Does Speech-To-Text Assistive Technology Improve the Written Expression of Students with Traumatic Brain Injury?

Michaela Ann Noakes

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DOES SPEECH-TO-TEXT ASSISTIVE TECHNOLOGY IMPROVE THE WRITTEN EXPRESSION OF STUDENTS WITH TRAUMATIC BRAIN INJURY?

A Dissertation

Submitted to the School of Education

Duquesne University

In partial fulfillment of the requirements for

the degree of Doctor of Education

By

Michaela Ann Noakes, M.A., M.B.A., M.S. - I.S.M.

August 2017
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Michaela Ann Noakes

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Dissertation

Submitted in Partial Fulfillment of the Requirements
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Instructional Technology and Leadership

Presented by:

Michaela Ann Noakes
B.A. Legal Studies, Point Park University, 1992
M.A. Social and Public Policy, Graduate School of Arts, Duquesne University, 1996
M.B.A. Graduate School of Business, Duquesne University, 2006
M.S. - I.S.M. Graduate School Business, Duquesne University, 2008

June 20, 2017

DOES SPEECH TO TEXT ASSISTIVE TECHNOLOGY IMPROVE THE WRITTEN EXPRESSION OF STUDENTS WITH TRAUMATIC BRAIN INJURY?

________________________, Chair
Ara J. Schmitt, Ph.D.
Associate Professor, Counseling, Psychology, and Special Education
Duquesne University

________________________, Member
Elizabeth McCallum, Ph.D.
Associate Professor, Psychology
Duquesne University

________________________, Member
Joseph C. Kush, Ph.D.
Professor, Instructional Technology
Duquesne University

Program Director
Misook Heo, Ph.D., Professor
Director, Doctoral Program in Instructional Technology and Leadership
School of Education
Duquesne University
ABSTRACT

DOES SPEECH-TO-TEXT ASSISTIVE TECHNOLOGY IMPROVE THE WRITTEN EXPRESSION OF STUDENTS WITH TRAUMATIC BRAIN INJURY?

By

Michaela Ann Noakes

August 2017

Dissertation supervised by Dr. Ara J. Schmitt

Traumatic Brain Injury outcomes vary by individual due to age at the onset of injury, the location of the injury, and the degree to which the deficits appear to be pronounced, among other factors. As an acquired injury to the brain, the neurophysiological consequences are not homogeneous; they are as varied as the individuals who experience them. Persistent impairment in executive functions of attention, initiation, planning, organizing, and memory are likely to be present in children with moderate to severe TBIs. Issues with sensory and motor skills, language, auditory or visual sensation changes, and variations in emotional behavior may also be present. Germane to this study, motor dysfunction is a common long-term sequelae of TBI that manifests in academic difficulties. Borrowing from the learning disability literature, children with motor dysfunction are likely to have transcription deficits, or deficits related to the fine-motor production of written language.
This study aimed to compare the effects of handwriting with an assistive technology accommodation on the writing performance of three middle school students with TBIs and writing difficulties. The study utilized an alternating treatments design (ATD), comparing the effects of handwriting responses to story prompts to the use of speech-to-text AT to record participant responses. Speech-to-text technology, like Dragon Naturally Speaking converts spoken language into a print format on a computer screen with a high degree of accuracy. In theory, because less effort is spent on transcription, there is a reduction in cognitive load, enabling more time to be spent on generation skills, such as idea development, selecting more complex words that might be otherwise difficult to spell, and grammar.

Overall, all three participants showed marked improvement with the application of speech-to-text AT. The results indicate a positive pattern for the AT as an accommodation with these children that have had mild-to-moderate TBIs as compared to their written output without the AT accommodation.

The findings of this study are robust. Through visual analysis of the results, it is evident that the speech-to-text dictation condition was far superior to the handwriting condition (HW) with an effect size that ranged + 3.4 to + 8.8 across participants indicating a large treatment effect size. Perhaps more impressive, was 100 percent non-overlap of data between the two conditions across participants and dependent variables.

The application of speech-to-text AT resulted in significantly improved performance across writing indicators in these students with a history of TBIs. Speech-to-Text AT may prove to be an excellent accommodation for children with TBI and fine motor skill deficits. The conclusions drawn from the results of this study indicate the Speech-to-Text AT was more effective than a handwriting condition for all three participants. By providing this AT, these
students each improved in the quality, construction, and duration of their written expression as evidenced in the significant gains in TWW, WSC, and CWS.
DEDICATION

Dedicated to the memory of my mother and father, Marion C. and Edward T. Noakes and their many sacrifices to provide me with a Catholic school education, a deep faith in our Good Lord, a determined spirit, a love for knowledge, and the strength and courage to follow my dreams and reach my life-long goals. They encouraged and inspired me; and, their love and support were steadfast. I was blessed to have been their daughter.
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Chapter I: INTRODUCTION

Incidence and Prevalence

Traumatic brain injury (TBI) is a debilitating condition and a major cause of death in the United States (Centers for Disease Control, 2010). Approximately, 2.5 million emergency department visits, hospitalizations, or deaths were ascribed to TBI events in 2010. The TBIs reported either occurred independent of or in combination with other injuries (CDC, 2011). In 2009, emergency department personnel treated 248,418 children (age 19 or younger) for sports and recreation-related injuries which included a diagnosis of concussion or TBI (CDC, 2011). Of all injury-related deaths in the United States, 30.5% (one third) involved TBI as a contributing factor (CDC, 2011).

In a majority of TBI cases involving children and youth between the ages of 0-14 years, the epidemiology has been identified by the National Institutes of Health (1998) as falls, vehicle-related collisions, violence (e.g. assaults, child abuse, shaken baby syndrome, and gunshot wound), and sports injuries. The CDC (2010) further quantified these principal causes of TBIs as falls, 40.5%, blunt force, 15.5%, motor vehicle, 14.3%, assaults, 10.7%, and unknown/other, 19.0%. The CDC (2010) reports each year that there are an estimated 3,000 deaths, 29,000 hospitalizations, and 400,000 emergency department visits related to TBIs. Overall, the male-to-female incidence ratio for TBIs is approximately 1.8:1. However, that ratio increases to 2.2:1 for children between the ages of 5-14. This trend continues into adolescence, where brain injury rates increase for males but decrease for females. The proportion of brain injury caused by motor vehicle or motor vehicle-related accidents increases with age from 20% in children ages 0-4 years to 66% in adolescents. Pedestrian or bicycle-related brain injuries are more likely to affect younger children, whereas adolescents are more often injured in motor vehicle accidents.
According to the CDC (2010), 64% of all infant head injuries are caused by child abuse, approximately 1 in 500 school-age children acquire a TBI and are hospitalized, 1 million children sustain a head injury each year and 165,000 are admitted to a hospital facility, of those hospitalized, 1 in 10 suffer moderate to severe impairments. These impairments can result in functional deficits in cognition, attention, and memory, speech, vision, and hearing, behavior, and motor skills. Some of the factors which contribute to the deficit variability among children are age at injury, injury site, and injury severity.

Upon discharge from a hospital, 80% to 90% of the treated cases are diagnosed as mild, 7% to 8% are moderate, and 5% to 8% are classified as severe brain injury. Since many mild TBI cases go unreported or are treated in outpatient settings, these numbers may be underestimated.

Another aspect related to TBI injuries is the financial impact from long-term medical treatment and the projected loss of productivity. Corso et al. (2006) estimated the cost of the injuries sustained in 2000 to be approximately $406 billion dollars: $80 billion for medical treatment and $326 billion for lost productivity. Besides the prolonged economic cost associated with a TBI event on children, their families, and society, there is also a cost of reduced quality of life. One way to address the cost associated with reduced productivity is to use effective technologies and programs that will allow children with TBIs to develop the skills to lead productive lives.

Additional research in this area is necessary in the field of educational technology to design effective technological solutions and academic modalities that are purposeful, ability adaptive, and are customizable to the unique requirements of each individual. These interventions may include growth-related models that bridge the gap between normal and disrupted child and adolescent cognitive progression, which address not only the effects of a TBI
but also how these effects relate to functional development as compared to a learning disability. Designing appropriate educational services has the potential to affect the management process associated with TBI injuries by integrating individuals with TBI into the mainstream educational system in addition to specialized educational and neurorehabilitative settings.

Neuropsychological Consequences

Outcomes and recovery of TBIs vary by individual and by the type of contributing factors, such as age at the onset of injury, the location of the injury, and the degree to which the deficits appear to be pronounced. For example, a TBI in the frontal and temporal regions can cause cognitive dysfunction in several domain areas, which include memory, attention, and executive function deficits (Writer & Schillerstrom, 2009). That said, the consequences of a TBI must be understood within the context of typical neuropsychological functioning and this framework can be provided by Luria (1973) in his seminal work, *The Working Brain.*

Luria (1973) proposed that cerebral activity was the result of three principal functional units of the brain: the first unit is for *regulating tone or waking*, the second unit is for *obtaining, processing and storing information* from external stimulus, and the third unit is *programming, regulating and verifying* mental activity. Each unit is comprised of a complex and integrated hierarchical system of cortical zones identified by Luria (1973) as the primary, secondary, and tertiary framework for cerebral activity. Including Luria’s (1973) cohesive systems approach provides a platform to understand the organization and relationship among human neuropsychological skills. The hallmark of Luria’s work (1973) was the conception of these complex component processes as a series of links in a chain of consecutive movements that extend beyond kinesthetic and spatial apraxia; if any one of these performance domains becomes disturbed by a pathological lesion, it is consistently reflected in the sequence of movement.
When this system is disrupted and any links are broken following a TBI event, this cohesiveness is lost. The disruption will be distinct, and is directly related to the link(s) that have become dysfunctional (Podd, 2012).

Yeates, Ris, and Taylor (2000) subsequently reviewed the literature regarding pediatric TBI and identified several different neuropsychological domains that may be impacted. These include alertness and orientation, intellectual functioning, language skills, nonverbal skills, attention, memory, executive functions, corticosensory and motor skills, and academic performance.

**Alertness and Orientation.** While in the recovery phase, most children experience some degree of fluctuation in sustaining their levels of arousal. Some children appear disorientated, confused, and experience memory loss (Yeates et al., 2000). Their alertness or ability to remain attentive and prepared to act or react is diminished; as is their ability for orientation and self-awareness to time and place in their surroundings.

Post injury, many children experience a period of Post-Traumatic Amnesia (PTA) which is used as a measure of injury severity (Yeates, et al., 2000). Children are subsequently evaluated using a test standard known as the Children’s Orientation and Amnesia Test (COAT) to evaluate the presence and duration of a PTA event. The results of this test have been used to predict post-traumatic memory functions for up to 12 months (Ewing-Cobbs, Levin, Fletcher, et al., 1990).

**General Intellectual Functioning.** Various components of cognition can be severely impacted following a TBI event. General intellectual skills and problem-solving of novel tasks is frequently impacted after a TBI (Anderson, Catroppa, Morse, Haritou, and Rosenfeld, 2000). Direct effects in an individual’s ability to reason are evidenced in deficiencies in problem-solving and complex judgment. When these cognitive skills are disrupted, it becomes
significantly more difficult to find the correct solution(s) in a timely manner; or in severe cases, not at all.

Ylvisaker and Szekers (1989) defined reasoning as “considering evidence and drawing inferences and conclusions, involving flexible exploration of possibilities (divergent thinking) and use of past experiences” (Ylvisaker, 1998, p. 144). Effective reasoning whether deductive or inductive is often disrupted following a TBI event; direct effects in an individual’s ability to reason are evidenced in deficiencies in problem-solving and complex judgment. Difficulty in this area can present itself as an emotional state expressed as feelings of incompetence, low self-esteem and mood disturbances when attempting to engage in daily tasks (Rath et al., 2003). These emotions can intensify when it becomes increasingly more difficult to process abstract information and screen out irrelevant distractions.

In the process of learning or reasoning through novel information, the knowledge must be received through the senses, analyzed, encoded, compared with semantic memory, and be manipulated in mental symbols and images between objects and events in working memory (Morrison, et al. 2004). Injury to the prefrontal cortex typically results in a disruption in the processing of external stimuli, lack of preparation for appropriate action, the formation and deliverable action(s) of a response plan, and validation that the plan occurred as it was intended (Luria, 1966). The effect from this type of TBI event is resulting degradation in reasoning performance, and an inability to inhibit irrelevant information (Morrison et al., 2004).

**Language Skills.** Communication skills are either characterized as receptive or expressive language skills (White, Campbell, Echeverria, Knox, and Janulewicz, 2008). The ability to read and write is also predicated on these two components of language and includes the
ability to produce the linguistic aspects of reading and writing including: phonemes, lexical development and production of words, and speech comprehension (White et al., 2008).

Since learning is centered on the comprehension and articulation of language, students with a TBI may experience difficulties in integrating spoken or written information, may struggle with vocabulary and expressive language, may have limited recall, may encounter difficulties with following multiple instructions and event sequencing, and may not be able to complete tasks, even though they can articulate the purpose for the task. The complexity of functional injury which results in receptive and expressive deficits can have a significant and long-term impact on academic outcomes.

For example, students with receptive (Wernicke’s) aphasia have poor speech comprehension and produce fluent but meaningless speech (Miller, 2013). Those students with expressive (Broca’s) aphasia may have difficulty in oral language production (Miller, 2013). Students may experience difficulty in locating the right word to say and display slow and non-fluent speech; however, they can still comprehend speech.

