maria, Pinkston, Browndyke, and Gouvier (1997) would have had more exposures to the two-stroke number formations and consequently a higher probability of learning these formations (based on tactile cues) during task administration than the participants in the present study who were exposed to the two-stroke number formations only one time on each hand making learning during the task less likely. This interpretation is congruent with the practice effect research conducted by Maxwell and Niemann (1984) and Maxwell, et al. (1984).

A final possible explanation for the differences between past and present research is the presence of examiner error. The study by Santa

Maria, Pinkston, Browndyke, and Gouvier (1997) does not detail procedures for training examiners on administration procedures, nor does it document whether such procedures were carried out with integrity. As such, it is possible that issues regarding the fidelity with which the Finger Tip Number Writing Task was administered contributed to resultant significant findings.

The current study incorporated a treatment fidelity procedure in order to ensure accuracy in task administration. Although analysis of the treatment integrity checklists suggests a high degree of overall accuracy in task administration, inconsistencies were noted on items assessing administration procedures for practice items, addressing curled palms, tracing numbers at appropriate rate, and using appropriate placement on the palm. Although inconsistencies were also recorded on the item assessing whether the examiner solicited questions prior to dismissing participants, all recorded errors on this item resulted because the video-camera was turned off immediately following administration of task items. As such, although the examiners all self-reported that they had carried this out properly, it could not be verified via video-recording. The presence of inconsistencies in the aforementioned areas is a potential threat to the validity of the current study. However,

Error Rates and Age

This study also aimed to determine the presence of a relationship between age and number of errors on the modified QNST-II Palm Form Recognition task. The following research question was presented: Do error rates vary as a function of age? In order to answer this question, correlational analyses were conducted to investigate the degree of association between age and mean errors obtained by participants, regardless of treatment condition.

In a review of relevant studies assessing age effects on performance on the Halstead-Reitan Finger Tip Number Writing tasks, Casey and Rourke (1992) noted a sharp increase in performance from ages 6 to 7 and a trend toward decreased imperceptions from ages 9 to 14. Based upon these findings, it was hypothesized that error rates would vary as a function of age, such that as age increased, a trend toward decreased errors would emerge. The results of correlational analyses did confirm this hypothesis. A significant negative correlation was found to exist between age and total errors, such that as age increased errors decreased.

Additional nonparametric analyses were conducted to see if performance varied by age when total errors were split into right hand errors and left hand errors. Although no significant correlation was found between age and total errors made with numbers presented on the right hand, there was a significant negative correlation that emerged between age and total errors made with numbers presented on the left hand. It stands to reason that this finding emerged because of practice effects. That is, older participants demonstrated fewer errors on the left hand because there was some degree of learning that occurred when numbers were presented to the right hand first. This practice effect may have been greater in older participants because of developmental maturity in factors such as attention, information processing, and strategy use (Santrock, 1995; Sullivan, Kantack, & Burtner, 2008).

Error Rates and Sex

Investigations into a potential association between sex and number of errors on the modified QNST-II Palm Form Recognition task were also of interest in the present study. The following research question was presented: Do error rates vary as a function of sex? In order to answer this question, correlational analyses were conducted to investigate the degree of association between sex (male and female) and mean errors obtained by participants, regardless of treatment condition.

Gordon and O'Dell (1983) conducted a study with university students and found statistically significant, but not clinically meaningful, sex differences on the Fingertip Number Writing task, favoring females specifically on left hand administrations. Gaddes and Edgell (1994) cite a study conducted by Gaddes and Crockett (1975) in which 353 boys and girls from the ages of 6 years to 13 years were administered the Spreen-Benton Aphasia Battery. The results of this study demonstrated no sex differences on tests of stereognosis for both hands. In more recent text, Kalat (1995) stated that while sex differences may exist, these differences are not significant. This statement was also supported by the comprehensive literature review conducted by Casey and Rourke (1992), who concluded that on finger localization and recognition tasks, no significant differences in level of performance emerge based upon sex.

Based upon the review of relevant literature, it was hypothesized that there would be no difference in error rates as a function of sex in the current study. The results of nonparametric correlational analyses did confirm this hypothesis. No significant correlation was found to exist between sex and total errors. Additional analyses were attempted to see if performance varied by sex when total errors were split into right hand errors and left hand errors. The results of nonparametric statistics revealed no significant differences or correlations.

