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The Effects of Word Prediction on Writing Fluency for Students with Physical Disabilities

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ACCEPTANCE

This dissertation, THE EFFECTS OF WORD PREDICTION ON WRITING FLUENCY FOR STUDENTS WITH PHYSICAL DISABILITIES by PETER JOHN MEZEI was prepared under the direction of the candidate's Dissertation Advisory Committee. It is accepted by the committee members in partial fulfillment of the requirements for the degree Doctor of Philosophy in the College of Education, Georgia State University.

The Dissertation Advisory Committee and the student's Department Chair, as representatives of the faculty, certify that this dissertation has met all standards of excellence and scholarship as determined by the faculty. The Dean of the College of Education concurs.

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ABSTRACT

THE EFFECTS OF WORD PREDICTION ON WRITING FLUENCY FOR STUDENTS WITH PHYSICAL DISABILITIES
by
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Writing is a multifaceted, complex task that involves interaction between physical and cognitive skills. Individuals with physical disabilities vary in terms of both their physical and cognitive abilities. Often they must overcome one or more significant barriers in order to engage in the task of writing. Minimizing or eliminating barriers is important because opportunities are greater for individuals who can effectively communicate their ideas via writing. Assistive technology (AT) is an increasingly effective solution to increase typing fluency. The purpose of this study is to examine if word prediction software, a commonly used software program used with individuals with learning disabilities, will be effective for those with physical impairments to increase typing rate and reduce spelling errors (fluency). Data will be collected for words correct per minute (WCPM) and errors (e.g., spelling). Four middle- or high school-aged participants with diverse physical disabilities will be recruited in this single subject, alternating treatment design. Participants will type for three-minute timed sessions using either a standard word processor or Co:Writer 4000, a word prediction software program. Specific research questions are: (a) to what extent will students with physical and health disabilities produce greater WCPM when writing a draft paper on a common topic using word prediction rather than word processing, (b) to what extent will the use of word prediction software result in the

production of different types of errors compared to errors produced using word processing, (c) to what extent will the use of word prediction software increase accuracy by decreasing spelling errors, (d) to what extent will more text be produced using word prediction software than with word processing, and (e) to what extent will word prediction increase motivation or willingness to write? Data will be graphed and analyzed for bifurcation. Bifurcation will be determined by examination of the means, level of performance, and trend. Finally, examination of errors will be used to verify spelling accuracy.

THE EFFECTS OF WORD PREDICTION ON WRITING FLUENCY FOR STUDENTS WITH PHYSICAL DISABILITIES

by

Peter John Mezei

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ABBREVIATIONS

AT	Assistive Technology
CNS	Central Nervous System
CP	Cerebral Palsy
DMD	Duchenne Muscular Dystrophy
LD	Learning Disabilities
OI	Orthopedic Impairment
PD	Physical Disability
ROM	Range of Motion
SMA	Spinal Muscular Atrophy
WCPM	Words Correct Per Minute
WPM	Words Per Minute
WPS	Word Prediction Software

CHAPTER 1

THE EFFECTS OF WORD PREDICTION ON WRITING FLUENCY FOR STUDENTS WITH PHYSICAL DISABILITIES: A REVIEW OF THE LITERATURE

Introduction and Purpose

Writing is a multifaceted, complex task that involves the interaction between physical and cognitive skills. Individuals with physical disabilities (PD) must develop adequate writing skills in order to access the general education curriculum, express themselves in personal, academic and vocational situations, have an opportunity to graduate from high school with a general education diploma, seek post-secondary education and employment, and achieve a high quality of life. Individuals with physical disabilities vary in terms of their physical and cognitive abilities even when they have the same diagnosis. Importantly, they often must overcome one or more significant barriers in order to physically engage in the task of writing. Minimizing or eliminating these barriers is vital because personal, academic and vocational opportunities are greater for individuals who can communicate ideas effectively through writing.

Among the most common barriers to writing experienced by individuals with physical disabilities is difficulty with voluntary motor movements necessary to write. In fact, some individuals are so physically impaired they cannot handwrite and must type (Castellani & Jeffs, 2001). Inefficient and ineffective motor patterns may have a significant, negative impact on typing speed and accuracy, leading to a slow rate of typing and a high rate of unintended errors. Moreover, this disfluency may require greater attention (Graham & Harris, 2000), that may in turn overburden cognitive processes needed to attend to planning what to say, generate text, grammar, and spell correctly (Flowers & Hayes, 1981). Therefore, individuals with physical disabilities may experience an earlier onset of mental fatigue than their non-disabled peers (Bourdin & Fayol, 2000). Other functional factors that may impact typing speed and accuracy include sensory deficits, cognitive impairments, and sparse experience with writing activities.

Environmental factors may also contribute to inefficient typing speed and accuracy. The inability to physically access a computer is one significant environmental factor that must be addressed. In such instances, modifications to seating, workspace, computers, and keyboards may be necessary or required. Other environmental factors include lack of exposure to reading materials, an ineffective learning environment, and reduced expectations from school personnel due to misguided perceptions of the student's limitations. Finally, psychosocial factors that may impact writing include motivation, emotional issues, and learned helplessness. Each of these three domains: functional, environmental, and psychosocial may contribute to slower typing speed and accuracy.

Nonetheless, individuals with physical disabilities receive writing instruction through a general education or modified general education curriculum; therefore, teachers must have knowledge of effective and appropriate strategies to increase typing speed and accuracy. Due to the great variability in characteristics and abilities of individuals with physical disabilities, solutions that increase typing fluency and accuracy understudied. One increasingly preferred solution to address typing fluency involves assistive technology (AT). Currently, assistive technology solutions exist to support individuals with physical limitations with writing. One type of AT that has been developed to meet this objective is word prediction software (WPS). Although designed for individuals with physical disabilities, the majority of existing research on its effectiveness involves individuals with learning disabilities. Few studies can be found in the literature evaluating word prediction with individuals with physical disabilities. Therefore, the purpose of the literature review is to examine studies featuring word prediction with individuals who have disabilities. Special emphasis will be placed on research involving word prediction and individuals with physical disabilities including neuromotor disorders, degenerative and terminal diseases, and musculoskeletal diseases or disorders.

Review of the Literature

Types of Physical Disabilities That Impact Writing

There are different types of physical disabilities or impairments that may negatively impact writing fluency (typing rate and accuracy). Physical disabilities or orthopedic impairments can be easily understood and described by three general categories: Neuromotor, degenerative or terminal diseases, and musculoskeletal disorders (Heller, Alberto, Forney, & Swartzman, 1996). Common neuromotor disorders include cerebral palsy and acquired brain damage due to trauma or infection. Examples of musculoskeletal disorders include arthrogryposis, limb deficiencies, and there are a variety of degenerative, or terminal, diseases; however, the most common is Duchenne Muscular Dystrophy (DMD) and spinal muscular atrophy (SMA; Heller, et al., 1996). Each of these impairments may possibly impact education in a negative fashion and result in eligibility for special education services. In Georgia, any individual will qualify for special education if an impairment is present, if it negatively impacts education, and if the individual has an intelligence quotient of fifty-five or greater. Specifically, criteria for eligibility for special education in Georgia are:

> Any student whose severe orthopedic impairments affect their educational performance to the degree that the student requires special education. This term may include:

> (1) Impairment caused by congenital anomalies, e.g., deformity or absence of some member.
> (2) Impairment caused by disease, e.g., poliomyelitis or bone tuberculosis.
> (3) Impairment from other causes, e.g., cerebral palsy, amputations, and fractures or burns that cause contractures. [refer to 34 CFR 300.7 (8)]
> Secondary disabilities may be present, including, but not limited to, visual impairment, hearing impairment, communication impairment and/or intellectual disability.(http://public.doe.k12.ga.us/DMGetDocument.aspx/exceptional_eligibility_oi.pdf?p=4BE1EECF99CD364EA5554055463F1FBBF5D074D5FB1F2CAEB3B63B3ECB220CDD26C2114F3C57D8D25C69F04B76A08C8D&Type=D)

Among the most likely individuals to qualify for special education due to a physical disability and also have difficulty with writing fluency, are those with cerebral palsy and degenerative diseases such as muscular dystrophy and spinal muscular atrophy.

Cerebral Palsy (CP) is a non-inherited, non-progressive disorder that results in damage to the central nervous system (CNS) occurring pre-natally (prior to birth), peri-natally (during birth), or post-natally (soon after birth) (Heller, et al., 1996). Damage to the CNS frequently leads to altered and impaired fine and gross motor functions and fluctuating muscle tone that, in school-aged children, may negatively impact writing fluency (Best, Heller, & Bigge, 2005). Additionally, due to the nature of CNS damage, other impairments including cognitive, sensory, and speech disorders may be present and result in an impaired ability to engage in writing activities (Best, Heller, & Bigge, 2005; Kotler & Thomas-Stonell, 1997).

One way cerebral palsy is characterized or defined is by its motor impairment type (Heller, et al., 2008). A common type of CP is Spastic Cerebral Palsy. Damage to the primary motor cortex, located in the cerebral cortex, can create physical impairments that negatively impact handwriting and keyboarding. Spasticity (rigidity) of the skeletal muscles, characterized by high or fluctuating muscle tone, may lead to contractures of the elbow, wrists and fingers that lead to a shortening of the length of muscles, eventually causing permanent disfigurement (Miller, 2005). Spasticity and contractures may reduce the range of motion (ROM) in each of these joints affecting voluntary motor function needed to hand write and to type (Heller, et al., 1996). Additionally, damage to the central nervous system may create involuntary motor movement patterns that affect the ability to voluntarily coordinate a series of correct motor movements needed to write or type.

A second type of cerebral palsy is Dyskinetic, or Athetoid CP. This form of cerebral palsy is characterized by involuntary and non-purposeful motor movement patterns (Guyton & Hall, 2006). Similar to Spastic CP, fluctuating muscle tone often exists in athetoid cerebral palsy, which interacts with involuntary movement and further impacts coordination necessary to engage in writing and typing activities. Mixed Cerebral Palsy, a third type of CP, involves a combination of spastic and dyskinetic types (Miller, 2005). Individuals with mixed CP may display aspects of each type of cerebral palsy further complicating coordination necessary to hand write and to type..

When an individual with one or more types of cerebral palsy initiates a voluntary motor movement (e.g. hand writing, typing), a complex interaction between contractures, limited range of motion in the joints, and fluctuating muscle tone and impaired motor coordination is created (Miller, 2005; Best, Heller, & Bigge, 2005). When this interaction is not affected by cerebral palsy, handwriting and typing may occur with little effort, and with great speed and efficiency; however, when one or more of the above characteristics is present due to spastic, athetoid or mixed CP, hand writing and typing coordination may be significantly impacted. In this circumstance, individuals who are able to handwrite may be unable to hold a writing utensil (e.g., pencil) in the hand, unable to coordinate motor movement of the arm, hand, and fingers to write legibly, and therefore may be unable to reach all or part of the target paper to write on.

In individuals who either choose to type or have to type, keyboarding access and efficiency may also be significantly impacted. Gross motor movements may be affected by contractures in the shoulders, elbow, wrists, and fingers may physically impede an individual's limbs from reaching out to access a keyboard. Even when physical access is not completely impeded, an individual may not have sufficient range of motion of the arms, hands and fingers to access the entire keyboard. Fine motor movements may be affected by fluctuating muscle tone and involuntary motor movements that inhibit the speed and accuracy needed to correctly select a specific key (e.g., the letter "a"), as well as impede the ability to select a series of keys needed to complete a word (e.g., aardvark) causing the user to mistype one or more incorrect letters, and dramatically slowing the rate of selecting a key. Moreover, the interaction among these problems typically varies by individual and can lead to unique access and efficiency problems (Heller, et al., 1996.).

Muscular dystrophies are a "group of inherited disorders characterized by progressive muscle weakness due to primary degeneration of muscle fibers" (Lovering, Porter, & Bloch, 2005). There are specific criteria for inclusion in this group of diseases. First, it is a primary myopathy (i.e., a disease of the muscle). Second, it is genetically based. Third, it has a progressive course, and fourth, there is degeneration and death of the muscle fibers occurring at some stage in the disease process. Duchenne muscular dystrophy (DMD) is the most common form of muscular dystrophy and is the second most common lethal human genetic disorder affecting approximately 1 in 3,500 live male births (Van Deutekom & Van Ommen, 2003; Lovering, Porter, & Bloch, 2005).

DMD is also the most severe form of muscular dystrophy resulting in muscle weakness and loss of function early in life, and death usually occurs in the late teens or early twenties; therefore, Duchenne is the type which is most commonly seen in schools

(Heller, et al., 2008). During school years, individuals with DMD lose muscular strength, endurance, and control over their upper limbs which all negatively impact the writing fluency. Loss of muscular strength and endurance typically causes fatigue during writing activities, minimizing the time and physical energy needed to complete writing tasks. Reduced muscular strength, weakness and endurance may impact the fine motor control needed to effectively and efficiently handwrite or type. Duchenne muscular dystrophy does not produce CNS or cognitive degeneration, although some individuals afflicted with DMD have IQ (Intelligent Quotient) scores in the low average to mild mental retardation range (Behrman, Kleigman, & Jenson, 2004; Cotton, Voudouris, & Greenwood, 2001).

Spinal Muscular Atrophy (SMA) is an inherited disorder that affects approximately 1 in 6,000 births (Botta, Filareto, Spitalieri, & Novelli, 2006). There are several types of spinal muscular atrophy with the most severe leading to death soon after birth, and less severe types leading to death in school age children or early adulthood. SMA affects motor neurons innervating (e.g., supplying electrical impulses from the CNS) to skeleton muscles. Spinal Muscular Atrophy is progressive, and when diagnosed in childhood, gross and fine motor function declines in a way similar to Duchenne muscular dystrophy and can also lead to early death (Heller, et al., 2008). The progress of SMA varies from individual to individual, but generally impacts gross motor abilities first -- typically in the trunk and legs -- and progressively reduces fine motor skills in the shoulders, arms, hands, and fingers. In school-aged children, handwriting is feasible until loss of muscle function and increasing writing demands make typing more functional. As gross muscle strength and endurance declines, the range of motion of the arms decreases, limiting access to the entire keyboard, and key selection becomes slower and more laborious as more time and strength is required to select each key. As the disease progresses further, fine motor problems develop in the hands and fingers further impacting typing fluency.

Specific Characteristics That Affect Writing

There are several characteristics that are commonly found in students with physical disabilities that may affect the writing ability, including issues of access, the mechanics of writing, and the writing process. These affects may be explained by the Physical and Health Disabilities Performance Model (Heller, et al., 2008). In this model, the performance of the student is affected by the (a) type of physical or health disability (e.g., cerebral palsy), (b) functional effects of the disability and (c) psychosocial and environmental factors. Some of the various functional affects and psychosocial and environmental factors that pertain to writing ability in students with cerebral palsy, muscular dystrophy and spinal muscular atrophy are described below.

Functional affects of cerebral palsy include impaired and atypical motor movements. For some individuals cerebral palsy, altered motor movements due to spasticity (e.g., rigid muscles) athetosis (involuntary motor movements), and fluctuating muscle tone may impact keyboarding. Contractures in muscles may limit the range of voluntary movement of the joints such as the shoulder, elbow, wrist, and fingers. Any one of these problems may impact typing fluency, and some individuals have two or more problems to contend with (Heller, et al., 2008).

In contrast, individuals with Duchenne muscular dystrophy may achieve normal development milestones in the first years of life. Physical declines may appear at any time, and the rate of decline varies from person to person. Typically, gross motor movements are impacted first, limiting the muscular strength and endurance needed to complete a physical task without accommodations such as rest and modifications such as shortening the length of a writing assignment. Declines in gross motor movement and physical strength will eventually limit the range of motion in the arms and hands inhibiting access to and around a keyboard. As these diseases progress, fine motor skills, which are required, decline in the hands and fingers that impede voluntary and purposeful motor movements needed to type quickly and efficiently. As gross and fine motor strength and endurance decline further, individuals will require assistive technologies such as miniature or expanded keyboards, onscreen keyboards with scanning, and speech recognition software to engage in the mechanics of writing.

Spinal Muscular Atrophy (SMA) is a degenerative and terminal disease with characteristics that impact functional, psychosocial, and environmental factors in ways similar to individuals with muscular dystrophy. The degree of impact in the functional domain depends on whether the type of SMA is mild or severe. Motor limitations may begin in early infancy, or through the early toddler years, and may progress slowly for some individuals, while rapidly for others. By school age, many individuals with SMA require a power wheelchair for ambulation. Muscle strength, endurance and motor limitations typically affect the legs and trunk first, following with the torso, and continuing with the arms and hands later. Depending on the rate of disease progress, some individuals will not have difficulty with writing tasks until upper elementary, middle, or high school years. Once the upper body is affected, motor limitations will impact writing activities in much the same way as with Duchenne muscular dystrophy. Eventually, individuals with SMA will experience muscle fatigue and declining physical endurance to the extent that keyboarding is preferred over handwriting. As time passes, assistive technologies such as modified keyboards and alternative input devices will become necessary to aid with the mechanics of typing.

Speech impairments are a common form of communication problems among individuals with cerebral palsy. Individuals with CP who have speech impairments may have speech deficits that range from mild dysarthria to substantially or completely nonverbal. For some individuals, speech production may temporarily improve or decline based on physiological changes in muscle tone and involuntary motor patterns that affect the muscles involved in breathing and speaking. Speech impairments may affect the development of the writing process when an individual has an impaired ability to ask questions, seek help, or obtain clarification during instruction and guided or independent practice (Heller, et al., 2008). They may also be unable to express difficulty with physical barriers that impede the writing process, and they may be unable to declare other concerns such as: fatigue, headache, or restroom needs. When a person is unable to ask questions, receive clarification, or acquire help, misunderstandings of the writing process and correctable errors may persist over time that negatively impacts their writing development.

In the early to middle stages of muscular dystrophy and spinal muscular atrophy, communication problems are rare. Depending on the type of SMA, communication problems may have an early onset and progress more rapidly than typical. Most individuals with DMD and SMA continue to maintain adequate verbal, handwriting and keyboard communication skills. As the disease progresses, fatigue and endurance start to impact writing and keyboarding activities more than verbal activities. Increasing physical fatigue and decreasing endurance are hallmarks of disease progression for both disorders. At some point in time, speech skills will be impacted by weakness in the diaphragm that causes breathing problems which will invariably lead to speaking difficulty. Additionally, muscles needed to control the mouth and tongue needed for speech production become affected. This causes speech to become breathy, which causes the speech volume to decrease. Eventually, an individual may become nonverbal due to breathing or muscle weakness or due to the presence of an intubation tube and ventilator to assist with breathing.

Physical fatigue and endurance remain significant problems for individuals with cerebral palsy, muscular dystrophy and spinal muscular atrophy. For individuals with cerebral palsy, the onset of fatigue will vary from person to person, even for those who have the same diagnosis. Reasons for this variability include the type(s) of CP and the severity (e.g., mild to severe) of the condition. Other factors that may affect muscle strength and endurance include the amount of physical energy required to engage in the mechanics of writing, the time of day, the degree of activity prior to writing, the length of writing assignment and other factors. Mental fatigue and endurance may also vary based on the abovementioned factors.

Individuals with muscular dystrophy and spinal muscular atrophy usually do not have cognitive declines associated with their disease. Physical decline in strength and endurance is a hallmark of the disease process. In muscular dystrophy, muscles in the legs reveal weakness early although all skeletal muscles are impacted. In spinal muscular atrophy, muscle weakness begins distally (e.g., in the legs), and progresses upward through the body, and eventually neurons in the spinal cord die. The disease process begins at the bottom of the spinal cord and progresses upward through the lumbar, thoracic, and cervical spinal cord. In both diseases, physical strength and endurance may be affected by physical activity. Generally, the greater the activity level, the faster strength and endurance decline. As the disease process approaches the final stages, physical abilities may be limited to control over a single finger, facial expressions and speech, although some individuals even will lose these abilities.

There are numerous health factors that may impact the mechanics of writing. Although individuals with cerebral palsy are prone to certain medical conditions including epilepsy, visual disturbances, contractures, scoliosis and fluctuating tone, virtually any other health condition may be present, and concomitant health conditions are common (Heller, et al., 2008). Depending on the type (i.e., absence, generalized tonic-clonic), the length and severity of the seizure, an individual will generally be unable to engage in the mechanics of writing or the writing process during the seizure and for some period of time after the seizure is finished. The most severe seizure may leave an individual disoriented, with the need to sleep for up to several hours (Heller, et al., 2008). Cortical vision impairments are generally non-treatable and may make it arduous to distinguish text on a screen even with enhanced font size, and contrasting colors and hues between foreground and background. Cerebral palsy often causes contractures in body joints causing pain, disfigurement, reduced range of motion and voluntary control. The effects of spastic and fluctuating muscle tone may lead to scoliosis and other spinal deformities that, in addition, may cause pain, disfigurement and reduced range of motion, especially in the upper limbs. Although the progression of scoliosis may be slowed by medicine, braces, and surgery, for many the progress cannot be completely stopped and is often controlled by wheelchair, positioning and seating requirements. However, wheelchair use and positioning issues may lead to respiratory illnesses and decubitous ulcers as a result of limited mobility and appropriate positioning in a wheelchair, which often require additional medicines and hospitalization for treatment.