**Nonverbal Skills.** Nonverbal skills, which include visual-perceptual and constructional abilities evident in motor output, are often impacted following a TBI event (Yeates et al., 2000). For example, when visual-spatial problem-solving skills are impacted, children and adolescents often experience difficulty in using blocks to create designs, analyzing patterns to determine what is missing, and have difficulty with the mental manipulation of the design in their mind.

**Attention.** Mirsky, Anthony, Duncan, Ahearn, and Kellam (1991) proposed a paradigm to further identify the cognitive process components of attention which were categorized as: focus, sustain, and shift. This model was further synthesized by Catroppa, Anderson, Godfrey, and Rosenfeld (2011) to include: sustained attention or vigilance, selective attention, shifting
attention, divided attention, attentional control, and speed of processing. Catroppa et al. (2011) conducted a 10 year TBI exploratory analysis, and found that consistent with earlier research, age at injury and injury severity are predictors of attentional deficits. In this longitudinal study, the results confirm that persistent deficits are observable 10 years post-injury.

**Memory.** Levin and Eisenberg (1979) identified memory as the most frequently disrupted neuropsychological domain based on their comparison of composite scores in the areas of memory, language, motor and somatosensory functioning, and visuospatial ability. During the period of confusion and amnesia following a TBI event, the slowing of intellectual processes can also impact memory in the recalling of new material, contribute to attentional issues, and present as changes in personality (Malojcic, Mubrin, Coric, Susnic, and Spilich, 2008). Yeates, Blumenstein, Patterson and Delis (1995) found that children and adolescents who were administered the California Verbal Learning Test subsequent to sustaining a TBI, exhibited memory deficiencies in their ability to learn, demonstrated less retention over time, and generally had better recognition than recall following the TBI.

Consistent with the TBI literature, latency in response time (RT) with word generation and a slowing down of information processing is symptomatic of Postconcussion Syndrome. These findings and their contribution to educators will serve to enhance their understanding that students with TBIs may require more time to think and interact not only with the content presented for processing and retrieval but also when encountering any cognitive-linguistic impairments (e.g. disorganized language or language processing, tangential speech, verbosity, and pragmatic deficiency) which may be evidenced in their verbal engagement with their peer group during social interactions. Should these deficits be globalized, they could impair a
student’s reading and writing cognitive abilities which can ultimately impact their ability to keep pace in the classroom.

**Executive Functions.** Executive function includes planning, working memory, resource allocation, strategies for problem solving, and behavior inhibition (Levin and Hanten, 2005). When cognitive deficits occur in executive functioning, an increased load is placed on working memory performance and is proportional to the degree of injury severity and time post-injury, which can result in an underperformance in analogical reasoning (Krawczyk et al., 2010).

This loss in overall performance increases when distraction is present and relational complexity is higher. Brain research suggests that formal thought is a key component of executive functioning in the frontal lobe structure of the neocortex. There is a strong connection between sustaining a TBI and the impact on students’ metacognitive abilities to engage in a self-reflective and self-monitoring process.

Savage, Depompei, Tyler and Lash (2005) reported that youths who experienced a TBI event often have communication problems which become evident when attempting to apply what has been learned. These behaviors may be manifested in several ways. For example, students may be easily distracted and may appear restless. Multiple or sequential tasks may become overwhelming. Additional time may be required for grasping and processing information. Students may experience difficulty with retention of events, facts, and other information. Their communication may appear rambling. They may have trouble interpreting non-verbal communication accompanied by a lack of clear understanding of the consequence to actions. Impaired judgment may become apparent in their decision-making process. Other problematic areas may include difficulty in logical thought organization and the presentation of ideas.
**Sensory and Motor Skills.** Levin and Eisenberg (1979) found that following a significant TBI event, at least 25% of children exhibited deficits on tests of stereognosis (tactile recognition of an object without visual observation), finger localization (identification, naming, and location of the fingers based on touch), and graphestesia (ability to recognize a letter or number drawn on the skin using sensory information). Children who have experienced closed-head injuries in the primary cortical areas for motor, sensory, and visual functions often have an inability to execute voluntary movements (the intention to move) to perform goal-oriented actions (motor apraxia). Apraxia (poor motor planning) and Dysarthria (muscle control) can be evidenced as indecipherable speech production, slurred speech, a slower rate of speech or an inability to use speech following paralysis (Savage et al., 2005).

**Academic Performance.** Following a TBI event, crystallized knowledge tends to remain intact; however, over time, as academic performance becomes more fluid with learning and retaining new information, a decline in academic performance becomes more evident especially with children who sustained a TBI between the ages of 2-7 years (Yeates, Ris, Taylor, 2000; Taylor, Swartwout, Yeates, Walz, Stancin, and Wade 2008; Anderson, Catroppa, Morse, Haritou, and Rosenfeld, 2009). The complexity of functional injury which results in expressive and receptive language deficits can have a significant, persistent, and long-term impact on academic outcomes. Ewing-Cobbs, Prasad, Kramer, et al. (2006) found that an early onset TBI event may interfere with the acquisition of later-developing academic skills as the deficits of lower I.Q. and impaired learning efficiency are cumulative.

These impairments in executive functioning can include struggles with structure, planning, reasoning, problem-solving and judgment, impaired attention and a decreased speed in processing. With regards to age at injury, developmental level, and the degree of injury severity,
these impairments often affect functional outcomes, including reading decoding, reading comprehension, spelling and arithmetic as these skills are often developed in childhood (Catroppa, Anderson, Muscara, et al., 2009).

Furthermore, Babikian et al. (2011) conducted a longitudinal analysis at one, six, and twelve months post-injury which controlled for the effect of pre-injury risk factors such as ADHD and cognitive learning disabilities. The results of this study indicate that several deficits are apparent up to one year post-injury particularly in the areas of “memory abilities, language, and rapid psychomotor tests” (p. 893). When these results are extrapolated into this current discussion, they further highlight the importance of early identification in the path of cognitive recovery and to the abilities of children and adolescents who are still in an acute developmental position to acquire new skills.

**Written Expression as an Area of Functional Impairment**

As an academic area, written expression is very likely to be impacted as a result of these deficits particularly due to fine motor output. Berninger (2004) defines the components of writing as transcription and generation. The transcription involves spelling and motor output. First, a student must think of what he or she would like to communicate and then link the sounds of oral language (phonemes) to the corresponding letters of written language. Then, the student must use fine motor skills to handwrite. When children and adolescents experience a TBI, fine motor deficits often result in impaired abilities to effectively and efficiently form letters. This results in illegible writing and, impaired written communication. The generation component of writing involves translating these ideas into expressive language (composition).
Technology that Accommodates for Handwriting Deficits. The intention of this dissertation is to evaluate speech-to-text assistive technology (i.e. Dragon Naturally Speaking) as an accommodation to bypass fine motor control deficits to enhance output for written expression for children and adolescents who have sustained a TBI. A common accommodation is to have students type, but the dexterity needed for keyboard input may also be difficult. So, speech-to-text assistive technology, as an accommodation for fine motor difficulties, may bypass the use of handwriting movements in the generation of written expression by allowing the students to speak the desired content into a microphone. The speech-to-text technology will convert the spoken subject matter into a print format on a computer screen for subsequent editing. What is undetermined is the extent to which this speech-to-text assistive technology will accommodate for fine motor impairments and produce writing of greater length and quality.

Higgins and Raskind, (1995) and Lewis (1998) evaluated the effects of voice recognition technology (VRS) as an accommodation for written expression. In the Higgins and Raskin (1995) study, the Dragon Dictate System was used to evaluate written composition of post-secondary students previously diagnosed with a learning disability and concluded that while the writing samples incorporating the VRS instead of a transcriber had a higher score, a design element in the software could have contributed to a significant successful outcome in written comprehension and that more research was warranted. Lewis (1998) further evaluated the effectiveness of word processing tools (text entry, text editing, and speech synthesis) to enhance the literacy capabilities of learning disabled students in grades 4-12 with a multi-year study. Lewis (1998) concluded that while some areas of student performance improved, the spell checking software influenced the student’s writing quality more than synthesized speech. While
these findings have produced positive outcomes in some areas, they have also provided a basis for further discovery.

Subsequent to these earlier studies, Manasse, Hux, and Rankin-Erickson (2000) conducted a single case study with a 19-year old TBI survivor with mild ataxic dysarthria using the *Dragon Naturally Speaking* speech recognition software to evaluate: 1) the accuracy levels in the interaction with the software by a subject with speech impairments, 2) the level of system training for effective navigation which is required when cognitive-communication impairments are evidenced, and 3) a comparison of the quantity and quality of writing samples with and without the use of the VRS. Manasse, Hux, and Rankin-Erickson (2000) found improvements in speech recognition with some variability attributed to length and frequency of system training, characteristics in the speech of the participant, and cognitive demands on the participant while using the system. The writing samples using a standard keyboard and general word processing software had higher results than using the *Dragon Naturally Speaking* software for written generation. However, Manasse, Hux, and Rankin-Erickson (2000) attributed this result to the amount of erroneous words produced by the system that the participant needed to navigate and correct which resulted in fewer words produced. Additionally, the generation of word complexity in this study using the speech recognition software to produce text was greater than when using the word processing software which supports the earlier findings of Higgins and Raskin (1995).

**Problem Statement**

Because the effects of TBI often result in motor deficits that impact handwriting and therefore written expression, there is a need to accommodate for handwriting of students with TBI in the classroom. No known research has studied the impact of *Dragon Naturally Speaking* with children with TBIs who have marked fine motor deficits.
Research Questions

**Research Question One:** Does use of *Dragon Naturally Speaking*, a speech-to-text assistive technology accommodation for impaired handwriting skills, increase the total written words generated by students with traumatic brain injuries compared to handwriting alone?

**Hypothesis:** *Dragon Naturally Speaking* will result in greater words written as compared to handwriting.

**Research Question Two:** Does use of *Dragon Naturally Speaking* as an accommodation increase correctly spelled words within the content produced by students with traumatic brain injuries compared to handwriting alone?

**Hypothesis:** *Dragon Naturally Speaking* will result in more words spelled correctly.

**Research Question Three:** Does *Dragon Naturally Speaking* as an accommodation improve the quality of writing as measured by correctly written sequences in students with traumatic brain injuries compared to handwriting alone?

**Hypothesis:** *Dragon Naturally Speaking* will result in improved correctly written sequences.
Chapter II: LITERATURE REVIEW

Incidence and Prevalence

Traumatic brain injury (TBI) is a debilitating condition and a major cause of death in the United States particularly for children and adolescents (Centers for Disease Control, 2010).

The Individuals with Disabilities Education Act (IDEA) (2004) defines TBI as:

…an acquired injury to the brain caused by an external physical force, resulting in total or partial functional disability or psychosocial impairment, or both, that adversely affects a child's educational performance. Traumatic brain injury applies to open or closed head injuries resulting in impairments in one or more areas, such as cognition; language; memory; attention; reasoning; abstract thinking; judgment; problem-solving; sensory, perceptual, and motor abilities; psychosocial behavior; physical functions; information processing; and speech. Traumatic brain injury does not apply to brain injuries that are congenital or degenerative, or to brain injuries induced by birth trauma.

In the period between 2002 and 2006, an estimated average number of TBIs occurring in the United States was collected by the U. S. Department of Health and Human Services Centers for Disease Control (CDC, 2010). The reported 1.7 million traumatic brain injuries, occurring in the United States each year can be further delineated: 80.7% are attributed to Emergency Department visits, 16.3% required hospitalizations, and 3.0% resulted in deaths as is illustrated in Figure 1.

Figure 1: Estimated Average Annual Number of Traumatic Brain Injury-Related Emergency Department Visits, Hospitalizations, and Deaths, United States, 2002-2006

Of all injury-related deaths in the United States, 30.5% (one third) reported TBI as a contributing factor (CDC, 2011). Approximately 75% of the TBIs occurrences each year are determined to be concussions or other forms of mild traumatic brain injury (MTBI). Nearly 80% were treated and released from an emergency department (CDC, 2011).

Further, children (0 to 4 years), older adolescents (15 to 19 years), and adults (aged 65 and older) are most likely to endure a TBI as shown in Figure 2.

![Figure 2 Percent Distribution of TBI-related Emergency Department Visits by Age Group and Injury Mechanism — United States, 2006-2010](http://www.cdc.gov/traumaticbraininjury/data/dist_ed.html)

Consistent in these findings across all age groups, is that the TBI rate for males is higher than females. Males aged 0 to 4 years account for the highest rates of TBI-related emergency department visits, hospitalizations, and deaths combined (CDC, 2011). Yeates et al., (2000) noted, however, that there are limited registries at the local, regional, and national levels for head injuries.
trauma in the United States, making it difficult to obtain accurate statistics for incidence and prevalence as the reported numbers are related to hospital admissions and may not accurately reflect milder cases of TBI.

**Epidemiology**

The National Institutes of Health (1998) reported the causes of TBI injury in a majority of cases involving children and youth ages 0-14 years to be: falls, vehicle-related collisions, violence (e.g. assaults, child abuse, shaken baby syndrome, and gunshot wound), and sports injuries. The CDC (2010) further delineated these injury mechanisms as represented in Figure 3.