Error Rates and Match Between Preferred- and Presented- Number Writing Style

The present study further aimed to examine whether performance on the modified Palm Form Recognition task is enhanced when participants are presented with their preferred number writing style versus the examiner's method for number writing. The fourth research question addressed by this study was "Do error rates vary as a function of the correspondence between preferred number writing style and number presentation format". In order to answer this question, Chi Square analyses were conducted to examine whether the differences in errors under a match- vs. no-match condition exceeded the probability of chance.

There was no relevant research base available for review to aid in the development of a hypothesis. However, given the fact that the directions for both the Halstead-Reitan Reitan-Klove Finger Tip Number Writing task and the QNST-II Palm Form Recognition task suggest determining and incorporating preferred number writing style in task administration, it appears as if authorities in the field acknowledge a potential moderating effect of this variable (Mutti, Sterling, Martin, & Spalding, 1998; Reitan & Wolfson, 1992). As such, it was hypothesized that participants would demonstrate fewer errors when presentation format matched with preferred number writing style.

Results of nonparametric tests revealed no significant relationship between total errors on the collective numbers 4, 5, 8, and 9 and total matches between preferred- and presented- number writing style on the collective numbers 4, 5, 8, and 9. Further analyses were conducted to determine if total errors on the individual numbers of 4, 5, 8, and 9 were related to the match between preferred- and presented- number writing style. Although no significant relationship was noted between errors and the match between preferred- and presented- number writing style on the numbers 5, 8, and 9, there was a significant difference between variables that exceeded the probability of chance for total errors on 4 as a result of the match or mismatch between preferred- and presented- number writing styles.

Visual inspection of the data sets suggests that this significance on the number 4 may have surfaced due to the emergence of strong preferences for preferred number writing style on this number in the test sample. That is, the vast majority of participants preferred writing the number 4 in two-strokes (96%). This may suggest that this number is more concretely represented in the brain in two-stroke formation (lacking continuous motion), and any deviation from this representation (i.e. presenting the number in a one-stroke formation with continuous motion) results in greater difficulty integrating the sensory input with some degree of understanding of such input for perception to occur.

Error Rates, Age, and Presentation Format

As indicated in a previous section, the current research aimed to investigate the degree of association between age and mean errors obtained by participants. Based upon the review of the literature, it was hypothesized that error rates would vary as a function of age, such that as age increased, a trend toward decreased errors would emerge. Subsequent correlational analyses did, indeed, indicate the presence of a significant negative correlation between age and total errors, such that as age increased errors decreased.

In order to gain further insight into this relationship, the fifth research question addressed in the current study was “Do error rates vary as a function of the interaction between age and presentation format?”. Linear regression analysis was utilized for statistical examination of the relationship among the variables of age, presentation format, and total errors.

There is only one known study to date that has examined the effects of variations in number presentation format procedures on a graphesthesia assessment. Santa Maria, Pinkston, Browndyke, and Gouvier (1997) compared performance outcomes on the Halstead-Reitan Reitan-Klove Finger Tip Number Writing task when numerals were traced with one-stroke versus two-stroke presentations. Based upon the data collected, the researchers found that participants made significantly more errors when numbers were presented in one-stroke versus two-strokes. The authors argued that two-stroke presentations provided additional tactile cues and generally made the test easier.

Based upon this finding, the present study proposed the hypothesis that trends toward decreased errors as a function of age would be less significant in the two-stroke presentation format condition versus the one-stroke presentation format condition. This hypothesis was largely based on logic, as Santa Maria, Pinkston, Browndyke, and Gouvier (1997) had utilized a much older sample (mean age ranged from 25.5 to 24.8) than the present study and no age effects were investigated. That is, if indeed the two-stroke presentation format does make the task easier by presenting additional tactile cues, older (10, 11, and 12 year old) and younger (8 and 9 year old) participants should benefit equally from this. However, without the provision of additional tactile cues on the one-stroke presentation format, the age effects as outlined by Casey and Rourke (1992) should hold constant.