In many instances, people with cerebral palsy may take one or more prescription pharmaceuticals which may cause both physical and cognitive effects. Common examples include the medications for epilepsy that cause drowsiness, dizziness, dry mouth, and appetite suppression. Medication to reduce muscle tone and slow the scoliotic process in individuals with spastic CP may cause drowsiness and may increase the frequency of seizures in people with epilepsy. Fatigue and endurance may be impacted by other health impairments and also from the medications needed to treat them (e.g. asthma, Attention Deficit Disorder) causing drowsiness, irritability, and other cognitive disturbances.

A common health problem associated with muscular dystrophy involves the heart. Although the heart muscle is comprised of a different type of cell than skeletal muscle, it does require the enzyme Dystrophin to function normally. As the disease progresses, individuals with Duchenne muscular dystrophy are prone to reduced heart function and increased risk of heart attacks. Weakening heart function, in addition to problems related to wheelchair use and lack of physical movement, may lead to respiratory illnesses, which may require medications, hospitalizations and significant time to heal. Spinal muscular atrophy is not associated with heart conditions; however, respiratory illnesses are of major concern. As people with these diseases become wheelchair users at some stage of the disease process, decubitious (skin and muscular) ulcers and spinal deformities (e.g. scoliosis) are common.

Individuals with physical disabilities such as cerebral palsy will often have different and sometimes fewer common life experiences as compared with typically developing children. Beginning at birth, children with cerebral palsy may have motor limitations, health impairments and other problems that interfere with their physical, social, and language development. Infants with CP may not meet physical development milestones such as attaining head control, crawling, walking and exploring the environment. These limitations may be significant barriers to participation in early typical family activities including as a parent holding a child while reading a book, a trip to the store, a picnic, or visit to a museum. Children may spend substantial periods of time both at home, as well as at a doctor’s office.

As a child with cerebral palsy matures, opportunities to participate in family, school, and social events may decrease. Usually at some point in early to mid-childhood, the child becomes too large to carry, and although able to ambulate (e.g., walk), or use a wheelchair, in many cases independent movement throughout an environment is inhibited. Individuals with CP often have one or more additional impairments (e.g., vision, seizure disorder), and require numerous doctor and therapy services that reduce the amount of available time for both social activities and academics. Some individuals with cerebral palsy have numerous hospitalizations which further restrict their physical and health independence which reduces opportunities for experience development.

Physical limitations in the child combined with competing family demands may lead to reduced and delayed experience with overall literacy development. Research shows that reduced literacy experiences in early childhood may lead to reading and writing deficits throughout the school years. In some instances, opportunities to be read to, to hold, or to touch a book, point to a picture or word, or turn a page are not possible due to physical limitations. Children who are nonverbal or have dysarthric speech may be unable to choose a story, ask questions, or otherwise verbally interact with the reader and the text.

Physical limitations, along with environmental access problems, are potential barriers to common public and private places, negatively impacting experiential growth. Many families with children who have cerebral palsy, muscular dystrophy or spinal muscular atrophy often lack transportation capable of transporting people with physical disabilities, especially those who utilize wheelchairs, and therefore limiting family outings.

Specialized transportation costs may prohibit vehicle ownership for many families, and inadequate or available public transportation may limit opportunities to shop, use entertainment facilities, restaurants or parks. At schools, some classrooms or areas inside (i.e., art class, the stage), and outside (playground, stadium) are inaccessible and may curb opportunities to interact with peers and participate in daily activities.

In individuals with muscular dystrophy, loss of gross physical mobility becomes apparent in the later stages of childhood, and wheelchair use typically becomes necessary between the ages of ten and twelve (Behrman, Kleigman, & Jenson, 2004). Many children with DMD will have similar experiences as non-disabled peers, prior to requiring a wheelchair for mobility. The onset and rate of gross motor loss varies in individuals based on the type of SMA, with some children needing wheelchair assistance before age five and others not until the ages of eight and ten; therefore, opportunities for literacy, family and community activities vary from person to person.

Individuals with cerebral palsy also have cognitive deficits that may impact the mechanics of writing and the writing process. Individuals with cerebral palsy may experience mild to severe difficulties with attention, concentration, memory, and perception. Individuals with CP are at greater risk for sub-average IQ scores, including mental retardation and learning disabilities. In some cases, there may be one or more cognitive deficits which impact writing, resulting in significant barriers to communicating.

Degenerative diseases typically display cognitive and perceptual deficits at approximately the same prevalence as individuals without disabilities. This lack of cognitive and perceptual abilities may impact the effectiveness of writing instruction, interfere with written expression skills such as organizing one’s thoughts, and create problems physically interacting within the physical environment. Evidence exists that individuals with Duchenne muscular dystrophy have a slightly sub-average verbal IQ score, possible attributable to the effects of low levels of dystrophin in the brain (Cotton, Voudouris, & Greenwood, 2001). Individuals with a degenerative disease may also possess a gifted intellect.

One common problem that develops in individuals with severe physical limitations due to cerebral palsy involves motivation to achieve academically and to engage in basic, daily living activities which can lead to a sense of learned helplessness. One or more people are often required to assist with routine, academic daily tasks such as: writing, opening books and turning pages, and managing their physical environment. Assistance with dressing, bathing, brushing their hair, and feeding may also be needed. Learned helplessness may be a direct result of this assistance. When a person requires assistance to complete such tasks, the result may be learned helplessness. Learned helplessness is a condition in which an individual does not attempt to conduct tasks that they are capable of performing, often with difficulty, because they have become habituated with others performing tasks on their behalf (Hamill & Everington, 2002). Learned helplessness may impact writing tasks because it requires a great deal of cognitive and physical effort to complete, and for some individuals with cerebral palsy who have productive speech, verbal dictation is easier than writing or typing to accomplish a task.

Since individuals with physical disabilities often find writing to be a laborious and fatiguing activity, they may be unmotivated to begin, sustain, and complete a writing task (Heller & Swinehart-Jones, 2003). Poor motivation to write may be affected when communication through speech or argumentative and alternative communication (AAC) is necessary. Both of these communication methods are typically more efficient and less physically taxing, thus creating fewer errors than writing. The average individual with moderate to severe cerebral palsy will be more likely to have fewer life experiences, read a smaller number of books, and attempt to practice writing through play or academic experiences. Any of these issues alone or in combination may negatively impact an interest and a motivation to write. Furthermore, research suggests that children with moderate to severe physical disabilities receive little instructional time per day in the writing process and development (Heller, et al., 2008).

Individuals with degenerative diseases such as muscular dystrophy and spinal muscular atrophy, and low motivation for academic and nonacademic tasks pose a challenge for teachers. Depending on the age of onset and progression of the disease, children with degenerative disorders may have typical life experiences, opportunities to read text, and to practice writing through play and academic tasks, but the loss of physical strength and endurance will have an increasing impact on motivation to complete writing tasks. It is common that individuals with degenerative and terminal diseases lose interest in academic tasks (i.e., writing) because these tasks seem unimportant in comparison to genuine or perceived life challenges.

Individuals with severe physical disabilities who require assistance for physical tasks may develop a false self-concept and perceive themselves to be more disabled than they actually may be. Because of this low self-image, tasks that are within their ability are not even attempted, or are attempted with less than full effort and abandoned more easily when effort is required. In turn, this poor or altered self-concept may negatively affect self-esteem. In some instances, individuals with physical limitations struggle with emotional difficulties resulting from the frustration and anger that may occur when they are requested to attempt a task such as writing that they believe themselves unable to complete independently. Even when learned helplessness, poor self-concept and emotional problems are absent, individuals with cerebral palsy may lack social competency skills that may affect writing tasks. Individuals who have had fewer social opportunities in life as a result of all their physical, communication and health problems may lack an adequate understanding of verbal expression, which then translates to deficits in written expression.

Academic tasks that require cognitive and physical effort, such as writing, may be impacted by poor self-concept and self-esteem. As the disease progresses in individuals with muscular dystrophy and spinal muscular atrophy, the loss of the ability to run, walk, stand and eventually move one's legs impacts self-concept and esteem. In many cases, these changes in concept and esteem further impact motivation and may lead to emotional problems that affect writing. Some individuals with MD will develop learned helplessness over time as family, friends and school personnel assist or complete everyday tasks for them that the person might be able to conduct on their own or with minimal assistance, however, as well-intentioned as this aid may be, it has the effect of convincing the person with muscular dystrophy that they are unable to be independent. When presented with a writing task within their ability, individuals may convince themselves that they lack the intellect to complete the task.

As with muscular dystrophy, motivation for academic tasks such as writing may decline as the disease progresses and functional limitations increase. Over time, it is common for individuals with SMA to develop self-concept and esteem problems, which may interfere with motivation and interest in academic tasks, especially a task such as writing, which requires physical effort. In addition to this, individuals will develop emotional and behavioral problems that may affect academic tasks such as writing, especially due to the sadness and depression that may arise as the individual becomes older and more cognizant of the seriousness of the disease. As with other physical disabilities, some individuals with spinal muscular atrophy who have limited social experiences as a result of their disease may lack social competencies that are helpful to have when given a writing task that involves knowledge and experience in social interactions.

The extent to which individuals with physical disabilities advocate for themselves may have a significant impact on writing tasks. Self-advocacy skills include having knowledge of self-importance, and having the verbal skills required to seek assistance from teachers and peers. Research indicates that effective self-advocacy skills may improve academic achievement, including writing tasks in people without physical disabilities (Grover, 2005). An individual with cerebral palsy who is dysarthric or nonverbal may not be able to ask for help to overcome the physical barriers to perform the mechanics of writing, or to ask for clarification in the steps and procedures of the writing process. Although a teacher may recognize some of these barriers and learning deficits, in many instances a teacher or peer will fail to notice or recognize that there is a problem, and the student will be unable to complete the task. In contrast, individuals with degenerative diseases may possess the verbal ability to communicate their needs, but they may be unwilling because they lack a sense of self-importance. Many individuals will also have health needs that may influence the successful completion of writing tasks including: donning glasses, monitoring glucose, and suctioning a tracheotomy stoma (Heller, et al., 2008).

Individuals with physical disabilities may display difficult behaviors that may interfere with an academic task such as writing. Students with cerebral palsy, muscular dystrophy and spinal muscular atrophy may passively or actively resist writing activities for several reasons including the belief that writing is not meaningful to their lives, due to learned helplessness, or to avoid physically challenging tasks.

Mild to severe emotional problems may also exist, although not all individuals with physical disabilities will display psychiatric illness. Common problems include depression, anxiety, attention deficit disorder, schizophrenia, and bipolar disorder and obsessive/compulsive disorders (Levitt- Katz, et al., 2005; Heller, et al., 2008). Individuals with degenerative and terminal diseases such as muscular dystrophy and spinal muscular atrophy may be more prone to depression (Polakoff, Morton, Koch, & Rios, 1998).

Physical, learning, and social environment factors may affect the development of writing competence in individuals with cerebral palsy, muscular dystrophy and spinal muscular atrophy. For instance, an inadequate physical environment may cause writing and keyboarding to be more difficult or even impossible for some individuals. Functional limitations of a physical disability may require one or more environmental adaptations in order that appropriate physical access is obtained. Some individuals will need modified seating, specialized tables or desks, and slant boards in order to adequately reach and operate a computer. Other individuals may require adaptations including alternative keyboards, alternative input devices to make key selections (e.g., the letter "T"), and specialized software programs such as an on-screen keyboard and word prediction.

Even when the physical environment is appropriate, problems in the learning environment may affect a writing task. When an individual with cerebral palsy is placed in a classroom with students who are more cognitively impaired, and the learning environment is adapted toward the needs of these other students, learning expectations may be insufficiently challenging. In contrast, when a student with cerebral palsy is in a general education classroom with inadequate support and improper physical adaptations, and the learning expectations are targeted toward students without disabilities, it may be equally inappropriate and ineffective for the student with cerebral palsy.

For individuals with degenerative diseases, an inadequate learning environment may also impede writing tasks. This may occur when teachers lack information and training and feel insecure about the disease process and its physical and emotional effects on a student and neglect instruction in the writing process, believing that the student is unable or unwilling to complete the task. Teachers also may fail to provide adequate and appropriate feedback and require the student to engage in the revision process. This may occur when a teacher underestimates the physical strength and endurance of the student, or believes that writing tasks pale in importance in light of the terminal aspects of the disease. Moreover, the attitude of school personnel who may not understand the nature of terminal diseases may hold low expectations for individuals with degenerative and terminal diseases and lower academic expectations beyond what is appropriate.

Individuals with physical disabilities may develop deficits in social competence over time that may affect writing tasks (Heller, et al., 2008). Social competence develops over time through experiences interacting with peers and adults in different contexts. Writing topics are often chosen and based on personal experience. When social experiences are lacking in number and diversity, opportunities to develop writing skills decrease. An individual with cerebral palsy who has dysarthric speech, or who is nonverbal, or communicates through an AAC device, and those with degenerative diseases who have declining mobility, strength, and endurance may encounter fewer opportunities throughout the day to practice conversation and interact with others as the disease progresses. This may impact writing tasks because their repertoire of experiences to draw from is much smaller than a typically developing person.

Continuous evaluation of the physical, learning and social environment is necessary. An individual with a physical disability may demonstrate changes in physical abilities, strength, and endurance over time that require alterations, updates, and improvements to the physical environment. Changes over time in the learning environment such as the arrival of new teachers, paraprofessionals, and peers may lead to alterations and reductions in student instruction and expectations. With the passage of time, students with physical limitations, especially those who are declining in strength, may have fewer opportunities to engage in classroom activities, and participate in group discussions and personal conversations. Each of these environments may require ongoing adaptations to maintain or preserve maximum opportunities to learn and interact with others.

Writing Fluency

Writing process. Fluent writing is necessary for academic, personal and vocational success. Developing this skill takes time, practice and repetition and it is comprised of two major components: the writing process and the mechanics of writing. Prior to engaging in the mechanics of writing, cognitive processes must be initiated in which thoughts are generated and organized (Flowers and Hayes, 1981). The authors defined the writing process as a linear sequence of planning, text generation, and revision. Revision, according to Flowers and Hayes, is the process of returning to planning and text generation, repeating these steps as needed. In contrast, Male (2003) suggested that these three stages are overlapping, reciprocal, interactive and ongoing, but not necessarily sequential, until a final draft is generated.

Planning is a complex cognitive process involving many components. Planning, or prewriting, involves activating prior knowledge and organizing ideas into a coherent message. Various strategies may be employed to assist with the planning process in order to generate or organize thoughts prior to beginning a written draft. Common strategies include: researching, creating visual organizers, and formulating an outline. Having a visual recording of the planning process can assist in organization and help ensure that ideas and information are not lost. Individuals with physical disabilities, who are unable to use these strategies because of physical limitations, are at a disadvantage. In cases such as the above, they must rely on memory, the assistance of another person to document their thoughts, and assistive technology. When these alternative strategies are inefficient or unavailable, individuals with physical limitations may forget important ideas or have great difficulty organizing ideas into a logical and coherent manner, thus negatively impacting the next stages of the writing process.

The second stage of writing involves drafting. This step involves creating the general structure of a writing passage based on its organization and sequence of ideas. Organizing and sequencing ideas involves assigning words, phrases, and sentences to ideas in a specific sequence that can be clearly understood by the reader of the passage. Drafting is a two-part task that involves transferring information elicited in the planning process into a discreet, narrative form, which is followed by attention to the rules of composition including correct grammar, capitalization and punctuation. In this manner, the writer constructs full sentences that build upon each other to form a complete draft (Flower & Hays, 1987). Creating a draft is not necessarily a linear activity, as writers may choose to evaluate and revise words, phrases, and sentences as they write (Male, 2003).

The third and final stage is revision. In this stage, the writer analyzes words, phrases, sentences, grammar, spelling, and punctuation, and as well as overall effectiveness and coherence of the passage and then makes changes as needed. Revision may involve incorporating new ideas and material, and it may be a subtractive process that deletes extraneous or redundant ideas. For individuals with physical disabilities who are inefficient or unable to erase, delete, move, or insert words, phrases and sentences, the revision stage may pose significant barriers to completing the writing process.

Mechanics of writing. Writing fluency is significantly impacted by a host of mechanical factors. The speed and accuracy of handwriting and typing may affect writing fluency in several ways. Initially, it is essential that an individual utilizes the most cognitively and physically efficient means to write as measured by speed and accuracy. For individuals without disabilities and for some individuals with physical disabilities, handwriting is a more efficient means of generating a written passage; however, for individuals who choose to type or who are forced to type, the physical and cognitive efforts needed to facilitate the mechanics of keyboarding may have an adverse impact (Lueck, Dote-Kwan, Senge, & Clarke, 2001). For these individuals, typing requires constant attention and effort that may take needed cognitive resources away from the writing process and may cause mental fatigue. Additionally, the added cognitive effort to type may also limit physical endurance.

Lewis, Graves, Ashton, and Kieley (1998) conducted a study that assessed two groups of students, one group with learning disabilities and the second group without disabilities, in speed and accuracy when handwriting. Four variations of typing using a word processor (e.g., using a word processor alone, typing using a word processor following keyboard instruction, using a word processor with word prediction software, and using a word processor with word prediction and speech synthesis) were also compared. The authors measured the total number of both words and number of errors per 100 produced in three-minute sessions in pre- and post-tests. In the pre-test phase, both groups were given a writing prompt and wrote by hand. In the post-test phase, students wrote using one each of the word processing treatments. The results indicated that handwriting was the most efficient production method for both groups, although students with learning disabilities wrote slower than students without disabilities in both pre- and post-test phases. The next slowest treatment was typing with word prediction software. The slowest treatment reported was word prediction with speech, perhaps because students concentrated on the speech feedback during the writing process which had the effect of slowing down their typing rate the most. Furthermore, students with learning disabilities had fewer errors in all typing treatments as compared to the handwriting pre-test, possibly indicated that they were better able to detect typed versus handwritten errors.

For individuals without disabilities, the mechanics of writing may be achieved automatically, especially after practice, while requiring little or no conscious effort or attention. Individuals with physical disabilities may have one or more physical-mechanical links that require significant effort and attention, taxing physical and cognitive reserves. Individuals with physical disabilities may type more slowly, less accurately and with more spelling/keyboarding errors than individuals without disabilities. Even when modifications such as extended time, reduced expectations, and assistive software are employed, individuals with physical limitations frequently produce shorter writing passages than their peers without disabilities (Heller, 2003). Fast and accurate typing may be significantly impacted by motor planning deficits, especially for students with certain physical disabilities such as cerebral palsy. Individuals with CP frequently have damage to their central nervous system (e.g., the brain), that impairs the ability to quickly and efficiently plan to move arms, hands and fingers to select specific keys on a keyboard (e.g., for individuals who type using their upper limbs). Additionally, individuals with CP and other physical disabilities may have difficulty accurately selecting the target key due to involuntary or alternative motor movement patterns that cannot be corrected through therapy or practice as they are the result of brain damage. Any of the abovementioned deficits may lead to spelling/keyboard errors.

The onset of physical fatigue may happen earlier during writing activities for students with many different types of physical disabilities. Exhaustion may be due to the characteristics of the disability and the great effort needed to engage in the mechanics of writing. Frequently, individuals with physical disabilities have lower levels of endurance and require breaks, requiring a greater amount of time to complete a writing task. Some individuals, especially those with degenerative diseases such as muscular dystrophy, may be unable to return to writing on the same day once they have reached the breaking point. Even when fatigue is managed optimally, it still may lead to unintended spelling/keyboarding errors.

The effects of practice on typing speed and accuracy remains unclear for students with physical disabilities. Kellogg (1996) suggests that repeated practice in handwriting and typing should improve an individual's speed and accuracy; however, there are several explanations why this hypothesis may not apply equally to individuals with physical disabilities, if at all. Depending on the type of physical disability, the presence or absence of central nervous system damage, motor planning, and motor movement deficits, keyboard practice may be of little or no benefit. For individuals with these impairments, practice cannot improve speed or accuracy and spelling keyboarding errors may still occur.

The mechanics of writing involves memory, an important cognitive task, which when insufficient or impaired, may have a negative impact on the mechanics of writing. The Atkinson and Shriffrin (1968) information processing model helps to identify and explain memory and can be useful to describe its impact on the mechanics of writing. The authors describe a three-part model of cognition that includes a sensory register, short-term or working memory (henceforth referred to as working memory), and long-term memory, essentially, the sensory register involves a stimulus that is received by the brain through its sensory system (i.e., seeing, hearing, touching). Some stimuli will be transferred to working memory, while other stimuli are ignored and fade within seconds. Stimuli that are received by working memory will wither and be lost within seconds, rehearsed and used to achieve physical tasks (i.e., writing or typing) or cognitive tasks, or it may be passed into long-term memory.

Working memory has a limit that varies by individual. According to Miller (1956), working memory generally holds about seven units of information, plus or minus two units. The capacity of each unit varies to some degree depending on the type of information (i.e., single digits versus names of unfamiliar people), and the strategies employed to chunk information within units. For example, it is possible to gather a four digit number such as 5037 into one unit, rather than thinking of each digit as a separate unit.