Figure 3: Estimated Average Percentage of Annual Traumatic Brain Injury-Combined Emergency Department Visits, Hospitalizations, and Deaths, by External Cause, United States, 2002–2006


Overall, the male-to-female incidence ratio for TBIs is approximately 1.8:1. However, that ratio increases to 2.2:1 for children between the ages of 5-14. This trend continues into adolescence, where brain injury rates increase for males but decrease for females. According to the CDC (2010), 64% of all infant head injuries are caused by child abuse and approximately 1 in 500 school-age children acquire a TBI and are hospitalized. Further, 1 million children sustain a head injury each year and 165,000 are admitted to a hospital facility. Of those hospitalized, 1 in
10 suffer moderate to severe impairments. These impairments can result in functional deficits in cognition, attention, and memory, speech, vision, and hearing, behavior, and motor skills. Some of the factors which contribute to the deficit variability among children are age at injury, injury site, and injury severity.

Upon discharge from a hospital, 80% to 90% of the treated cases are diagnosed as mild, 7% to 8% are moderate, and 5% to 8% are classified as severe brain injury. Of those diagnosed with a mild TBI the mortality rate is <1%, moderate < 4%, and severe 12 – 62% (CDC, 2010). Since many mild TBI cases go unreported or are treated in outpatient settings, these numbers may be underestimated.

Neuropathology

In traumatic brain injury, there are two main categories of damage resulting from this type of trauma: focal damage and diffuse injury (Blennow, Hardy, and Zetterberg, 2012). A consequence of direct impact on the brain is known as focal damage which results in injuries that include cortical or subcortical contusions and lacerations. Depending on severity of the injury, these can also include intracranial bleeding (subarachnoid hemorrhage and subdural hematoma) (Blennow et al., 2012). When trauma occurs to the brain from acceleration/deceleration forces, this is known as a diffuse injury, which is a result of stretching and tearing of the brain tissue not resulting from a skull fracture or direct impact. When these biomechanical forces of acceleration/deceleration occur that lead to the shearing of axons, this is called a diffuse axonal injury (DAI) and is the primary neuropathology of traumatic brain injury (Blennow et al., 2012).

Yeates et al. (2000) found that a trauma from a closed-head injury can cause several brain injuries at the time of impact and that these changes to the brain can last for several days or a prolonged period of time depending on the severity of the injury. These alterations to the brain
can cause a variety of lesions and disruption of brain function. Yeates et al., (2000) further categorized these injuries as primary and secondary. The pathology for primary injuries includes skull fractures, intracranial contusions and hemorrhage, and shear-tear strain. Secondary injuries are an indirect result of the trauma and include brain swelling, cerebral edema, elevated intracranial pressure, hypoxia-ischemia, and mass lesions (hematoma). At the cellular level, there is an over production of free radicals, release of excitatory neurotransmitters, and a disruption of cellular calcium homeostasis. The delayed pathology includes white matter degeneration and cerebral atrophy, posttraumatic hydrocephalus, and posttraumatic seizures (Yeates et al., 2000).

The trauma to the brain can cause a variety of biomechanical forces that are identified as either impression (focal) or (diffuse) acceleration-deceleration (Yeates et al, 2000). Impression occurs when a blow to the head is caused by a physical force such as a moving object. Damage at the site of impact is called a coup. A blow to the head can cause a contusion (bruise) at the site of impact; should blood become trapped in the skull (hematoma), swelling (edema) can occur which can push the brain to the opposite side of the skull producing an additional bruise, known as a countercoup injury. Many of the common head injuries in children are associated with falls and traffic accidents and result in acceleration-deceleration injuries. In these types of injuries the disturbance to the brain can include translational and rotational trauma. The translational injuries are a linear motion and the rotational injuries involve linear and angular motion.

Closed-head injuries from vehicle-related collisions are particularly severe because the head is already moving when the accident occurs. This movement increases the velocity of the impact, the severity of the trauma, and the number of small lesions sustained. If the twisting and shearing force is significant enough, it may damage the fiber tracts crossing the midline of the brain, which can disrupt the connections between the two hemispheres. If the scarring of the
brain tissue is significant, it can also lead to epileptic seizures (Kolb and Whishaw, 2009). Bigler and Maxwell (2012) further noted the importance of understanding the pathological changes resulting from these biomechanical forces and the persisting symptoms which emerge following a traumatic brain injury event. However, it should be noted that traumatic brain injury is a heterogeneous condition and there is no single structural pattern to the injury attributes (Taber and Hurley, 2013; Bigler and Maxwell, 2012).

**Neuropsychological Consequences**

There are a variety of neuropsychological consequences that may result from a TBI. According to the CDC (2011), consequential effects of TBI can include impaired thinking, memory loss, attention deficits, and issues with movement, auditory or visual sensation changes, and variations in emotional behavior. Yeates (2000) noted that in extreme cases, many children experience a period of post-traumatic amnesia (PTA) which is used as a measure of injury severity. Children are subsequently evaluated using a test standard known as the Children’s Orientation and Amnesia Test (COAT) to evaluate the presence and duration of a PTA event. The results of this test have been used to predict post-traumatic memory functions for up to 12 months (Ewing-Cobbs, Levin, Fletcher, et al., 1990). Furthermore, Ewing-Cobbs, Levin, and Fletcher (1985) posited that outcomes from TBI related to injury severity can also include a persistent vegetative state.

Moreover, frequent long-term deficiencies in nonverbal domains can be exhibited in facial expressions, gestures, tone of voice, posture, or the inability to maintain eye contact. These deficiencies can be further evidenced in poorer non-verbal IQ performance which may be related to slower response speed, facial discrimination, and picture matching abilities. Attention deficits are evidenced by poorer response modulation and slower reaction times. Yeates et al. (2000)
found that memory deficiencies are exhibited in the impaired ability to learn and retain information over time. These deficits can be found on a variety of verbal tasks such as word list learning and paired-associates learning. Ashman, Gordon, Cantor, and Hibbard (2006) found that in addition to decreased memory performance and learning capabilities, the impact to executive functioning increases the likelihood of impairments with higher-order planning, sequencing, prioritization, abstract thinking, problem-solving skills, and inhibitory control. Dikmen et al. (1995) posited that these cognitive impairments were not restricted to measures of attention, memory, or speed of processing; but also included impairments in motor skills. Children with TBIs are likely to have difficulty with corticosensory/motor skills. Levin and Eisenberg (1979) found that following a significant TBI event, at least 25% of children exhibited deficits on tests of stereognosis (tactile recognition of an object without visual observation), finger localization (identification, naming, and location of the fingers based on touch), and graphestesia (ability to recognize a letter or number drawn on the skin using sensory information).

Furthermore, Schretlen and Shapiro’s (2003) meta-analysis of 39 cross-sectional studies from 1984 to 2003 explored the effects of mild, and moderate-to-severe TBI events on cognitive functioning and found while individuals with mild TBIs experience a more rapid recovery in the acute phase (first few weeks), a return to prior injury baseline occurs closer to 1-3 months. Conversely, while those patients with moderate-to-severe TBIs have demonstrable improvement in the early stages of recovery, they continue to be at risk for cognitive deficits 2 years post-injury. These persistent deficits may make it more difficult for children with TBIs to succeed in the classroom environment without appropriate accommodations (D’Amato and Rothlisberg, 1996).
**Language.** Language is typically characterized as having two aspects: receptive language and expressive language. Receptive language is the ability to listen and to understand both words and gestures. Following a TBI event, receptive language skills may be affected and be indicative of problems with the rate at which spoken or written information can be integrated. It may be difficult to follow multiple directions or sequence events properly. Understanding or recalling what has been read may be problematic (Savage et al., 2005).

Expressive language is the ability to use language effectively to communicate with others and includes the use of grammatical rules, the interpretation and use of gestures, and facial expressions (Miller, 2013). Some difficulties with expressive language in written expression include a child’s inability to develop and use new vocabulary. He or she may experience difficulty with remembering a preferred word when writing; may demonstrate a decreased ability to spell words correctly, may have written descriptions which are lengthy, unorganized, and rambling, and have difficulty writing sentences (Savage et al., 2005).

When a child or adolescent sustains a TBI, verbal or writing skills to communicate ideas can be negatively impacted. Verbal communication may appear rambling or repetitive, and the child may have difficulty maintaining one topic of conversation. Because learning is language based, the development of good communication and comprehension skills relates to later literacy skills in a child’s ability to read and write. Since the brain acquires specific language skills at different times across early childhood, a TBI may disrupt normal development making the negative consequences more severe.

**Memory.** Ewing-Cobbs, Levin, and Fletcher (1985) posited that the period of posttraumatic amnesia (PTA) immediately following a TBI is when the child or adolescent is unable to store or recall ongoing events in memory. In assessing both verbal and nonverbal
memory scores at three time periods following a TBI: 3 weeks, 6 months, and again at 12 months, Ewing-Cobbs, Levin, and Fletcher (1985) found significantly more cognitive impairments, difficulties with orientation, and more pronounced confusion at the earliest time point in the recovery phase as opposed to the 6 and 12 month intervals when evaluating these respective scores on the Children’s Orientation and Amnesia Test (COAT).

A child with many cognitive deficits may have difficulty with declarative (explicit) and non-declarative memory (implicit). Explicit (declarative) memory is the ability to consciously recall experiences, facts, or events which can be either episodic or semantic events (Kolb and Whishaw, 2009). Episodic events are context specific and often are autobiographical (an event memory). Semantic events are context free and represent general knowledge of symbols, concepts, and rules for manipulating them. For children with TBI, implicit dysfunction can manifest itself in a child’s inability to tie her shoes or remember how to ride a bike. A child may also have difficulty with retrieval and may require cueing and redirection.

**Attention.** The attention process is deliberate and requires conscious activity to not only be alert to a change in the current state, but also to be able to localize the source of the change (Schunk, 2012). For example, children with TBIs may not have a long enough attention span to pay attention (be vigilant) in class or listen long enough to receive directions and take appropriate action. Events must be perceived as meaningful and relevant to be attended to by the learner (Schunk, 2012). Children with TBIs often have difficulty focusing and sustaining their attention on educational materials. For example, distractors such as ambient noise and irrelevant stimuli in the classroom may be difficult for them to filter from the learning environment. As a result, they may have decreased classroom responses and slower reaction times (Yeates, et al., 2000).
**Executive Functions.** Since executive functions are purposeful and goal-directed, disruption from a TBI can impact planning ability, organizing, goal setting, and self-monitoring skills which may result in lasting consequences limiting academic performance. For example, academic achievement in the areas of reading, spelling, and arithmetic may be compromised (Catroppa et al., 2009). Taylor et al. (2002) examined scholastic achievement with children who had sustained moderate-to-severe TBIs four years post-injury in a follow-up study and found poorer behavioral outcomes and writing skills compared to children with orthopedic injuries not involving brain trauma.

Mangeot, Armstrong, Colvin, Yeates, and Taylor (2002) evaluated long-term executive function deficits in children who sustained a TBI event between the ages of 6 – 12 and found that 5 years post-injury the sequelae of TBI often continues beyond the acute recovery phase. As discussed previously, age at time of injury and degree of severity are key predictors for potential negative long-term outcomes in school performance, behavioral adjustment, and adaptive functioning (Mangeot et al., 2002).

**Sensory and Motor Skills.** Behavioral deficits in sensory and motor skills following mild-to-severe TBI often manifest as: attention difficulties (sustaining and/or shifting attention), problems with depth-perception, decreased impulse control, loss of sensation, decreased organizational ability, task orientation difficulties, visual problems and impairments, and sensory overload (D’Amato and Rothlisberg, 1996). Motor skills (the smoothness and timing of movements) are developed gradually and require practice, repetition, and consistency of muscular movements (Schunk, 2012). Children with TBIs often experience problems with their fine motor skills, such as issues with eye-hand coordination, completing hand movements, writing speed, and letter formation fluency (D’Amato and Rothlisberg, 1996).
Klonoff, Clark, and Klonoff (1993) conducted a 23-year follow-up study on participants enrolled in the National Institute on Disability and Rehabilitation Research to identify group changes regarding long-term outcomes of children with head injuries who received in-patient rehabilitation, and found that motor changes peak by 1 year after injury, while cognitive changes continue to persist several years after the TBI event. Klonoff et al. (1993) further noted that subsequent research was needed to identify differences among individuals who have sustained a TBI rather than homogeneous group changes to further ascertain the long-term recovery progression and to better identify those most likely to continue to deteriorate.

**Academic Performance.** Academic skills are generally considered to be crystallized or overlearned skills and are negatively impacted immediately after the injury to the extent that the head injury is moderate to severe. Catroppa and Anderson (2004) conducted a longitudinal study with children who had sustained a mild, moderate, or severe TBI and found residual impairments in the language areas at 24 months in moderate to severely injured children, suggesting that deficits may continue to manifest and influence academic ability in expressive, receptive, and written communication.

Children with mild head injuries are likely to retain previously learned academic skills. However, over time, academic performance may decline as new learning is required and the complexity of material increases (Ewing-Cobbs, Prasad, Kramer, et al., 2006). New learning appears to be impacted the most and a decline in academic performance becomes more evident especially with children who sustained a TBI between the ages of 2-7 years (Yeates, Ris, Taylor, 2000; Taylor, Swartwout, Yeates, Walz, Stancin, and Wade, 2008; Anderson, Catroppa, Morse, Haritou, and Rosenfeld, 2009).
In a 10-year longitudinal study of early TBI cases in children less than 3 years of age, Anderson, Godfrey, Rosenfeld, and Catroppa (2012) found an elevated risk of persisting deficits in those children who sustained a severe TBI event. Anderson, Godfrey, Rosenfeld, and Catroppa (2012) further noted that 1 in 3 of these children was most likely to have an elevated risk of disrupted development and sustain permanent impairment. Those children in the study, whose injuries were less severe, tended to recover much of their age-appropriate functioning at approximately 10 years post injury. With regard to previous literature, these findings further substantiate the residual effects that long-term deficits have on scholastic ability and academic performance (Anderson et al., 2012).