The results of linear regression analyses indicated that there was not a statistically significant prediction between age and total errors on the modified Palm Form Recognition task under the two-stroke treatment condition, but that there was a significant prediction under the one-stroke treatment condition. Although these findings appear to support the current research hypothesis, the coefficient of determination for the one-stroke model predicted only about 1/10 of the total variance in the model. This suggests that 90% of the variance is not attributable to this model. As such, the relationship between these variables should be interpreted with caution.

Error Rates, Age, and Match Between Preferred- and Presented- Number Writing Style

As presented above, the current study intended to investigate the relationship between error rates and match between preferred- and presented- number writing style. It was hypothesized that participants would demonstrate fewer errors when presentation format matched with preferred number writing style. Although no significant findings emerged for total errors on the collective numbers 4, 5, 8, and 9 in association with total matches on the collective numbers 4, 5, 8, and 9, a significant finding did emerge for the individual number 4.

To further clarify this issue, the sixth and final research question addressed in the current study was “Do error rates vary as a function of the interaction between preferred vs. presented number writing style and age?”. Linear regression analysis was utilized for statistical examination of the relationship among the variables of age, match between preferred and presented number writing style, and total errors. It was hypothesized that trends toward decreased errors when presentation format matched preferred number writing style would be more evident in younger participants (e.g. 8- and 9- year olds) than in older participants (i.e. 10-, 11-, and 12-year olds).

As a whole, this hypothesis was not supported by the linear regression analyses. Data analyses did reveal a statistically significant prediction for the model age, total errors, and match between preferred- and presented number writing style on 5, and age, total errors, and no match between preferred- and presented number writing style on 8. These findings should be interpreted with caution, however, as the coefficients of determination were extremely low (0.193 and 0.102, respectively). This indicates that these models predicted only a small portion of the total variance, leaving the majority of variance attributable to other unidentified variables.

Practical Implications

In the field of psychological assessment, it is critical that test developers create explicit guidelines for test administration, scoring, and interpretation procedures in order to minimize the effects of extraneous variables on test performance and allow for valid comparisons between the performances of individually obtained test scores and those of the norm group (Murphy & Davidshofer, 1994). Although the current study did not reveal significant differences in error rates in participants administered a modified version of the QNST-II Palm Form Recognition Task as a function of altered presentation formats, previous researchers have suggested that any modification in standardized test administration procedures could have a significant impact on test performance. For example, in the cognitive/neuropsychological domain, alterations to standardized administration procedures including task instructions, voice inflection, presentation rate, delay periods, presentation modalities (visual versus auditory; standard versus computerized), response formats (spontaneous versus multiple choice), administration order, presence of observers, and provision of reinforcements all yielded significant affects on test performance (Lee, Reynolds & Willson, 2003). Despite these findings, a plethora of assessment tools continue to be created with considerable flexibility afforded in test administration procedures. It is essential that researchers continue to explore these areas and that test developers incorporate the resulting recommendations of such researchers into their projects. It is only through such collaboration that practitioners will be able to conduct valid and reliable assessments that can be linked directly to effective interventions.

Limitations

Because all examiners selected to administer the modified version of the Palm Form Recognition task of the Quick Neurological Screening Test-II were certified school psychologists, a primary assumption of this study was that they had been properly trained in best practices of test administration including building rapport, following standardized test procedures, accurate scoring procedures, etc. In addition, specific to the current study the Primary Investigator reviewed with each administrator the methods and procedures for data collection as outlined in the Methods section and provided training on the standardized administration procedures for the modified Quick Neurological Screening Test-II Palm Form Recognition Task utilized (e.g. pressure to be applied when tracing numbers, speed of numeral-tracing, how to address sweaty palms/curled palms, etc.)

However, despite the equality of training, test administration varied due to uncontrollable factors such as student characteristics and environmental circumstances. For example, the student characteristic of response style influenced whether the length of the testing session actually occurred within the proposed 5 to 7 minute time frame. In some instances, student non-response delayed test length by as much as fifteen minutes and standardized procedures for examiner reaction to student non-response had not been built into the modified protocol. With regard to environmental circumstances, due to limitations in space availability within the various school settings, some students participating in this study were evaluated in small, quiet rooms while others were assessed in large rooms adjacent to busy hallways. Resultant variations in the testing situation may threaten the validity of the results.

