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

PETER J. MEZEI AND KATHRYN WOLFF HELLER

Georgia State University

Author Note

Peter Mezei and Kathryn Wolff Heller, Department of Educational Psychology and Special Education, Georgia State University.

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Correspondence concerning this article should be addressed to: Kathryn Wolff Heller, Department of Educational Psychology and Special Education, P.O. Box 3979, Georgia State University, Atlanta, GA 30302-3979. E-mail: kheller@gsu.edu

ABSTRACT

Many students with physical disabilities have difficulty with writing fluency due to motor limitations. One type of assistive technology that has been developed to improve writing speed and accuracy is word prediction software, although there is a paucity of research supporting its use for individuals with physical disabilities. This study used an alternating treatment design between word prediction versus word processing to examine fluency, accuracy, and passage length on writing draft papers by individuals who have physical disabilities. Results indicated that word prediction had little to no effectiveness in increasing writing speed for all of the students in this study, but it shows promise in decreasing spelling and typographical errors.

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

Students with physical disabilities may have difficulty with the physical mechanics of writing due to motor, strength, or endurance limitations. This is often evident with students who have cerebral palsy, muscular dystrophy, or spinal muscular atrophy when spasticity or deteriorating motor function affects hand function. Individuals with these conditions often have difficulties with their handwriting, and their typing may be slow and inaccurate. This can result in incomplete assignments with spelling and typographical errors. Further studies are needed to investigate methods to increase writing fluency, which refers to how quickly and accurately a person can write or type (Heller, 2010).

Assistive technology may be used with the intention of increasing writing fluency. Although there are several types of assistive technologies that may enhance typing speed, an assistive technology that also addresses spelling or typographical errors is needed. One form of assistive technology that has the potential of both increasing writing fluency and decreasing spelling errors with students with physical disabilities is word prediction software.

IMPACT OF PHYSICAL DISABILITIES ON WRITING

Students with physical disabilities may have functional, psychosocial, and environmental factors affecting their writing fluency (Heller, 2009). In individuals with cerebral palsy, several types of motor impairments may negatively impact the functional use of the arms, hands, and fingers, causing problems in accurate and efficient typing; this may even cause typing to be impossible (Hall, 2011; Miller, 2005). Motor problems affecting the fingers and hands can include uneven or extraneous movements, uncontrolled movements, restricted range of motion, decreased strength, decreased speed of movement, lack of movement, difficulty isolating the fingers, lack of coordination of the hand or fingers, and finger deformity (Heller, 2009).

Students with degenerative diseases, such as muscular dystrophy and spinal muscular atrophy, often have declining muscle strength in the arms, hands, and fingers, that impact their 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 students from reaching and selecting a desired key (Heller, 2009). Any of these motor and strength issues, either independently or in combination, can have a negative impact on writing fluency. In addition, spelling and typographical errors may occur from these inefficient motor movements, as well as from poor spelling ability.

Although motor, endurance, and fatigue issues commonly result in academic problems for students with physical disabilities, the Physical and Health Disabilities Performance Model (Heller, 2009) suggests that there are additional factors that can impact learning and performing in academic areas such as writing. These factors include expressive communication impairments, other health factors, experiential deficits, sensory loss, and cognitive impairments (including processing issues). Communication deficits (e.g., dysarthric speech in individuals with cerebral palsy, or speech volume and clarity in individuals with muscular dystrophy) may limit the opportunity to seek assistance with writing issues even when an augmentative communication device is present. Health factors may result in a high absentee rate or medication side effects that impair learning. Experiential deficits are common among individuals whose physical limitations appear at a young age, which may affect writing content. Cognitive deficits also may impact writing acquisition. These factors include information processing problems, attention and concentration difficulties, and memory problems.

Other possible factors found in the model that may affect writing fluency occur in the psychosocial and environmental domains (Heller, 2009). These include problems with motivation, self-concept, self-advocacy, behavioral and emotional function, social environment and social competence, physical and technological environments, as well as the learning environment involving the attitudes of teachers, staff and peers. Writing performance can be negatively affected if the student is not interested in writing due to motivational factors, has competing behaviors such as learned helplessness, or does not ask for assistance due to poor self-advocacy skills. Also, the environment must support writing by providing appropriate adaptations and expectations for learning. One way to foster writing may be the use of appropriate adaptations, such as choosing appropriate assistive technology solutions.

WORD PREDICTION USE

Assistive technology exists to assist individuals who have physical disabilities with the mechanics of written communication. Assistive technology solutions are driven by functional needs, individual user characteristics, and personal preferences (Lueck, Dote-Kwan, Senge, & Clarke, 2001). One type of assistive technology that may address these areas is word prediction software which generates a list of correctly spelled word from which the user can select. Word prediction software may improve writing fluency for students whose typing is slow and laborious, and also has the potential to increase accuracy by decreasing spelling and keyboarding errors. However, few studies have been conducted examining its effectiveness with students with physical disabilities, although word prediction was originally conceived and designed to assist people with physical disabilities to type more rapidly and to produce fewer spelling errors (MacArthur, 1999a).