As a result of the effect on these neuropsychological skills, written expression can be negatively impacted by these deficits particularly due to fine motor output. As Berninger et al. (1997) noted this becomes increasingly apparent in the primary grades when neurodevelopmental factors interfere in the transcription processes complicating a child’s ability to convert ideas into output by translating these thoughts into expressive language. When children have difficulty with handwriting automaticity and spelling skills, this can lead to problems in the translational generation for written expression. Of these neuropsychological consequences, germane to this study, is the disruption of motor output as one of the common consequences of TBI and its impact on written expression output. Further exploration in the literature requires a scaffolding of theoretical constructs of these functions as they were developed in contemporary terms. One such theoretical paradigm was posited by Luria (1973) in his seminal work, *The Working Brain*. 
Theoretical Framework Guiding the Dissertation

Luria’s (1973) theoretical context of functional systems and underlying principal and subordinate deficits provides the framework for neuropsychological dysfunction in children following an episodic TBI. Luria (1973) posited a comprehensive and systematic assessment approach to cognitive disorders through the analysis of disrupted cognitive paths. Korkman (1999) theorized that although Luria’s schema (1973) was the result of his work with adults in late-stage cognitive development, his theory and methods could provide a foundation for understanding early acute brain damage in children. Luria (1973) regarded the processes of the brain as a highly complex and interrelated system of perception, speech and intelligence, movement and action, and goal-directed conscious activity. Luria (1973) suggested that when these processes (linkages) become disrupted from brain trauma, changes in human behavior and mental activity are manifested.

Luria (1973) described the following neuropsychological domains for typical written expression output: symbolic perception (letters, words, numbers, and punctuation), spatial orientation, internal speech (decoding meaning), attention, and memory. For example, difficulty with spatial positioning may manifest in trouble forming letters. Given Luria’s (1973) identification of efferent (or kinetic) motor aphasia, letter production may result in the same letter being produced numerous times, or it may be omitted, or displaced. When language (speech) is impaired, sounds may become confused in phonological memory and this can result in words spelled in a dysphonic fashion or word choice that does not make sense giving the meaning of the sentence. Disruptions in any of these domains can have a profound impact on written expression.
**A Series of Links.** The hallmark of Luria’s seminal work (1973) was the description of how discrete neuropsychological skills are linked together like a chain as component processes to complete an action. If any one of these performance domains becomes disturbed by a pathological lesion, such as in a traumatic brain injury, a functional impairment will manifest (Luria, 1973).

Luria (1973) posited that these human mental processes require the participation of groups of functional units that work in concert in this purposeful system of three principal hierarchical units described as the primary, secondary, and tertiary cortical areas. The first unit is concerned with cortical activity and alertness; the second unit is responsible for the synthesis of the reception, analysis, and storage of information from visual, auditory, and general sensory information; and the third and final unit is considered overlapping and provides regulatory analysis and symbolic schemes of conscious activity (Luria, 1973). As an overall functional system, these three units and their interconnected underlying processes form the basis of all cognitive activity (Korkman, 1999).

Luria’s (1973) discussion of Vygotsky’s theory of “dynamic localization” advanced the concept that lesions occurring in early childhood have a systemic effect and may lead to underdevelopment of higher-order thinking processes, whereas a similar lesion in an adult would not have a comparable impact since many of these processes were well-established at an earlier stage in development. Luria (1973) further expounded on the ‘*dynamic localization*’ of higher mental functions as concertedly “working zones” of the brain. Luria’s (1973) intricate components or links were used as the framework to identify the structural organization of writing. germane to the present study, the functional outcome of interest is written expression.
Therefore, if any one of these linkages was disrupted, poor written expression could occur. For example, if the motor-sensory part is disrupted, then there would be written expression difficulty.

The neuropsychological consequences of an acquired TBI are not homogeneous; they are as varied as the individuals who experience them. Some of the factors which contribute to this variability among children are the site of injury, injury severity, and time since injury. Since written expression is a complex undertaking, disruption in any of the domains can have a negative impact on expressive output and academic performance. Within Luria’s (1973) framework, one commonly identified broken link with TBI is fine motor skills. Impairments in fine motor skills interfere with the production of written expression. The Dragon Naturally Speaking software will be implemented as an accommodation to by-pass fine motor skills. The purpose of this study is to investigate the effects of speech-to-text technology on the written expression of children with TBI.

**Overview of Written Expression**

Flower and Hayes’ (1981) *Cognitive Process Theory of Writing* posited that “writing is best understood by a series of distinctive thinking processes (planning, translating, reviewing, and revising) which writers orchestrate or organize during the act of composing… a goal directed thinking process” (p. 366). Flower and Hayes (1981) compared and contrasted the rigid linear stage models of writing which include the planning and revision process with a cognitive higher-order thinking process of writing. This higher-order process includes decision making and choice selection in the generation of ideas starting with the knowledge retrieved from long-term memory, while subsequently attending to the design of a meaningful representation through creativity, innovation, and discovery. This goal-setting method originates as an initial abstract planning process. The end product is the translation of these ideas which may include syntax,
symbols, and imagery of emotions, relationships and sensations “into a linear piece of written English” (p. 373). This integrated and complex process of communication from idea formulation to the generation of written language comprises many neuropsychological interrelated components which demonstrate that writing is not a linear process but one which is iterative with distinctive structural attributes.

Building upon the earlier work of Flowers and Hayes (1981) and further investigating this iterative process, Ewing-Cobbs, Levin, Eisenberg, and Fletcher (1987) investigated language function following closed head injury and noted a more significant impact on written language in children versus adolescents in their study. Ewing-Cobbs et al. (1987) findings suggest that there is a predisposition to disruption in emerging written-language skills following a closed head injury especially in the preschool years when language is in rapid development.

Other researchers have also attempted to conceptualize the processes involved in writing. Graham (1990) succinctly outlined two component skills involved in written expression. These are transcription and generation skills. Low-level transcription skills involve the motor output for handwriting and spelling. Generation skills involve higher-order skills and include the planning of ideas, word choice, grammar and syntax.

**Transcription Skills.** McCutchen (2000) proposes the process of transcription is both a cognitive and physical progression through the symbolic, written representation of text rather than its oral or spoken representation. In the earliest stages of writing development, spelling and handwriting seem to be constraining (McCutchen, 2000). Graham, Berninger, Abbott, Abbott, and Whitaker (1997) investigated the mechanical requirements for text production of spelling and handwriting and posited that transcription skills are lower level skills that should be automatized so the writer can develop higher order skills of planning and content generation.
For example, when a writer must switch attention during composing to word spelling, creative ideas and schemes may become lost or disjointed. Moreover, if the writer is struggling with handwriting fluency in text production, demands may be placed on working memory and the composition process, which may further interfere with amount and quality of content generation. When working memory is constrained, errors in complex syntax tend to increase.

Some of these constraint conditions result from the creation of letter form representations in memory, the speed by which these representations can be accessed and retrieved from memory, motor planning and motor production (Berninger et al., 1997). When attentional resources are autonomous, more attention can be devoted to planning the content, interpreting, reviewing, and revising the processes of composition.

Berninger and Richards (2011) further expounded on this process by elaborating on the integral relationship between learning how to read and learning how to write. The process begins with audible word and letter sounds (associated with phonemes) and their internalization into working memory as coded, orthographic word-forms. Decoding becomes the process of translating written word-forms into spoken language, and writing becomes an integrated process of letter construction and letter awareness comprised of a coordination of fine-motor and visuospatial skills (Berninger et al., 2011).

Working memory is one of the most heuristic and important concepts of cognitive psychology. In order for the transference and preservation of the information into long-term memory, deliberate action such as articulatory rehearsal or coding it for storage is essential. To increase the limited information capacity in working memory, automating processes such as handwriting, spelling, vocabulary and “chunking” information into meaningful units can increase functional capacity and reduce the burden placed on working memory (Ylvisaker and Szekeres,
Phonological awareness is a necessary component of developing effective spelling skills. Accomplished readers develop orthographic knowledge of likely spelling patterns so they can easily decode the printed words with the shapes and names of letters and the series of sounds associated with them to establish meaning of the text. Handwriting is the symbolic representation of these collective letters and sounds; written expression is dependent on the development of fluency in handwriting skills.

**Generation Skills.** According to Vacca et al. (2012), there are three distinct systems in written language: the graphophonemic system, the syntactic system, and the semantic system. The graphophonemic system utilizes graphic symbols to visually represent speech sounds which consist of both regular and irregular letter-sound relationships. The syntactic system illustrates the grammatical relationship within sentence patterns; and, the semantic system, which has been influenced by cultural beliefs, attitudes, and values by forming a connection to previous experience and prior knowledge. In essence, it is the ability to think and to reason with the written word that yields meaning which leads to comprehending. Children’s prior knowledge is a composite of their social experiences, conceptual understandings, attitudes, beliefs, and unique skills which provide the framework for the organization, categorization and meaning construction for new information to create new comprehension (schemas), increasing their intellectual capacity and the scalability of deeper understanding.

Graham (1990) identified several factors which could interfere with production in the writing process: the impact of mechanical interference on idea production, the rate of production,
and a restricted or constrained vocabulary. Graham, Berninger, Abbott, Abbott, and Whitaker (1997) investigated the mechanical demands involved in compositional fluency and compositional quality of 300 children in primary and intermediate grades 1-6 and found that a significant proportion of the variance in compositional fluency (41% to 61%) and compositional quality (25% to 42%) was accounted for by handwriting fluency and spelling. These findings indicate the constraint effects that mechanical skills may assert on the quantity and quality of content generation.

Attentional switching places a demand on cognitive abilities when focusing on lower-level processes such as handwriting and spelling. The mechanics of letter sounds and correct groupings to form words and subsequently translate them to paper through orthographic-motor movements may interfere with the conveyance of ideas during the translation process. Difficulty with spelling may cause students to choose alternative words from their vocabulary as substitutes they can spell but which may not adequately express their thoughts and related concepts as they intended. Incorporating appropriate syntax in the development of sentence structures further complicates the production process and may increase cognitive load demands, resulting in disorganized written expression. This cognitive effort can be attributed to the competing of limited (working memory) resources for both activity levels during written language production with more resources being utilized for those low-level activities which have not been automated.

Berninger and Amtmann (2003) suggested in their progressive model that writing is a developmental and systematic process with transcription as a fundamental element in converting ideas into written language. The executive functions involved in the organizing, storing, and retrieval from memory guide text generation and monitoring of written expression. During the composition phase, short-term memory is engaged with changing ideas into symbolic language
for text generation while long-term memory is active in the self-regulated revision phase of orthographic production. Improving handwriting automaticity or spelling, can have a direct impact on text generation (compositional fluency) and the quality of composition by having more cognitive resources available for higher-level constructive content skills. In their intervention study of 144 at risk 1st graders, Berninger et al., (1997) determined that “frequent, brief, explicit instruction” (p. 665) enhanced the children’s letter production automaticity which resulted in improved composition quality.

Generation disorders can therefore be causally linked to difficulties with executive functioning and language constraints, while transcription can be hindered as a result of difficulties in handwriting and spelling associated with motor impairments and phonological/orthographic deficiencies (Fletcher, Lyon, Fuchs and Barnes, 2007). In contrast, when children are taught explicit strategies which focus their attention and memory on problem-solving, planning, and self-regulation techniques during the composition process, there is demonstrable improvement in their written expression (Fletcher et al., 2007).

However, cognitive and motor disturbances, as a result of a TBI event, can impact both transcription and generation skills in written expression. For example, children and adolescents with this type of trauma may develop functional deficits in fine motor control which can impact the quality and dexterity of movements and limit their ability to reach and to grasp, both of which are necessary for the formation of letters, handwriting speed, and legibility. In addition to poor handwriting, an increase in spelling, grammar and punctuation errors in the mechanics of writing may be evident, as well as limited word choices within the context of idea generation and paragraph composition (Berninger and Amtmann, 2003).
As discussed previously, persistent impairments in executive functions of attention, initiation, planning, organizing, and memory are likely to be present in children with moderate to severe TBIs. The cumulative, negative consequences of these cognitive deficits from an early TBI can impact a child’s ability to read, write, or perform mathematical calculations (Fay et al., 1994). Farmer, Clippard, Luehr-Weimann, Wright, and Ownings (1996) noted that for children who have experienced a TBI, the emphasis on written expression in the classroom is on the production of writing, rather than the process of writing. Germane to this study, is the exploration of a written expression accommodation to by-pass these deficits and mitigate the obstacles to this process.

