CHARACTER STROKE-BASED TEXT ENTRY FOR A CHILD WITH CEREBRAL PALSY AND LOW VISION

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INTRODUCTION

Typing can be an immensely valuable functional activity for individuals with severe and/or multiple physical disabilities. Some of these individuals cannot engage in either verbal or gestural communication because of limitations to their physical abilities. Typing allows these individuals to express their thoughts via written text. Being able to type is especially important for children because writing facilities learning and participation in the classroom [1].

Some individuals with severe physical disabilities can use a single binary control input (i.e., a single switch) and nothing more [2]. Nevertheless, a single switch is sufficient to operate virtual keyboards that support scanning. A row-column scanning keyboard such as WiViK (www.wivik.com) first visits each keyboard row, until the user selects one by switch activation, and then the columns of the selected row, until the user makes a second switch activation to select the desired key. An alternative to scanning-based text entry is code-based text entry such as Morse code [3]. Typically, the code words of a single-switch code-based text entry system are timing-dependent sequences of switch activations.

Text entry involves sensory and cognitive functions in addition to motor skills. Scanning-based text entry requires intact vision and/or hearing in order to track the selectable options. Code-based text entry requires the user to memorize code words. Sensory and/or cognitive impairments can become barriers to successful text entry.

The following sections summarize a case study pertaining to the development of a character stroke-based text entry system for a child with severe motor impairment and low vision. The full details of the design, theoretical and empirical evaluations can be found in [4].

CASE PROFILE

The participant was an 11-year-old girl with spastic quadriplegic cerebral palsy (Level 4 on the Gross Motor Function Classification Scale [5]). She had no independent mobility and used a manual wheelchair in the community. She had limited control of her upper limbs, although she could reach and toggle a proximally mounted button with her left arm. Her articulation was not clear enough to use speech recognition.

The participant had intact hearing but was affected by cortical visual impairment. Her visual impairment limited her perception to only colors and line segments and chords presented against high-contrast backgrounds, as well as a narrowed field of view and proneness to visual fatigue. Conventional scanning-based text entry such as WiViK was not effective because the visual presentation of the keyboard was too complex for the participant to keep track of, even with portions of the keyboard enlarged.

The participant tried Morse code and was able to memorize the code words. However, she did not have sufficient control of her left arm to produce the short and long pulses. Having separate buttons for the short and long pulses eliminated the timing problem, but her left arm's range of motion was not adequate to alternate between the two buttons.

CHARACTER STROKE-BASED TEXT ENTRY

The character stroke-based text entry system was designed to accommodate the participant's limited upper limb functions and low vision. The proposed solution is single-switch scanning-based. Although the participant could not handle the stringent timing requirements of Morse code, she had no problem timing her switch activations in scanning with a suitable dwell time.

The participant's low vision implied the use of simple figures, shown one figure at a time. However, even uppercase letters of the manuscript English alphabet were too complex for the participant to see. Hence, the proposed solution implements text entry at a character stroke level. Character strokes can be visually depicted by a line segment or chord against a colored, high-contrast background (see examples in **Figure 1**).

Some character strokes are common to two or more uppercase letters. Figure 1 of [4] showed a sufficient set of 16 character strokes that can compose the 26 uppercase English letters. The proposed solution uses a scanning hierarchy to facilitate text entry of the 26 letters from the set of 16 strokes. Uppercase letters that share a similar first stroke are grouped together. These common first strokes form the first hierarchy level. Within a letter subgroup, the letters' second strokes form the second hierarchy level. Additional hierarchy levels are added onto a stroke if two or more letters share the same second stroke, same third stroke, etc. As such, the hierarchy need not be balanced in terms of levels. Numerals, punctuation marks, whitespace characters and editing functions (e.g., backspace, delete, etc.) form their own individual groups, separate from the alphabet. Table 1 of [4] showed the proposed scanning hierarchy consisting of 6 first strokes and 2 to 6 strokes (letters) within each subgroup. Most letters can be resolved with two strokes. Only four letters require a third stroke to disambiguate. **Figure 1** below explains the text entry process using the scanning hierarchy.