One study by Tam, Reid, Naumann, and O'Keefe (2002a), analyzed the effects of word prediction and typing rate for ten- to fourteen-year-old students with spina bifida and hydrocephalus. The authors reported that 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 (Tam, Reid, Naumann, & O'Keffe, 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 topics and time to brainstorm ideas before three-minute typing sessions were conducted. The results of the study show that students with high baseline typing rates (10.9 and 14.6 wpm) were faster using word processing while students with slower initial typing rates (2.9 and 4.7 wpm) improved their typing rate by 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 have increases in spelling accuracy when using word prediction.

The results of these two studies (Tam et al., 2002b; Tumlin & Heller, 2004) with students with physical disabilities may be explained by Koester and Levine's (1998) thoughts on the effect of keypress delay. In model simulation, Koester and Levine reported that list search time (scanning the word prediction list), keypress time (the time it takes to motorically press the key), and keypress delay (the time to takes to decide what to press) vary by individual and 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 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 two letters are selected, the predicted word choices are ignored, and the third letter (or three letter word) is typed.

Mezei and Heller (2005) examined the use of word prediction on typing speed and spelling accuracy for three, thirteen-year-old participants with physical disabilities (who had spina bifida, muscular dystrophy, or cerebral palsy). Participants were given a topic and wrote a draft prior to the timed sessions. A reversal design was implemented in which there were baseline phases in which no word prediction was used alternating with intervention phases in which word prediction was used. The study included both three minute and six minute timed phases. Unlike the previous studies, all three participants made gains in typing rate reported as words per minute. The first participant increased from a mean typing rate of 17.1 wpm in first baseline to a mean typing rate of 20.4 wpm across three-minute typing intervention sessions, and mean typing rate of 22.5 wpm across six-minute intervention sessions. A second participant increased from a mean typing rate of 13.2 wpm in the first baseline to a mean typing rate of 15.6 wpm in three-minute intervention sessions, and a mean typing rate of 17.5 wpm in six-minute intervention sessions. The third participant increased from a mean typing rate of 7.2 wpm in the first baseline to a mean typing rate of 8.8 wpm in three-minute intervention sessions, and mean typing rate 10.0 wpm in six-minute sessions.

DRAFT STAGE OF WRITING AND WORD PREDICTION

Fluent writing is comprised of two parts: the physical mechanics of writing and the stages of the writing process. The mechanics of writing include the speed and accuracy with which text is generated. Stages of the writing process consist of the sequential steps a person takes to develop a written product. There are several models of the writing process, with many including prewriting and initial draft stages, such as the model proposed by Mercer & Pullen (2004). Prewriting and draft stages are particularly critical for students with physical disabilities to help organize thoughts, since physical barriers may limit the students' ability to effectively edit information or complete revisions due to fatigue and slow typing speeds

In the prewriting stage, a topic is selected and a purpose for writing is identified. The writer is encouraged to consider the characteristics of the intended audience. Following these decisions, the writer may employ one or more strategies to gather and organize information, such as developing an outline, using a visual organizer, or making note cards. Experienced writers may use a combination of these or other strategies.

In the initial drafting stage, a writer develops a rough first draft of the passage. In this stage, writers are encouraged to focus greater attention on the content of the passage than on mechanics, grammar, and spelling accuracy (Mercer & Pullen, 2004). Later stages include revising the rough draft and editing (both of which may occur several times), and eventually moving to the document stage.

Word prediction software may be helpful for individuals in the initial drafting stage of the writing process. The construction of a draft requires physical demands that may pose challenges for individuals with physical disabilities due to slow typing speeds and endurance issues. The use of word prediction software to speed up the writing process by having fewer keystrokes to type a word has potential with this population and may also have a benefit of possibly decreasing motor fatigue and endurance.

This study is designed to further examine the use of word prediction versus word processing with students with physical disabilities who write draft papers. Specifically, the purpose of study is to examine the use of word prediction and word processing conditions across fluency, accuracy, and passage length. An added component will look at the influence of word prediction and word processing on keyboarding errors and spelling errors.

METHODOLOGY

PARTICIPANTS

Participants were solicited from a large metropolitan school district. Criteria for participation were: (a) meeting eligibility requirements for Orthopedic Impairments as defined by the state of Georgia (students with a physical impairment[s] with an intellectual functioning of mild mental retardation or higher); (b) receiving, or having received, services through an orthopedic impairment special education program; (c) being of middle school age or older; (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 grade level or age. Only four participants who agreed to be part of the study met the criteria for this investigation (see Table 1).

Tom was a 12-year-old male in seventh grade. He had a stroke during early infancy. The stroke left Tom with mild to moderate left-side hemiparesis, bilateral hypotonia and a mild speech impairment that impacted speech volume and pace. Tom was ambulatory throughout school grounds. He used a laptop computer for lengthy writing assignments. Tom's handwriting was nearly illegible unless he was given extended time to handwrite and prompted to be as neat as possible.

Brian was a 12-year-old six grade male who had Duchenne muscular dystrophy. Brian used a power wheelchair independently. He was able to handwrite legibly although at a moderately slower pace than his peers. However, given the degenerative nature of his disorder, it was anticipated that he would need to type increasingly more often, and probably move to an adapted keyboard over time. Brian required assistance to retrieve and manipulate his books (e.g., open the 3-ring binder) and personal effects.