**Written Expression Accommodations.** Shaftel, Yang, Glasnapp, and Poggio (2005) defined accommodations as “… those alterations to test presentation, setting, timing, scheduling, and response that mitigate the barrier of disability and allow a student with disabilities to demonstrate actual achievement in a particular academic area without changing the underlying construct of what is being measured” (p. 358). Furthermore, Shaftel et al. (2005) noted that accommodations can be provided to any student based on need as a part of routine instruction and not necessarily based on a disability position. For example, extra time, frequent breaks, and verbal instructions are generic classroom accommodations. Specific to written expression, example accommodations include: typing on alternative keyboards; touch screens; spell checkers with a visual display or auditory output; grammar and style checkers that will verify syntax, sentence structure, punctuation and capitalization, and writing style; word completion and word prediction software; word processor with speech synthesis; and graphic organizers to assist in content organization through visual mapping software (MacArthur, 1996; Merbler, Hadadian, Ulman, 1999).
MacArthur, Graham, and Schwartz (1991) reviewed the writing behavior of students with learning disabilities using paper and pencil, and word processors for written output and found that while the technology accommodation augmented their written expression, these students still experienced issues regarding when to evaluate and revise their text without instructional prompting to correct the errors. Students tended to add more content information with less attention to clarity, consistency, and structure (MacArthur et al., 1991).

Subsequent to this research, MacArthur and Graham (1993) continued to explore the word processing technology for the development of writing skills and found mixed results regarding the value of this type of technology as an accommodation to improve written expression. MacArthur and Graham (1993) concluded that instructional support was still needed to provide students with an appropriate level of knowledge to effectively and efficiently complete the editing and revising process to improve their writing skills.

**Assistive Technology for Written Expression.** The Individuals with Disabilities Education Act (2004) defines assistive technology as “any item, piece of equipment, or product system, whether acquired commercially off the shelf, modified, or customized, that is used to increase, maintain, or improve functional capabilities of a child with a disability” (Office of the Federal Register, 2006, p. 46756). According to Lewis (1998), computerized technologies are most often associated with the term assistive technologies (AT). However, AT can be more broadly conceptualized as any technology that enhances the functional capabilities of a person with disabilities. For example, one type of AT is a paper-based computer pen that captures audio while a student is taking notes on special paper during a lecture. The student can then listen to any section of his notes by touching the pen to his handwritten notes or drawings and retrieve the audio playback.
Another type of AT involves optical character recognition (OCR) which is based on a scanning technology. The text is scanned and then read aloud to the student. These two technologies can assist individuals who struggle with reading, listening, memory, and writing (Stanberry and Raskin, 2009). Building on this definition, Lewis (1993) further noted that an assistive technology has two fundamental purposes: 1) to enhance the strengths of the individual to offset their limitations, and 2) to by-pass the disability entirely. For children with TBI who have difficulty with fine motor output, the speech-to-text application of the Dragon Naturally Speaking software program will be evaluated as an AT accommodation to by-pass these deficits.

**Speech-to-Text Assistive Technology.** Higgins and Raskind (1995) investigated the use of speech recognition software (Dragon Dictate System) to evaluate written composition performance with twenty-nine post-secondary students previously diagnosed with a learning disability at California State University, Northridge (CSUN). The students were tested under three conditions: using the speech recognition software, with a human transcriber, and with no assistance to assess their proficiency in written production. Higgins et al. (1995) noted that there was a statistically significant difference (p = .048) with written comprehension using the speech recognition software as compared to the other two assessed areas. Higgins et al. (1995) attributed this finding to the technology ‘encouraging’ the students to select longer words (seven or more letters) rather than shorter, less complex words, suggesting that a design element existed in the software to more accurately determine multi-syllabic words as opposed to uni-syllabic words, thus contributing to this outcome. Some limitations of this study are the relatively small sample size (n = 29), the mean age of the participants (M = 24.9), and the expansiveness of their vocabulary choices (multi-syllabic = 7 letters or more) which “may not apply to populations of students with learning disabilities at lower grade levels” (Higgins et al., 1995, p.169).
Lewis (1998) further evaluated the effectiveness of word processing tools (text entry, text editing, and speech synthesis) in enhancing the literacy capabilities of learning disabled students in grades 4-12 with a multiyear study. The results of Lewis’ (1998) studies were reported to the U.S. Department of Education, Office of Special Education and Rehabilitation Services and determined that 1) word processing impacts the accuracy of student writing by reducing the number of errors in mechanics and syntax, 2) word prediction improves text entry speed, 3) spell checks enhance effectiveness of editing tools, grammar checkers did not, and 4) spell checks influence student’s writing quality and accuracy more than synthesized speech.

De La Paz (1999) investigated dictation and speech recognition systems for oral composition by students with learning disabilities as a process to by-pass the mechanical transcription demands of handwriting, spelling, and punctuation to improve the focus on higher-order planning and idea generation. De La Paz (1999) posited these two factors impede composition construction as a result of difficulties with mechanics and slow rate of production for students with learning disabilities; and, that speech recognition software, such as Dragon Naturally Speaking is beneficial because it allows for more focused attention on content generation. De La Paz (1999) however noted a need for individuals with learning disabilities to plan before composing as the dictation and speech recognition systems alone were not sufficient to compensate for these difficulties. Moreover, time in training students with learning disabilities is required to learn speech commands, the keyboard, and error correction strategies prior to system use.

Keyboarding enables the user to find and choose the correct keys and to more easily see the relationship between letters (symbols) and words on the keyboard and the computer monitor. By reducing cognitive load of the fine motor skills required in handwriting, letter and word

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spacing, and the enabling of error detection and letter/word correction through spelling and grammar checkers, total words written can be improved. However, individuals with impaired motor disorders may be limited in their abilities to use keyboards. They may lack sufficient motor movement abilities, or the process of working on a keyboard may be too taxing causing fatigue and increased frustration.

An alternative to keyboard entry is the use of human-computer interaction (HCI) tools. As a rehabilitation strategy, HCI has increased significantly as an assistive technology (AT) domain. Leveraging technology to mitigate cognitive deficits and physical impairments has provided the learning disabled (AT) interventions in attention, memory, sequential processing, and social cueing of appropriate behaviors. Such AT accommodations have included speech synthesizers, word analyzers, word processors, spelling and grammar checkers, graphical organizers as concept mapping tools, and voice recognition systems (Lewis, 1998).

Hui, Liaskos, and Mylopoulos (2003) have explored HCI from a customizable software approach by designing applications solutions from a user requirements perspective rather than a design-level requirements process. In creating customizable software for the TBI population, Hui, Liaskos, and Mylopoulos’ (2003) model follows a goal-oriented progression rather than a traditional use case process for this population by identifying a set of required and supported skills for the end-users to interface and actively engage with the software application. The required user profile skills included selection, attention, memory, initiation, and self-awareness. For example, an individual with TBI uses the selection skill in conjunction with the required motor skill to move a mouse, or depress a key on a keyboard. When interacting with voice recognition software, such as Dragon Naturally Speaking, it requires both speech articulation and motor skills. In the error checking and editing function, these skills are both visual and motor
based for hand-to-eye coordination. Developing new techniques for software applications such as goal-oriented customization will result in a broader outreach to meet the diverse needs and abilities of individuals who have experienced a TBI event.

Voice Recognition Systems (VRS) such as *Dragon Naturally Speaking* provide a speech-to-text accommodation negating the need for a human scribe. Since less time is spent in transcription, there is a reduction in cognitive load, enabling more time to be spent on generation skills, such as idea development, selecting more complex words that might be otherwise difficult to spell, and grammar. It is therefore important to consider the accuracy of speech recognition software when it is used with individuals who have acquired dysarthric speech and other motor disorders resulting from a TBI event.

Hux, Rankin-Erickson, Manasse, and Lauritzen (2000) expanded on the earlier research of Higgins and Raskin (1995) and investigated the word accuracy of three speech recognition systems: Microsoft Dictation, *Dragon Naturally Speaking*, and VoicePad Platinum and compared and contrasted the speech patterns of two participants: one with TBI and mild dysarthria, and a speaker without dysarthria (as a control participant). These authors evaluated the percentage of word accuracy of the three speech recognition software programs between the participants under two treatment conditions: preselected sentences read aloud and the generation of novel sentence production over five training sessions with each system.

Hux et al., (2000) noted the differences in continuous speech recognition systems of Microsoft Dictation and *Dragon Naturally Speaking*, and the discrete speech recognition system of VoicePad Platinum® with the TBI patient and the mild dysarthria as compared to the speaker without dysarthria. Depending on the idiosyncrasies of the speech patterns, the severity of the dysarthria, and the TBI cognitive challenges presented, each system had varying percentage
accuracies. However, of the three systems evaluated in this study, the *Dragon Naturally Speaking* program achieved a higher percentage of word accuracy consistency which may be attributable to the word prediction capabilities of the system.

The aim of this study is to assess the effectiveness of *Dragon Naturally Speaking* as an accommodation to improve transcription skills necessary for written expression through a systematic approach to evaluate the software platform based on its inherent merit and programmatic outcomes. *Dragon Naturally Speaking* (voice recognition software – VRS) will be used as an accommodation to bypass the fine motor component of writing to increase written expression. The probability for improvement will be quantified through a direct assessment of the writing samples.

It can be inferred from these earlier studies that incorporating technology into the writing production process can enhance some aspects for students with learning disabilities. However, no known studies have investigated the effects of speech-to-text assistive technologies on the written expression of children with traumatic brain injuries who have marked fine motor control deficits. By being able to transfer ideas out onto the screen, students can achieve more complex thoughts and express themselves more clearly, thus improving self-management of one’s writing skills.
Chapter III: METHOD

Participants and Setting

The participants for this study included three middle school students with TBI who also had fine motor skill deficits that must be accommodated and written expression difficulties. The special services administrator at the respective school district was provided with a recruitment letter and parental permission forms to provide to each potential participant’s parent or guardian. These documents were subsequently given to each participant’s teacher and sent home with the child for parental/guardian review and consent. The signed forms were returned to the school with the child and provided to the researcher by the teacher. Parents were encouraged to contact the researcher if they had any questions. Each teacher then individually introduced each participant to the researcher. The researcher developed a data collection schedule. Students, parents, and guardians were notified that the student participants would receive a $25 Visa gift card at the end of their participation in the study’s procedures.

For the purpose of this investigation, the first participant is identified as James. James is an African-American male enrolled in the 4th grade who receives special education services under the category of TBI. James’ head injury was the result of a pedestrian motor vehicle accident when he was less than 5 years old. He apparently was in a coma for approximately one month. Anecdotally, James has the most severe head injury of the three participants.

The second participant, Ivan, an African-American male enrolled in the 8th grade. He also receives services as a student with TBI. When Ivan was three years old, he fell from a second story window. Roger, the third participant, is an African-American male who is enrolled in the 9th grade and has a formal TBI designation. Roger experienced physical trauma as an infant. Of the three participants, Roger appeared to have experienced the least severe head injury. All
condition sessions were conducted in a quiet conference room or classroom setting, in the respective student’s public school building. Students participated in each session individually.

**Materials**

**Story Prompts.** Each participant was provided with ten different story prompts across the five week data collection period (i.e., five story prompts for the handwriting control condition and 5 story prompts for the speech-to-text condition) in order to stimulate narrative writing in this research study. The story prompts were auto-generated from AIMSweb and randomly selected for this research study. An example story prompt is, “Yesterday the children went for a picnic and …” (AIMSweb, 2004). The story prompts were scored for Total Words Written (TWW), Words Spelled Correctly (WSC), and Correct Writing Sequences (CWS) to determine the effectiveness of the intervention.

**Handwriting Condition Materials.** Each participant was provided with a typed story prompt on the top of a lined sheet of paper in order to write a narrative consistent with the story prompt. Each handwriting condition data point involved a unique story prompt. Each participant was provided with a sharpened pencil with an eraser and the researcher used a stopwatch to time the participant consistent with Written Expression – Curriculum Based Measurement (WE-CBM) administration rules.

**Speech-to-Text Condition Materials.** Each participant was provided with a laptop computer pre-loaded with the Dragon Naturally Speaking (DNS) voice recognition software program (VRS). Each participant was provided with a USB microphone in order to speak aloud responses to the story prompts and be recorded using the speech-to-text software. Each participant was presented with a data file stored on the laptop that contains a unique story prompt for each of the five speech-to-text sessions. Each participant used the USB microphone to dictate
his narrative from the end of the story prompt which was displayed on the laptop screen. For example, the experimenter read aloud: “I couldn’t fall asleep in my tent. I heard this noise outside and...” (AIMSweb, 2004), and then the participant began speaking a response to the prompt. The researcher used a stop watch to time the participant consistent with WE-CBM administration rules.

**Experimental Design**

Barlow and Hayes (1979) posited the use of the alternating treatments design (ATD) as appropriate for a single-participant with the intended purpose of a rapid comparison of two counterbalanced conditions to determine relative efficacy. Some of the advantages to this type of design are that baseline data is not required, ATD does not require the withdrawal of treatment thus avoiding ethical concerns, counterbalancing helps to eliminate sequencing effects, and data points can be analyzed by visual inspection (Herrera and Kratochwill, 2005; Richards, Taylor, Ramasamy, and Richards, 1999; Ollendick, Shapiro, and Barrett, 1981).

With respect to this research study utilizing an ATD, it is appropriate to have a minimum of three-to-five participants. The three participants selected for this study were at least in the 3rd grade or higher (up to grade 12) with a history of TBI from the surrounding school districts. Initial contact for the study was made through ongoing professional relationships of the researcher with the local schools. All condition testing sessions and data collection occurred within the student’s school building in a quiet location determined by the school staff (e.g., computer lab, reading room, unused classroom, etc.).