Bourdin and Fayol (2000) used the term “cognitive load” to describe the capacity of working memory. The authors differentiated cognitive tasks in working memory that were high in comparison to tasks that are low. High cognitive tasks require constant effort and attention. Conversely, cognitive tasks that are low require little effort and attention and for some individuals, this may be automatic. For individuals with physical disabilities, the effort and attention required to plan and execute the motor components that are necessary to write are often high, sometimes leaving little or no capacity to devote to the high demands of the writing process (planning, drafting, and revising) and efficient keyboarding. As described earlier, the writing process is considered to be a high cognitive task for both individuals with and without disabilities, as it requires effort and attention to complete specific tasks such as recalling information from long-term memory, organizing ideas, utilizing spelling and grammar, and constructing a sentence. Therefore, writing fluency may be negatively impacted for individuals with physical disabilities who must devote a substantial portion of working memory capacity to plan and execute the physical mechanics of writing and also to the writing process.

Adaptations and Assistive Technology

Lueck, Dote-Kwan, Senge, and Clarke (2001) suggested that assistive technology decisions should: (a) promote individual independence, (b) consider functional needs, and (c) consider personal preferences. Based on the individual characteristics of the writer, a wide variety of adaptations and assistive technologies exist to support writing fluency (Heller, 2005; Cook & Hussey, 2002). For individuals with handwriting difficulties and those who are unable to handwrite, typing is an adaptation and an assistive technology. Typing using a word processor has become common in middle and high school age children for individuals with and without disabilities, and it is becoming increasingly common in elementary schools. Word processors are available with a variety of features and can be found on virtually every computer. Although word processors are middle to high level technology, users typically require minimum instruction and practice to operate the software adequately.

Individuals with physical disabilities may require adaptations in seating and positioning to be able to access a computer with a word processor. Assistive technology may be used to address some of the motor problems associated with typing fluency and spelling/keyboarding errors. When keyboards, a mouse or alternative input devices are inaccessible for individuals who use wheelchairs, adaptations to the table, stand, and mounting of the computer hardware is needed. In some cases, adaptations to the seating and positioning on which the individual sits may be necessary. Seating and positioning adaptations may also be necessary to reduce physical fatigue and increase endurance for individuals with CP who have motor limitations, and for individuals with muscular dystrophy who have muscle weakness.

Some individuals with physical disabilities are unable to access a standard keyboard, a mouse, and a monitor, even with adaptations to seating and to the positioning of computer hardware devices. In these instances, alternative keyboards, keyboard layouts, and input devices may be required. Many alternative sized keyboards exist to support typing access. An individual who types with a mouth stick may need a small keyboard that reduces the surface area of the entire keyboard, enabling the stick to reach each key. Alternatively, an individual who types with a toe may need a larger keyboard with larger keys for the toe to strike.

Individuals with severe motor deficits, who are born without limbs, or who have limited physical strength, may use alternative input devices from a keyboard or a mouse to assist with fluency and accuracy. Assistive technologies such as an onscreen keyboard, scanning software, can be combined with devices such as a joystick, tract balls, or sip and puff switch may be employed to aid with typing. For individuals who type with one hand, or who have cognitive deficits, an alternative keyboard layout to the standard QWERTY may be utilized. Examples of common alternative keyboards are DVORAK and an alphabetical layout. Individuals with impaired vision or visual deficits may use keyboards with highly contrasting foreground and background colors and larger keys. Individuals with severely limited physical abilities may use an on-screen keyboard in combination with a word processor. The virtual keyboard may be accessed through one or more switches to make selections. On-screen keyboards are frequently combined with scanning software, which highlights an individual key, word, or command in a continuous fashion. A user “selects” a highlighted choice by clicking (e.g., switch), and the selection is placed into a word processor or the command is carried out.

Even when these accommodations and assistive technologies described above are employed, many individuals with physical disabilities still need extended time to complete writing assignments. Although extended time may seem like a routine and appropriate accommodation, there are drawbacks. Some individuals may require extra hours, several days or longer to complete writing tasks that require only minutes for people without disabilities. When a person requires hours or days to complete one writing task, the impact on other academic responsibilities and personal pursuits may be significant. Some individuals who require extensive periods of time to achieve a writing task may fall behind in class work, homework and studying.

Adaptations to Address Writing Fluency

Dictation. For individuals who have physical disabilities that do not significantly impair speech production, dictating to another person may be an alternative to completing written assignments (MacArthur, 2000). For many people with learning disabilities, dictation can be faster (De la Paz, 1999), easier, less time consuming, less cognitively and physically fatiguing, and therefore, causing the student to produce more work (De la Paz & Graham, 1997). Individuals with physical disabilities may derive the same benefits from dictation. Savings in each of these domains may increase overall productivity because more time and energy is available for other activities and tasks. According to MacArthur (1999a), dictation may permit greater attention to idea generation due to the fact that less attention would be directed to the mechanics of writing. Dictation can sometimes be disruptive to classroom activities, and this may be burdensome for the person taking dictation, thus increasing learned helplessness.

Speech recognition. Advances in technology have led to the development of specialized software that recognizes human speech, while working simultaneously with a word processor. A user speaks into a microphone and the software interprets what is spoken, then places the information directly into the word processing document. There are several potential benefits and limitations to speech technology as it currently exists. Duhaney and Duhaney (2000) suggested that speech recognition technology may offer an alternative means for individuals with physical disabilities as a means to write, although little research exists to support whether this technology will be effective.

De la Paz (1999) defined five general factors that may affect the overall effectiveness of speech recognition technology: whether the user's voice can be recognized, whether the user's voice can be adequately trained, the accuracy rate, error correction procedures, and the size of the system vocabulary. Perhaps the most significant benefit for individuals with physical disabilities may be the possibility in creating a writing passage independently. At optimum performance, speech recognition software may assist the user to create a complete, error free document ready to read on the screen, print, or send electronically. Once the two software programs are ready and the user has access to a microphone, words, phrases and sentences spoken into the microphone will appear on the computer screen. A series of voice commands allow the speaker to format the document, perform a variety of typical commands, and correct errors in both grammar and spelling. However, creating an error-free document may be time consuming and effortful for the user.

In order to maximize the full potential that speech software offers, the user must be able to enunciate words clearly. Most available speech programs require the user to complete a training trial so that the software can learn to recognize the user's voice, speech patterns and pronunciations. These training trials may be lengthy, and unfortunately may be unsuccessful for users with speech impairments, significant accents, breathing problems and low volume speech. In some instances, an individual who seems to have clear speech will still be unable to successfully use speech software, although no specific explanation can be determined.

The quality of a passage created with speech recognition software may depend on the size of the program's dictionary, which varies among commercial products. Most programs will actively learn and incorporate new vocabulary during the training and operation phases, however, teaching this new vocabulary may be time consuming and effortful, and will require the user to use voice commands to achieve this goal. In instances when vocabulary is esoteric (e.g., describing the parts of a muscle cell), the use of additional vocabulary will definitely be needed.

The overall accuracy rate of speech recognition software varies by both the product and the individual user. Because there are so many factors involved in accurately capturing spoken words and translating them correctly into text, it is feasible that a significant amount of errors can be made in this process. Because of this, a user may try to increase system accuracy through training and practice. Each program has a set of error correction procedures that the user must learn to use proficiently. Typically, error correction can be accomplished through voice commands, through physical contact with a keyboard, or alternative means of access previously discussed. The extensive number of voice commands in some speech programs may be a significant barrier for some individuals.

In a study by Garrett (2008), high school students with physical disabilities were evaluated on writing fluency, accuracy and passage length when using speech recognition technology versus keyboarding and word processing software. The author reported that all participants revealed higher fluency when using speech recognition, although gains varied by participant. Conversely, all participants had fewer spelling errors using word processing. The author suggested that higher spelling errors using speech recognition could be attributed to multiple causes, but may have been due to deficits in the current level of technology. For example, the most common error in speech recognition occurred when the software placed an incorrect word rather than the word actually spoken by the student. The result of this study suggests that for some users with physical disabilities and adequate speech, speech recognition technology may be an adequate alternative means of writing.

Word processing. Word processors are a ubiquitous form of assistive technology used by people with and without disabilities to complete writing tasks. For the typical user, word processors appear to have many benefits and few drawbacks. Some decisions will need to be addressed prior to a user beginning word processing, such as keyboard and mouse access, screen and font size and color, and the availability of features such as spelling and grammar support, dictionaries and a thesaurus.

MacArthur and Graham (1987) suggested that word processing may have several potential benefits for typical users. Since word processed documents are likely to be more legible and neat as apposed to handwritten passages, both the creator (e.g., student) and the reader (e.g., teacher) may perceive the passage in a more positive light. Another potential benefit involves the ease and speed that a user is able to make corrections, substitutions and deletions to a passage. A final advantage for users with some experience with keyboarding and word processing commands is that word processing may reduce the physical demands needed to carry out the mechanics (e.g., motor planning and movement, physical fatigue) of writing.

A review of research focused on school-aged users with and without disabilities revealed mixed support for its use (Bangert-Drowns, 1993; MacArthur, 1999a). Englert, Wu, and Zhao (2005) suggested that word processing, as a form of assistive technology used for writing, may reduce some of the cognitive load needed to complete the writing process (.e.g., planning, drafting, revising), may offer assistance with spelling, and may impact a user's motivation to write. For users without physical disabilities, Graham (1990) suggested that typing may reduce the physical effort needed to complete a writing activity. MacArthur, Schwartz, and Graham (1991) reported that the act of typing was easier for students with fine motor deficits.

In addition, to support spelling, some writers may create longer passages using a word processor versus handwriting. Outhred (1989) compared the length and spelling accuracy of handwritten versus typed passages with all participants that had learning disabilities and the author reported that the overall length of passages increased over time under both conditions, but participants who had the shortest handwriting passages made the greatest gain in passage length. Participants with generally fewer spelling errors when handwriting, made no noticeable gain when using a word processor; yet, those with a higher rate of spelling errors in handwriting made significant gains in spelling accuracy. The study did not investigate whether the quality of writing improved with word processing.

Hetzroni and Shieber (2004) also investigated the effects on passage length and spelling using a word processor, featuring a spelling correction function where the three participants with learning disabilities and writing difficulty were examined. The authors reported that two of the three participants wrote longer passages and all three had fewer spelling mistakes when using a word processor as compared to handwriting. The authors speculated that the spelling correction feature which underlined incorrectly spelled words offered the participants a visual advantage in locating and revising incorrectly spelled words. The authors further speculated that this feature improved appearance of the word processed document overall, and this may lead to a higher motivation to engage in the writing activity. MacArthur and Graham (1987) suggested the use of word processors to create written passages could lead to increased motivation and confidence in students to express themselves because the final document would promise to be more legible and contain fewer spelling errors.

In contrast, MacArthur, Schwartz and Graham (1991) reported that the overall value of word processing versus handwriting is minimal at best if word processing skills are not taught. Furthermore, specific knowledge of the keyboard and basic commands (e.g., opening and closing a file, indenting) of the word processor was necessary for optimum use (MacArthur & Schneiderman, 1986). Additionally, Male (2003) stated that students required opportunities to practice multiple forms of writing including writing across subjects, narratives, persuasive essays, comparing and contrasting ideas. In addition to this, the author also suggested that students were provided with sufficient opportunities to practice keyboarding skills.

MacArthur, Schwartz, and Graham (1991) indicated that a user must be able to type at least as fast as they write, in order for word processors to be an effective tool. Male (1997) suggested that a teacher may need to assist students who are unable to type quickly enough or to expand an idea with verbal prompts or typing partial words and phrases for students to expand upon, possibly increasing dependence.

Word prediction. Word processing can be combined with Word Prediction Software (WPS) to enhance the useful aspects to ameliorate some of the negative aspects of stand alone word processors for individuals with physical disabilities (Merbler, Hadadian, & Ulman, 1999). Many types of WPS exist, each with differing features. In some instances, word prediction is a feature built into a word processor. Several stand alone WPS programs are also commonly used. In general, WPS provides the user with a list of correctly spelled words to choose from as they type. Typically, several variations of word lists are possible including the number of choices, the position of the word list on the screen, the size of the dictionary, the ability of the dictionary to learn new words, and the ability to predict the next word the user will type based on previous writing sessions. Some WPS contain a voice feedback option that benefits some users.

One commonly used WPS program is Co:Writer 4000 (Johnston, 1992). It is a standalone tool designed to be used with a common word processor such as Microsoft Word. This prediction program features a separate window that can be moved to the upper or lower portion of the viewing screen in order for users to have the option of viewing both windows simultaneously. The Co:Writer window may also be collapsed into a separate tool bar if the user wants to view the word processor alone. The most common setup involves placing the WPS program window at the top of the screen and the Co:Writer screen at the bottom. Initially, the user types the first letter of a word in the prediction software window and a numbered set of words (e.g., five) is offered by the program. If one of the choices is the word the user wants, the user selects it by typing the number associated with the choice or by clicking on the choice. If the user does not want one of the available choices, they type the next letter of the word which changes the offered choices. Following this is a second consultation of the word list. At this time either a word is selected or typing is continued. If the user selects a word from the menu of choices, the software then places the complete word into the sentence, and the user types the first letter of the next word in the sentence. This process continues until the user reaches the closing of the sentence. Next, the user selects end punctuation, and the software transfers the complete sentence to the word processor in the above window making the Co:Writer window empty and available for the next sentence.

There are several ways in which WPS may benefit a user in improving typing fluency, which is the number of correctly spelled words typed in a given period of time (e.g., one minute). Typing fluency varies from person to person. Some individuals are unable to achieve rapid typing rates due to physical disabilities. Any method that increases typing rate is called rate enhancement, and one way to potentially increase typing rate is through WPS. Rate enhancement is achieved when the method permits a user to generate more characters (letters) than she physically selects on a keyboard (Cook & Hussey, 2002). Rate enhancement is accomplished when a user types one or two letters of a word and then selects one of the complete word choices from the word prediction menu by selecting the number associated with the chosen word or clicking on the word. The word prediction software then places the selected word into the sentence for the user. In this way, a user may achieve rate enhancement because fewer keystrokes were needed to type the complete word using the WPS then would have been needed to type the complete word processing (Merbler, Hadadian, & Ulman, 1999). Gains in rate enhancement may increase as the length of the writing passage accrues. Shorter words (e.g., cat) will achieve lower gains than longer words (e.g., constitution). A rate enhancement is only achievable if the user attends to the word menu, recognizes or locates the sought after word, and selects the word. Otherwise, the user must type the entire word in the WPS and achieve no gain in rate.

Spelling accuracy affects writing fluency. For individuals who are poor spellers or who misspell a word due to physical disabilities and limitation, any method that increases spelling accuracy has the potential to improve writing fluency. With word prediction software, the menu of options provided to the user contains all correctly spelled choices; therefore, when a user is making a selection from the word menu, they have the potential to construct a writing passage free from spelling errors. There are, however, several limitations in achieving an error-free passage. As stated above, a user must select from the word menu in order to benefit from the correctness of the spelling. If the user identifies the preferred word in the menu choice, but unintentionally selects the wrong choice from the menu, the end result will be an incorrect word. In some instances users may ignore the word menu and proceed to incorrectly spell the word. It is also possible that the user does not recognize correct desired choice in the word menu and therefore proceeds to guess at the spelling. Additionally, it is may be that the word the user wishes is not available in the dictionary. Another potential reason that words are misspelled is due to involuntary key selection on the keyboard, creating a keyboarding error. Finally, a user may become confused by homonyms in the word menu and make an incorrect selection.

Word prediction software may also increase writing fluency for some users by decreasing capitalization and spacing errors and by achieving rate enhances by correctly adding a space between each word in the sentence. Capitalization errors may be reduced because WPS automatically capitalizes not only the first word of each sentence, but proper nouns as well. In some instances the WPS dictionary may not recognize a proper noun and leave it uncapitalized; however, the teacher or the user may add words to the dictionary that are correctly capitalized and spelled, or the user may many capitalize a word using standard keyboard commands.

Typing fluency is often negatively impacted by unintentional spacing errors. Spacing errors may occur due to lack of attention, lack of practice, or unintentional key selection. Whichever the cause of the error, a spacing mistake either creates a spelling or formatting error in the writing passage. Word prediction software automatically places a single space between each word if the words have been selected from the word menu by the user; therefore, spelling errors and spacing errors are potentially eliminated, thereby improving fluency. Spacing errors may still arise when a WPS user does not select a word from the menu, inadvertently or intentionally adding a space by selecting the space key on the keyboard.

The cognitive and physical effort, or load, required to accurately and efficiently use word production software may impact writing fluency, and the impact may vary due to individual factors (Englert, Wu, & Zhoa, 2005)**.** Individuals with severe physical limitations, or who physically fatigue quickly, may realize that keystroke savings decrease the physical effort and endurance needed to complete a writing passage. A student with any physical disability who is a poor speller may find that word prediction requires less effort since correctly spelled words are provided. For other users, using word prediction software may increase the physical and cognitive load to the extent that fluency and spelling accuracy is greatly reduced. A student with adequate typing fluency who can type a word and space faster than the time required to visually scan the word prediction list and make a selection, may find word processing an easier writing method. Many students with severe physical disabilities who require scanning software to select a key or word will have to wait a substantial amount of time while the software scans the alphabet or word list awaiting the user to make a selection. This wait time may increase the cognitive load needed for word prediction because the user must recall what she plans to select and remember what she plans to say in the future, placing a great strain on working memory (Atkinson & Shriffrin, 1968). For individuals whose physical and cognitive strength fluctuates throughout the day or from day to day, one method (e.g., word prediction) may be preferred at a specific time and the other method preferred at a different time.

Factors Affecting Word Prediction

All disabilities. Although word prediction software was originally developed and may be an effective tool to assist students with physical disabilities in increasing typing speed and accuracy, and reducing spelling errors, much of the literature on word prediction software features students with learning disabilities (MacArthur, 2000). Of the reported studies, the focus of the majority of the research involved spelling accuracy and less often reported on rate enhancement.

In a study by Lewis, Graves, Ashton, and Kieley (1998), 132 students with learning disabilities and without disabilities were evaluated to determine differences in writing fluency between hand writing and word processing with several variations. The authors used a pre-test/ post-test control design with three-minute sessions. Typing rate was reported as the number of characters per minute. Errors were reported as a number per 100 words. In the pre-test, all participants handwrote a passage after being given a writing prompt. In the post-test, participants were divided into six groups. One group served as a control and handwrote, while the other five groups typed in a word processor (word processor alone, with an alternative keyboard, after keyboard instruction, with word prediction software, and with WPS with speech feedback). The authors reported mixed results. Handwriting was the fastest word production method for all groups; however, among the word processing groups, participants made greater typing gains using word prediction versus word processing. In contrast, the slowest group was the WPS with speech feedback, suggesting that this function served to divert the participants' attention. Participants without disabilities did not make significant gains in spelling accuracy in post-test analysis; however, students with learning disabilities did make appreciable gains using word processing. The authors suggested that a lack of keyboard practice may explain why handwriting was superior to word prediction for all students, and students with learning disabilities may have more easily identified spelling errors on the screen versus in their own handwriting, possibly indicating that legibility is a factor in spelling accuracy.

MacArthur conducted a series of studies with word prediction and students with unspecified learning disabilities that examined rate enhancement and spelling accuracy. In one study, MacArthur (1998b) conducted a multiple baseline and withdrawal study featuring students with learning disabilities to assess whether spelling accuracy improved using word prediction software. He reported that 4 of the 5 participants made gains in spelling accuracy. MacArthur (1999a) reported gains in spelling accuracy in a series of studies featuring the same three participants with learning disabilities. The first study used an alternating treatment design to compare handwriting to word prediction or to word processing in a journal writing activity. Only one of the participants made gains in spelling accuracy; however, the second study placed higher vocabulary demands on the participants, possibly causing participants to use word prediction more often. In a follow-up study, MacArthur (1999b) reported gains in spelling accuracy for four middle school-aged children with learning disabilities.

In a study using word prediction software featuring students with learning disabilities, (Golden, 2001) reported that initial typing rate in word processing impacted the rate achieved when word prediction was added. Although spelling accuracy was not reported, higher typing rates in word processing led to a lower rate with word prediction. The author speculated that prior keyboard practice and time spent searching word menus in word predictors may be important factors that impact the outcome for users.

Physical disabilities. A few studies exist that examine the use of word prediction with students with physical disabilities. Koester and Levine (1997) compared eight participants without disabilities and six participants with high-level spinal cord injuries, who used mouth sticks to access keyboards. Although results were mixed, both groups decreased text production when using word prediction; however, fewer keystrokes were used with word prediction than with word processing independently. For the participants with spinal cord injury, the rate of text generation was an average of 41% lower when word prediction was utilized. Conversely, each key selection took significantly longer to make, especially for users with spinal cord injuries; this possibly accounts for the shorter passages in word prediction. The authors suggested key selection length was attributed to the cognitive and perceptual factors needed for word prediction. The authors concluded that word prediction would only increase text generation rate if the amount of keystrokes that are saved using word prediction exceeds the selection rate (which is influenced by such cognitive and perceptual factors as search time, deciding on the selection, and key press time (Koester & Levine, 1997, 1998). However, practice with word prediction may have also contributed to slower key selection although the authors did not examine this possibility.