Belle was a 13-year-old female in the sixth grade with mild quadriplegic spastic cerebral palsy. Belle demonstrated difficulty gripping her writing instrument and maintaining her grip for more than a few seconds even with the use of a grip support. Belle also had deficits in fine motor control and motor planning. Her handwritten work was difficult to read and was comprised of overlapping letters and words, inappropriate spacing between

Table 1.

Participant Characteristics

Name	Age & Placement	Disability	Initial WCPM	Initial Spelling Accuracy	Passage Comp. G.E.*	Word ID. G.E.*	Spell-ing G.E.**
Tom	12yr General ed 1 resource class per day	Left hemi paresis cerebral palsy	17.6	93.8%	8.0	9.0	6.3
Brian	12yr Resource placement all day	Duchenne Muscular Dystrophy	9.3	94.8%	5.7	5.7	4.9
Belle	12yrs Resource placement all day	Mild quadriplegic spastic cerebral palsy	5.0	90.0%	3.5	4.9	3.8
Kathy	18yrs General ed 1 resource class per day	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

letters and words, letters or words crossed out, and evidence of other corrections. Belle frequently appeared to forget what she was writing and required time to gather her thoughts before proceeding.

Kathy was an 18-year-old female who had spinal muscular atrophy and used a power wheelchair tray to support her papers, books, and laptop computer. Although her handwriting was legible, she preferred to use her laptop computer for lengthy assignments since it was less fatiguing. Kathy's physical strength and endurance were limited and progressively declining due to the degenerative nature of her disorder. She required assistance for most motor tasks (e.g., lifting a text-book from her wheelchair tray, opening the rings of her binder).

SETTING AND MATERIALS

Instructions were provided in a one-on-one format in a classroom, 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). Microsoft Word was the word processor for this study. All spelling, grammar, and dictionary support functions were disabled during baseline and alternating treatments for this study. Font size and color were adjusted to meet the visual preference of each participant.

Word prediction. Co:Writer 4000 (Johnston, 1992) was the word prediction software used in this study in conjunction with Microsoft Word. Co:Writer features a separate window that was placed in the bottom half of the screen; Microsoft Word was in the top half of the screen, and users viewed both windows simultaneously. The user typed the first letter of a word in the prediction window and the program offered a numbered set of words in a vertical menu. In this study, users were instructed to type two letters, then to scan the word choices. Five word choices were displayed at one time, based on a previous study (Tumlin & Heller, 2004). If one of the numbered choices was the word the user wanted, it was selected by typing the number associated with the choice, or by clicking on the choice using the mouse or alternative input device. Once a choice was indicated, the software program inserted the complete word into the sentence followed by a space (so that a space key was not needed before the next word was typed). If the correct word was not in the list, the user typed the next letter and the list of predicted words changed accordingly until the word was displayed and selected or until the typist typed the entire word. The user then typed the first two letters of the next word. Sentences were formed through this process. When ending punctuation was selected, the software transferred the complete sentence from Co:Writer 4000 to the word processor.

Co:Writer 4000 features dictionary options for beginner, intermediate, and advanced writers. 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 and this option had a largest and most complex list of words. In addition, the participant's own individualized user file stored new vocabulary words in the dictionary and was available in future typing sessions. Other features were disengaged including the speech feature and predict ahead feature to prevent spelling cues or grammatical support that could interfere with the study.

OPERATIONAL DEFINITIONS

Writing fluency. The primary interest of the study was facilitating the writing fluency for students with impaired hand functions due to a physical disability, as measured in words correct per minute (WCPM). A word was considered correct if it was 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 does 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, to provide statistical means of averaging word length. A character could be a letter, space, punctuation mark, numeral, or symbol.

The following formula determined the writing fluency (WCPM):

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

Spelling/Keyboarding Accuracy. Accuracy was defined as the percent of words in the passage that were typed correctly 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 appear to be spelling errors but they are mechanical errors that lead to mistakes such as: selecting the wrong key, omitting a key, duplicating a key, hitting two keys at once, 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.

Accuracy was calculated by subtracting the number of misspelled words from the total number of words divided by the total number of words multiplied by 100. In this formula, whole words were counted (instead of groups of 5 characters), since the length of the word was not relevant. The following formula was used:

$$\text{Percent Correct} = \frac{\text{Total number words} - \text{number of misspelled words}}{\text{Total number of words}} \times 100$$

Additional Errors. In addition to spelling and keyboarding errors, the written product was examined for capitalization errors, spacing errors, and failure to type end punctuation. Under the word prediction condition, the typed passages were compared to the handwritten copy to ascertain if the student selected an incorrect word from the display of word choices in the word prediction menu.

Passage length. The passage length was the number of words in the draft. Passage length was calculated as follows: 1) Highlight the original passage (that included spelling/keyboarding and word errors). 2) Determine the number of characters using the Microsoft Word character count. 3) Divide the characters by five and this equals the passage length.

PROCEDURES

Pre-intervention measures of current functioning. Several pre-intervention assessments determined current functioning: (a) a reading comprehension measure, (b) a spelling measure, (c) a word identification measure, (d) a word processing skills checklist, and (e) student's typing rate (WCPM).