In this alternating treatment design (ATD), two separate conditions (Handwriting and Speech-to-Text) were compared for their effects on written expression (Barlow and Hayes, 1979). The collection of multiple data points better ensured that any differences that resulted
may be validly linked to the experimental conditions. The counterbalancing used in the alternating treatment design will eliminate sequencing effects, which, if not removed, have the potential to obscure the results. Further adding to the robustness of the design, the two treatment conditions in this study are sufficiently different from each other so that the participants can discriminate between them (Richards, Taylor, Ramasamy, and Taylor, 1999).

The alternating treatment design was used to compare the effects of 1) a handwriting condition, and 2) a speech-to-text condition on written expression output with a single subject (Richards et al., 1999). The two writing conditions, handwriting and speech-to-text, was evaluated across five sessions using ten distinct story prompts. After each story prompt was administered, one of the treatment conditions was implemented followed by the second treatment condition with an alternative story prompt. The treatment conditions were counterbalanced at each session so that one treatment condition is not always implemented first or last (see Appendix A for the treatment condition schedule). The data collection took place across five weeks.

**General Experimental Procedures**

**Speech-to-Text Training Session.** Each participant was provided with an introduction to Dragon Naturally Speaking (DNS) and a training session to ensure familiarity with the program, the USB microphone, and the laptop computer prior to the administration of the first speech-to-text condition. In the training session, each participant was introduced to the Accuracy Center tutorial in DNS. In this tutorial, the participant was guided through general training and set-up steps so the voice recognition software program (VRS) could learn what his voice sounds like, how to position the microphone to avoid distortion of the sound of his voice, and a quality to check to insure the audio is set to the correct volume level for clear voice input. These steps were
accomplished when the participant was asked to read a short story when prompted by the computer program. The DNS program did record the story as it was being read by the participant and provided a beep tone acknowledgement for sound, clarity, and the individual participant’s voice recognition pattern, signaling the program was ready to begin. This process sequence is necessary to train the program to recognize each participant’s voice and unique speech patterns which leads to greater accuracy in the dictated words that appear on the computer screen. The DNS tutorial preparation took approximately 15-20 minutes to complete. However, it should be noted due to possible Dysarthric speech patterns, the DNS training may take additional time prior to starting the procedures.

**Handwriting Condition Procedures.** Each participant was provided with a typed story prompt on the top of a lined sheet of paper in order to write a narrative consistent with the story prompt. Each participant was provided with a sharpened pencil with an eraser and instructed to write his story on the form. Each student was instructed to not pick up his pencil until he hears the phrase, “*Now begin writing.*” The participant had one minute to reflect on the story starter and three minutes to write the story. A stop watch was used for accurate timing of the reflection (one minute) and the writing session (three minutes). Each participant was provided with specific oral instructions: “*You are going to write a story. First, you will read the beginning of a sentence, and then you will write about what happens next. You will have one minute to think about what you will write, and three minutes to write your story. Remember to do your best work. If you do not know how to spell a word, you should guess (AIMSweb, 2004, p. 24).*”

Once the participant had read the story prompt, the researcher started the stop watch for the one-minute reflection period. After one minute, the researcher instructed the participant to “*Now begin writing*” (and time the writing session for three minutes). At the end of the three
minutes, the researcher said, “Stop. Put your pencil down.” The researcher collected the assessment form from the participant for scoring.

**Speech-to-Text Condition Procedures.** With respect to the collection of each speech-to-text data point, each participant was provided with a laptop with the DNS software pre-loaded. The researcher retrieved the stored data file with a pre-typed story prompt. Each participant was given specific oral instructions: *You are going to write a story using the Dragon Naturally Speaking software program. First, you will read the beginning of a sentence on the computer screen, and then you will write about what happens next. You will have one minute to think about what you will write, and three minutes to write your story by clearly speaking into the microphone. Remember to do your best work.*

Once the participant had read the story prompt on the computer screen, the researcher started the stop watch for the one-minute reflection period. After one minute, the researcher instructed the participant to “Now begin to write the story by speaking clearly into the microphone.” When the participant begins speaking, the researcher will time the participant for three minutes. At the end of the three minutes, the researcher said “Stop.” The participant’s verbal output was recorded on the computer screen by the software program; the researcher saved the word processing file for later scoring.

**Dependent Variables**

Written Expression Curriculum Based Measurement (WE-CBM) is a tool used to measure the dependent variable. As a growth and development curricula tool, Curriculum Based Measurement (CBM) can provide effective insights into the four academic domains of reading, spelling, writing, and mathematical achievement as a reliable and valid form of measurement. The *Written Expression-Curriculum Based Measurement (WE-CBM)* is applicable through grade
six for typically developing students and is relevant for individuals with severe writing impediments (Powell-Smith and Shinn, 2004). Deno, Fuchs, Marston, and Shin (2001) posited that CBM provides an integrated framework approach to measurement by creating a bridge between standardized measurements and traditional reliability and validity with qualitative behavioral and observational measurements. Deno, Fuchs, Marston, and Shin (2001) suggest that this blending of frameworks provides a process for assessment at variable time periods with alternative interventions for the same participant.

CBM written expression is measured in Total Words Written (TWW), Words Spelled Correctly (WSC), and Correct Written Sequence (CWS). The Written Expression CBM tool assesses correct spelling and capitalization usage and the order of words and sentence structure in written samples. The scores can be calculated and represented in a graphical format. The graph provides educators with trending patterns through which they can determine if changes in instruction are indicated based on the student’s rate of learning progress and level of academic competence.

**Total Words Written (TWW).** Total words written is an indicator of the amount of written output produced by a student. A word is defined as any letter or group of letters separated by a space and is counted even if misspelled or considered to be a nonsense word (AIMSweb, 2004). TWW are calculated by underlining the discrete words produced and summing the total. For example, The red car went fast. TWW = 5

**Words Spelled Correctly (WSC).** Words spelled correctly are intended to be one measure of the quality of written output produced by a student. A word is considered to be spelled correctly, within the appropriate context of the English language, if it can be understood using low-inference judgment (AIMSweb, 2004). WSC are calculated by circling the incorrectly
spelled words, summing the circles, and subtracting this number from TWW. For example, “Sally read the book to Sam” would be considered to have 5 WSC (i.e. reed was incorrectly spelled in the context of the sentence).

**Correct Written Sequences (CWS).** Correct written sequences is the second indicator of writing quality provided by WE-CBM. Scoring for a correct written sequence will be evaluated on two adjacent, correctly spelled words which produce mechanical, semantic, and syntactically correct writing sequences. CWS is calculated by identifying correct written sequences (CWS) with a caret mark (^) for mechanical, semantic, and syntactically correct written sequences (AIMSweb, 2004). For example, ^I^never^saw^a^polar^bear^. CWS = 7.

**Reliability.** Germane to the AIMSweb WE-CBM measures used in this study (TWW, WSC, and CWS), two types of reliability are relevant: alternate-form reliability and interrater reliability (AIMSweb Technical Manual, 2012). A summary of studies are presented as an indicator of these three measures. Fuchs, Deno, and Marston (1983) investigated the effects of administering forms of a test several times and aggregating the results to improve test reliability. This particular research focused on the CBM written expression measure, number of words spelled correctly (WSC). Fuchs, Deno, and Marston (1983) found an increase in stability coefficients from .55 (2-observations), .72 (4-observations), .85 (6-observations), .88 (8-observations), and .89 (10-observations) resulting in significantly improved test reliability for this measure (p < .001).

Tindal, Germann, and Deno (1983) evaluated spelling skills of students in Grades 4 and 5 with two scoring methods: WSC and CLS (correct letter sequence) using alternate-form (probe) reliability and found WSC = .82 and CLS = .82. A subsequent study by Gansle, Noell, VanDerHeyden, Naquin, and Slider (2002) investigated written expression in their
administration of story-writing probes to students in Grades 3 and 4 with the measures of TWW, 
WSC, and CWS. Gansle, Noell, VanDerHeyden, Naquin, and Slider (2002) noted that the results 
of alternate-form reliability were TWW = .62, WSC = .53, and CWS = .46; and the interrater 
scores were TWW = .96, WSC = .95, and CWS = .86. Similarly, Espin et al. (2000) examined 
students in Grades 7 and 8 through their administration of story-writing probes and found the 
alternate-form reliability of TWW = .73, WSC = .72, and CWS = .76. As indicated by the results 
of these studies, the correlation between the measures range from moderate to strong, and are 
moving in a positive direction (Gravetter and Wallnau, 2009).

**Validity.** The validity of the probe scores is based on the accuracy of inferences drawn 
from assumptions constructed from the scores (AIMSweb Technical Manual, 2012). Correlations 
of the writing probes with the criterion variables of TWW, WSC, and CWS were evaluated in the 
literature. Gansle et al. (2002) correlated the probe scores with the teacher’s assessment of the 
student’s writing abilities and found that (TWW = .08, WSC = .20, and CWS = .36); the ITBS 
Total Language Score (TWW = .05, WSC = .24, and CWS = .43); the LA Educational 
Assessment Program, Write Competently subtest (TWW = .28, WSC = .29, and CWS = .28); and 
the LA Educational Assessment Program, Conventions of Language subtest (TWW = .06, WSC 
= .26, and CWS = .40). Furthermore, Espin et al. (2000) correlated the probe scores with how the 
teacher’s ranked each students writing ability in Grades 7 & 8 and found that (TWW = .46, WSC 
= .48, and CWS = .59); the Grade 8 students’ probe scores were correlated with the district 
writing test and their validity coefficients were TWW = .46, WSC = .48, and CWS = .60.

Deno, Martson, and Mirkin (1982) evaluated six indices of written expression that were 
correlated with the criterion measures of the Test of Written Language (TOWL) (Hammill and 
Larsen, 1978), Stanford Word Usage (Madden, Gardner, Rudman, Karlsen, and Marvin, 1978),
and Developmental Sentence Scoring (Lee and Carter, 1971), and found the following
correlation scores: Mature Words (.61 – .83), Letter Sequences Correct (.57 – .86), Total Words
Spelled Correctly (.57 – .80), and Total Words Written (.58 – .84). These results indicate the six
indices have a high correlation to the criterion measures.

Videen et al. (1982) extended this research with the criterion variables of published
achievement measures and holistic ratings of writing to investigate the validity of correct word
sequences (CWS) as a CBM writing measure (Marston, 1989). Videen et al. (1982) found that
CWS was highly representative and a valid and reliable measure of written expression with a
correlation of .85 and an average inter-scorer agreement of 90.3%. Lastly, a summary of validity
studies for WE-CBM measures have reported the correlations between WSC and the criterion
measures to be .45-.92 (as cited in Marston, 1989 pp. 46-47). The summary results of these
studies indicate a moderate to strong correlation with the WE-CBM measures with regards to the
students’ written expression output.

**Treatment Integrity.** A treatment integrity worksheet (Appendix B) was developed and
includes a checklist indicating the procedural steps needed to implement the control and
treatment conditions as intended. The researcher completed the checklist for each participant and
trial (two per session). Total Words Written (TWW), Words Spelled Correctly (WSC), and
Correct Written Sequences (CWS) were calculated for each probe and verified by an
independent scorer in order to calculate inter-scorer reliability of each of the three dependent
variables. The inter-scoring reliability was calculated as follows:  Agreements/(Agreements +
Disagreements) x 100 (AIMSweb, 2004). A 4th year School Psychology Doctoral Student, with
experience in CBM methods, scored all CBM probes. A School Psychology Faculty member
then scored 20% of the CBM probes and found TWW = 100% agreement, WSC = 100% agreement, and CWS = 97.97% agreement.

Data Analysis

At the end of the data collection, writing samples were scored according to the WE-CBM measurement criteria of TWW, WSC, and CWS. Specifically, the data was graphically displayed and visually analyzed for levels of performance, degree and direction of trends, and consistent patterns in the data path in each phase (Richards et al., 1999). Visual analysis of the line graphed data indicates that all of the AT intervention condition data points on the data path were above the HW baseline condition which correlates to 100% of non-overlapping data points (PND) for any of the three participants (Riley-Tillman and Burns, 2009).

Specific analyses compared the data patterns between the two conditions to directly compare the effects. The means and standard deviation were calculated for each dependent variable across the conditions (AT and HW). Effect sizes were calculated to compare each condition using the standard mean difference equation (SMD). This computational technique is achieved by taking the difference of the mean performance for the two treatment conditions: AT (the intervention condition) and HW (the baseline control condition) and then dividing the results by the pooled standard deviation of the two conditions (Weiner, Sheridan, and Jenson, 1998; Olive and Smith, 2005; Olive and Franco, 2008).

Olive and Franco (2008) further indicated that SMD is the most appropriate non-regression measure for determining effect sizes in single subject research designs due to several factors: simplified analysis and interpretation by readers, a straightforward calculation method, and the ease by which intervention effects are comparable across studies.
Chapter IV: RESULTS

No known research studies have investigated the effects of speech-to-text assistive technologies on the written expression of children with traumatic brain injuries who have marked fine motor control deficits. The purpose of this study was to evaluate speech-to-text assistive technology (Dragon Naturally Speaking) as an accommodation to bypass fine motor control deficits to enhance output for written expression for children and adolescents who have sustained a TBI. Three students ages 9, 14, and 15 with TBI designation participated in this study.