In addition to test administration variations due to uncontrollable factors, on several occasions examiners self-reported that they had made errors on standardized test administration procedures due to difficulty navigating the protocol created by the Primary Investigator, despite repeated exposure to it during examiner training. They reported that they had difficulty assessing which format (one-stroke or two-stroke) was used during observation of student number writing, difficulty flipping back and forth between pages to administer or re-administer items, and problems locating the standardized directions for correcting errors on sample items or sweaty palms quickly.

A third unanticipated complication of this study resulted from parent response to learning that their child, whom they had graciously volunteered for participation in this study, would not be able to participate in this study due to exclusionary criteria. Several parents became quite agitated, expressing the feeling that their children were being discriminated against due to their diagnosed disorders. Although most parents were placated once the rationale for the exclusion was further explained to them, the Primary Investigator felt it necessary to notify the building administrators of the parents' dissatisfaction as a courtesy, should the parents bring their displeasure to the attention of district personnel.

Furthermore, the logistical complications of scheduling after-school testing sessions for ninety students pending approval of secretarial staff, custodial staff, building administrators, and parents far exceeded those foreseen during project development. Frequent issues emerged due to parent inability to provide after-school transportation, conflicting after-school schedules limiting room availability within the buildings, end-of-the-day release time conflicting with examiners schedules, etc. Ultimately, the Superintendent of the one school district agreed to allow the researcher access to students in his respective elementary buildings (3) on one 8-hour day. Although this resolved many of the aforementioned issues, additional unforeseen logistical issues emerged as access to children was limited by changing classes, recess time, lunch time, and specials.

As indicated in Santa Maria, Pinkston, Browndyke and Gouvier (1997), clinical neuropsychology measures may require adaptation for use in neuropsychological research studies. The current study required significant modifications to the standardized test administration of the QNST-II Palm Form Recognition task, as detailed in the Method’s Section. As such, the current study cannot truly address issues of reliability and validity of the QNST-II Palm Form Recognition task, which does represent a limitation of the study.

Finally, the current study is limited with regard to the generalizability of the results. Due to the need to use a sample of convenience and to limit the scope of the current study for practicality purposes, the resulting outcomes are applicable to only a small portion of the population (i.e. 8- to 12- year old students in rural school districts of South Central Pennsylvania).

Recommendations for Future Research

The present study employed parent-volunteered participants without diagnosed disabilities ages 8 through 12. A relatively small sample size, with uneven distribution of ages resulted, with higher numbers surfacing at ages 8 and 9, than at ages 10, 11, and 12. Future researchers may wish to draw on a larger, more evenly distributed sample size in order to further investigate the moderating role of age on error rates of graphesthesia assessments. Since this instrument is commonly used in children with diagnosed disabilities, future researchers may also wish to incorporate various disability categories into their samples. If indeed performance on the graphesthesia assessment, regardless of number presentation format, is dependent upon learning between and within trials, one would anticipate significantly different outcomes in individuals with identified cognitive processing deficits. In addition, the field may benefit from additional research into the moderating role of matching preferred- and presented- number writing styles on graphesthesia assessments. Although the current research suggests some degree of association between this variable and error rates, it has not clarified this issue. Finally, future researchers are encouraged to conduct further analyses regarding reliability and validity of the QNST-II Palm Form Recognition task. For the purposes of experimental research, the Palm Form Recognition task was modified significantly from its original form. As such, issues related to the clinical sensitivity of this task cannot be directly addressed. However, there is a significant lack of research regarding this, and other, graphesthesia assessments that needs to be addressed in order to validate the ongoing utility of such instruments.

Summary

This chapter has presented a discussion of the results, structured according to individual research questions, hypotheses, and findings. These results have been interpreted in the context of previous research findings. In addition, the practical implications and limitations of the present study, as well as directions for future research, have been presented.

In summary, the present study supports previous research in finding a significant negative correlation between age and number of errors on a graphesthesia assessment. In addition, the current research aligns with more recent studies of sex-related differences in tactile functioning assessments, as it has revealed no statistically significant differences in error rates as a function of sex. With regard to the primary research question posited by the present study, there were no significant differences between the number of errors obtained by participants in the one-stroke treatment condition and those obtained by participants in the two-stroke treatment condition. When the multi-variable relationships of age/error rate/presentation format and age/error rate/match between preferred- and presented-number writing style were assessed, statistically significant, but clinically non-meaningful prediction models emerged between 1.) age and total errors under the one-stroke treatment condition, 2.) age, total errors, and match between preferred- and presented number writing style on 5, and 3.) age, total errors, and no match between preferred- and presented number writing style on 8.