Reading comprehension, word identification and spelling measures were obtained for the participants. The Passage Comprehension and the Word Identification tests of the Woodcock Reading Mastery Test- Revised (Woodcock, 1987) determined reading level. Spelling measures were gained through the Peabody Individual Achievement Test-Revised (Markwardt, 1989). Reading comprehension, word identification, and spelling scores were reported as grade-level equivalents. WCPM was also calculated based on five, 3-minute writing sessions. The percentage of spelling errors also was determined during these writing sessions.

Pre-intervention instruction of Co:Writer. Before the study began, each student received individualized instruction on the use of Co:Writer 4000. The teacher described, demonstrated, and then modeled the features of the software. 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, then end punctuation was selected and the sentence was sent to the top portion of the screen. Instruction of Co:Writer 4000 continued until each student was able to achieve 100% accuracy on opening the software and using the procedure.

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. A teacher then discussed the writing topic with the student to be sure the topic was appropriate for school. Participants were given opportunities to amend their personal list choices throughout the study.

After the discussion about the writing assignment, the participants were provided time to prepare their preferred prewriting strategy (e.g., visual organizer, outline). Using their strategy, the participants composed a handwritten draft of their topic. Feedback on spelling and grammar errors were not provided. 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 a critical feature used prior to timed-typing sessions for several reasons. First, having students copy written material is in line with word prediction studies that used this procedure to determine 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, Heller, Fowler, Alberto, Fredrick, et al., 2011; Lewis, Graves, Ashton, & Kieley, 1998; Mezei & Heller, 2005; Tam et al., 2002a). Third, an initial handwritten draft affords an opportunity to assess whether the word prediction facilitated improvements in spelling or keyboarding 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 from 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 pre-intervention typing passages became baseline data for WCPM, accuracy and other word errors.

Next, the students were instructed to type using the word processor alone or word prediction (depending on the treatment condition) with their draft in view. After three minutes, the participants were then instructed to stop. All words remaining in the Co:Writer window were sent to the word processor window to be included in each student's writing draft. This was important in order to include all of the words the students' had typed during their timed sessions. WCPM, spelling/keyboarding errors, other types of errors, and passage length were recorded on data sheets.

RESEARCH DESIGN

The independent variables were the use of word prediction software and word processing and the dependent variables were writing fluency (WCPM), spelling accuracy, types of word errors, and passage length. An alternating treatment design (Alberto & Troutman, 2008) was selected to compare the effectiveness of using word prediction versus using word processing on writing fluency.

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: three consecutive data points that varied less than 50% of the mean of the previous five consecutive data points (Alberto & Troutman, 2008; Kazdin, 1982).

During the intervention phase, the treatment design alternated between two conditions: (a) word processing and (b) word prediction. An alternating treatment design was used to establish a functional relationship between the independent variables and WCPM and spelling accuracy. Alternating treatments was counterbalanced by using an ABBABAAB design (with A being word processing condition and B being word prediction condition for half of the participants and opposite for the other half). After these 8 sessions were completed, the inverse order was implemented (e.g. BAABABBA) for the next sessions. The treatment pattern repeated until bifurcation between the word processing and word prediction conditions was evident based on visual analysis of the graph or until twenty sessions occurred (Alberto & Troutman, 2008).

Besides visual analysis of the graphs to determine the results of the study, the mean WCPM between the two conditions was calculated. Also, when the graphs showed a bifurcation of the data, the percent of data points between the word prediction condition and word processing condition that did not overlap were calculated (referred to as percent of nonoverlapping data) to help determine the effect size between the two conditions.

Social validity, reliability and procedural fidelity. Social validity was assessed through a written post-study questionnaire which consisted of several questions designed to assess the participant's attitudes toward using word prediction. Questions addressed such areas as accuracy, time savings, fatigue, effort to use, and interest in using it at home. Responses were based on a standard five-point Likert-type scale ranging from strongly disagree to strongly agree.

A trained observer and second observer determined Inter-Observer Reliability (IOR) in 20% of both the word processing and word prediction sessions. IOR was calculated by dividing the number of agreements by the number of agreements plus disagreements and multiplying this result by 100. Treatment Integrity Checklists for training and writing sessions were completed by a trained observer.

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 and keyboarding accuracy, c) additional word errors; and (d) passage length.

TOM

Writing fluency (WCPM). As seen in Figure 1, Tom demonstrated a slightly higher rate of WCPM using word prediction versus word processing. In baseline, Tom's mean typing fluency was 17.6. The mean WCPM in the word prediction treatment condition was 20.6, versus 16.4 in word processing. Word prediction software produced a mean increase of 4.2 WCPM. There was 60% of nonoverlapping data between word prediction and word processing, indicating a small effect size. However, when recalculating to wpm, Tom had only 40% of nonoverlapping data, indicating that increases in fluency were due to increases in spelling/keyboarding accuracy, not typing speed.

Spelling/keyboarding accuracy. Tom had a higher accuracy rate in the word prediction condition (see Figure 2). He originally produced a mean of 3.6 spelling/keyboarding errors per typing passage for an accuracy rate of 94.2% in baseline. During intervention, in the word processing condition, Tom compiled a mean of 2.5 spelling/keyboarding errors, producing an accuracy rate of 94.9%. Using word prediction software, Tom made 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%.