An alternating treatments design (Barlow and Hayes, 1979) was used to compare the written expression effects of a speech-to-text assistive technology accommodation against a handwriting control condition. Each participant completed the handwriting and the speech-to-text components and served as their own control. The two writing conditions were evaluated across five sessions, with both conditions occurring in each session, using ten distinct story prompts. The experimental conditions were counterbalanced across sessions to control for treatment order effects. The results for each of the three participants will be discussed individually.

**Research Question One:** Does use of Dragon Naturally Speaking, a speech-to-text assistive technology accommodation for impaired handwriting skills, increase the total written words generated by students with traumatic brain injuries compared to handwriting alone?

**Research Question Two:** Does use of Dragon Naturally Speaking as an accommodation increase correctly spelled words within the content produced by students with traumatic brain injuries compared to handwriting alone?
**Research Question Three:** Does *Dragon Naturally Speaking* as an accommodation improve the quality of writing as measured by correctly written sequences in students with traumatic brain injuries compared to handwriting alone?

**Qualitative Observations Regarding James’ Performance**

James was perhaps the participant with the most severe TBI sequelae. His handwriting was marked by abnormally large letter sizes and, letter reversals. No actual words were produced, instead James wrote a string of random letters. James displayed marked intention tremor and poor fine motor control throughout each handwriting session. James’ written samples demonstrated apraxic agraphia in which his written production was also impaired, meaning it was not just his fine motor skills impacting his ability to communicate through writing. De Smet, Engelborghs, Paquier, De Deyn and Marien (2010) noted patients with apraxic agraphia have difficulty in sequencing letter movements necessary to produce correct letter forms. This could be symptomatic of neural circuit implications which are beyond the scope of this study. However, it should be noted that James’ letter formation was distorted, incomplete, and imprecise. Some letters were so poorly formed, they were almost illegible writings. Conversely, when the AT condition was applied, James was able to express his ideas with marked improvement.

**Outcome Data Regarding James**

Visual analysis of Figure 4 reveals that the increasing levels of the AT accommodation resulted in an increase in TWW for 4 of the 5 sessions. All data points were higher than the control condition. With respect to TWW, all control performances were consistent at 3 TWW. All the speech-to-text (AT) condition sessions ranged from 34 to 58 TWW. A review of Figure 4 reveals 100% non-overlapping data points in favor of the AT accommodation condition. Table 1
presents mean and standard deviation data across participants and conditions for TWW. James’ mean TWW score during the handwriting condition was 3, and, during the AT condition, the mean was 44.4. This corresponds to an effect size of 8.2 in favor of the AT condition. Effect size is designed to measure the “absolute magnitude of a treatment effect, independent of the size of the sample(s) being used” (Gravetter and Wallnu, 2009). Cohen’s $d$ (1988) evaluated effect size as 0.2 = small effect, 0.5 = moderate effect, and 0.8 = large effect. Effect size data between conditions and across participants is displayed in Table 4 and have been interpreted with the SMD formula used to compute effect size (Olive and Franco, 2008).

Table 1

Mean and Standard Deviation of Total Words Written (TWW) Across Participants and Conditions

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<thead>
<tr>
<th></th>
<th>Mean TWW (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HW</td>
</tr>
<tr>
<td>James</td>
<td>3 (0)</td>
</tr>
<tr>
<td>Ivan</td>
<td>1.8 (0.45)</td>
</tr>
<tr>
<td>Roger</td>
<td>23.4 (3.78)</td>
</tr>
</tbody>
</table>

Note: HW = Handwriting Condition; AT = Speech-to-Text condition
Visual analysis of Figure 5 reveals that the increasing levels of the AT accommodation resulted in an increase in WSC for 4 of the 5 sessions. All data points were higher than the control condition. With respect to WSC, James did not produce any words spelled correctly in the control condition. All control performances were consistent at 0 WSC. All AT condition sessions ranged from 34 to 58 WSC. A review of Figure 5 reveals 100% non-overlapping data points in favor of the AT accommodation condition. Table 2 presents mean and standard deviation data across participants and conditions for WSC. James’ mean WSC score during the handwriting condition was 0. During the AT condition, the mean was 44.4. This corresponds to an effect size of 8.8 in favor of the AT condition. Effect size data between conditions and across participants is displayed in Table 4 and have been interpreted with the SMD formula used to compute effect size (Olive and Franco, 2008).
Table 2

Mean and Standard Deviation of Words Spelled Correctly (WSC) Across Participants and Conditions

<table>
<thead>
<tr>
<th></th>
<th>Mean WSC (SD)</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>HW</td>
</tr>
<tr>
<td>James</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Ivan</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Roger</td>
<td>22.8 (3.96)</td>
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</table>

Note: HW = Handwriting Condition; AT = Speech-to-Text condition

Words Spelled Correctly (WSC)

Figure 5: James – Words Spelled Correctly (WSC)

Visual analysis of Figure 6 reveals that the increasing levels of the AT accommodation resulted in an increase in CWS for 4 of the 5 sessions. All data points were higher than the control condition. Regarding CWS, James did not produce any correct writing sequences during the controlled condition. All control performances were consistent at 0 CWS. All AT condition
sessions ranged from 29 to 55 CWS. A review of Figure 6 reveals 100% non-overlapping data points in favor of the AT accommodation condition. Table 3 presents the mean and standard deviation data across participants and conditions for CWS. James’ Mean CWS score during the handwriting condition was 0; and, during the AT condition, the mean was 42.0. This corresponds to an effect size of 8.3 in favor of the AT condition. Effect size data between conditions and across participants is displayed in Table 4 and have been interpreted with the SMD formula used to compute effect size (Olive and Franco, 2008).

Table 3

*Mean and Standard Deviation of Correct Written Sequence (CWS) Across Participants and Conditions*

<table>
<thead>
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<tr>
<td>Ivan</td>
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</tr>
<tr>
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Note: HW = Handwriting Condition; AT = Speech-to-Text condition
Correct Written Sequences (CWS)

![Figure 6: James – Correct Written Sequences (CWS)](image)

**Table 4**

*Effective Size Between Conditions and Across Participants*

<table>
<thead>
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<th>WSC</th>
<th>CSW</th>
<th>Effect Size</th>
<th>AT &gt; HW</th>
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</thead>
<tbody>
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<td>8.2</td>
<td>8.8</td>
<td>8.3</td>
<td>AT &gt; HW</td>
<td></td>
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<tr>
<td>Ivan</td>
<td>6.4</td>
<td>6.6</td>
<td>7.2</td>
<td>AT &gt; HW</td>
<td></td>
</tr>
<tr>
<td>Roger</td>
<td>3.4</td>
<td>3.5</td>
<td>3.4</td>
<td>AT &gt; HW</td>
<td></td>
</tr>
</tbody>
</table>

*Note:* HW = Handwriting condition; AT = speech-to-text condition
Qualitative Observations Regarding Ivan’s Performance

All handwriting samples produced only a collection of capital letters and no combination actually spelled a recognizable word. Letter production was also immature for his age. Ivan’s writing was also indicative of lexical agraphia issues. As he produced a letter, he spoke aloud, and it seems he intended each letter to represent a word. While he could not visualize the spelling of a word during the HW condition, he could sound them out.

Outcome Data Regarding Ivan

Visual analysis of Figure 7 reveals that the increasing levels of the AT accommodation resulted in an increase in TWW for 4 of the 5 sessions. All data points were higher than the control condition. With respect to TWW, the range for all control performances was from 1 to 2 TWW. All the speech-to-text (AT) condition sessions ranged from 74 to 147 TWW. A review of Figure 7 reveals 100% non-overlapping data points in favor of the AT accommodation condition. Table 1 presents mean and standard deviation data across participants and conditions for TWW. Ivan’s’ mean TWW score during the handwriting condition was 1.8; and, during the AT condition, the mean was 100.8. This corresponds to an effect size of 6.4 in favor of the AT Condition. Effect size data between conditions and across participants is displayed in Table 4 and have been interpreted with the SMD formula used to compute effect size (Olive and Franco, 2008).
Visual analysis of Figure 8 reveals that the increasing levels of the AT accommodation resulted in an increase in WSC for 4 of the 5 sessions. All data points were higher than the control condition. With respect to WSC, Ivan did not produce any words spelled correctly in the control condition. All control performances were consistent at 0 WSC. All the speech-to-text (AT) condition sessions ranged from 74 to 147 WSC. A review of Figure 8 reveals 100% non-overlapping data points in favor of the AT accommodation condition. Table 2 presents mean and standard deviation data across participants and conditions for WSC. Ivan’s mean WSC score during the handwriting condition was 0. During the AT condition, the mean was 100.6. This corresponds to an effect size of 6.6 in favor of the AT condition. Effect size data between conditions and across participants is displayed in Table 4 and have been interpreted with the SMD formula used to compute effect size (Olive and Franco, 2008).
Figure 8: Ivan – Words Spelled Correctly (WSC)

Visual analysis of Figure 9 reveals that the increasing levels of the AT accommodation resulted in an increase in CWS for 4 of the 5 sessions. All data points were higher than the control condition. Regarding CWS, Ivan did not produce any correct writing sequences during the controlled condition. All control performances were consistent at 0 CWS. All AT condition sessions ranged from 62 to 122 CWS. A review of Figure 9 reveals 100% non-overlapping data points in favor of the AT accommodation condition. Table 3 presents the mean and standard deviation data across participants and conditions for CWS. Ivan’s mean CWS score during the handwriting condition was 0; and, during the AT condition, the mean was 87.2. This corresponds to an effect size of 7.2 in favor of the AT condition. Effect size data between conditions and across participants is displayed in Table 4 and have been interpreted with the SMD formula used to compute effect size (Olive and Franco, 2008).
Qualitative Observations Regarding Roger’s Performance

All handwriting samples produced normally formed letters (graphemes) and recognizable words. However, letter production was immature for his age. Of the participants, Roger displayed the best developed writing skills.

Outcome Data Regarding Roger

Visual analysis of Figure 10 reveals that the increasing levels of the AT accommodation resulted in a decrease in TWW for 2 of the 5 sessions. All data points were higher than the control condition. With respect to TWW, the range for all control performances was from 20 to 28 TWW. All the speech-to-text (AT) condition sessions ranged from 36 to 78 TWW. A review of Figure 10 reveals 100% non-overlapping data points in favor of the AT accommodation condition. Table 1 presents mean and standard deviation data across participants and conditions for TWW. Roger’s mean TWW score during the handwriting condition was 23.4; and, during the
AT condition, the mean was 57.0. This corresponds to an effect size of 3.4 in favor of the AT Condition. Effect size data between conditions and across participants is displayed in Table 4 and have been interpreted with the SMD formula used to compute effect size (Olive and Franco, 2008).

**Total Words Written (TWW)**

![Graph of Total Words Written (TWW) for Roger]

Figure 10: Roger – Total Words Written (TWW)

Visual analysis of Figure 11 reveals that the increasing levels of the AT accommodation resulted in a decrease in WSC for 2 of the 5 sessions. All data points were higher than the control condition. With respect to WSC, Roger did produce words spelled correctly. All control performances were consistent with a range of 19 to 26 WSC. All the speech-to-text (AT) condition sessions ranged from 36 to 78 WSC. A review of Figure 11 reveals 100% non-overlapping data points in favor of the AT accommodation condition. Table 2 presents mean and standard deviation data across participants and conditions for WSC. Roger’s mean WSC score
during the handwriting condition was 22.8; and, during the AT condition, the mean was 57.0. This corresponds to an effect size of 3.5 in favor of the AT condition. Effect size data between conditions and across participants is displayed in Table 4 and have been interpreted with the SMD formula used to compute effect size (Olive and Franco, 2008).

**Words Spelled Correctly (WSC)**

Visual analysis of Figure 11 reveals that the increasing levels of the AT accommodation resulted in a decrease in CWS for 2 of the 5 sessions. All data points were higher than the control condition. Regarding CWS, Roger did produce correct writing sequences during the controlled condition. All control performances were consistent with a range from 19 to 27 CWS. All AT condition sessions ranged from 33 to 71 CWS. A review of Figure 12 reveals 100% non-overlapping data points in favor of the AT accommodation condition. Table 3 presents the mean and standard deviation data across participants and conditions for CWS. Roger’s mean CWS score during the handwriting condition was 22.8; and, during the AT condition, the mean was 51.8. This corresponds to an effect size of 3.4 in favor of the AT condition. Effect size data
between conditions and across participants is displayed in Table 4 and have been interpreted with the SMD formula used to compute effect size (Olive and Franco, 2008).

Correct Written Sequences (CWS)

![Figure 12: Roger – Correct Written Sequences (CWS)](image-url)

Figure 12: Roger – Correct Written Sequences (CWS)
Chapter V: DISCUSSION

Traumatic brain injury (TBI) is a debilitating condition and a major cause of death in the United States particularly for children and adolescents (CDC, 2010). As an acquired injury to the brain, the neurophysiological consequences are not homogeneous; they are as varied as the individuals who experience them. Similarly, TBI outcomes vary by individual due to age at the onset of injury, the location of the injury, and the degree to which the deficits appear to be pronounced, among other factors.

Persistent impairment in executive functions of attention, initiation, planning, organizing, and memory are likely to be present in children with moderate to severe TBIs. Issues with sensory and motor skills, language, auditory or visual sensation changes, and variations in emotional behavior may also be present. Germaine to this study, motor dysfunction is a common long-term sequelae of TBI that manifests in academic difficulties. Borrowing from the learning disability literature, children with motor dysfunction are likely to have transcription deficits, or deficits related to the fine-motor production of written language. When post-injury fine motor impairment and resulting low written output is present, speech-to-text assistive technology (AT) may be applied as an accommodation to improve the written expression of children with TBI.