Complications in conducting this study were noted with regard to test administration variations due to uncontrollable factors such as student characteristics and environmental circumstances, variations in test administration due to examiner error, addressing negative parent feedback as a result of student non-eligibility for participation in the study, and the logistical complications involved in carrying out the research. Additional limitations of the present study were noted with regard to generalizability of results and inability to comment on reliability and validity of the QNST-II Palm Form Recognition task due to significant modifications in the task for research purposes.

Despite the emergence of non-significant results on the primary research question, the current study adds to the body of literature relevant to the effects of alterations to standardized test procedures on performance outcomes. Research conducted by Lee, Reynolds and Willson (2003) suggest that these effects are unpredictable. As a result, these authors recommended that all modifications to standardized test administration procedures be validated empirically prior to institution. The current study continues to support this recommendation in order to ensure that the field is currently using practices that would produce a valid and reliable assessment which can be linked to appropriate programs for intervention and remediation.

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APPENDICES

Appendix A

Informed Consent Form

My name is Shannon Harmon. I am a doctoral student at Indiana University of Pennsylvania. I am working toward completion of my dissertation. To this end, I would like to invite your child to participate in a research study. The following information is provided in order to help you to make an informed decision whether or not you wish to have your child participate. If you have any questions please do not hesitate to ask. Your child is eligible to participate because he/she is a student participating fully in a general education 2nd, 3rd, 4th, or 5th grade classroom at a rural elementary school in south central Pennsylvania.

The purpose of this study is to see if children's ability to feel numbers traced on the palm of their hand is affected by the manner in which the numbers are traced. Participation in this study will require approximately 7 minutes of your child's time and is not considered a part of classroom requirements. Participation or non-participation will not affect the evaluation of your child's performance in the classroom. When you submit the signed Permission to Participate Form giving consent for your child's participation, your child will be randomly assigned (similar to a flip of the coin) to one of two groups. When both groups are large enough (by Spring of 2008), you will be contacted by the Primary Investigator to schedule an appointment for your child's participation in the study one day after school at your child's school. Both groups will be administered a portion of a standardized test of perception. First, your child will be asked to write the numbers one through ten on a piece of paper. Then, your child will be asked to hold out his/her hands, palms up, toward the examiner. Out of your child's sight, the examiner will then trace (using a stylus which is a utensil made of wood/plastic that looks like a pencil but contains no lead) the numbers two through nine on both palms. Some children will have numbers traced on their hands in a form that is familiar to them, and other children will have numbers traced on their hands in a form that is not familiar to them.

After each number is traced, your child will be asked to tell the examiner what number they feel being traced on their palms. After all numbers are done in this manner, your child will be given an opportunity to ask any questions he/she may have. Your child's errors will be recorded on a piece of paper that contains only a non-identifying number, their age, and their gender. No identifying personal information will be associated with your child's performance. To ensure that the examiners are carrying out the task as they are supposed to, your child's hand only may be videotaped. This video will only be seen by the Primary Investigator and/or Faculty Supervisor and will be erased after the study has been completed. Your child's performance on the number tracing task will be compared to other children's performance on the same task. There are no known risks or stressors associated with this research. Your child may actually find the experience to be fun. The information gained from this study may help us to better understand the best way to give certain types of tests.

Your child's participation in this study is voluntary. You and your child are free to decide not to participate in this study or to withdraw at any time without adversely affecting any relationship with the investigators or the school. Your and/or your child's decision will not result in any loss of benefits to which you may otherwise be entitled. If you and your child choose to participate, you and your child may withdraw at any time by notifying the Primary Investigator or informing the person administering the test. Upon request to withdraw, all information pertaining to you and/or your child will be destroyed. If you and your child choose to participate, all information will be held in strict confidence and will have no bearing on academic standing or services received from the school. Your child's responses will be considered only in combination with those from other participants. The information obtained in the study may be published in scientific journals or presented at scientific meetings but your and your child's identity will be kept strictly confidential. If you give consent for your child to participate in this study, please sign the attached Permission to Participate Form and return it to your child's classroom teacher. Keep the extra unsigned copy for your records. If you and your child choose not to participate, simply dispose of the forms at your convenience. You may receive a follow-up call simply to verify that you do not wish to participate.