Tam, Reid, Naumann, and O'Keefe (2002a) conducted an investigation using an alternating treatment design comparing word processing to word prediction with four students with Spina Bifida and hydrocephalus. The participants' ages were between ten and fourteen. Individuals with Spina Bifida and hydrocephalus typically have fine motor and perceptual deficits that may negatively impact typing fluency (Heller, et al., 1996). Typing sessions lasted five minutes in duration. The authors reported that none of the participants made gains in typing rate when word prediction software was used. Tam et al. (2002a) discussed the following limitations to their study: (a) participants may have lacked practice with word prediction which may have affected gains, (b) the length of the study was brief, (c) the study methodology was weak, and (d) idiosyncrasies of the population that may not generalize to other disabilities. Participants in the study perceived benefits to using word prediction and would consider using it for future writing assignments (Tam, Reid, Naumann, & O'Keefe, 2002b).

Tumlin and Heller (2004) conducted a study using high school aged participants who had a variety of physical disabilities. Participants included students with cerebral palsy and traumatic brain injury who also had physical disabilities. The authors investigated the effects of word prediction on increasing typing fluency using a reversal design and three-minute typing sessions. Participants were provided writing prompts and given a brief period to collect their thoughts before writing. Results indicated that typing speed and accuracy varied by participant, based upon the severity of the physical disability and the students' typing speed. The two students with the most severe physical disabilities and slowest typing speeds (2.9 words per minute (wpm), 4.7 wpm) using word processing (2.9 wpm, 4.7 wpm) had increases in typing speed using word prediction software. Conversely, the two students with greater initial typing speeds (10.9 wpm, 14.6 wpm) and less severe physical disabilities either showed no improvement or typed slower using word prediction software. The authors concluded that several investigated factors may have contributed to the limited effectiveness of word prediction software. Since the participants in this study had severe physical disabilities, physical fatigue may have played a part in the outcome. As discussed by Koester and Levine (1996), keypress rate, which was not measured, also may have negatively impacted word processing and word prediction speed. Attention and motor planning variables in individual participants could not be controlled or analyzed. Finally, the authors concluded that pre-intervention typing rate may play a key role in the effectiveness of word prediction use. Two participants who had between five and twelve percent spelling errors using word processing, made zero to three percent errors using word prediction. The other two participants demonstrated mixed results having fewer spelling errors in some, but not all, writing passages using word prediction.

Mezei and Heller (2005) conducted a similar investigation featuring three participants, all of whom were thirteen years old. One participant had cerebral palsy, one had Duchenne Muscular Dystrophy, and the third participant had Spina Bifida and hydrocephalus. Typing speed and spelling accuracy were measured in word processing and with word prediction software. The present study also used a reversal design, but featured three- and six-minute typing sessions. Prior to each typing session, participants were given a writing prompt (e.g., Describe your favorite TV program, vacation, or food), and allowed sufficient time to handwrite or type a draft prior to engaging in timed writing sessions. This methodology was chosen to reduce or eliminate thinking or "wait time" during timed typing sessions. The results of the study were mixed. All three participants had higher baseline typing rates than those reported by Tumlin and Heller (2004). Two of the three participants in the present study made noticeable gains in typing speed using word prediction in six-minute typing sessions, but modest gains in three-minute sessions. These same two participants demonstrated little variability in typing speed using a word processor alone; however, they showed a consistent increase in typing speed in word prediction across the length of the study suggesting that a learning or practice affect using word prediction software. The third participant demonstrated modest, although mixed gains in typing speed.

For spelling, all three participants made improvements in spelling accuracy, although spelling mistakes still continued to occur. The two participants with the lowest spelling errors in baseline phases achieved modest improvements using word prediction. One participant with an initially high error rate in spelling using a word processor alone, made significant improvements in spelling accuracy using word prediction. The authors reported that some of these errors would not be picked up by word prediction as they were typographical errors, while other errors would have been caught by word prediction, but the student apparently ignored the correctly spelled choice and proceeded to type a misspelled word.

Several limitations in this study were identified by the authors. Replication studies featuring participants with diverse physical characteristics included type of disability, initial typing rate, and age are needed to determine the effectiveness of word prediction oftware as the current literature base is small. Replication is also needed due to the small population that comprises single-subject studies. The subjects in the present study did not have severe physical disabilities that greatly affected hand use, although inclusion in the study requires some measurable arm and hand limitations. The methodology of this study was unique in having the students pre-write their answers and then copy the answers either using word prediction or word processor. Although the authors reasoned that copying their own written work in timed typing sessions best reflected true typing speed by eliminating thinking time and allow spelling errors, there are alternative methodologies in the literature (MacArthur, 1999a; Tam, et al., 2002a; Koester & Levine, 1998). Further research into using featuring different methodologies is warranted.

Conclusions

Assistive technology such as word prediction software may improve writing fluency and spelling accuracy; however, individual factors will impact effectiveness (e.g., initial typing rate ceiling and floor, search time, keypress time, motivation, etc.) However, there are several potential benefits and limitations that may apply based on individual characteristics and ability. Therefore, more research featuring participants with physical disabilities is needed to evaluate the efficacy of word prediction for this population.

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CHAPTER 2

THE EFFECTS OF WORD PREDICTION ON WRITING FLUENCY FOR STUDENTS WITH PHYSICAL DISABILITIES

Statement of the Problem

An important form of communication for all people is written expression. Individuals with physical disabilities may have difficulty with the mechanics of writing due to motor, strength, and endurance limitations. Individuals with cerebral palsy, muscular dystrophy and spinal muscular atrophy may have problems with handwriting due to physical disabilities therefore forcing them to type. Writing fluency, which is the ability to type quickly and accurately, may inhibit developing the skill to engage in the mechanics of writing, and limit the opportunity to practice and develop skills required to support the writing process. Assistive technologies that permit people with physical disabilities access to computers with word processors may be insufficient to assist them with the mechanics of writing in an accurate and efficient way. People with physical disabilities may potentially benefit from assistive technology that enhances keystroke rate (Garret, 2008), which allows keystroke savings (Koester & Levine, 1997), and improves spelling accuracy (Sandburg, 1998). One form of assistive technology that may improve writing fluency for people with physical disabilities is word prediction software (WPS). However, some students are provided with word prediction software without appropriate training or verification that it is effective.

Impact of Physical Disabilities on Writing

People with physical disabilities may have functional, psychosocial, and environment factors that can affect typing fluency (Heller, Alberto, Forney, & Schwartzman, 1996). Cerebral palsy, muscular dystrophy, and spinal muscular atrophy are medical conditions that can impact the efficient and effective motor coordination needed to type fluently and accurately. In individuals with cerebral palsy, several types of motor impairments may affect the efficient coordination of the arms, hands, and fingers, causing problems typing accurately and efficiently; this may even cause typing to be impossible (Guyton & Hall, 2006; Miller, 2005). In individuals with degenerative diseases such as muscular dystrophy, declining muscle strength and endurance in the arms, hands, and fingers, impact the ability to sustain and complete writing activities. Reduced range of motion in the arms, hands and fingers from contractures and muscular fatigue may limit or inhibit an individual from reaching and selecting a desired key (Heller, Alberto, Forney, Best, & Schwartzman, 2008). Any of these motor and strength issues, either independently or in combination with others, will have a negative impact on typing fluency. In addition, spelling errors may occur for several reasons, including involuntary and inefficient motor patterns, contractures in the joints, and fatigue in the arms, hands, and fingers.

In addition to motor problems, fatigue, and endurance, many individuals with physical disabilities have other health problems that may affect writing fluency. Students with cerebral palsy may require medication to control seizures, reduce high muscle tone, treat asthma, or many other reasons. Medications that treat these conditions may affect motor coordination, and range of motion in the limbs and may cause drowsiness and nausea. Individuals with muscular dystrophy and spinal muscular atrophy are prone to respiratory illness which may require medication, and people with muscular dystrophy may have cardiac problems. Individuals with cerebral palsy, muscular dystrophy, and spinal muscular atrophy are at serious risk for spinal deformities, which cause pain and discomfort and limit the range of motion of the upper limbs. Each of these physical impairments also may lead to contractures, a progressive shortening of the ligaments and tendons in the arms, hands, and fingers causing pain and inhibiting efficient motor movement and control.

Communication deficits may result from the physical disability from birth onward, or may become a problem as a physical disability progresses. Individuals with cerebral palsy, a congenital disorder, may be dysarthric or nonverbal. In either instance, the opportunity to communicate with parents, siblings, teachers, and peers may be limited or impossible. Any person, who is unable to enunciate or converse at all, may be unable to seek assistance, ask questions, and express a preference. Additionally, a person with limited or total speech impairment may be unable to express difficulties with the mechanics of writing or ask for help to obtain skills needed to master the writing process. In muscular dystrophy and spinal muscular atrophy, the muscle involved in breathing and speaking will become affected in the later stages of the disease. As this process occurs, speech will decline progressively and may cease to be understandable. Some people will require a ventilator to sustain life, which completely inhibits speech production. In addition to speech limitations, some individuals with physical disabilities who use an alternative or augmentative communication system (AAC) may have a method of expressive communication, but AAC devices create other communication problems due to the cognitive and physical requirement for successful operation of the device, limitations in the programming of communication choices, and problems with technology maintenance. Whenever communication deficits are present, instruction and practice in writing activities may suffer, leading to low acquisition and slow progress in writing fluency.

Experiential deficits are common in individuals whose physical limitations appear at a young age. Individuals with cerebral palsy are born with brain damage that affects motor coordination and voluntary muscle control; therefore, they are at risk for not meeting physical developmental milestones necessary to build cognitive growth. These types of physical and health impairments may make common childhood experiences such as reading a book or going on a picnic difficult or impossible. Children with spinal muscular atrophy may experience severe physical problems at an early age, or not until middle to late childhood, depending on which type of the disease is present. Although signs of muscle weakness may appear early in children when a person has muscular dystrophy, the typical progression of the disease makes a wheelchair necessary between the ages of ten and twelve. People with physical disabilities may be limited in mobility to the extent that they cannot engage in family, school, and community activities, thus having a smaller repertoire of experiences to bring to a writing activity. Cognitive impairments including learning problems, attention concentration difficulties, and memory deficits may impact knowledge and skill acquisition during both academic and non-academic life experiences.

Psychosocial factors, such as poor motivation, self-concept, self-advocacy, and emotional and behavioral problems may impact the mechanics and acquisition of skills needed to engage in the writing process. People with physical disabilities tend to be unmotivated to engage in writing activities for a variety of reasons. Some individuals with cerebral palsy may think that the mechanics of writing are too difficult in light of their physical limitations. In contrast, people with a degenerative and terminal disease may consider writing and other academic tasks pointless.

An individual with a physical disability who has a poor self-concept may be disinterested or unwilling to engage in writing tasks. People with physical disabilities may look, sound, and move differently than their peers leading to a self-perception that they are qualitatively different. When a person feels different from a peer, it is not unusual for him to feel incompetent when attempting to complete a writing task, even when he is capable. At times, poor self-concept may lead an individual with a physical disability to become disinterested in both the common activities and the pursuits of peers.

In other instances, people with physical disabilities may be interested in writing, but lack skills to advocate for the opportunity to engage in the mechanics of writing and to practice the writing process. Some people with physical disabilities who require assistance to engage in any physical activity lack specific communication skills to advocate for their desires and preferences leading to few and ineffective opportunities to write (Hamill & Everington, 2002). Sometimes teachers and school staff are occupied with other children and fail to provide adequate assistance to a student who needs physical aid. At other times, children with physical disabilities may not be provided with sufficient instruction, feedback, and practice in acquiring wring skills. Although emotional and behavioral problems are not a direct result of cerebral palsy, muscular dystrophy, or spinal muscular atrophy, when they do occur, they may become barriers to engaging in writing activities.

There are several factors in the physical and learning environment that may affect writing. A person with a physical disability may become isolated within a classroom due to physical barriers that impede proximity to the teacher which leads to problems learning the writing process and developing writing skills. Social isolation from peers may impact learning when an individual with physical disabilities is relegated to a segregated part of a classroom due to the presence of specialized equipment, or due to the presence of an adult or peer assistant, or when a person has a speech impairment and cannot interact with others. When a person with a physical disability is unable to participate in class discussion and activities due to physical barriers, learning opportunities decrease. This often occurs due to the presence of a wheelchair or specialized seating that is placed on the periphery of the classroom. Students with physical disabilities may not have the technological supports, such as a computer with specialized software, or AAC device, which is critical to actively participate and adequately learn.

Some individuals with physical disabilities become easily fatigued during writing activities. Individuals with cerebral palsy may become tired due to the effort needed to write. People with degenerative diseases may have a limited store of energy to devote to writing. People who fatigue easily require a greater period of time and frequent breaks to complete writing activities. Some people have motor deficits and fatigue leading to brief writing passages and numerous errors.

The cognitive effort needed to facilitate the mechanics of keyboarding may have an adverse impact for people with physical disabilities (Lueck, Dote-Kwan, Senge, & Clarke, 2001). For such individuals, typing requires continuous attention and effort that may take needed cognitive resources away from the writing process, thus causing mental fatigue. Additionally, the added cognitive effort used to type may also limit physical endurance. The mechanics of writing also may be impacted by cognitive factors like memory. According to the model proposed by Atkinson and Shiffrin (1968), short-term memory, or working memory, has a limited capacity and varies by individual. A writer must hold information in short-term memory regarding what he plans to type immediately and also what he plans to type following this time in short-term memory. When the amount of data a writer intends to communicate exceeds the short-term memory capacity, writing fluency may be impacted, even in an individual without physical or health impairments. Individuals with physical disabilities may have impaired or insufficient short-term memory that further limits the speed of writing production (Boyer, Yeates, & Enrile, 2006). Therefore, individuals with a physical disability should use writing strategies that minimize cognitive and physical demands on memory.

Assistive Technology for Writing

Assistive technology (AT) solutions exist to enable individuals with physical disabilities to address limitations in the mechanics of written communication. AT choices should be driven by functional needs, individual user characteristics, and personal preferences (Lueck, Dote-Kwan, Senge, & Clarke, 2001). People with physical disabilities who are unable to handwrite must type. One common method used to generate writing is the use of a word processor. Many people use word processors efficiently with little practice or adaptations. Word processing may produce more legible and accurate writing passages than handwriting (MacArthur & Graham, 1987). Many people with physical disabilities require adaptations to the physical environment in order to access a computer and word processor. Such adaptations may include wheelchair accessible desks and alternative seating.

When environmental and seating adaptations are insufficient in overcoming physical limitations, some individuals may require alternative keyboards with varying size keys. Other individuals may require alternative keyboard layouts than the standard QWERTY arrangement, and some people may require alternative input devices such as a joystick or trackball rather than a standard mouse. Individuals with severe physical limitations may require all of the abovementioned adaptations to access a word processor. Even when adaptations are utilized in the most efficient manner, some individuals with physical disabilities will require extended time to complete the assignment, frequent rest breaks, and shorter writing assignments.

For individuals with physical disabilities who have recognizable speech, assistive methods such as dictation and speech recognition software are possible alternatives. Many people with physical disabilities are not fluent, or are nonverbal and cannot use these methods. For these individuals, typing is the primary means of written work, although it may be slow, laborious, and contain frequent spelling errors.

Word prediction. Word prediction software (WPS) may improve writing fluency for students whose typing is slow and laborious. It also has the potential to increase accuracy by decreasing spelling and keyboarding errors. Word prediction technology works in conjunction with a word processor and provides a generated list of correctly spelled word choices. Word prediction programs may have additional features such as text-to-speech output and beginner, intermediate, and advanced dictionaries.

The majority of studies assessing word prediction software's effect on spelling accuracy and writing rate have targeted participants who have learning disabilities. For example, MacArthur (1998ab, 1999ab, 2000) reported mixed results in a series of three studies using single-subject design with students with learning disabilities. In each study, some students made gains in spelling accuracy using word prediction software versus word processing, and gains in spelling accuracy increased using word prediction when the level of vocabulary words increased. The author suggested that participants may have known how to spell easier vocabulary words and could have ignored word prediction lists. In a study examining rate, Golden (2001) compared the typing rate of students who used word processors or word prediction and reported that typing rate decreased slightly with word prediction software.

Although word prediction was originally designed to assist people with physical disabilities to type more rapidly and to produce fewer spelling errors (MacArthur, 1999a), few studies have been conducted examining its effectiveness. Tam, Reid, Numman, and O'Keefe (2002a) examined the effects of word prediction and typing rate for ten- to fourteen-year-old students with Spina Bifida and hydrocephalus. The authors reported that contrary to prediction, none of the participants made gains in typing rate when using word prediction. They suggest the results may have been due to the relatively brief length of the study. In lengthier studies, the authors suggest participants may gain experience through practice with word prediction, which could affect gains in typing rate. Participants in the study perceived benefits to using word prediction and would consider using it for future writing assignments (Tam et al., 2002b).

Tumlin and Heller (2004) used a withdrawal design study to examine typing rate and spelling accuracy in high school aged students with cerebral palsy and brain injury resulting in physical disabilities. Participants were given a topic to write about and time to brainstorm ideas for three-minute typing sessions. The authors reported mixed results in typing rate and accuracy. Students with high baseline typing rates (mean 10.9 and 14.6 wpm) were faster using word processing, while students with slower initial typing rates (2.9 and 4.7 wpm) made modest gains in typing rate using word prediction. Participants who had higher rates of spelling errors made gains in spelling accuracy using word prediction, but students with low initial spelling errors did not demonstrate a gain in spelling accuracy.

Mezei and Heller (2005) also used a reversal design to evaluate the effects of typing speed and spelling accuracy on three, thirteen-year-old participants. The participants had Spina Bifida, muscular dystrophy, and cerebral palsy, respectively. Participants were given a topic to write about and time to either write or type a draft prior to the timed session. The initial baseline and reversal phases were three minute typed sessions, while the subsequent phases were six minutes in length. Participants typed from their drafts into a word processor alone or with word prediction. All three participants made gains in typing rate reported as words per minute. One participant increased from 17.1 wpm in baseline to 20.4 wpm in three-minute typing sessions and 22.5 wpm in six-minute sessions with word prediction. A second participant achieved 13.2 wpm in baseline, 15.6 wpm in three-minute sessions and 17.5 wpm in six-minute sessions with word prediction. The third participant typed 7.2 wpm in baseline, 8.8 wpm in three-minute sessions, and 10.0 wpm in six-minute sessions with word prediction. The third participant, who had cerebral palsy, demonstrated fluctuating results in typing rate and spelling during the course of the study.

Koester and Levine (1998) suggested several other factors that could impact the effectiveness of word prediction software. In model simulation, the authors reported that list search time (scanning the word prediction list), keypress time (time it takes to motorically press the key), and keypress delay (time to takes to decide what to press) will vary by individual and will, in turn, impact typing rate. Additionally, the configuration of the word prediction system and the strategy used to search the word list may impact typing speed. Koester and Levin (1997) presented the following search options: (a) searching the word prediction list before each selection; (b) selecting two letters and then searching the word prediction list before subsequent selections; and (c) discontinuing the search if the word is not found after so many letters.

The literature assessing the value of word prediction software as it increases typing rate and spelling accuracy is limited and offers mixed results (MacArthur, 2000, Tumlin & Heller, 2004). Although word prediction was invented to assist individuals with physical disabilities, most participants tested had unspecified learning disabilities rather that physical disabilities (Lewis et al., 1998, MacArthur, 1998a, 1999a). Results for participants with learning disabilities may not generalize to a population with physical disabilities because of the differences in physical and cognitive characteristics (MacArthur, 1999b). Studies that involve participants with physical disabilities reported mixed results for typing rate and spelling accuracy gains, potentially due to design weaknesses (Tam et al, 2002a) and differences in individual characteristics of the participants (Mezei & Heller, 2005; Tumlin and Heller, 2004).

Writing Process

Fluent writing is comprised of two parts: the mechanics of writing and the writing process. The mechanics of writing include the speed and accuracy with which text is generated. For some individuals with physical disabilities, handwriting is not possible and these individuals must type; however, the writing process is the same as the format in which it is submitted. Although several models of the writing process exist, one model involves five discreet stages (Mercer & Pullen, 2004). The first stage is prewriting. In this stage, a topic is selected and a purpose for writing is identified (e.g., persuasion). In addition, the writer is encouraged to consider the nature of the audience for whom the writing is intended. Following these decisions, the writer may employ one or more strategies to gather and organize information and then to begin to organize ideas. The prewriting stage may include constructing an outline, developing a visual organizer (e.g., a web), or the producing of note cards. Experienced writers may use a combination of strategies.

Second, the writer begins the drafting stage, where the writer develops a rough first draft of the passage. In this stage, writers are encouraged to focus greater attention to the content of the passage than to the mechanics, grammar, and spelling accuracy (Mercer & Pullen, 2004). In the third stage, a writer begins to revise the rough draft. This stage is accomplished by rereading the passage and adding, subtracting, and moving text to improve the coherence for the audience. For some writers, the revising stage is time consuming. Feedback and suggestions may be obtained from a teacher, classmate, or peer.

The fourth stage involves the mechanics to edit the written passage. In the editing stage, writers proofread the passage, word for word, identifying and correcting grammar, spelling, word choice, capitalization, and punctuation. Some writers will use tools such as a grammar text, a dictionary, or a thesaurus which provides additional support. Writers may return to the revising stage then regress back to the editing stage one or more times before being ready to move to the final publishing stage. The publishing stage typically involves writing or typing the final draft in a form ready to be received by an audience. The final product may be in the form of an essay, a report, a book, or a display.