Additional errors. In addition to spelling/keyboarding errors, data were taken on capitalization, spacing and end punctuations, as well as word selection

Figure 1. Words correct per minute across participants.

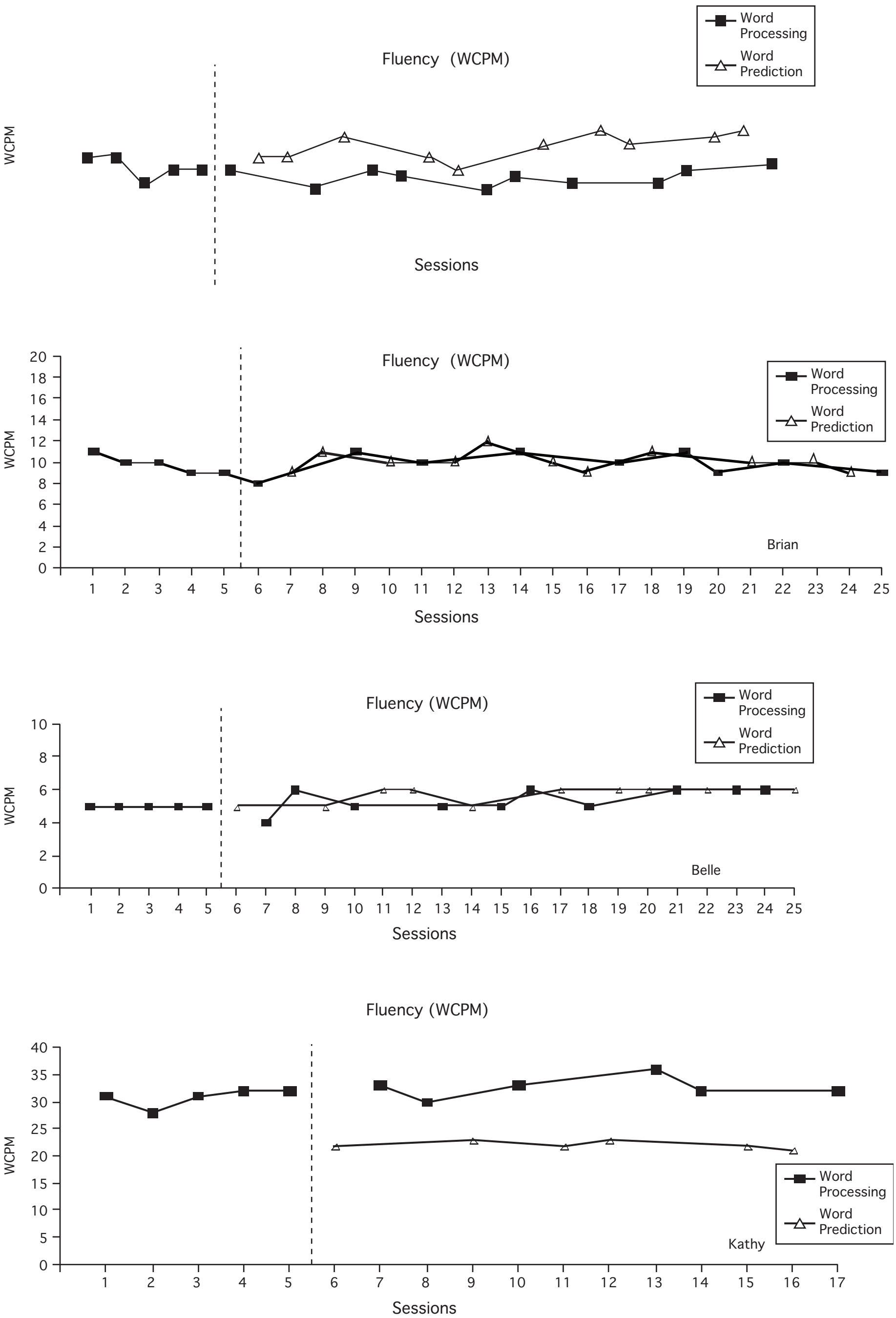
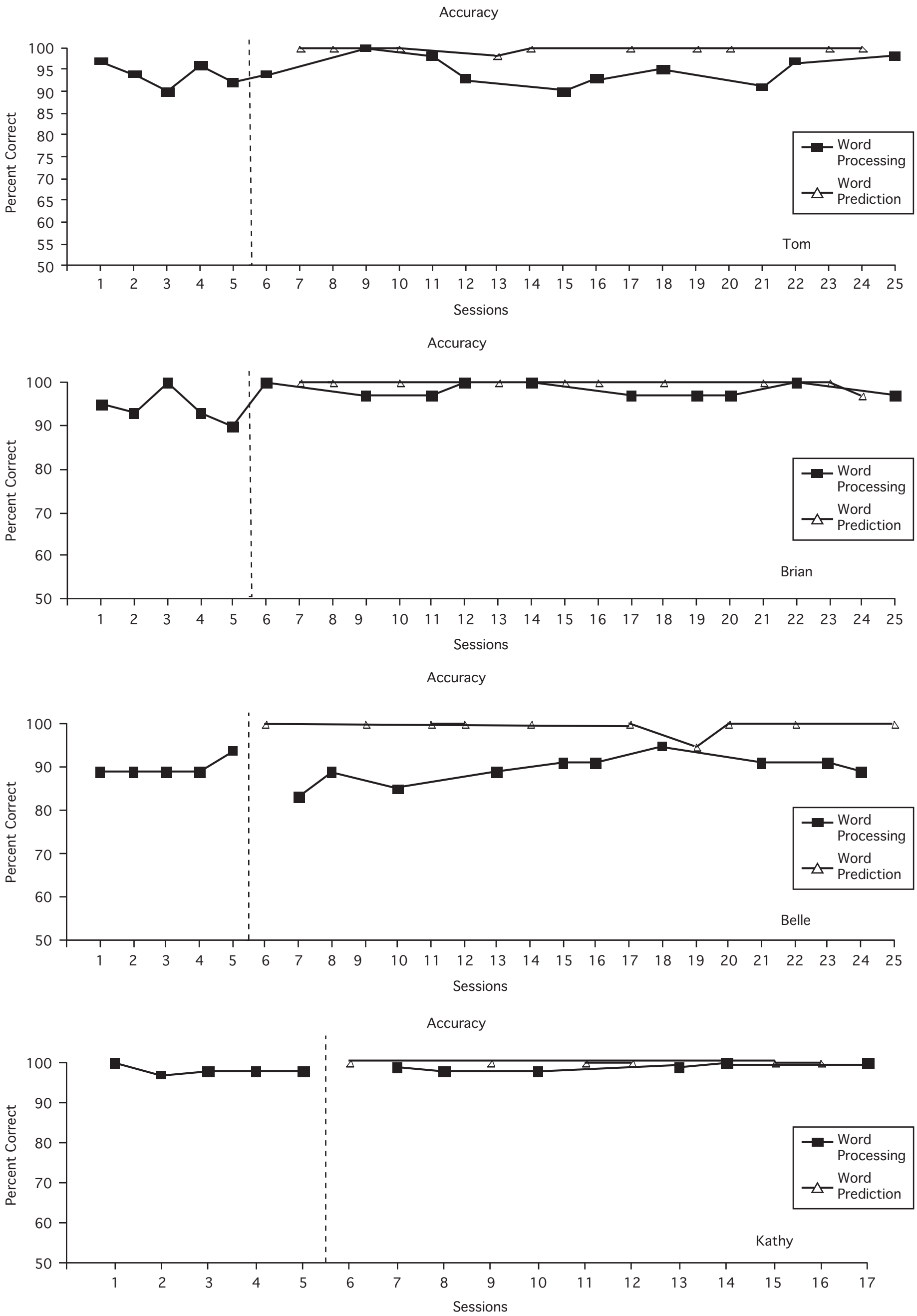