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This project has been approved by the Indiana University of Pennsylvania Institutional Review Board for the Protection of Human Subjects (Phone: 724/357-7730).

Appendix B

Permission to Participate Form

I have read and understand the information on the Informed Consent Form and I give my permission for my child to volunteer to be a subject in this study. I understand that my information and my child's responses are completely confidential and that my child and/or I have the right to withdraw at any time. I also understand that my child's hand only may be videotaped to ensure that examiners are carrying out the task as they are supposed to and that this video will be erased upon completion of the study. I have received an unsigned copy of the Informed Consent Form to keep in my possession.

Child's Name ________________________Child's Date of Birth ____________

Child's School of Attendance ____

Has your child ever experienced any damage to their hands directly, or to other parts of the body that may influence their hands (e.g. burns, peripheral nerve damage, prolonged exposure to cold or heat, accidents resulting in serious cuts or bruises to the hands, etc.)?
____NO
____YES Please provide a brief description
____
____

Parent's Name (PLEASE PRINT) _____________________________________

Parent's Signature:____

Date: ________________________

Phone Number where you can be reached to schedule appointment for your child:________________________

Best days and times to reach you: ______________________________________
____
*** Please return this completed form to your child's classroom teacher.**
****If you wish to discuss the study with the Primary Investigator prior to providing consent, please call (717) 530-3189 ext. 3337**

Appendix C

<u>Sample Testing Schedule</u>

School District A

May 20th, 2008

School A

Examiner 1		Examiner 2	
2:30			2:30
2:40			2:40
2:50			2:50
3:00			3:00
3:10			3:10
3:20			3:20
3:30			3:30

May 21st , 2008

School B

Examiner 1		Examiner 2	
2:30			2:30
2:40			2:40
2:50			2:50
3:00			3:00
3:10			3:10
3:20			3:20
3:30			3:30

May 22nd , 2008

School C

Examiner 1		Examiner 2	
2:30			2:30
2:40			2:40
2:50			2:50
3:00			3:00
3:10			3:10
3:20			3:20
3:30			3:30

May 29th , 2008

School D

Examiner 1		Examiner 2	
2:30			2:30
2:40			2:40
2:50			2:50
3:00			3:00
3:10			3:10
3:20			3:20
3:30			3:30

School District B
May 23rd, 2008

School A

Examiner 1		Examiner 2	
8:30	____________	____________	8:30
8:40	____________	____________	8:40
8:50	____________	____________	8:50
9:00	____________	____________	9:00

School B

Examiner 1		Examiner 2	
9:30	____________	____________	9:30
9:40	____________	____________	9:40
9:50	____________	____________	9:50
10:00	____________	____________	10:00
10:10	____________	____________	10:10
10:20	____________	____________	10:20
10:30	____________	____________	10:30
10:40	____________	____________	10:40
10:50	____________	____________	10:50
11:00	____________	____________	11:00

School C

Examiner 1		Examiner 2	
1:30	____________	____________	1:30
1:40	____________	____________	1:40
1:50	____________	____________	1:50
2:00	____________	____________	2:00

Appendix D

Student Assent Form

I am inviting you to participate in a research study.

The purpose of this study is to see if you can recognize numbers by touch alone.

You will be asked to write some numbers. Then, without you looking, an adult will trace some numbers on the palms of your hands and see if you can correctly guess what number has been traced. An adult will write down the numbers you guess.

After you actually complete the number tracing activity, nobody at home or school will use your name or talk about how you did on the activity. This information will be kept a secret and will not have anything to do with your grades at school. You may see a video camera on the table, but it is only looking at your hand. It is just to make sure that the adult who is working with you is doing the activity correctly.

Even though you will not be given anything to be in this study, you may find the experience of being a part of scientific research to be fun. The information gained from this study may help us to better understand the best way to give certain types of tests to children. The number tracing activity will not be painful in anyway!