Speech-to-text technology, like Dragon Naturally Speaking converts spoken language into a print format on a computer screen with a high degree of accuracy. In theory, because less effort is spent on transcription, there is a reduction in cognitive load, enabling more time to be spent on generation skills, such as idea development, selecting more complex words that might be otherwise difficult to spell, and grammar.

This study aimed to compare the effects of handwriting with an assistive technology accommodation on the writing performance of three middle school students with TBIs and
writing difficulties. The study utilized an alternating treatments design (ATD), comparing the effects of handwriting responses to story prompts to the use of speech-to-text AT to record participant responses.

The three participants in this study were age 9, 14, and 15 years of age. All three were African-American males with TBIs and fine motor skill deficits. Each participant was initially introduced to the Accuracy Center tutorial in Dragon Naturally Speaking which provided general training and set-up steps so the speech-to-text software could be taught to recognize each participant’s voice and idiosyncrasies of their speech patterns. This step in the training of Dragon was very necessary so that the program could adapt and continue to learn how each participant speaks and writes. Dragon’s word prediction capabilities consistently provided high word accuracy. Of the three participants, James’ presented with mild dysarthria and was difficult to understand at times. Because of this, the Dragon Naturally Speaking training required additional time to complete.

Overall, all three participants showed marked improvement with the application of speech-to-text AT. The results indicate a positive pattern for the AT as an accommodation with these children that have had mild-to-moderate TBIs as compared to their written output without the AT accommodation. The AT accommodation enabled the generation of written expression as a result of bypassing fine motor deficits in each of these participants. Through visual analysis of the results, it is evident that the speech-to-text dictation condition was far superior to the handwriting condition (HW) with an effect size that ranged + 3.4 to + 8.8 across participants indicating a large treatment effect size. Perhaps more impressive, was 100 percent non-overlap of data between the two conditions across participants and dependent variables.
Of particular interest and reviewed next, two of the three participants (James and Ivan) may be considered agraphic. Although the neural circuits related to agraphia are beyond the scope of this dissertation, De Smet, Engelborghs, Paquier, De Deyn and Marien (2010) note patients with apraxic agraphia have difficulty sequencing letter movements necessary to produce correct letter forms.

James was perhaps the participant with the most severe TBI sequelae. His handwriting was marked by abnormally large letter sizes and letter reversals. No actual words were produced; instead, James wrote a string of random letters. Conversely, when the AT condition was applied, James was able to express his ideas and record strings of words with meaning. In fact, 100% non-overlapping data points was present in favor of the speech-to-text AT condition regarding TWW, WSC, and CWS.

Regarding Ivan, review of the handwritten samples revealed only a collection of capital letters that did not actually spell a recognizable word. Letter production was also immature for his age. Ivan’s writing was indicative of lexical agraphia. As he produced a letter, he spoke aloud, and it seemed he intended for each letter to represent a word. Like James, 100% non-overlapping data points were present in favor of the speech-to-text AT condition regarding TWW, WSC, and CWS.

The third participant, Roger, produced handwritten samples which generally yielded typically formed letters (graphemes) and recognizable words, but some letters produced may be considered immature. Of the three participants, Roger displayed the best developed writing skills. Like the other two participants, 100% non-overlapping data points was present in favor of the speech-to-text AT condition regarding TWW, WSC, and CWS.
Implications of Findings

The findings of this study are robust. The application of speech-to-text AT resulted in significantly improved performance across writing indicators in these students with a history of TBIs. Speech-to-Text AT may prove to be an excellent accommodation for children with TBI and fine motor skill deficits. As a relatively low-cost software program, it is easy to implement, train users, and use in the K-12 setting. School personnel, including special education teachers, school psychologists, and occupational therapists in particular should regularly consider children with TBI for this AT.

A limitation of this study is that it only considered TWW, WSC, and CWS as dependent variables. However, teachers that evaluate the writing of students and State standards consider additional factors such as the 6 Trait Writing method developed by Spandel and Stiggins (1990). The model is comprised of ideas and content, organization, voice, word choice, sentence fluency, and conventions. It provides a functional framework for writing improvement. Ideas and Content captures the extent to which writing has a discernable main theme or message. Organization evaluates the story’s structure, including linkages of concepts between the introduction and the conclusion. Voice refers to the tone of the study and the presence of the writer and Word Choice evaluates the complexity of vocabulary used. Sentence Fluency judges sentence structure and flow, while Conventions pays attention to the mechanics (spelling, punctuation, grammar etc.).

The present study did not include indicators of complex writing as variables. The short time period of writing simply would not allow for enough content to judge these because the written output was relatively small. Anecdotal observations of the writing suggest that the AT may have increased production output, grammatical output, and correctly spelled words, and elements of the 6 Traits may have been improved to varying degrees. Further researchers may
wish to study the effects of the current AT on these traits specifically. Relatively clear is that additional writing intervention beyond the application of speech-to-text AT is necessary to further improve these students’ writing.

One such comprehensive intervention that may also be implemented along with the speech-to-text AT is Self-Regulated Strategy Development (SRSD). Harris, Graham, and Mason (2003) discussed SRSD as an instructional approach to assist with focusing attention and planning, composing, modifying, and editing students’ written production. The SRSD model provides a systematic and progressive, multi-phase approach to goal-setting, self-monitoring, and self-evaluation increasing student efficacy and diverse writing strategies by the students spending more time planning their writing and producing longer compositions. Harris, Graham, and Mason (2003) further identified the positive impact of SRSD improvements in four areas of students’ writing performance: quality of writing, knowledge of writing, approach to writing, and self-efficacy. To illustrate the effectiveness of SRSD, Graham and Harris (2003) conducted a meta-analysis of 18 writing studies integrating SRSD instruction across different populations of students (learning disabled, poor writers, and average students) and four variables: quality, elements, story grammar scale and length. Results indicated large positive effect sizes (Quality = 1.47, Elements = 1.87, Story Grammar = 3.52, and Length = 2.07), demonstrating improvement in quality, organization, and duration in students’ writing. With its explicit and structured instruction methodology, SRSD provides an individualized approach to writing strategies addressing the diverse learning requirements of all students. SRSD can be used to frame the writing produced, but then speech-to-text AT may be used when it comes time to get words on a computer screen resulting in even more improved writing. Future studies may explore this perspective.
A less comprehensive intervention, but one that still may be applied with speech-to-text AT is the graphic organizer. Graphic organizers can provide a visual diagram that can be used to identify relationships between thoughts, theme concepts, and written expression. Strangman, Hall, and Myer (2003) discussed many different types of graphic organizers that can be incorporated to meet specific informational requirements within a learning assignment such a Descriptive or Thematic Map for graphing generic information and hierarchical relationships, a Sequential Episodic Map for cause and effect scenarios, a Comparative and Contrast Map for concept comparisons based upon their attributes, a Series of Events Chain to organize steps or stages, and a Fishbone model for causal analysis with detailed linkages. Some of the benefits of incorporating graphic organizers into the curriculum include improvements in reading comprehension, note taking and organization, relating main ideas or themes, and enhancing critical thinking skills and problem-solving abilities.

Ciullo and Reutebuch (2013) investigated the use of digital-based organizers in a comparative meta-analysis of 12 studies using computer-based graphic organizers with learning disabled students. In four of the studies regarding written expression, the effect size was notable (ES = .80) in social studies (which is considered a content course with a writing requirement), and in the planning stages in preparation for writing, particularly in grades 4-12. In the discussion of their findings however, Ciullo and Reutebuch (2013) further noted the need for more research to support a broader acceptance of digital–based organizers as compared to hand-mapping techniques to further demonstrate their efficacy in improving written expression. Moreover, they identified the necessity for teacher-student instruction and engagement, constructive feedback, and software proficiency among student-learners.
Bahr, Nelson, and Van Meter (1996) investigated the effects of two software-based planning tools (text-based and graphics-based) on the narrative writing skills of students who had language-related learning disabilities in fourth through eighth grade and found that students’ writing improved when their individual needs where matched with the planning features of each tool. Students who had strong organizational skills achieved a better effect with the graphic-based tool, and students will less internal structural skills produced a better quality narrative with the text-based tool. Unzueta and Barbetta (2012) further explored the use of digital-based graphic organizers on persuasive writing with students’ specific learning disabilities (SLDs) and found a substantial increase in number of words written. Increases were also evident in the other dependent variables with more time spent in planning, generation of more supporting details, and an increase in T-units (writing growth). A concern of the study was the ability to transfer planning techniques used with a graphics organizer when students who have SLDs only have paper and pencil available.

Schmitt, McCallum, Rubinic, and Hawkins (2011) in studies of other AT have cautioned interventionists against assuming an AT will result in clinically significant improvement in performance for any particular student. Effects vary by student, and are likely due to the difficulty an individual student has with reading or writing. This study also underscored that AT should be tested before committing to its use.

The Wisconsin Assistive Technology Initiative (WATI) has many resources, such as the WATI Assessment which provides a clear, comprehensive, and systematic framework to determine a child’s specific needs for an Assistive Technology in their environment (Reed and Lahm, 2004). The WATI Assessment Package integrates an *Assistive Technology Consideration Guide* that is task oriented and inclusive of special strategies and accommodations. For example,
the WATI Student Information Guide (Sections 1, 2, and 3) addresses: Fine Motor Related to Computer (or Device) Access, Motor Aspects of Writing, and Composing Written Material. Each of these guides can be instrumental in conducting effective and individualized assessments to provide a customizable accommodation for each student. The WATI also reminds educators to check for student satisfaction (i.e., if the student likes the technology and will actually use it).

**Limitations and Areas for Future Research**

This study is not without limitations. Although the results of this study are robust across participants, the sample size was small. A larger sample size would allow for the study of AT effects across age of onset, location of injury, and injury severity. A larger sample size would allow for the use of inferential statistics.

This study only included TWW, WSC, and CWS. Future studies that afforded students with more writing time may be able to study the 6 Traits discussed previously. Online rubrics exist, such as the Pennsylvania System of School Assessment (PSSA) manual which includes the writer’s checklist for a narrative writing prompt for grades 3 through 8 which has the potential for use to measure the 6 Traits as dependent variables (Pennsylvania Department of Education, 2017). A longer written product, to increase meaningful output, may provide researchers additional insights into the quality of the work, depth, and logical flow of the ideas being generated.

Higgins and Raskin (1995) compared the use of *Dragon Dictate System* to a human scribe in the study of the written expression of post-secondary students previously diagnosed with a learning disability. These authors concluded that writing samples incorporating the assistive technology resulted in greater performance and that more research was warranted. Since the *Dragon Naturally Speaking* is an advanced technology compared to what was available in
1995, future researches might replicate earlier studies and specifically compare the effects of this newer technology to a human scribe to determine what differences in the two conditions may now exist.

Traumatic Brain Injury is not the only disorder associated with fine motor deficits. Cerebral palsy is a common motor disability in childhood and impacts movement ability, balance, and posture and is caused by abnormal brain development or damage to a developing brain which affects muscle control (CDC, 2017). As another example, muscular dystrophy is a disorder that primarily involves motor dysfunction (CDC, 2017). This current study could be replicated for students with these neuromuscular disorders by applying the AT with SRSD, and more time to produce writing to see what improvement results.

Conclusion

The Speech-to-Text AT was more effective than a handwriting condition for all three participants. By providing this AT, these students each improved in the quality, construction, and duration of their written expression as evidenced in the significant gains in TWW, WSC, and CWS. Prior to the study, these students were identified by their teachers as having extensive writing deficits. Offering assistive technologies that meet the specific needs of each student enhances the potential to affect the recovery process associated with TBI injuries by providing teachers with supplementary accommodation instruments to create a more effective means of addressing each student’s academic requirements, particularly, their ability to communicate through written expression.
References


Appendix A

Treatment Condition Schedule

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<th>Session 2:</th>
<th>Session 3:</th>
<th>Session 4:</th>
<th>Session 5:</th>
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*Treatment Integrity

Condition A = Handwriting
Condition B = Speech-to-Text
Appendix B

Treatment Integrity Check List

Handwriting Condition

1. _____ Provide students with sharpened pencils with erasers.
2. _____ Provide students with lined form that includes a story prompt.
3. _____ Read the Handwriting directions to the students.
4. _____ Instruct the students to begin the procedure.
5. _____ Begin timing the students for one minute reflection.
6. _____ Instruct students to start writing.
7. _____ Begin timing the students for three minute writing session.
8. _____ Prompt students to continue writing, if needed.
9. _____ Instruct students to stop writing and put their pencil down.
10. _____ Collect Handwriting lined form.

Speech-to-Text Condition

1. _____ Place laptop with DNS pre-loaded software in front of students.
2. _____ Provide students with USB microphone for dictation into program.
3. _____ Upload data file with story prompt for students.
4. _____ Read the Speech-to-Text directions to the students.
5. _____ Instruct the students to begin the procedure.
6. _____ Begin timing the students for one minute reflection.
7. _____ Instruct students to start dictating their story narrative.
8. _____ Begin timing the students for three minute writing session.
9. _____ Prompt students to continue writing, if needed.
10. _____ Instruct students to stop speaking into the microphone.
11. _____ The researcher will save the data file.