Figure 2. Spelling/keyboarding accuracy across participants.



errors (from the word prediction list). Of these errors, Tom produced 0 to 2 capitalization errors, 0 to 3 spacing errors, and 0 to 1 end punctuation errors per session under the word processing condition (mean 1.9 errors). In the word prediction condition, he made 0 to 1 capitalization errors and 0 to 3 spacing errors per session (mean 0.7). There were no incorrect choice selections from the word prediction menu.

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 to 64 words (mean 58.2). The overall passage length in the word processing treatment was 48 to 56 words (mean 51.0), while the length in the word prediction treatment was 50 to 71 (mean 62.2).

BRIAN

Writing fluency (WCPM). As seen in Figure 1, there was no bifurcation of the data between the word processing and word prediction conditions, indicating that Brian's writing fluency was the same whether he was writing a passage using word processing or using word prediction. In baseline, Brian's mean typing fluency was 9.3 WCPM. The mean WCPM in the word prediction treatment condition was 10.2 and in the word processing treatment condition, Brian achieved 10.0 WCPM.

Spelling/keyboarding accuracy. Figure 2 shows that 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, achieving an accuracy of 98.2%. Using word prediction software, Brian made zero spelling/keyboarding errors in nine of ten passages, with one error in session twenty-four, for an accuracy rate of 99.7%.

Additional errors. Brian produced 0 to 1 capitalization errors and 0 to 1 spacing errors per session in the word processing condition (mean 0.8 errors), as well as 0 to 1 spacing errors in the word prediction condition (mean 0.1). There were no incorrect choice selections from the word prediction menu.

Passage length. In baseline, the passage length for Brian was 29 to 34 words (mean 30.6 words). In word processing, Brian ranged from 24 to 35 (mean 30.7 words), while the length in word prediction was 27 to 36 words (mean 30.2 words).

BELLE

Writing fluency (WCPM). As seen in Figure 1, there was no bifurcation of the data between the two treatments for Belle. In baseline, Belle demonstrated a typing rate of 5.0 WCPM. In word processing treatment condition, Belle typed a mean of 5.6 WCPM. Belle's mean typing rate was 5.7 WCPM when using word prediction software.