Your parent (s) have already said it is okay for you to participate in this study, but we want you to know that being in this study is totally up to you! You can ask any questions that you have about this study. If you have a question later that you didn't think of now, you can ask us then! Even if you say that you want to participate now, and then change your mind, that is okay too! You can stop at any time if you want to and you won't get in any trouble!

By signing below, I am saying that I have read this form (or this form has been read to me) and I have asked any questions that I may have. All of my questions have been answered so that I understand what I am being asked to do. By signing, I am saying that I am willing and would like to participate in this study. I also have received a copy of this form to keep!

_______________________________________ ______________

Signature of Child Date

Appendix E

Assessment Protocol

Student Numeric Code ID____________________

Student Age (circle one) 8 9 10 11 12

Student Gender (circle one) male female

Treatment Condition (circle one) one-stroke two-stroke

Examiner: Read Student Assent Form with student. Ask student, ***"Do you have any questions?".*** After answering any questions, obtain student signature.

Examiner: Place pencil at student's midline

Examiner: Give student piece of lined paper. Say, ***"Write the numbers one through ten on this piece of paper".*** Complete observational records below as the student completes this task. Upon completion, place paper with student's written response OUT OF VIEW.

Observational Records:

Handedness	Right	Left
Preferred Number Writing Style		
4	One-Stroke	Two-Stroke
5	One-Stroke	Two-Stroke
8	One-Stroke	Two-Stroke
9	One-Stroke	Two-Stroke

Examiner: Say, ***"I am going to take a look at how you use your hands. This will tell me something about how you read, write, and do numbers. This won't take us long, and when we're finished, you can ask as many questions as you like. Even if what I ask you to do is hard, just try to do your very best".***

RIGHT HAND
Examiner: While demonstrating, say, ***Please extend your right arm toward me with the palm of your hand facing up.*** Place shield between yourself and child to block child's line of vision. ***I'm going to be making some drawings on the palm of your hand. This is the top part*** [touch part closest to wrist] ***and this is the bottom part*** [touch part closest to fingers]. Demonstrate as you say, ***Be sure to keep your hand flat against the table the whole time.*** Use this demonstration and prompt as needed if child begins to curl hand or raise hand off table at any time during testing.

For practice, let's start with some letters. See if you can tell me what letter I'm writing. What letter is this?" Begin tracing practice letters on hand as presented below. If child makes an error, record the error on the form and correct the error by saying, ***Good try, but that was the letter ___. Let me write it again.*** Trace the same letter again and then ask child, ***Now, what letter was that?*** After child responds (correctly or incorrectly) say, ***Let's try the next one.*** Proceed with remaining practice letters until all have been administered and corrected as necessary following the above instructions. *(If during administration of practice items, examiner notes excess sweat on the palms of the hands, say,* ***Your hand seems a little sweaty. I'm going to use a tissue to dry your hands before I write more [letters/numbers].*** *Wipe a tissue over the child's palm and fingers until dry then say,* ***Okay, let's continue. What [letter/number] is this?*** *Use this prompt as needed if excess sweat is evident at any time during testing.)*

Now I'm going to write some numbers on the palm of your hand. Remember, this is the top part [touch part closest to wrist] ***and this is the bottom part*** [touch part closest to fingers]. ***See if you can tell me what number I'm writing. What number is this?*** Begin tracing numbers on hand as presented below and record errors. Repeat question, ***What number is this?*** with each new numeral presented. *(One request for repetition is allowed; additional requests for repetitions should be considered as errors and the reply is,* ***Let's try the next one.)***

One-Stroke Condition- Right Hand		
	+/-	*Answer*
PRACTICE ITEMS		
T		
C		
X		
O		
TEST ITEMS		
3		
9		
5		
7		
2		
8		
4		
6		
Total Test Item Errors		

Two-Stroke Condition- Right Hand		
	+/-	*Answer*
PRACTICE ITEMS		
T		
C		
X		
O		
TEST ITEMS		
3		
9		
5		
7		
2		
8		
4		
6		
Total Test Item Errors		

LEFT HAND
Examiner: Remove shield. While demonstrating, say, ***Now, please extend your left arm toward me with the palm of your hand facing up.*** Place shield between yourself and child to block child's line of vision. ***Now I'm going to be making some drawings on the palm of this hand. Remember, this is the top part*** [touch part closest to wrist] ***and this is the bottom part*** [touch part closest to fingers]. Demonstrate as you say, ***Be sure to keep your hand flat against the table the whole time.*** Use this demonstration and prompt as needed if child begins to curl hand or raise hand off table at any time during testing.