Assistive technology may be helpful for individuals in the drafting stage of the writing process. The construction of a first draft requires physical demands that may pose challenges for individuals with physical disabilities and limitations, even when the draft is typed rather than handwritten. For people without disabilities, keyboarding may become fast and efficient, especially with practice. Individuals with physical disabilities may have both altered and involuntary movement patterns that may negatively impact efficient keyboarding. In addition, deficits in motor planning and involuntary motor movements may cause keys to be selected slowly and inaccurately. Some individuals may have limited physical strength and endurance and be unable to meet the physical demands for writing a first draft. Each of these limitations and any combinations and interactions between them may lead to short writing passages and frequent errors. Practice may have little or no effect on fluent and accurate typing for individuals with physical disabilities. Assistive technology is required to assist individuals with physical limitations to type as fast, as efficiently, and as accurately as possible. One assistive technology that may support individuals with physical disabilities in the writing process is word prediction software.

Purpose

Many students with physical disabilities have problems with writing fluency due to motoric, strength, and endurance issues. Therefore, teachers must have knowledge of effective and appropriate strategies to increase typing speed and accuracy. Due to the great variability in characteristics and abilities of individuals with physical disabilities, solutions that increase typing fluency are highly individualized and understudied. One increasingly preferred solution to address typing fluency involves assistive technology (AT). One type of AT that has been developed to meet this objective is word prediction software (WPS). Although designed for individuals with physical disabilities, the majority of existing research on its effectiveness involves individuals with learning disabilities (Lewis et al., 1998, MacArthur, 1998a, 1999a). Few studies could be found in the literature which evaluate word prediction featuring individuals with physical disabilities (Koester & Levine, 1997; Mezei & Heller, 2005; Tam, Reid, Naumann, &

O'Keefe, 2002a, 2002b; Tumlin & Heller, 2004). Collectively, these studies investigate few participants with physical disabilities to enable conclusions to be made about the effectiveness of word prediction on fluency, and the methodology of these studies does not permit spelling and word errors to be examined to determine whether they are spelling errors or keyboarding errors. Therefore, the purpose of this study is to examine the effects of word prediction on typing fluency (speed) and accuracy with individuals with physical disabilities. As word prediction was designed to increase spelling accuracy (MacArthur, 1999a), accuracy will be defined as the percent of words spelled correctly. However, since additional errors may occur, this study also will examine other types of errors (e.g., spacing, end punctuation). In addition, the length of each typed passage will be examined to determine whether word prediction software increases, decreases, or has no effect on passage length.

Research Questions

1. To what extent will students with physical and health disabilities produce greater fluency (WCPM) when writing a draft paper on a common topic using word prediction rather than word processing?
2. To what extent will the use of word prediction software increase accuracy by decreasing spelling/keyboarding errors?
3. To what extent will the use of word prediction software result in the production of different types of errors compared to errors produced using word processing?
4. To what extent will more text be produced using word prediction software than with word processing?
5. To what extent will word prediction increase motivation or willingness to write according to participant's self-reports?

Methodology

Participants

Four participants with physical disabilities were selected for this study. Criteria for participation included: (a) meeting eligibility requirements for Orthopedic Impairments (O.I.) as defined by the state of Georgia (students with a physical impairment(s) with a minimal intellectual functioning of mild mental retardation or higher); (b) receiving, or having received, services through an orthopedic impairment special education program; (c) being middle or high school age; (d) having basic competency skills using a word processor on a computer; and (e) having an average to below average typing rate or below average spelling ability for their grade level or age. Word processing skills were determined through testing students on the ability to select keys (including letters, punctuation marks, and space bar), capitalize letters, delete unwanted text, place cursor in correct area, and save text. Grade level spelling measures were assessed through the Peabody Individual Achievement Test-Revised and through the Woodcock Reading Mastery (PIAT-R: Macwardt, 1989; WRMT-R: Woodcock, 1987).

The four participants selected for this investigation were Tom, Brian, Belle and Kathy (see Table 1). Tom was a 12-year-old Caucasian male who was a seventh grade student at the time of this study. Tom was eligible for special education services in the area of orthopedic impairments as a result of a stroke during early infancy. The stroke left Tom with mild to moderate left-side hemi-paresis, bilateral hypotonia and a mild speech impairment that impacted speech volume and pace. Tom was ambulatory throughout school grounds; however, he used a wheeled suitcase-like case to hold his books, laptop computer and personal effects rather than a backpack. Tom used a laptop computer for lengthy writing assignments (e.g., journal, book report, note taking) at school and at home. Routine assignments that involved worksheets of math computation were completed by hand. Tom's handwriting was nearly illegible unless he was given extended time to handwrite and prompted to be as neat as possible. Tom received special education services through the O.I. program on a consult basis in general education classes, and received one resource class per day in the O.I. classroom.

Brian was a 12-year-old Caucasian male in the sixth grade. Brian has Duchenne Muscular Dystrophy (DMD), a progressive terminal neuromuscular disease that impacts muscular strength and endurance. Brian independently used a power wheelchair. He was able to handwrite legibly although at a moderately slower pace than his peers.

Table 1

Participant Characteristics

NAME	AGE	DISABILITY	INITIAL WCPM	INITIAL SPELLING ACCURACY	PASSAGE COMP. G.E.*	WORD ID. G.E.*	SPELL-ING G.E.**
Tom	12yr 10mth	Left hemi paresis cerebral palsy	17.6	93.8%	8.0	9.0	6.3
Brian	12yr 3mth	Duchenne Muscular Dystrophy	9.3	94.8%	5.7	5.7	4.9
Belle	12yrs 6mth	Mild quadriplegic spastic cerebral palsy	5.0	90.0%	3.5	4.9	3.8
Kathy	18yrs 6mth	Spinal Muscular Atrophy	30.6	98.2%	16.9	13.0	12.9

* Passage Comprehension and Word identification test of Woodcock Reading Mastery Test- Revised
** Peabody Individual Achievement Test- Revised

Brian was served in resource classrooms with a paraprofessional assistant in all academic classes and in one resource class each day in the O.I. classroom. Additionally, Brian received occupational, physical, and speech support from school personnel. Brain required adult or peer assistance to retrieve and manipulate his books (e.g., open the 3-ring binder) and personal effects. Brian's teachers reported that he had a strong work ethic and was a student who always wanted to complete an assignment before moving on, but that he often exhibited perfection-like qualities that impacted his ability to complete tasks in a given period of time.

Belle was a 13-year-old Caucasian female in the sixth grade. According to school records, Belle was diagnosed with bilateral hemi-paresis, a form of cerebral palsy (CP). Belle's handwriting was difficult to read due to a variety of issues. Belle used her right hand for handwriting and typing tasks. She wore a wrist brace on her left hand and an orthotic device on her left ankle. Belle demonstrated difficulty gripping her writing implement accurately and maintaining her grip for more than a few seconds even with the use of a grip support. Belle also demonstrated deficits in fine motor control and motor planning. Finally, Belle frequently appeared to forget what she was writing about and required time to gather her thoughts before proceeding. Her handwritten work was comprised of overlapping letters and words, inappropriate spacing between letters and words, letter or words crossed out, and evidence of other corrections. Belle received special education support in resource classes for academic classes, and for one class per day in the O.I. resource classroom. Belle had one elective class per day without special education support, but she was not permitted by her physician to partake in a general physical education class.

Kathy was an 18-year-old Caucasian female who had just graduated from high school at the time of the investigation. Kathy has Spinal Muscular Atrophy (SMA), a progressive and terminal neuromuscular disease that impacts global muscular strength and endurance. Kathy had moderate to severe scoliosis and lordosis and had surgically implanted rods in her spine to address this issue. Kathy wore eyeglasses for a mild astigmatism. Kathy used a power wheelchair tray to support her papers, books, and laptop computer. In high school, Kathy received support in her general education classes from a special education teacher and paraprofessional. Kathy also received resource support in the O.I. classroom one out of every four class periods each day. Kathy was able to handwrite legibly but reported that handwriting was fatiguing. She preferred to use her laptop computer for assignments when it was possible and appropriate. Kathy's physical strength and endurance was limited and progressively declining over time. At the time of the study, she was unable to lift a text book off her wheelchair tray or open the rings of her binder, but she was able to feed herself independently. She required assistance to retrieve her books and materials and to position her laptop computer on her tray in an accessible position.

Setting and Assistive Technology

All student participants were instructed by the teacher certified in Orthopedic Impairments. Instructions were provided in a one-on-one format in a classroom, computer room, media center, or other convenient, quiet location. Each student either used a desktop or a laptop computer with the assistive technology typically used by the student. Other student-specific adaptations were provided based on student need (e.g., low lighting conditions, special desk). All four participants conducted all typing sessions using a standard laptop computer with windows XP.

Students required few environmental or assistive technology adaptations to participate in this study. Tom did not require any specific adaptations for this study. Alternatively, Kathy required a wheelchair tray to hold her laptop computer at the correct height and to provide appropriate elbow support. Brian required a wheelchair accessible desk adjusted to the appropriate height to hold a laptop computer, an external mouse, and a QWERTY mini-keyboard placed directly in front of the laptop. Belle required a clipboard to hold her paper while writing handwritten drafts and a pencil grip for her writing implement. Although Tom, Kathy, and Brian used laptop computers throughout this study, as they were physically unable to access a desktop computer keyboards, Belle used a laptop computer out of convenience. During all typing sessions, a red font color was preferred by Belle, and a size 18 font was preferred by Brian.

Materials

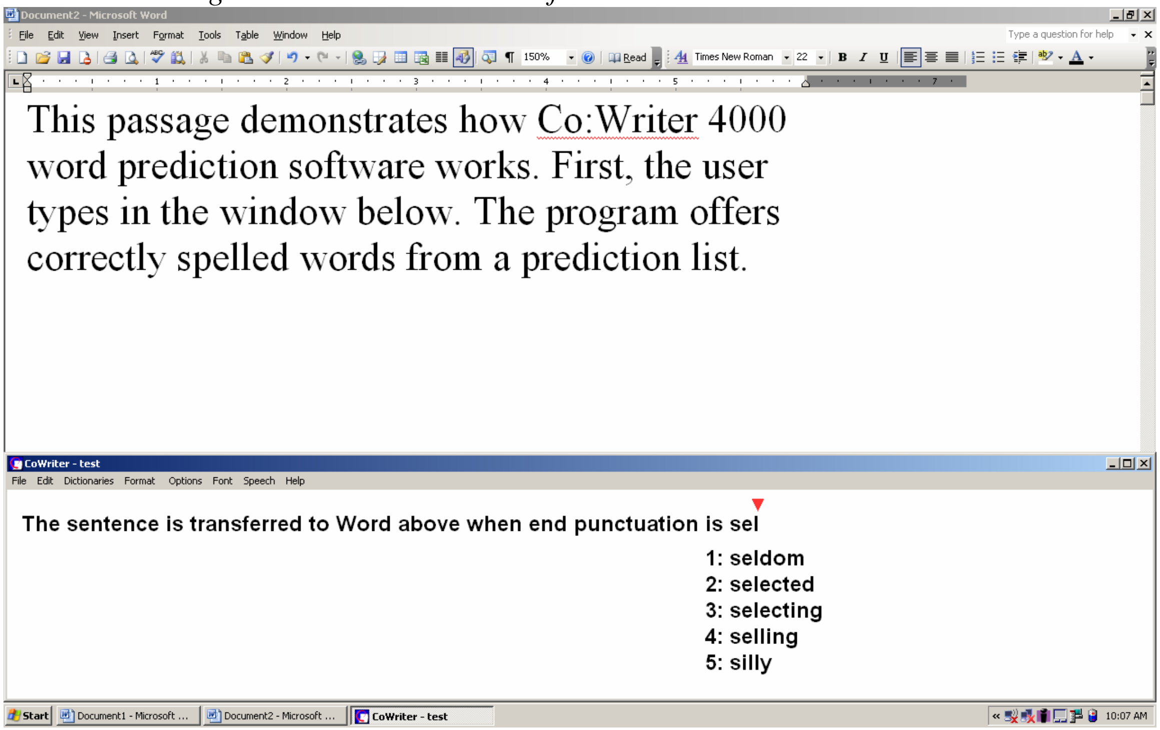
Word processing. Microsoft Word (Word) was selected as the word processor for this study. Word was a widely available word processing program used in schools and is familiar to students with disabilities. Additionally, Word was commonly used with desktop and laptop computers. Three of the four participants were physically only able to access a laptop computer due to their physical limitations. All spelling, grammar, and dictionary functions were disabled during baseline and alternating treatments for this study. Font size and color were adjusted to meet the visual preference of the participants.

Word prediction. Co:Writer 4000 was selected as the word prediction software for this study since it is frequently used by individuals with physical disabilities (Johnston, 1992). Co:Writer 4000 is a commercially available word prediction program that can be used in conjunction with any word processor including Microsoft Word on a desktop and laptop computer. Co:Writer features a separate window that is typically placed in the bottom half of the screen; word prediction is in the top half of the screen, and users view both windows simultaneously (see Table 2).

The user types the first letter of a word in the prediction window and the program offers a numbered set of words in a vertical menu. The choice menu is located to the left of the cursor in the word prediction window and is numbered (e.g., 1 to 5). If one of the numbered choices is the word the user wants, it is selected by typing the number associated with the choice, or by clicking on the choice using the mouse or alternative input device (e.g., joystick). Once a choice is selected, the software program inserted the complete word into the sentence followed by a space. If the correct word is not in the list, the user continues to type and the list of predicted words changes accordingly. The user either selects a word from the menu or types the entire word and the spacebar to place a word in the sentence. The user then types the first letter of the next word. Sentences are formed through this process. When ending punctuation is selected, the software transfers the complete sentence from Co:Writer 4000 to the word processor.

Table 2

Word Processing with Word Prediction Software.



Co:Writer 4000 features beginner, intermediate, and advanced writer and dictionary options. The intermediate and advanced writer options permit the user to generate complex sentence structures and punctuation. Intermediate and advanced dictionaries had a larger and more complex list of words than the beginning dictionary. For the present study, the advanced writer and dictionary options were selected as the most appropriate because study participants were in middle or high school. Co:Writer 4000 has a speech option that can read text to the user. The speech feature was disengaged because participants could receive cues of spelling and other writing errors, and these cues might interfere with fluency. The menu of word choices can be set from 3 to 9 choices. The program was set to display five word choices (Tumlin & Heller, 2004), and font size was adjusted to be between 12 and 18 to meet individual participant preferences.

Co:Writer 4000 can create an individualized user file. This feature was important because it permitted the separation of user profiles. Co:Writer is able to remember and store new vocabulary in the dictionary so that it is available to be used again in a following typing session. In this manner, a user is able to build the dictionary and potentially select the word from the menu in a later typing session. Because the user profiles are separate, new words added to the dictionary by one user are not available to other users. The "predict ahead" feature was disengaged to limit grammar support because predict ahead allowed the software to offer word choices in the menu that are grammatically likely to be used.

Word prediction is used within a word processing program. Microsoft Word (Word) was selected as the word processor for this study. Word is a widely available word-processing program used in schools and is familiar to students with disabilities. Additionally, Word is commonly used with desktop and laptop computers. All Word spelling, grammar, and dictionary functions were disabled during this study.

Operational Definitions

The independent variable in this study was the use of word prediction software. The dependent variables were writing fluency (as measured by words correct per minute), accuracy (as measured by percent of words spelled correctly), type of word errors, and passage length. Each will be operationally defined below.

Writing fluency. The primary interest of the study is writing fluency, as measured in words correct per minute (WCPM). A word is considered correct if it is spelled or keyboarded correctly. A consistent way of determining WCPM other than counting whole words was needed due to the variability of word length because it will affect accurate measurement of typing speed. As with other studies (Feng, Karat, & Sears, 2005; Kotler & Tam, 2002; Tumlin & Heller, 2004), five characters were counted as one word as a statistical means of averaging word length. A character could be a letter, space, punctuation mark, numeral, or symbol.

When determining the writing fluency (WCPM), the following formula was used (with a misspelled word including errors from inaccurate spelling or keyboarding):

$$\text{WCPM} = \frac{(\text{Total characters produced} - \text{all characters in each misspelled word}) \div 5}{\text{Number of minutes (3)}}$$

To determine WCPM using the 5 character approach, the following procedure was used: 1) Saved student's original passage as "Original student first name and session number". 2) Copied and pasted the passage into a second file and labeled it working and added a student's first name and session number to the title.

3) Using the working file, counted the total number of words produced = Total number of words. 4) Counted the total number of misspelled/keyboard error words = Total number of misspelled words. 5) Subtracted the misspelled words from the total number of words = Number of correct words in the passage. 6) Took the corrected passage (with the incorrect words deleted) and used Microsoft Word's character count to determine the total number of correct characters. 7) Divided the total number of correct characters by 5 = Adjusted correct words. 8) Divided the adjusted correct words by the number of minutes (3) in each session = words correct per minute (WCPM; see Appendix A).

Spelling/Keyboarding Accuracy

Accuracy is defined in terms of percent correct and takes into account spelling and keyboarding errors. Spelling errors are made when there is a lack of knowledge of a correctly spelled word. Keyboarding errors may also occur. Keyboarding errors may appear to be spelling errors but they are mechanical errors that lead to mistakes that include: selecting the wrong key, omitting a key, duplicating a key, or transposing two keys. Mechanical errors may occur due to typical typing errors or due to a physical disability. Both types of errors result in incorrectly typed words. Spelling and keyboarding errors do not include capitalization, spacing, end punctuation, or errors due to a failure to follow study procedures.

Accuracy was calculated by subtracting the number of misspelled words (from step four above) from the total number of words (from step three above) divided by the total number of words multiplied by 100 (see Appendix A). In this formula, whole words were counted, with five characters equaling one word. The following formula was used:

$$\text{Percent Correct} = \frac{\text{Total Number words} - \text{number of spelling/keyboarding errors}}{\text{Total number of words}} \times 100$$

Word Errors

In addition to spelling/keyboarding errors, other types of word errors may occur in both typing conditions. Word errors that may occur under the word processing condition include: (a) capitalization; (b) spacing error; and (c) failure to type end punctuation (see Table 3). All errors within a word were recorded, but reported as a single mistake. Since spelling and grammar support functions were disengaged, these errors may occur and the participant would not be alerted by the software that the mistake occurred. It was vital that these functions were disengaged, so as not to distract the student during timed sessions.

Word errors that could occur under the word prediction condition included: (a) capitalization; (b) spacing error; (c) end punctuation; and (d) incorrect choice selection (out of the array of word choices displayed in word prediction and compared to handwritten copy). All errors within a word were recorded but reported as a single error to maintain the integrity of the percent correct formula.

Table 3

Word Errors Types in Word Processing and Word Prediction Conditions

Word Processing Errors	Word Prediction Errors
Spelling/Keyboarding	Spelling/Keyboarding
Capitalization	Capitalization
Spacing error	Spacing error
End punctuation	End punctuation
	Incorrect choice selection

Passage length. The length was the number of words in the draft (see Appendix A). It was calculated as follows: 1) Opened the original passage (that included spelling/keyboarding and word errors). 2) Determined the number of characters using the Microsoft Word character count. 3) Divided the characters by five = passage length.

Procedures

Preintervention measures of current functioning. There were several preintervention assessments that were conducted prior to intervention to determine current functioning. These assessments consisted of: (a) a reading comprehension measure, (b) a spelling measure, (c) a word identification measure, (d) a word processing skills checklist, and (e) students' typing rate (WCPM). All of these except reading level were needed to determine student eligibility for the study. Reading level was included to assist with data interpretation and replication of the study by other researchers.

Reading comprehension, word identification and spelling measures were obtained for the participants. The principal investigator administered the Passage Comprehension and the Word Identification tests of the Woodcock Reading Mastery Test- Revised (WRMT-R: Woodcock, 1987) to obtain reading level. Spelling measures were obtained through the Peabody Individual Achievement Test-Revised (PIAT-R; Marcwardt, 1989). Reading comprehension, word identification and spelling scores were reported as grade-level equivalents.

Students needed require basic competency skills using word processing in order to be eligible for this study. A checklist was used to determine if the student had these skills. Students who performed each item on the checklist qualified for the study (see Appendix B).

Once a participant was determined to be eligible for the study but prior to the initiation of any other preintervention procedures, the participant's WCPM was determined. Participants were given a topic, asked to make a handwritten draft, and then typed from the draft into a word processor in three-minute timed sessions. This method allowed students to copy from their own writing, reduce wait and thinking time during timed sessions, and produce the most accurate determination of WCPM. A minimum of five, 3-minute writing sessions were conducted (Alberto & Troutman, 2006). More sessions were used to determine typing rate if typing speed greatly varied (i.e., 3 consecutive typing rates needed to vary less than 50% of the mean of the previous five sessions; Alberto & Troutman, 2006). Participant typed using only word processing and any assistive technology normally used for writing activities (e.g., trackball). The WCPM was calculated as discussed under operational definitions.

On the writing samples taken above to determine typing speed, the percentage of spelling errors was determined as described under operational definitions. The percentage of spelling errors provided additional spelling information in addition to the PIAT-R.