Spelling/keyboarding accuracy. Belle has a higher accuracy rate in the word prediction condition (see Figure 2). Belle had produced an average of 1.8 spelling/keyboarding errors per typing passage in baseline. In the word processing condition, Belle produced a mean of 1.9 spelling/keyboarding errors and an average of 89.8 accuracy. Using word prediction software, Belle made 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.

Additional errors. Belle made 0 to 1 capitalization errors and 0 to 2 end punctuation errors per session (mean of 2.2 errors) in word processing condition. She produced no capitalization, spacing, or end punctuation errors using word prediction. There were no incorrect choice selections from the word prediction menu.

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

KATHY

Writing fluency (WCPM). Figure 1 indicates that 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 condition was 22.1, versus 32.6 in word processing. For Kathy, word processing software produced a mean increase of 10.5 WCPM over word processing with word prediction. There was a 100% of nonoverlapping data between word prediction and word processing, indicating a high effect size with word processing being more effective than word prediction

Spelling/keyboarding accuracy. Kathy had higher accuracy in the word prediction condition (see Figure 2). In baseline, Kathy averaged 1.8 spelling/keyboarding errors per typing passage producing a 98.2% average. In word processing condition, Kathy made an average of 0.9 spelling/

keyboarding errors and an average of 99%. Using word prediction software, Kathy produced zero spelling/keyboarding errors.

Additional errors. Kathy only errors were spacing errors. She made 0 to 1 spacing errors per session in the word processing condition (mean 0.7%). In the word prediction condition, Kathy made 0 to 1 spacing errors (mean 0.1%). However, it should be noted that she made far fewer errors under the word prediction condition (with only 1 spacing error for the entire condition, compared to 7 spacing errors in word processing). There were no incorrect choice selections from the word prediction menu.

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

IOR, PROCEDURAL FIDELITY, & SOCIAL VALIDITY

Inter-observer reliability and procedural fidelity were calculated at 100%. The second observer was in close agreement with the primary observer on the checklist and procedural fidelity was calculated to be 94.8%.

A survey to address social validity was administered at the conclusion of the study to each participant. Only 1 student (Brian) agreed that word prediction helped save time (overall mean 3.0 on a 5 point Likert scale with 5 representing "strongly agree"). Two students (Tom and Brian) agreed or strongly agreed that they made fewer mistakes when they used word prediction (with an overall mean of 3.8). Two students (Brian and Belle) agreed that they would use word prediction at home, although 1 student disagreed (Kathy) for an overall mean of 3.5. None of the students responded that it took less effort to use word prediction (overall mean 2.3) and only one student agreed that it was less fatiguing (Brian; overall mean 3.3).

DISCUSSION

The purpose of this study was to examine the effects of word prediction software on fluency and accuracy with individuals with physical disabilities. Overall results indicated that typing speed increased minimally or not at all under the word prediction condition. A decrease in spelling and keyboarding errors were found across all students when using word prediction software.

Word prediction did not increase typing rate for any of the four participants; Kathy had poorer typing speeds using word prediction. The literature suggests 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). Thus, faster typists will not benefit from word prediction (Koester & Levine, 1996; Mankoff, Fait, & Juang, 2005; Tam, et al., 2002a). This is supported in the present study with Kathy, who had the fastest typing speed (typing speed was 30.6 WCPM), and her fluency rate was substantially slower when using word prediction.

The other three students in the study had inconsequential or no increases in typing speed using word prediction. The literature is mixed regarding the specific typing speed which may predispose a student to have increases in typing speed when using word prediction. Mankoff and colleagues (2005) suggested that individuals who have typing speeds from five to eight words per minute would obtain the most benefit from word prediction. However, Tumlin and Heller (2004) found word prediction increases typing speeds for students with cerebral palsy and traumatic brain injury who typed fewer than 5 wpm. Tam et al., (2002a) found no typing speed benefit for students with spina bifida who had baseline typing speeds of 4.16 to 9.21 WCPM. However, there have been examples of some students having slightly higher typing speeds who could type in the 13 to 17 wpm range (Mezei & Heller, 2005). In the present study, Tom, who had a 17.4 WCPM rate, had a slightly higher rate when using word prediction. This was due to a decrease in spelling errors (40% PND when WCPM was changed to wpm). Brian and Belle had the slowest typing rates of 9.6 and 5 wpm and showed no increase in typing speed with word prediction which is consistent with the Tam et al., (2002a) and the Tumlin and Heller (2004) research.

It is probable that additional factors need to be examined to determine whether word prediction will increase typing speed for a typist who is slow due to physical impairment. For example, the students with spina bifida in the Tam et al. (2002a) study may have shown no increase in typing speed when the baseline typing speed was less than 5 WCPM, because of visual-perceptual issues that are commonly found in this population. Students may have more problems with word prediction if they have difficulty shifting attention or executing motor movements upon pausing to look at a list. Further research will need to be conducted to examine the various factors that may influence typing speed with the use of word prediction. However, the research in word prediction does not always support its advertisement of increasing typing speed with students with physical disabilities.