For practice, let's start with some letters again. See if you can tell me what letter I'm writing. What letter is this?" Begin tracing practice letters on hand as presented below. If child makes an error, record the error on the form and correct the error by saying, ***Good try, but that was the letter ___. Let me write it again.*** Trace the same letter again and then ask child, ***Now, what letter was that?*** After child responds (correctly or incorrectly) say, ***Let's try the next one.*** Proceed with remaining practice letters until all have been administered and corrected as necessary following the above instructions. *(If during administration of practice items, examiner notes excess sweat on the palms of the hands, say,* ***Your hand seems a little sweaty. I'm going to use a tissue to dry your hands before I write more [letters/numbers].*** *Wipe a tissue over the child's palm and fingers until dry then say,* ***Okay, let's continue. What [letter/number] is this?*** *Use this prompt as needed if excess sweat is evident at any time during testing.)*

Now I'm going to write some numbers on the palm of this hand. Remember, this is the top part [touch part closest to wrist] ***and this is the bottom part*** [touch part closest to fingers]. ***See if you can tell me what number I'm writing. What number is this?*** Begin tracing numbers on hand as presented below and record errors. Repeat question, ***What number is this?*** with each new numeral presented. *(One request for repetition is allowed; additional requests for repetitions should be considered as errors and the reply is,* ***Let's try the next one.****)*

One-Stroke Condition- Left Hand		
	+/-	*Answer*
PRACTICE ITEMS		
T		
C		
X		
O		
TEST ITEMS		
8		
6		
4		
7		
5		
3		
9		
2		
Total Test Item Errors		

Two-Stroke Condition- Left Hand		
	+/-	*Answer*
PRACTICE ITEMS		
T		
C		
X		
O		
TEST ITEMS		
8		
6		
4		
7		
5		
3		
9		
2		
Total Test Item Errors		

Examiner: Praise student for their participation. Ask student, ***Do you have any questions?*** Answer any questions and dismiss child.

Note any unusual reactions to touch (e.g. pulling away, rubbing off, complaints about tickling, complaints about pain, involuntary reflexive responses, etc.)____

If unusual reaction was noted, was task still able to be completed according to standardized procedures? (circle one) Yes No

Appendix F

Treatment Integrity Checklist

Examiner: A B C D

1. Was Student Assent Form reviewed by examiner and signed by student?	YES	NO
2. Was lined paper with student-generated numerical drawings placed out of view by examiner prior to test administration?	YES	NO
3. Were task directions administered as outlined on the research protocol?	YES	NO
4. Did examiner follow the procedures for curled palms as outlined on the research protocol? If not needed, circle yes.	YES	NO
5. Was the shield placed between the subject and the examiner prior to administering task?	YES	NO
6. Did examiner follow the procedures for correcting errors on the sample items as outlined in the research protocol? If not needed, circle yes.	YES	NO
7. Were practice items administered to both hands?	YES	NO
8. Did examiner follow the procedures for sweaty palms as outlined on the research protocol? If not needed, circle yes.	YES	NO
9. When presenting practice items and test items, were they presented in correct order as outlined on protocol?	YES	NO
10. Were practice items and test items presented to right hand first?	YES	NO
11. Did examiner use the same condition (one-stroke or two-stroke) consistently throughout testing?	YES	NO
12. Did examiner trace the numbers utilizing appropriate pressure (i.e. leave a trail of white where the stylus has been)?	YES	NO
13. Did examiner trace the numbers slowly and distinctly (i.e. approximately 3 seconds per item)?	YES	NO
14. Did examiner use appropriate placement on the palm when tracing the numbers (i.e. utilizing maximum palmar surface)?	YES	NO
15. Did examiner use appropriate formation of number based upon condition (one-stroke or two-stroke)?	YES	NO
16. Did examiner solicit questions from subject prior to dismissing?	YES	NO