Preintervention instruction of Co:Writer. Before the study began, each student received individualized instruction on the use of Co:Writer 4000 from a trained teacher certified in Orthopedic Impairments. The teacher described, demonstrated, and then modeled the features of the software. Participants received guided practice and then were allowed independent practice until they reached 100% criteria on a checklist (see Appendix C). Participants were instructed to ignore the word prediction menu for words with only one or two letters (e.g., I, me). During guided practice, the students were taught to: (a) mentally choose a word; (b) type the first two letters of the word; (c) look at the word list to see if the choice was offered; (d) select the choice (by clicking or selecting the number on the keyboard) or continue typing the third letter; (e) look at the word list to see if the choice was offered; (f) select the choice (by clicking or selecting the number on the keyboard) or continue typing the word without looking at the word list (Koester & Levine, 1998; Tam, et al., 2002a). The student proceeded until the sentence was complete, end punctuation was selected, and the sentence was sent to the word processor. Instruction of Co:Writer 4000 continued until it was observed that each students was able to achieve 100% accuracy on the checklist. Items on the checklist included opening Co:Writer 4000 with Microsoft Word, typing, scanning the list after each typed letter, selecting the word from the list, finishing the sentence, adding punctuation or selecting enter, either of which will automatically send the sentence to Word, then returning to the Co:Writer 4000 window. All four students achieved 100% accuracy on demonstrating Co:Writer use during preintervention.

Intervention procedure. At the beginning of the study, participants were asked to make a list of at least twenty-five topics of interest that could be developed into writing passages. These topics were used for baseline and intervention writing and typing passages. Prior to every typing session, each participant was shown his or her list and was asked to choose one topic to write about. Participants were given opportunities to amend their personal list choices throughout the study. The researcher, a teacher, or a paraprofessional then discussed the writing topic with the student to be sure the topic was appropriate for school.

After the discussion about the writing assignment, the student was provided time to prepare a visual organizer, outline, or preferred prewriting strategy with key ideas, words, and phrases (via handwriting or computer). Using their prewriting organizer, outline, or other prewriting information they created, the students wrote a handwritten draft of their topic. Feedbacks on spelling or grammar errors were not provided. Additionally, all drafts were examined to determine whether the length was sufficient for the participant to type for three minutes without running out of draft material. Participants were directed to add to their drafts if they were thought to be too short. A handwritten draft was an important step prior to timed-typing sessions for several reasons. First, having students copy written material is in line with word prediction studies that had students copy written material to determine their writing speed (De La Paz & Graham, 1997; Higgins & Raskind, 1995; Reece & Cumming, 1996). Second, studies featuring students with learning disabilities indicate that creating a first draft improves the rate of production when the draft is typed (De La Paz & Graham, 1997; Higgins & Raskind, 1995). For students with physical disabilities, having a first handwritten draft may eliminate physical or cognitive pauses and permit a more accurate typing fluency rate since these pauses may occur unequally across different writing topics (Garrett, 2008; Mezei & Heller, 2005; Tam, Reid, Naumann, & O'Keefe, 2002a; Lewis, Graves, Ashton, & Kieley, 1998). Third, a first handwritten draft will permit assessment about whether the word prediction facilitated improvements in spelling errors by comparing the spelling in the handwritten draft to the spelling in the written draft (MacArthur, 1998b, 1999b). Fourth, it will indicate if the student selected a different word in the word prediction list than the word in the draft. Finally, the draft may facilitate examination of other differences (e.g., capitalization) between the handwritten draft and the timed draft. After completing the draft, the student was permitted up to five minutes rest to reduce physical fatigue during timed-typing sessions. All preintervention typing passages became baseline data for WCPM, accuracy and word errors and are reported as baseline.

Next, students were instructed to type using the word processor alone or word prediction (depending on the treatment condition) with their draft in view. This method avoided pauses or breaks in typing due to cognitive issues such as the student thinking about what to type next, and permitted spelling errors to occur. If a student was not using word prediction software as trained to do so during the word prediction condition, the session was stopped and the procedures were reviewed. Sessions began again when the student met 100% criteria on a checklist (see appendix D). After three minutes, the participant was then verbally instructed to stop.

When students were instructed to stop writing, all words remaining in the Co:Writer window were sent to the word processor window to be included in the student's writing. Adding the words together in each window was necessary as some users would not have selected enter and transferred the remaining words to the word processor when the session was completed. After this is done, a teacher or trained assistant printed the page and labeled the page with the student's name, date, and writing topic.

Data sheets were used to record WCPM, spelling/keyboarding errors, other types of errors, and passage length. Words correct per minute, accuracy, and length were calculated and the types of word errors were recorded as discussed under the operational definitions. Typing rate was determined by counting five characters as a word and was reported as words correct per minute (WCPM; Feng et al., 2005; Kotler & Tam, 2002; Tumlin & Heller, 2004).

Research Design

The independent variables were the use of word prediction software and word processing and the dependent variables are writing fluency (WCPM), spelling accuracy, types of word errors, and passage length. Since the primary question in this study was with fluency, the WCPM was graphed. An alternating treatment design was selected to compare the effectiveness of using word prediction versus using word processing on writing fluency (Kazdin, 1982; Richards, Taylor, Ramasamy, & Richards, 1999).

Baseline sessions were three minutes in length, which replicated other studies using three-minute typing sessions (Lewis, Graves, Ashton, & Kieley, 1998; Mezei & Heller, 2005). Baseline sessions consisted of a minimum of five data points. Baseline sessions ended when a stable baseline was reached. For this study, a stable baseline session was three consecutive data points that varied less than 50% of the mean of the previous five consecutive data points (Alberto & Troutman, 2006). First, participants were given a writing topic and created a visual organizer and a rough draft. The researcher or trained assistant assisted with dictation if the participant was unable to handwrite or complete the prewriting organizer (i.e., outline, topic web). Second, participants typed using word processing for 3, 3-minute sessions, with spelling and grammar features disabled. Words correct per minute were determined in the same manner as in the preintervention typing rate. Spelling accuracy also was determined and used as a preintervention measure of spelling accuracy. The preintervention measure to determine the typing speed was used as baseline data.

During the intervention phase, the alternating treatment design alternated between two conditions: (a) word processing and (b) word prediction. Alternating treatments followed an ABBABAAB order (Alberto & Troutman, 2006). Scheduling of the treatments was counterbalanced so that three of the six participants followed a BAABABBA order. If necessary, the treatment pattern repeated and followed the same ABBABAAB or its inverse order until bifurcation was evident based on visual analysis of the graph or until twenty sessions occurred. Twenty typing sessions were chosen as the terminal point for this study to limit physical and cognitive fatigue for participants and because bifurcation was expected to appear by this time.

Word processing. Participants typed using a word processor for three-minute timed sessions (Lewis, Graves, Ashton, & Kieley, 1998). Spelling and grammar functions were disengaged. The total number of correct words per minute was determined by counting five characters including a space, end punctuation or symbol, and reported as WCPM. The total percentage of spelling errors was determined by subtracting the number of spelling errors from the total WCPM, dividing by the total number of WCPM and multiplying by 100 to determine percent spelling errors. Data were graphed after each session.

Word-prediction intervention. Participants typed using Co:Writer 4000 and a standard word processor for three, 3-minute times sessions (Lewis, et al., 1998). Options selected included the intermediate dictionary as the best choice due to the age and grade level of the participants. Spelling and grammar functions in the word processor were disabled. The word prediction menu was set to offer exactly 5 word choices for all participants in all intervention typing sessions, and each choice was numbered from 1 to 5. There were three ways that participants could select a word from the prediction menu. Participants could either select a number key on the keyboard, use the up and down keyboard arrow keys to highlight a word and then select the enter key, or use trackpad to move the curser over a word, then double tap or press enter to select the word. Words correct per minute and spelling errors were determined and graphed in the same way as for word processing.

An alternating treatment design was used to establish a functional relationship between the independent variables and WCPM and spelling accuracy (Alberto & Troutman, 2006; Kazdin, 1982).

Data Analysis

The graph was analyzed after each session for bifurcation of the data. Bifurcation was determined through examination of the means, level of performance, and trend (Kazdin, 1982). Data collection was stopped when clear bifurcation of the data paths existed or after a total of twenty sessions. Bifurcation was said to have occurred when three consecutive data points varied less than 50% of the mean of the previous five consecutive data points (Alberto & Troutman, 2006).

Social validity. Social validity was assessed through a written post-study questionnaire. The questionnaire consisted of several questions designed to assess the participant's preference for word processing or with word prediction (i.e., it will help me get higher grades; it will help me save time; my work looks neater when I use word prediction; I make fewer mistakes when I use word prediction). Answers were chosen based on a standard five-point Likert-type scale (see Appendix E).

Reliability and procedural fidelity

Interobserver reliability (IOR). IOR was calculated in 20% of sessions for both the word processing and word prediction sessions. A classroom paraprofessional with more than three years experience working with students with physical disabilities and who had knowledge of assistive technologies including word prediction software was trained and served as the second observer. The second observer completed a written checklist for each reliability session (see Appendix D). IOR was calculated as follows:

$$\text{IOR} = \frac{\text{Number of agreements}}{\text{Number of agreements plus disagreement}} \times 100$$

Procedural fidelity. Appendix D also was used to ensure treatment integrity for initial handwriting drafts and typing session. The protocol described each step of study procedures to ensure that they were carried out as planned. Treatment integrity checklists for training and writing sessions were followed 100% of the time by the researcher. The researcher trained a classroom paraprofessional to complete the procedural fidelity checklist at least 20% of all sessions to ensure that the researcher followed study procedures.

Results

The purpose of this study was to examine the effects of word prediction on typing speed and accuracy with individuals with physical disabilities. The following dependent variables were examined: (a) writing fluency as measured by WCPM; (b) spelling accuracy; (c) word errors; (d) passage length; and (e) participant interest. The results revealed mixed results for the effectiveness of word prediction software across the four participants.

As seen in Figure 1, two of the four students, Brian and Belle, had nearly equal rates for typing fluency (as calculated by WCPM) using word prediction software as compared to word processing. One student, Tom, had a slightly higher fluency rate using word prediction while Kathy demonstrated a higher rate of fluency using word processing. In regard to errors, all five students had higher rates of errors in word processing versus word prediction; however, the types of errors varied by participant. Some participants demonstrated a greater number of word errors while others had more spelling errors. Passage length also varied as participants who typed at higher rates in word processing tended to achieve slower rates using word prediction.

Tom

Writing fluency (WCPM). As seen in Figure 1, Tom demonstrated a slightly higher rate of WCPM using word prediction versus word processing. There was a 60% of PND, between word prediction and word processing, indicating a small effect size. In baseline, Tom's mean typing fluency was 17.6. The mean WCPM in the word prediction treatment was 20.6, versus 16.4 in word processing. Tom's typing fluency ranged from 16.8 WCPM to 23.3 WCPM using word prediction, and from 15.3 to 19.4 in word processing. For Tom, word prediction software produced a mean increase of 4.2 WCPM.

Spelling/keyboarding accuracy. As seen in Figure 2, Tom had a higher accuracy rate in the word prediction condition. In baseline, Tom produced a mean of 3.6 spelling/keyboarding errors per typing passage, with a range of 2 to 5 errors, for an accuracy rate of 94.2%. During intervention, in the word processing condition, Tom produced a mean of 2.5 spelling/keyboarding errors, with a range of 0 to 5, producing an accuracy rate of 94.9% (see Table 4). Using word prediction software, Tom produced zero errors in nine of ten passages and one error in session thirteen for a mean number of

0.1 spelling errors and an accuracy rate of 99.8%. The exact spelling/keyboarding errors are provided on Table 5 (which also includes errors on the handwritten draft).

Word error type. In addition to spelling/keyboarding errors, data were taking on several types of other word errors that could have occurred. In both conditions, spacing, capitalization, and end punctuations errors were possible. However, in the word prediction condition, other errors were possible including not searching the prediction list after two letters, selecting an incorrect word from the list, or selecting the wrong choice.

As seen in Table 4, Tom's word accuracy was greater in word prediction versus word processing. Using word processing, Tom produced an average of 1.9 errors, with a range of 0 to 5 errors. In the word prediction treatment, Tom produced an average of 0.7 word errors, with a range of zero to one error per passage.

Passage length. Passage length is reported in three-minute typing sessions without adjusting for word and spelling errors. In baseline, the passage length for Tom was a range of 53-64 words (mean 58.2). The overall passage length in the word processing treatment ranged from 48-56 words (mean 51.0), while the length in the word prediction treatment ranged from 50-71 (mean 62.2).

Brian

Writing fluency (WCPM). As seen in Figure 1, there was no bifurcation between the two conditions. In baseline, Brian's mean typing fluency was 9.3 WCPM. The mean WCPM in the word prediction treatment was 10.2, with a range of 8.8-12.0 WCPM. In the word processing treatment, Brian achieved 10.0 WCPM with a range from 7.9-11.2 WCPM. For Brian, word prediction software produced a mean increase of 0.2 WCPM.

Spelling/keyboarding accuracy. As seen in Figure 2, Brian has a higher accuracy rate across most sessions in the word prediction condition. In baseline, Brian's spelling/keyboarding accuracy was 94.2 percent. In the word processing treatment, Brian's produced a mean of 0.6 errors across the ten sessions, with a range of 0-1 errors per typing session, achieving an accuracy of 98.2% (as seen in Table 4). Using word prediction software, Brian produced zero spelling/keyboarding errors in nine of ten passages, with one error in session twenty-four, for an accuracy rate of 99.7%. Exact spelling and keyboarding errors can be seen in Table 6.

Word errors. Brian's word accuracy was greater in word prediction versus word processing (see Table 4). Using word processing, Brian produced an average of 0.8 errors, with a range of 0-1 errors. In the word prediction treatment, Brian produced an average of 0.1 word errors, and only one error in one passage. In word processing, Brian ranged from 24-35 (mean 30.7 words), while the length in word prediction ranged from 27-36 words (mean 30.2 words).

Passage length. In baseline, the passage length for Brian ranged from 29–34 words (mean 30.6 words). The overall passage length in the word processing treatment

Belle

Writing fluency (WCPM). As seen in Figure 1, for Belle, there was no bifurcation of the data between the two treatments. In baseline, Belle demonstrated a typing rate of 5.0 WCPM. In word processing, Belle typed a mean of 5.6 WCPM with a range of 4.5 to 6.4 WCPM. Belle's mean typing rate was 5.7 WCPM using word prediction software, with a range of 4.6 to 6.4 WCPM. For Belle, word prediction software produced a mean increase of 0.1 WCPM.

Spelling/keyboarding accuracy. As seen in Figure 2, Belle has a higher accuracy rate in the word prediction condition. In baseline, Belle produced an average of 1.8 spelling/keyboarding errors per typing passage. In the word processing condition, Belle produced a mean of 1.9 spelling/keyboarding errors, with a range of 1-3, and an average of 89.8% (see Table 4). Using word prediction software, Belle produced zero errors in nine of ten passages and one error in passage nineteen for a mean of 0.1 and a 99.5% accuracy rate. The exact spelling and keyboarding errors are seen in Table 7.

Word errors. In baseline Belle produced an average of 2.2 word errors, with a range of 1-4 errors. As seen in Table 4, in word processing, Belle produced one capitalization error and three end punctuation errors. Belle produced no word errors using word prediction.

Passage length. In baseline, the passage length for Belle ranged from 14-17 words (mean 16.2 words). The overall passage length in the word processing treatment ranged from 16-22 words (mean 19.4 words), while the passage length in word prediction ranged from 15-21 words (mean 17.5 words).

Figure 1. Words correct per minute across participants.

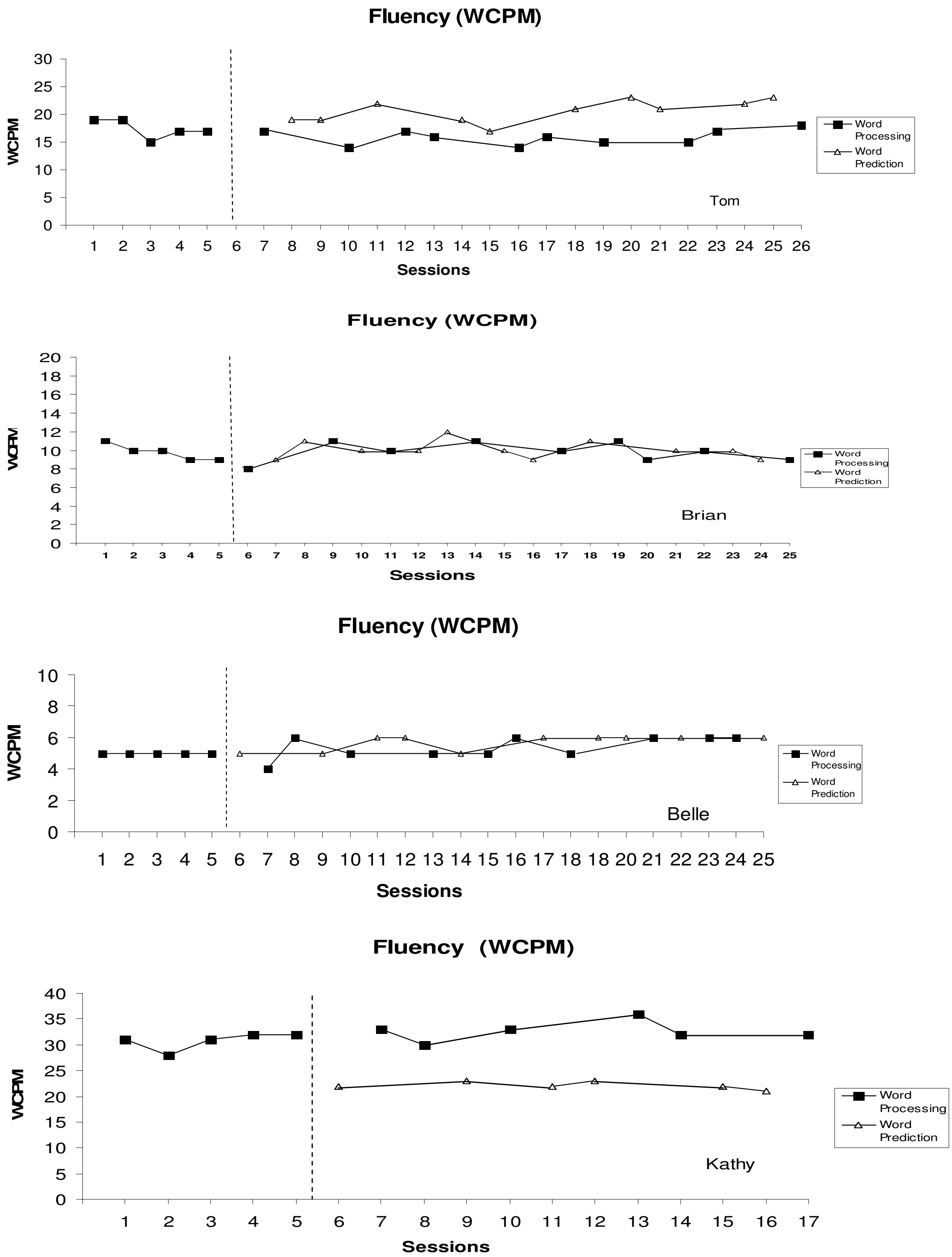


Figure 2. Spelling/keyboarding accuracy across participants.

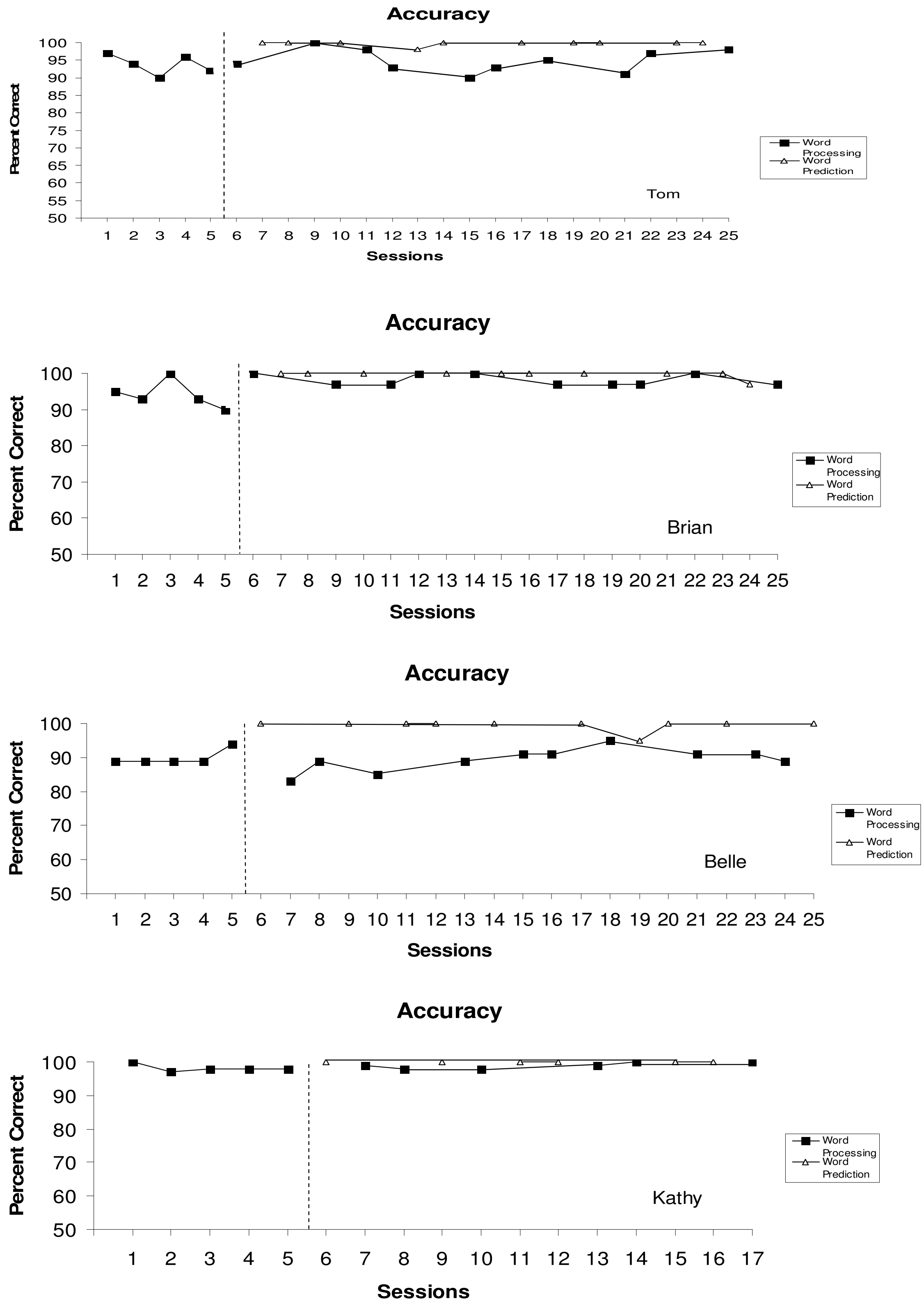


Table 4

The Range of Error Type Across Sessions and Overall Mean for Each Condition (not including baseline).