Several studies have shown a higher rate of accuracy in typed text using word prediction with poor spellers (MacArthur, 1998a, 1999a, 2000; Tam et al., 2002a). In the present study, all four participants made fewer spelling errors using word prediction versus word processing; hence the results of the study are aligned with the literature. However, unlike other studies, this study also sought to establish the effect of word prediction in decreasing keyboarding errors. In addition to keyboarding errors occurring from typical motor errors or inattention, students with physical disabilities often make these errors due to fine motor and range of motion deficits. 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.

There were considerable keyboarding errors for all four students. For Belle, six of the twenty-eight total errors were keyboarding errors (21.4%). Of Tom's forty-one errors, twenty-four may be attributed to keyboarding errors (58.5%). For Brian, out of a total of fifteen errors, ten were keyboarding errors (66.7%). All sixteen words that Kathy typed incorrectly were correctly spelled in the handwritten draft, indicating they were all keyboarding errors (100%). Many of the errors appeared to be common keyboarding errors such as hitting two keys as once, selecting a letter beside the intended letter, and omissions. Due to the higher accuracy rates in the word prediction condition, it appears that word prediction was beneficial in addressing keyboarding errors, as well as spelling errors.

The participants made more capitalization, spacing, and end punctuation errors in the word processing condition. Word prediction automatically capitalizes the first word of each sentence and all proper nouns, although one capitalization error occurred in word prediction when the proper noun (Hollywood) was not contained in the word prediction dictionary. In the word prediction condition, a space is automatically added between words when a user selects a word from the prediction list; this typically resulted in fewer spacing errors in the word prediction condition. However, spacing errors can occur in word prediction when the participant adds an additional space between the words, which occurred when Tom added additional spaces (although he made fewer errors in word prediction condition). Training about this aspect of word prediction may be needed. There were no end punctuation errors in the word prediction condition. This 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.

The selection of the word in the word prediction list was also examined to determine if the participants would choose a different word other than the one they had originally written on their draft. This could occur due to a keyboarding error or due to preferring a divergent word. In this study, none of the students selected divergent words from their handwritten copy. This may be partly attributed to the students being told to copy their handwritten draft which may have prevented them from selecting a different word, even if one was displayed that they may have preferred. Also, having a divergent word selected due to a keyboarding error may be less likely to occur since the process of scanning for a word and then selecting it may result in a slower and more deliberate keyboard selection.

The word prediction condition ranged from no increases to minimal increases in passage length for all participants except for Kathy. 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 (Koester & Levine, 1997; Tam et al., 2002a). Kathy, whose typing speed decreased when using word prediction, typed shorter passages with an average of 32 words less in the word prediction condition.

Students with degenerative conditions may need to seek alternate keyboarding solutions multiple times as their conditions progress. In this study, two students (Brian and Kathy) had degenerative diseases. However, at this time, word prediction provided no benefit in typing speed for Brian and clearly hindered Kathy's typing speed. Kathy did make a spontaneous comment that word prediction might become useful to her later in life as her physical disability worsened. For Kathy and Brian, a reassessment of the benefits of word prediction on typing fluency and accuracy may be indicated when user typing speeds significantly decrease. More research is needed that examines participants with progressive diseases to determine the effectiveness of word prediction as motor movement declines, typing speed slows, and fatigue increases. Also, many students will need other forms of input (e.g., alternate keyboard, scanning using an onscreen keyboard) and further research as to the efficacy of word prediction is needed when these forms of access devices are used.

Students with physical disabilities who experience fatigue may benefit from word prediction software if it limits fatigue through rate enhancement or keyboarding strike savings. However, this could not be accurately determined in this study since it used three-minute timed typing sessions. Studies that use non-timed, open-ended procedures to examine the effectiveness of word prediction are needed to determine if there is a difference in typing speed, level of fatigue, and passage length.

Word prediction software continues to be commonly used in schools with students who have physical disabilities. Given the results of this and other research, teachers should be cautioned not to assume that word prediction will increase typing speed, since research has shown that in many cases there is no change or word prediction may even decrease typing speed. However, this study and other research (Golden, 2001; MacArthur, 1998a, 1999a; Mezei & Heller, 2005) support the use of word prediction for students who are poor spellers or make keyboarding errors. If word prediction is to be used primarily to reduce spelling or keyboarding errors, further studies are needed to 1) compare word prediction and the use of spelling and grammar check software and 2) identify important individual characteristics that impact the efficacy of word prediction software for students with physical disabilities.

The present study adds important information to the literature about the efficacy of word prediction software for students with physical disabilities. Although this technology was originally designed to address typing fluency and accuracy for this population, the present study did not see sufficient gains in typing rate for any of the students; in one case it proved to be detrimental to typing speed. The results of this study align with the research literature which reported that word prediction impedes students with faster typing rates and may not improve typing rate for others, but the software does reduce spelling errors for poor spellers. Keyboarding errors were also found to be reduced with the use of word prediction software. A post-study survey suggests that of the two users (Tom and Belle) who would especially benefit from word prediction in terms of improving spelling and keyboarding, only Belle indicated she would use it at home. Based on this and other research on the use of word prediction with students with physical disabilities, teachers need to be cautious in selecting word prediction for their students and to systematically determine if it helps their students by assessing the student's typed work with and without word prediction as well as examining motivational factors for a word prediction program.

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