The ordering of the first strokes and second strokes of the subgroups affects text entry speed. For faster text entry, more frequently used letters should be reachable in fewer scanning steps. For the scanning hierarchy in Table 1 of [4], letters within a subgroup were sorted by letter frequencies in descending order and the first strokes were sorted in descending average letter frequencies of each subgroup. The letter frequencies were determined from the *New York Times* text corpus of [6].

THEORETICAL ASSESSMENT

In [7], Bhattacharya *et al.* proposed a computational model for the appraisal of scanning-based text entry systems. This model produces two metrics: 1) the error-free text entry rate, which measures maximum typing speed, and 2) Error-Proneness, which estimates the likelihood of user errors. The Error-

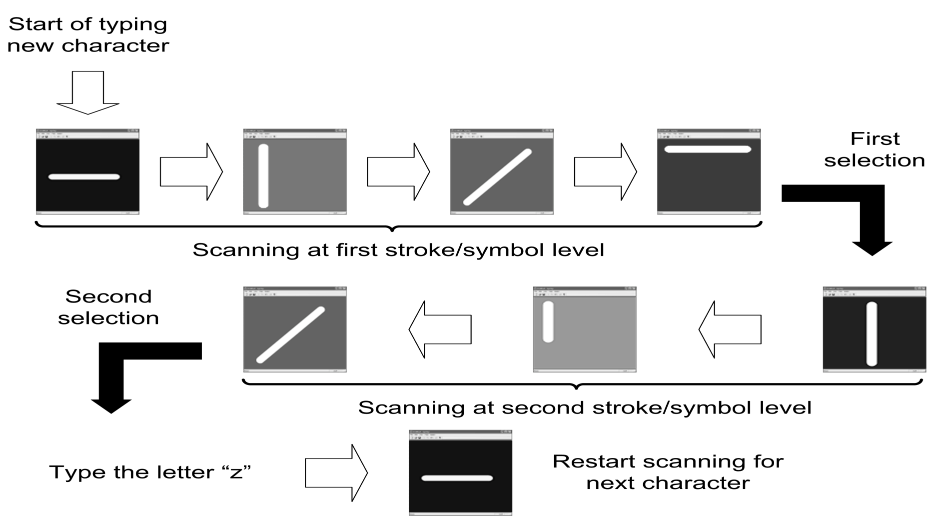

Figure 1: An example of typing the letter "z" with the character stroke-based text entry system. The system visits the first strokes until the upper horizontal stroke of "z" is selected. Then, it visits the second strokes within the subgroup of letters having the upper horizontal first stroke. After selecting the backslash stroke, the system has enough information to resolve the "z".

Table 1: Error-free text entry rates and Error-Proneness of the proposed character stroke-based text entry system and WiViK on four text corpora.

	Error-free text entry rate (in terms of reciprocal dwell time 1/*T*)				Error-Proneness (dimensionless, lower the better)			
	Encyclopedia	Brown	Web	Usenet	Encyclopedia	Brown	Web	Usenet
Proposed	0.1250	0.1257	0.1239	0.1231	0.0573	0.0575	0.0571	0.0568
WiViK	0.1539	0.1564	0.1532	0.1523	0.0604	0.0610	0.0602	0.0600

Proneness metric comes from a predictive model of user error frequencies, which was constructed from repeated typing trials with users with physical disabilities, including spastic cerebral palsy.

The proposed solution's theoretical performance was compared against the commercially available WiViK text entry system, configured as a single-switch row-column scanning keyboard, using the character frequency layout, and with the word prediction feature disabled. The four other text corpora from [6] were used as sample text. Full details of the analysis can be found in [4]. **Table 1** summarizes the analysis results. The proposed solution's slower text entry rate is attributed to not being able to truly optimize the scanning hierarchy by letter frequencies, due to the constraint of grouping letters by character strokes. On the other hand, both systems have comparable Error-Proneness.

EMPIRICAL ASSESSMENT

For 8 months, the participant worked with the character stroke-based text entry system while in the community. She had no prior knowledge of or training with the system beforehand. She practiced text entry with the system by typing out sentences read aloud by her caregiver. For each sentence (typing trial), the system recorded a log entry consisting of the typed string, the number of button presses, and the total time spent to type the string. The total time included moments when the participant may not be focused on the typing task due to physical discomfort.