Word Processing		**Tom**	**Brian**	**Belle**	**Kathy**
Spelling/ Keyboarding errors	Range (Mean)	0 – 5 (2.5)	0 – 1 (0.6)	1 – 3 (1.9)	0 – 2 (0.9)
Capitalization errors	Range (Mean)	0 - 2 (0.3)	0 – 1 (0.3)	0 – 1 (0.1)	0
Spacing errors	Range (Mean)	0 - 3 (1.5)	0 – 1 (0.5)	0	0 – 1 (0.7)
End punctuation errors	Range (Mean)	0 - 1 (0.1)	0	0 – 2 (0.3)	0
Word Prediction		**Tom**	**Brian**	**Belle**	**Kathy**
Spelling errors	Range (Mean)	0 – 1 (0.1)	0 -1 (0.1)	0 – 1 (0.1)	0
Capitalization errors	Range (Mean)	0 – 1 (0.1)	0	0	0
Spacing errors	Range (Mean)	0 - 3 (0.6)	0 – 1 (0.1)	0	0 – 1 (0.1)
End punctuation errors	Range (Mean)	0	0	0	0
Incorrect choice selection	Range (Mean)	0	0	0	0

Table 5

Spelling/Keyboarding Errors Across Each Condition.

Tom's Spelling/Keyboarding Errors			
Session	Handwritten Errors	Word Processing Errors*	Word Prediction Errors
1		favoraite* ar*	
2		favoraite * favoraite* whos* medicin*	
3	 chariter N/A N/A	favoriate* figting* charictar charactar seriies	
4	Straight	N/A trireed* because*	

5	 N/A N/A N/A	olsd* figting* plaied mian charictars	
6	 N/A N/A	regular* difrent different	
7			0
8			0
9		0	
10			0
11		An*	
12		Satardays* favorate* chariter	
13	struming		Struming
14			0
15	 verson commentarys	goin* meand* veson forgotten* commentarys	
16	 spend	beauase* barbrbeeque* probibly* spent	
17			0
18	recuem	recuem favorute*	
19			0
20			0
21	reially rally have	reillr probably* reilly hade	
22		untangled* wippped*	
23			0
24			0
25	great	average	

* Indicates spelled correctly in handwritten draft. (Blank indicates it was spelled incorrectly the same way in the handwritten passage and the typing condition.)
N/A means that the word in the handwritten draft was not used in the typewritten condition

Table 6

Spelling/Keyboarding Errors Across Each Condition.

Brian's Spelling/Keyboarding Errors			
Session	Handwritten Errors	Word Processing Errors*	Word Prediction Errors
1		their* their*	
2		adventare opponents	
3			
4		drov caf*	
5	tropies tropies	tropis tropis yhe*	
6	0		
7			0
8			0
9		breakfast*	
10			0
11	(truck)	track*	
12	0		
13			0
14	0		
15			0
16			0
17		envirомment*	
18			0
19		favorat*	
20		presidential*	
21			0
22	0		
23			0
24	brang		Brang
25		powerfull*	

Kathy

Writing fluency (WCPM). For Kathy, there was a 100% PND between word prediction and word processing (including baseline data), indicating no effect size. As seen in Figure 1, Kathy demonstrated a higher rate of WCPM using word processing versus word prediction. In baseline, Kathy's mean typing fluency was 30.6. The mean WCPM in the word prediction treatment was 22.1, versus 32.6 in word processing. The range of Kathy's typing fluency in word prediction was 21-23 WCPM, and 30-36 WCPM in the word processing condition. For Kathy, word processing software produced a mean increase of 10.5 WCPM.

Spelling/keyboarding accuracy. As seen in Figure 2, Kathy had 100% accuracy in all sessions in the word prediction condition. In baseline, Kathy produced an average of 1.8 spelling/keyboarding errors per typing passage producing 98.2% average. As seen in Table 5, in word processing condition, Kathy produced an average of 0.9 spelling/keyboarding errors, with a range of 0 to 2, and an average of 99%. Using word prediction software, Kathy produced zero spelling/keyboarding errors. Table 8 shows the exact spelling and keyboarding errors.

Word errors. Kathy produced a total of seven word errors in the word processing condition (see Table 4). All errors involved spacing. Kathy also produced one spacing error in the word processing condition. No other word errors were present in either condition.

Passage length. In baseline, the passage length for Kathy ranged from 91-101 words (mean 95.8 words). The overall passage length in the word processing treatment ranged from 93-112 words (mean 100.1 words), while the length in word prediction ranged from 62-80 words (mean 68.3 words).

Table 7

Spelling/Keyboarding Errors Across Each Condition.

Belle's Spelling/Keyboarding Errors			
Session	Handwritten Errors	Word Processing Errors*	Word Prediction Errors
1	sleepe (slept) borther	seept bother	
2	Satday Bother	Satday bother	
3	Chales (Charles) copien	Chales cople	
4	jod (job) willy (while)	Jod willy	
5	Haloween	Haloween	
6			0
7	peasent popobley	cannt* peasent popably	
8	jewlry jewelery	jewlry jewlry	
9			0
10	sotdad (soaked) relly jackes (jacket)	sotdad relly jackes	
11			0
12			0
13	fends pizes	frends pizes	
14			0
15	puple favite	puple favorite	
16		theters*	
17			0
18		intersting*	
19			vinyerds*
20			0
21		esplore* valuble*	
22			0
23	Jwelery	famly* jewelery	
24	Privlidges	privliges	
25			0

Table 8

Spelling/Keyboarding Errors Across Each Condition.

Kathy's Spelling/Keyboarding Errors			
Session	Handwritten Errors	Word Processing Errors*	Word Prediction Errors
1			
2		facinating* clases* usully*	
3		interperet* embaressed*	
4		phenominal* probly*	
5		esentially* fundimentals*	
6			0
7		intelectuals*	
8		ata* plethara*	
9			0
10		necessrily* redundent*	
11			0
12			0
13		slighgtly*	
14		0	
15			0
16			0
17		0	

IOR and Procedural Fidelity

Interobserver reliability was calculated in 20% of all word processing and word prediction sessions for each participant. IOR was calculated for fluency, accuracy, and length. The results of the IOR indicated 100% agreement for each dependent variable for each participant.

In addition to IOR, the Procedural Fidelity Checklist was filled out by the researcher in 100% of the sessions. In 20% of the sessions, a second observer checked to ensure that the researcher was following the checklist. The results indicated that the researcher followed all steps of the Procedural Fidelity Checklist 94.8% of the time. The 5.2% discrepancy is due to the researcher's inability to conduct one step (printing the typed page and labeling it with the participant's name and date) immediately following the conclusion of a timed typing session. This occurred because of unanticipated school related interruptions such as a class change, student personal needs, or in one instance, a fire drill.

Social Validity

An eight-question survey (see Table 9) was administered at the conclusion of the study to each participant to address social validity (see Appendix E). The survey measured user perceptions of the usefulness and attitude toward the word prediction program used in this study. A Likert scale from 1-5 measured participant responses, where 1 indicated "strongly disagree", 3 indicated "not sure", and 5 indicated "strongly agree". The survey revealed mixed results with regards to the perceived usefulness of word prediction software.

Responses varied across questions and among participants. Three of the four participants reported that they strongly agreed or agreed that word prediction software would lead to higher academic grades. One participant, Kathy, felt that word prediction would not save time for typed assignments. Two participants reported that they were unsure if word prediction would save time, and one participant reported strong agreement that word prediction would save time. With regard to word prediction software's ability to promote neatness, three of the four participants reported they either strongly agree or agree with this statement. When participants were asked if they were likely to make fewer mistakes using word prediction, two participants were in agreement with this statement, while two other participants were unsure.

Two of the four participants stated that they agreed that they would use word prediction for assignments completed at home, if it was available. In contrast, one participant disagreed and one participant was unsure. Three of the four participants were unsure if they would recommend word prediction software to a friend although one participant agreed that he would recommend it to a friend.

Two participants strongly disagreed with the suggestion that word prediction software required less effort than word processing, while the remaining two participants were unsure. Finally, two participants were unsure whether word prediction was less fatiguing, one participant strongly agreed that it would be less fatiguing than word processing, and the remaining participant disagreed. In summary, three participants expressed overall disagreement about the software's efficacy. One participant was unsure about word prediction's efficacy, and one participant reported a general agreement about the efficacy of word prediction.

Table 9.

Social Validity Questionnaire.

	Tom	Brian	Belle	Kathy	Mean
1. Using Co:Writer will help me et better grades.	4	5	4	2	3.8
2. Using Co:Writer will help me save time.	3	5	3	1	3.0
3. My work looks neater when I use Co:Writer.	4	5	4	3	4.0
4. I make fewer mistakes when I use Co:Writer.	4	5	3	3	3.8
5. I would use Co:Writer at home if I could.	3	5	4	2	3.5
6 .I would recommend Co:Writer to a friend.	3	3	3	3	3.0
7. It takes less effort to use Co:Writer than to use a word processor.	2	3	3	1	2.3
8. It is less fatiguing to use Co:Writer	3	5	3	2	3.3
Overall mean	3.25	4.5	3.4	2.1	

Discussion

The purpose of this study was to examine the effects of word prediction software on typing speed and accuracy with individuals with physical disabilities. The following dependent variables were examined: (a) writing fluency as measured by WCPM; (b) spelling/keyboarding accuracy; (c) word errors; (d) passage length; and (e) participant interest. An alternating treatment design was selected to compare the effectiveness of using word prediction versus using word processing on writing fluency (Kazdin, 1982; Richards, Taylor, Ramasamy, & Richards, 1999). Results indicated that there was mixed effectiveness on fluency in the word prediction condition. However, under word prediction there were increases in accuracy and decreases in overall errors for all four students. Two of the students wrote longer passages under the word processing condition.

Fluency

Upon examining writing fluency (rate or speed), there were mixed results across the four participants. One participant, Tom, achieved slightly higher rates of WCPM using word prediction software versus word processing (with 60% of nonoverlapping data). Alternatively, Kathy achieved appreciably higher WCPM using word processing (with 100% nonoverlapping data). The other two participants, Belle and Brian, achieved substantially equal rates of WCPM across both conditions. Participant's baseline typing speeds need to be considered when examining the fluency results.

It is suggested in the literature that there is a cutoff in the baseline typing rate at which the benefits of word prediction will no longer improve fluency due to the time it takes the eye to gaze over the word prediction list and make a selection (Bourdin & Fayol, 2000). It is suggested that faster typists will not benefit from word prediction (Mankoff, Fait, & Juang, 2005; Tam, et al., 2002a; Koester & Levine, 1996). This is supported in the present study with Kathy who had the fastest typing speed (typing speed was 30.6 WCPM), and she achieved substantially slower fluency using word prediction.

In contrast, Tom, who had the next fastest baseline typing speed, performed slightly better using word prediction. His baseline typing speed was 17.4 WCPM. Past studies are mixed regarding increases in fluency with students with physical disabilities typing near this rate. One study showed students with 17 wpm and 13 wpm typing rates improving typing speed with word prediction (Mezei & Heller, 2005), while two other studies showed participants typing slower using word prediction with baseline mean typing rates of 20 for six students with spinal cord injury (Koester & Levine, 1997) and 14.6 wpm for one student (Tumlin & Heller, 2004). Both of these studies examined typing rate using words per minute rather than words correct per minute. In the current study, when converting the data from words correct per minute to words per minute, the PND for Tom drops from 60% to 40%, hence the typing speed increase may be partially attributed to an improvement in spelling when using word prediction. Therefore, the data for Tom do not strongly support word prediction as appreciably increasing typing speed

Brian showed no difference in typing fluency under the word prediction versus word processing conditions. Brian's baseline typing rates was 9.6 WCPM. His results are similar to Tumlin's & Heller's student who had mixed results with a baseline typing rate at 10.9 wpm and Mezei's & Heller's student who also had mixed results with a 7 wpm baseline typing rate (when typing for three minutes).

Belle had the slowest baseline typing rate at 5 WCPM and showed no difference between the two conditions. Mankoff et al., (2005) and his colleagues suggested that individuals who have typing speeds from five to eight words per minute obtained the most benefit from word prediction. The authors used a simulation of typing speeds that was designed to represent individuals with motor limitation. These results were partially confirmed in other studies featuring participants with physical disabilities (Mezei & Heller, 2005; Tumlin & Heller, 2004). However, most students with physical disabilities have more impairments than motor impairments alone which the Mankoff article does not take into account. For example, students with Spina Bifida often have visual-perceptual problems and processing issues which may, in part, explain why all the students with Spina Bifida in the Tam, et al., (2002a) research article who had baseline typing speeds of 4.16- 9.21 WCPM typed slower using word prediction. In this study, Belle had the lowest preintervention scores for grade level spelling, Word Identification (Word ID), and Passage Comprehension. Because of her poor spelling accuracy, words per minute (WPM) data were also examined and there continued to be no fractionation of the data between the two conditions. These additional student attributes may be responsible for the lack of differentiation between the two conditions.

The first research question of this study asked to what extent students with physical and health disabilities produce greater fluency (WCPM) when writing a draft paper on a common topic using word prediction rather than word processing. The results of this study indicated that word prediction did not increase the fluency of students with physical disabilities. However, some increases in fluency have been found in other studies, indicating that more research is needed. In one study (Tumlin & Heller, 2004), increases have been found with students with cerebral palsy and traumatic brain injury who typed fewer than 5.0 wpm (2.9 wpm and 4.7 wpm) which suggests more studies are also needed at slower typing rates. The present study suggests that this technology erroneously promises gains in typing speed although further research is needed due to the limited research with this population.

Overall Accuracy

Research of word prediction software indicates that spelling accuracy may be higher than through the use of word processing. Many studies have examined the use of word prediction with poor spellers and have shown a higher rate of accuracy (with fewer errors) in typed text using word prediction (Macarthur, 1998a, 1999a, 2002; Tam et al., 2002a). In the present study, all four participants made fewer spelling/keyboarding errors using word prediction versus word processing.

As per the study methodology, participants were precluded from correcting any spelling/keyboarding or word errors during typing sessions in both word processing and word prediction. This procedure was chosen to ensure that the actual fluency rate and accuracy would be captured. This procedure was important because the purpose of the present study was to examine participants' actually typing fluency and not their revision skills.

The present study did not examine the context of spelling/keyboarding errors because this study the purpose of this study was not to examine the quality of written expression. Examination of subject-verb, tense errors and other grammatical errors was not conducted. Although Co:Writer 4000 has the potential to examine the words a student enters and later the word prediction list to limit or avoid contextual errors, this feature was disabled for the present study, which was interested in capturing participants' natural spelling/keyboarding errors.

Belle had the lowest initial spelling score, a 3.8 grade equivalent (which was two and one-half years below her actual grade level). Belle obtained the highest rate of spelling errors in the handwritten draft of the four participants. Additionally, Belle obtained an accuracy rate of 90% in baseline and approximately 89% in the word processing condition. In the word prediction condition, however, Belle achieved an accuracy rate of greater than 99%, supporting previous literature on the benefits of spelling accuracy for word prediction. Research indicates that word prediction software may be of benefit for students with spelling deficits (MacArthur, 1998a, 1999a, 2002; Tam et al., 2002a; Tumlin & Heller, 2004; Mezei & Heller, 2005). In one study by MacArthur, (1998a) five students with severe spelling deficits increased their spelling accuracy from 42 to 75% in handwritten journal entries and from 90 to100% using word prediction software. As with Belle, word prediction software improves spelling/keyboarding accuracy if the user locates and selects a correctly spelled word from the word list. The one instance that a misspelled word appeared in the word prediction treatment, the word (vineyards) appeared in the prediction list but Belle did not select it.

Tom and Brian made fewer spelling errors than Belle and also showed high accuracy under the word prediction condition. Both participants were approximately one grade level below in spelling achievement on the PIAT than the actual grade level at the time of the study. Tom made twenty-five spelling/keyboarding errors in the word processing condition, while producing only one error in the word prediction condition. Brian, who made six spelling/keyboarding errors in the word processing condition, also made only one error in the word prediction condition. Although their spelling achievements were better than Belle's, they were still behind in spelling and their improved performance under the word prediction condition is consistent with the literature (MacArthur, 1998a, 1999a, Tam et al., 2002). It is interesting to note that the two words that were incorrect in the word prediction condition did not display in the prediction menu. This was because neither word was preprogrammed into the intermediate dictionary level provided in Co:Writer 4000 software. A more advanced dictionary may have precluded these errors from occurring.

Given the poor spelling abilities of Tom and Brian, more spelling errors could be expected from Tom and Brian due to both participants being approximately one grade level below in spelling achievement on the PIAT. The relatively few number of spelling may have occurred as a result of the study methodology in which participants chose their own writing/typing topics and may have chosen topics with familiar words creating a higher spelling accuracy than would be expected if the writing/typing topic was given by a teacher and was unfamiliar.

Word prediction may even be helpful for students with strong spelling skills. Kathy was the strongest speller of the four participants with a greater preintervention spelling score on the PIAT than her actual grade level. During intervention, Kathy made a total of seven spelling/keyboarding errors in the word processing condition, and no errors in the word prediction condition. Hence, the word prediction condition appeared to produce more accurately typed text for this participant. These results add to the literature base on word prediction featuring participants with physical disabilities and facilitate teachers to make more informed decision whether or not to use this software with their students.

Spelling Versus Keyboarding Errors

Questions arise as to whether the errors were truly spelling errors or the result of keyboarding errors (or a combination of both). Keyboarding errors are inaccurate key selections on the keyboard which often occur when people type. In addition to keyboarding errors occurring from typical motor errors, or inattention, students with physical disabilities often make keyboarding errors due to fine motor and range of motion deficits. Keyboarding errors may impact typing fluency because they are reflected in typing speed and accuracy calculations. Since the present study required participants to handwrite a draft prior to typing in the word processing or word prediction condition, a comparison could be made between errors in the handwritten draft versus the typed draft. If the word is spelled correctly in the handwritten draft and is incorrect in the word processing draft, it is most likely a keyboarding error. Errors that were not spelled correctly in either draft, or misspelled in both drafts, were most likely spelling errors or a combination of spelling and keyboarding errors. In some instances, the participant may have differences between the handwritten and word processing or word prediction passage. This may occur in one of two ways: first, a word appears in a typed passage (in either condition) but does not appear in the handwritten passage, or a word may appear in the handwritten draft but does not appear in a typed passage. In either case, a comparison between handwritten and typed drafts would be unable to determine if the error was due to spelling or keyboarding mistake.

Since Belle was the poorest speller among the participants, it was expected that most of her errors would be spelling errors instead of keyboarding errors. Upon examining her handwritten versus word processing passages, six of the twenty-eight total errors (including baseline) were thought to be due to keyboarding errors. This is because these six words were spelled correctly in the handwritten draft and not in the word processing condition. Four of the six keyboarding errors were the omission of a single letter, one error occurred when the letter “s” was selected rather than “x”, and the final error was a failure to select the apostrophe key. Each of these six errors could have been an error caused or related to a physical disability (Heller et al., 2008). Importantly, word prediction is able to address both types of errors and has the potential to produce error-free drafts for Belle.

Tom and Brian had a combination of spelling and keyboarding errors, with both students demonstrating more keyboarding errors than spelling errors. This result is not surprising given that both participants were approximately one year behind in spelling achievement. Of Tom's forty-one errors in baseline and intervention, twenty-four of these errors may be attributed to keyboarding errors. For Brian, out of a total of fifteen errors, ten were keyboarding errors. In a few instances, there were errors that might be attributed to the physical disability. For example, in session fifteen, Tom selected the letter 'd' rather than the letter's'. As these keys are located adjacent to each other on the keyboard, this error may be a result of a motoric error (Heller et al., 2008). Brian had two instances in sessions seventeen and twenty-five of holding down a key too long, resulting in double letters being selected. This is a common error made by students with physical disabilities (Heller et al., 2008) and may have occurred in this case. Participants with more severe disabilities may have had more keyboarding errors than the present participants.

Kathy had above average spelling ability and it was assumed that most of her errors would be keyboarding errors. All sixteen words that were spelled incorrectly in the word processing condition were correctly spelled in the handwritten draft, indicating they these errors were all keyboarding errors. Since Kathy produced no errors in the word prediction condition, the present study supports the use of word prediction to correct keyboarding errors.

When examining the effect of word prediction on accuracy, this study did find that spelling accuracy was improved with Belle and Tom, which coincides with the literature on word prediction with poor spellers. However, this study further examined whether errors were due to spelling or keyboarding. It is important to note that while word prediction software has the potential to improve spelling accuracy it does not actually make the participant a better speller. This is especially a concern with students with physical disabilities, since keyboarding errors are common in the population of students. The present study confirms that some apparent spelling errors are most likely keyboarding errors. This study further found that word prediction may reduce keyboarding errors. Hence, the second research question of this study can be answered by acknowledging that word prediction software increases accuracy by decreasing both spelling and keyboarding errors.

Different Types of Errors

The third research question asks to what extent the use of word prediction software will result in the production of other errors as compared with word processing. When examining errors other than spelling and keyboarding errors, the participants made more total errors in the word processing condition. Word prediction automatically capitalizes the first word of each sentence and all proper nouns. Hence, a decrease in capitalization errors did occur with one to three capitalization errors occurring for three participants in the word processing condition and only one capitalization error occurred (hollywood) for one participant in the word prediction condition. This word, a proper noun, was not contained in the word prediction dictionary and therefore it was not offered in the prediction list

In the word prediction condition, a space between words is automatically placed by the software when a user selects a word from the prediction list. Hence, there are fewer spacing errors in the word prediction condition versus word processing. However, spacing errors can occur in word prediction when the participant adds an additional space between the words, perhaps due to forgetting that the software automatically provides a space or due to a keyboarding error (or through not selecting a word on the word prediction list and forgetting to put a space between words). Tom made the most improvement using word prediction as he made fifteen errors in the word processing condition and six errors in the word prediction condition. Tom's spacing errors in word prediction were adding an additional space between two words. In contrast, Tom's spacing errors in word processing were almost exclusively a failure to add a space between words, especially following a comma. Brian and Kathy also had spacing errors (five and four errors, respectively) in which an extra space was added, and the number of these errors decreased to one error for each participant in the word prediction condition.

With regards to end punctuation, two participants made end punctuation errors (one error for Tom, three errors for Belle), while there were no end punctuation errors in the word prediction condition for all participants. The results for participants in the word prediction condition may be explained by the procedure used in this study in which all participants were instructed to end each sentence with an end punctuation choice in order for the software to send the sentence to the accompanying word processor (word prediction software will send the sentence to the word processor either by adding an end punctuation choice or by selecting the "Enter" key).

One of the concerns with using word prediction software is the participants may randomly select a word from the word prediction list. This has been observed in elementary-aged students with physical disabilities. No participants made incorrect choice selections in the word prediction condition in the present study. This may be due to the participants' age, or because they are more experienced writers. It may also be explained by the study procedure that had participants type from their handwritten draft (although it should be noted that some participants occasionally deviated from their handwritten draft by typing additional words).

Overall, it appears that word prediction produces fewer errors than using word processing across spelling, capitalization, spacing, and end punctuation. Although the total number of errors in each condition may appear minimal, it is important to consider that the typing sessions were three minutes in length and a greater number of errors may be made in longer typing sessions.

Passage length

Overall, word prediction did not notably increase the passage length, and in one case it decreased the passage length. This is consistent with the literature in which two studies suggested that word prediction would decrease passage length when typing speed is decreased with word prediction (Tam et. al., 2002a; Koester & Levine, 1997), and one study (Mankoff, Fait, & Juang, 2005) that simulated users with physical disabilities who would be capable of typing more than eight words per minute. Kathy, who was the fastest typist of the participants, obtained a mean of 68.3 words in the word prediction condition, a mean of 95.8 words in baseline, and a mean of 100.1 words in the word processing condition. This result represents a decline of nearly 32 words between the conditions in three-minute typing sessions which clearly indicates that word prediction software decreases her typing rate.

For two of the students, there were no appreciable changes in length. Brian's means in baseline and in the word processing condition (30.6 and 30.7) were almost identical to the mean he obtained in the word prediction condition (30.2) during three-minute typing sessions. Belle, the slowest typist of the four participants, obtained a mean of 17.4 words in the word prediction condition, a mean of 16.2 words in baseline and a mean of 19.4 words in the word processing condition..

Tom produced a very slight increase in passage length in the word prediction condition (mean 62.2 words), as compared to word processing (baseline mean was 58.2 words) and word processing condition (mean 51.0 words). However, the four word increase over baseline using word prediction is not remarkable given this is a three-minute typing session (when five keystrokes are counted as a word), hence Tom demonstrated only a slight increase in typing rate in three-minute timed sessions.

Therefore, the answer to the fourth research question, the extent to which word prediction increases typing length, is that there is little to no increase in passage length and word prediction may decrease the length when students are fast typists.

Participant Survey

The participants in this study were surveyed in order to determine their views about the efficacy of word prediction software. Survey results revealed mixed opinions. Kathy's overall view (mean 2.1) indicates that she disagrees that word prediction software is an effective tool for her. In light of the fact that Kathy's WCPM was lower in the word prediction condition than in the word processing condition, this is not a surprising result. In contrast, Brian's view fell equally between 'agree' and 'strongly agree' (mean 4.5) that word prediction software would benefit him. The survey results also reveal Tom and Belle were generally unsure whether word prediction software would benefit (mean 3.3 and 3.4, respectively).

The four participants were most likely to agree that using word prediction would make their typed work appear neater (mean 4.0), would help them earn better grades (mean 3.8), and they would make fewer mistakes (mean 3.8) than they would using word processing. These results are consistent with the literature base that suggests that word prediction software may improve the appearance of typed drafts and have fewer errors than word processed drafts (MacArthur, 1998b, 1999b; Tam et al., 2002b; Koester & Levine, 1997). Participants were generally unsure whether they would use word prediction software at home (mean 3.5), and whether using word prediction software would be less fatiguing than using a word processor (mean 3.3), although the software was originally designed to help people with physical disabilities with fatigue and endurance deficits (MacArthur, 2000). Participants were unsure that word prediction could save them time (mean 3.0) or whether they would recommend the software to a friend (mean 3.0).

The four participants were in general disagreement with the suggestion that word prediction software takes less effort to use than a word processor, with Tom disagreeing and Kathy strongly disagreeing with this idea. The participants' attitude toward the extra effort needed to operate word prediction software may be due to the relatively short amount of time they used this Co:Writer, which was a new software program for them. Additionally, more experience with word prediction could influence fluency results and this may also affect user attitude regarding the effort needed to operate this software.

Current and Future considerations

Although word prediction software was originally designed and intended to assist people with physical disabilities to increase typing fluency (MacArthur, 2000) results of various studies remain mixed with most participants reporting declines in fluency compared with handwriting or word processing (MacArthur, 1998a, 1999a; Lewis et al., 1998, Tam et. al., 2002a). In the present study, one of the four participants made gains in fluency when using word prediction. This result is consistent with Tumlin and Heller

(2004) who reported that two of four participants and Mezei and Heller (2005) who reported that two of three participants made gains in fluency using word prediction software.

Studies have suggested that faster typists are more likely to demonstrate slower typing fluency using word prediction (Heinsche & Hecht, 1993; Koester & Levine, 1997; Lewis et al., 1998) and slower typists are more likely to demonstrate gains in typing fluency (Tumlin & Heller, 2004). Mankoff, Fait, and Juang (2005) conducted an intriguing simulation of the effects on typing fluency of people with physical disabilities and reported that word prediction software would be most beneficial for participants who typed between five and eight words per minute. Research is needed with more participants with physical disabilities to determine whether initial typing rate is a determinant of fluency using word prediction. Further research is also warranted featuring participants with more severe physical limitations to determine if severity of impairment affects typing fluency when word prediction software is considered.

Students with degenerative conditions may need to seek alternate keyboarding solutions as their condition progresses. In this study, one student (Kathy) was included who has spinal muscular atrophy, a degenerative disease that results in a progressive loss of gross and fine motor function which may eventually lead to nearly complete paralysis of all four limbs and eventual death (usually occurring in the late teenage years or early twenties). Although she was significantly older than the other participants, she was included with the idea that word prediction may assist her now and as she later physically declines, her typing fluency would continue to decrease to a point at which word prediction would clearly offer benefits. However, in the present study, Kathy demonstrated nearly a 50% decline in fluency using word prediction with an initial typing speed of approximately 30 words per minute. Clearly, word prediction was not effective for her given her current typing speed. However, the researcher recorded Kathy's spontaneous comment that word prediction might become useful to her later in life as her physical disability worsened with time. Brian, who has Duchenne Muscular Dystrophy, which is also a progressive and fatal disease, and who had notable declines in muscular strength and endurance, was in a relatively early stage of the disease process. Since Brian was considerably younger than Kathy and his physical disability will worsen over time, word prediction software may become a more effective technology in the near future. For Kathy and Brian, a reassessment of the benefits of word prediction on typing fluency and accuracy over time is warranted. Therefore, more research is needed that examines participants with progressive diseases to determine the effectiveness of word prediction as physical health declines.

Word prediction software continues to be a commonly used assistive technology in schools to support typing fluency and accuracy with students who have physical disabilities. Moreover, word prediction is an increasingly common feature of commercially available assistive technology software programs. Word prediction software is a specific technology chosen by special education teachers of students with physical disabilities to increase typing fluency and accuracy. Given this practice, and the mixed results of current research, more research with students of various ages, and types and degrees of impairment is required to inform practice and to attempt to establish best practice suggestions.

Word prediction software does hold promise to improve spelling errors. Several studies reported improvement in spelling accuracy using word prediction for some participants (MacArthur, 1998a, 1999a; Mezei & Heller, 2005; Tumlin & Heller, 2004).

These studies included participants with physical disabilities (Tam et al., 2002a; Tumlin & Heller, 2004; Mezei & Heller, 2005) and participants with learning disabilities who also had spelling problems (MacArthur, 1998a, 1999a). In the present study, some errors that appeared to be a result of spelling ignorance were shown to be keyboarding errors, possibly unrelated to aspects of the participants' physical disabilities. Notably, spelling errors did occur and word prediction did fix most of these errors. Specifically, three of the four participants who made spelling and keyboarding errors in the handwritten drafts and the word processing condition improved their accuracy in the word prediction condition, with each of the participants producing only one spelling error across all ten word prediction sessions. The participant with the lowest initial spelling ability, Belle, made the greatest gains using word prediction. Further investigation of the effects of word prediction with poor spellers is needed to determine if word prediction software is of greater benefit to participants who have physical disabilities and more significant spelling deficits. Such investigations will require participants to generate a handwritten draft as the present study did to facilitate a comparison between the handwritten and typed drafts. However, future studies could consider providing the writing topics to participants, unlike the present study in which participants chose their own writing topics. In the present study, this procedure was chosen to balance participant interest and motivation to write. Allowing participants to chose their own writing topics may unintentionally decrease spelling errors in the handwritten and typed drafts (in both conditions) because participants may chose topics to write about that have familiar words and are easily spelled. When given unfamiliar topics to write about, participants may generate more spelling errors in the handwritten draft and word prediction software may allow greater improvements in accuracy than the present study found.

Another consideration is the type of word prediction software program being used. This study selected Co:Writer 4000. This program contained a beginner, intermediate, and advanced dictionary with correctly spelled words. Other important features of this particular word prediction software was the ability to capitalize the first word of each sentence and all proper nouns (in the dictionary), to correct spacing between words, and to assist with end punctuation. There are several other word prediction programs available, some which operate independently as a word processor (like Co:Writer) and others that are incorporated into separate software. Because the features of word prediction software vary in each program, other spelling and word errors may be possible. Future research that compares the relative efficacy on spelling and word errors among word prediction software programs is needed.

A consideration of the study was that the intermediate dictionary was used. It was selected because it contained 40,000 words and was thought to be best suited for participants of middle and high school age (Mezei & Heller, 2005; Tam et al., 2002a; Tumlin & Heller, 2004). However, it is possible that by selecting the advanced dictionary, it would have allowed for one participant (Belle) to have identified and selected the word "vineyard" which was the only word misspelled in the word prediction condition across all participants in this investigation. Future studies should evaluate the effectiveness of advanced dictionaries on spelling, especially for older and more academically advanced participants. Since some word prediction programs, including Co:Writer 4000, permit words to be added to the dictionary, researchers may consider checking to make certain that the word prediction dictionary used contains every word generated in the participants' handwritten drafts. This procedure may help to avoid the possibility that the participant is scanning the word prediction list for a word that cannot appear (and therefore could not be corrected) as with Belle who was unable to locate and select “vineyard”.

People with physical disabilities who experience physical and cognitive fatigue may benefit from word prediction if the software limits fatigue through rate enhancement or keyboarding strike savings. The present study assessed passage length between word processing and word prediction and determined that word processing resulted in longer passages for three of the four participants in three-minute timed typing sessions. Passage length remains an under-studied feature in word prediction research. Studies that use non-timed, open-ended procedures to examine the effectiveness of word prediction on passage length are needed, although this type of methodology creates practical difficulties for people with physical disabilities who are prone to fatigue and endurance limitations.

One important consideration of the present study involves the length of timed typing sessions. Lewis et al., (1998) conducted the largest study with word prediction using over one hundred students with learning disabilities and one hundred students without disabilities. Their study featured three-minute typing sessions. The present study used a three-minute timed typing session in both the word processing and word prediction conditions. Previous research studies using participants with physical disabilities used a two-minute procedure (Tumlin & Heller, 2004), a thee- and six-minute procedure (Mezei & Heller, 2005), an untimed procedure (MacArthur, 1998a, 1999a, 2000; Tam et al., 2002a), or an untimed simulation procedure (Koester & Levine, 1996). A three-minute procedure was chosen in an attempt to simulate a realistic typing requirement while also limiting the effects of fatigue and endurance commonly experienced by people with physical disabilities. Three-minute typing sessions may not adequately reflect a realistic academic requirement and may not allow for differences in spelling, word errors, and passage length to be adequately studied. Therefore, studies that include longer or open-ended handwritten drafts followed by typing sessions are needed.

The effectiveness of word prediction may be partially dependent on the strategy used to search the prediction list. In the present study, participants were instructed to use the following "two letters then search" strategy (a) type the first two letters of a word; (b) search the list; (c) select the word if it was available; or (d) type the third letter and search the list again. If the word was available in the list after the third letter was typed, it was selected. If the word remained unavailable, the participant continued typing the word. This protocol was used because previous research indicates that typing two letters then searching is the most time efficient method (Koester & Levine, 1996). Limited research exists on the most effective search strategy. Only one study could be located that examined the comparative effectiveness of search strategies (Koester & Levine), and this study simulated participants with physical disabilities. Two studies reported using the "two letters then search" strategy (Tam et al., 2002a; Tumlin & Heller, 2005), while one study used a "one then search" strategy (Mezei & Heller, 2005), and other studies did not report their search methodology (Lewis et al., 1998; MacArthur, 1998a, 1999a). Research that examines different search strategies with participants with physical disabilities is needed to determine if one strategy is clearly more efficient than another.

The present study used a unique methodology that permitted a comparison of handwritten drafts to drafts typed in both conditions. Participants in the present study were required to generate handwritten drafts for two reasons. First, this procedure eliminated pauses or delays in keyboarding during timed sessions that could impact the calculation of correct words per minute (WCPM) and total passage length. Second, handwritten drafts permitted words in the handwritten draft to be compared to typed words in the word processing condition or chosen from the prediction list in the word prediction condition. Since these words could be compared between the handwritten and typed drafts, the present study added to the research base on word prediction software because many errors in the word processing condition that were assumed to be spelling or word errors (i.e., capitalization, spacing) were revealed to be likely keyboarding errors. Future studies of word prediction that include handwritten drafts that allow for comparison to typed drafts may help determine whether word prediction software is an effective technology for people with physical disabilities who do not have spelling deficits but who do make keyboarding errors.

The present study adds important information to the literature base on the efficacy of word prediction software for users with physical disabilities. Although this technology was originally designed to address typing fluency and accuracy for this population of users, many questions still remain as to its efficacy. The present study determined that three of four users did not make gains on fluency, three of four users made gains on accuracy and word errors, and one (Tom) of four users made gains in passage length. A post-study survey suggests that some users (Tom and Belle) who might benefit from word prediction do not necessarily want to use it, and one participant with an advancing degenerative disease (Kathy) may consider it in the future as her typing efficiency declines. Many questions still remain in regards to which initial user characteristics impact the expected efficacy of word prediction software and further research is needed to address them.

Conclusions

Word prediction software was originally designed to improve the typing fluency (word per minute) and spelling for people with physical limitations, but few studies have been conducted examining its use with students with physical disabilities. The results of the present study add to the literature base on the efficacy of word prediction software for students with physical disabilities. In terms of fluency, three of the four participants in this study produced no gain in fluency using word prediction, while one participant produced a slight gain. In the area of spelling, this study used a novel methodology that permitted the comparison of a handwritten draft to a typed draft in either a word processing condition or a word prediction condition to examine spelling versus typing errors. This study found that three participants with below average spelling ability made gains in spelling and/or typing accuracy using word prediction. Also, the same participants who made capitalization and spacing errors in word processing also improved their performance using word prediction. Word prediction software had no appreciable impact on writing length, except for Kathy, whose writing passages were noticeably shorter using word prediction. This study adds to a growing body of research indicating that word prediction may not necessarily be effective in increasing writing fluency for people with physical disabilities and may decrease fluency when the typing rate is of a sufficient speed. However, word prediction may be beneficial to improve spelling and typing accuracy. More research is needed to establish what user characteristics influence the efficacy of word prediction software on fluency, accuracy, and passage length for people with physical disabilities.

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APPENDIX A. WCPM Data Collection Sheet

Name: __________________________ Date: ________________

Session #: ________________ Topic: ________________

Circle one: Word Processing or Word Prediction

WCPM (using 5 characters = 1 word)

1. Total number of words = ______

2. Total number of misspelled words = ______

3. (A – B) = ______ Correct Words

4. Make a copy of passage & delete misspelled word from passage and do a character count = ______________ character count

5. Character count / 5 = __________ adjusted correct words

6. Adjusted Correct words (5) ÷ 3 minutes = [ ] WCPM

Percentage of Words Spelled Correctly

a) # of words in passage = ______

b) # of errors = ______

c) # of correct words (a – b) = ______ correct words

d) # correct words ÷ total number of words (c ÷ a) x 100 = [ ] % correct

LENGTH (using 5 characters = 1 word)

a) # of characters of original passage = ______

b) length (a ÷ 5) = [ ] number of words

APPENDIX B **Word Processing Pre-intervention Checklist**

Name___________________

Date											
User Opens Microsoft Word											
User selects letters											
User selects spaces											
User selects punctuation											
User can capitalize											
Delete unwanted text											
Place cursor											
Save text											
Percent correct											

APPENDIX C. **Co:Writer Instruction Pre-intervention Checklist**

Name____________________

Date											
User Opened Co:Writer with Microsoft Word											
User typed in Co:Writer											
User typed first two letters											
Looked at list											
Selected word or typed 3rd letter											
Continued to type letter & look at list or											
Typed whole word											
Selected end punctuation											
Returned to Co:Writer											
Percent correct											

APPENDIX D. **Procedural Fidelity Checklist for Writing Sessions**

Name____________________ **A**= Word processing **B** = Word Prediction

Date										
Condition A or B										
User given writing topic										
Teacher discussed topic										
User stated aloud plan if possible										
Users provided time to consider										
User completed visual organizer or outline, then hand written draft										
User told which treatment condition										
User instructed to begin, timer engaged										
User using treatment condition										
Told to stop after 3 minutes										
User stops after completing word										

Baseline and intervention

Teacher printed page, labeled name, date										
Teacher save electronic file										
Baseline and intervention timed in 3 minute sessions										

APPENDIX E. **User Survey of Co:Writer Word Prediction Software**

Please read or listen to each sentence carefully. Circle the number that best fits your opinion.

1 = Strongly Disagree 2= Disagree 3 = Unsure 4 = Agree 5 = Strongly Agree

1. Using Co:Writer will help me get better grades.	1	2	3	4	5
2. Using Co:Writer will help me save time.	1	2	3	4	5
3. My work looks neater when I use Co:Writer.	1	2	3	4	5
4. I make fewer mistakes when I use Co:Writer.	1	2	3	4	5
5. I would use Co:Writer at home if I could.	1	2	3	4	5
6. I would recommend Co:Writer to a friend.	1	2	3	4	5
7. It takes less effort to use Co:Writer than to use a word processor by itself.	1	2	3	4	5
8. It is less fatiguing to use Co:Writer than to use it is to use a word processor.	1	2	3	4	5