The proposed solution was evaluated empirically in terms of number of switch presses per character and typing time per character. Generally, fewer switch activations and shorter typing times reflect greater proficiency. **Figure 2** shows the movements of the two metrics over the 8 months. Both metrics have decreasing trends over the 8 months (regression test for zero slope; $p << 0.01$). Separate one-way analyses of variance of the two metrics among months identified three distinct phases of participant proficiency with the system. Months 1-3 can be labeled as the learning phase, months 4-5 as an improvement phase, and months 6-8 as the fluency phase where the participant demonstrated a functional level of typing. Full details of the statistical analyses can be found in [4]. The typing samples in **Table 2** shows improved text legibility as the participant gradually acquired proficiency with the system.

CONCLUSION

A character stroke-based text entry system was developed for a child with severe motor impairment and low vision. The simple graphical representations of character strokes made this text entry system accessible by the case study participant. While the proposed solution has slower maximum text entry rate, it is comparably usable to a conventional row-column scanning keyboard in terms of proneness to user error. Empirical evaluation found that the participant acquired proficiency with the proposed solution over time. Thus, the proposed solution feasibility addressed the typing needs of a user with motor and visual impairments.

ACKNOWLEDGEMENTS

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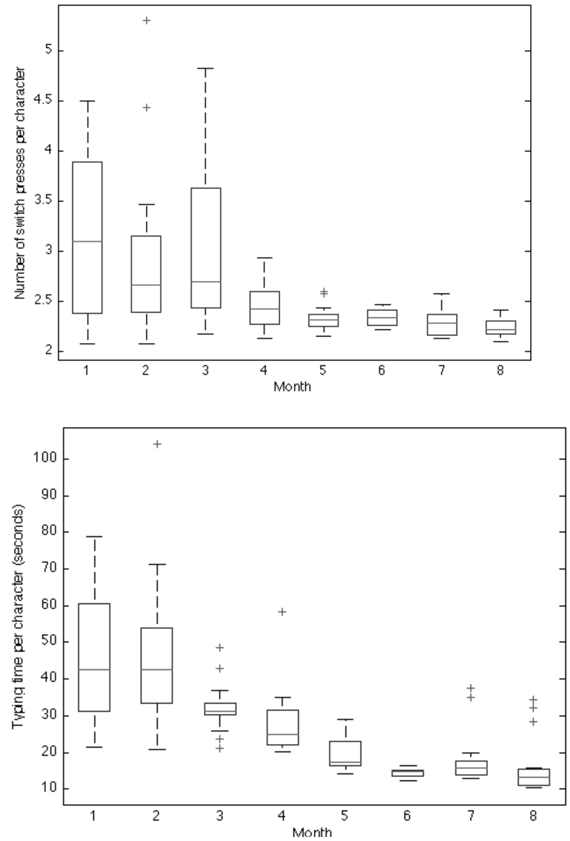

Figure 2: Progression of number of switch presses per character (top plot) and typing time per character (bottom plot) over eight months. The decreasing mean values and variances of the box plots over months are indicators of increasing participant proficiency.

Table 2: Typing samples from the three phases of participant proficiency with the proposed system.

Phase	Typing Sample
Training (Months 1–3)	efredereEdrbeedrg T i lookattherpooloopooLT heIsxxAtEaccPCherttTtOeeet ecx
Improvement (Months 4–5)	fherdaDIsAttihetraucktoeaxergcisemNNnnn mahmaaNdpapadidnotwanttoleavehome e qitwasscarywhennickalmostdiediNtherapiDs he reabd
Fluency (Months 6–8)	doyouthinkblakewillwanttoMeetherdae d blake hopes emliy will d ebE her friend thE fleas were a gift from godGod

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January 3, 2010

Dear Members of the RESNA SSPC Committee:

I am writing to confirm that Mr. Brian Leung has completed the majority of the work presented in his paper, "Character stroke-based text entry for a child with cerebral palsy and low vision".

Please do not hesitate to contact me if you have any further questions.

Yours truly,

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