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Speed–accuracy tradeoffs in specialized keyboards

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Abstract

Patients with locked-in syndrome are perceptually and cognitively aware of their environment but are unable to speak and have very limited motor capabilities. These patients frequently use a virtual keyboard with a cursor that moves over different items. The user triggers a selector when the cursor is over the desired item. For text entry such a method is excruciatingly slow, but is critical for patients who otherwise cannot communicate. We show how such keyboards can be optimally designed to maximize text entry speed while simultaneously controlling the entry error rate. The described method quantifies how different factors in keyboard design influence both entry speed and accuracy and demonstrates that different keyboard designs can greatly alter the efficiency of keyboard use. For a given text corpus and allowable average entry error proportion, the method identifies the cursor duration and character layout that minimizes average entry time. The method can easily be adapted to a variety of keyboard designs and selection devices and thereby improve the communication of locked-in syndrome patients.

Keywords: Optimization; Locked-in syndrome; Brain computer interfaces

1. Introduction

The ten-finger QWERTY keyboard has become a standard device for entering textual data into computers. Its influence is so pervasive that even in situations where ten-finger typing is not an option, such as cell phones and some military computers (Textware Solutions, 1998; Francis and Rash, 2005), there is a strong bias for the keyboard to be arranged in a QWERTY layout.

Nevertheless, there are some situations where specialized keyboards are used because they provide speed or accuracy that is not available with standard keyboard designs. Through a variety of medical situations, some people have very limited motor capabilities and can only utilize a binary switch to interact with a computer (Laureys et al., 2005). In some cases, the perceptual and cognitive capabilities of the patient are largely intact. To facilitate use of a keyboard, a computer may display an on-screen keyboard with a cursor that cycles through the possible characters. When the cursor covers the desired option, the user triggers the switch to choose that selection. The trigger event varies across individuals and depends on the details of the medical condition. The selection trigger can be a puff of air blown in a tube, a twitch of a cheek muscle, movement of a finger, an EEG response (e.g., Kaiser et al., 2001), or the blink of an eye (Bauby, 1997; see also Tavalaro and Tayson, 1997). For people whose conditions have caused a loss of speech these kinds of keyboards are a significant source of interaction with their companions and their environment.

To promote rich interactions with modern computers, such on-screen keyboards often include actions other than just text entry. For example, Fig. 1 shows a keyboard called SwitchXS that is created by a company called AssistiveWare. Possible selections include text characters, mouse clicks and movements (the top two rows), shortcuts for selecting predicted words (bottom row), and choices that lead to other screens (e.g., Foods). With these kinds of selections, users are able to create blogs, write books, and play videogames (see video demos on the AssistiveWare web site).

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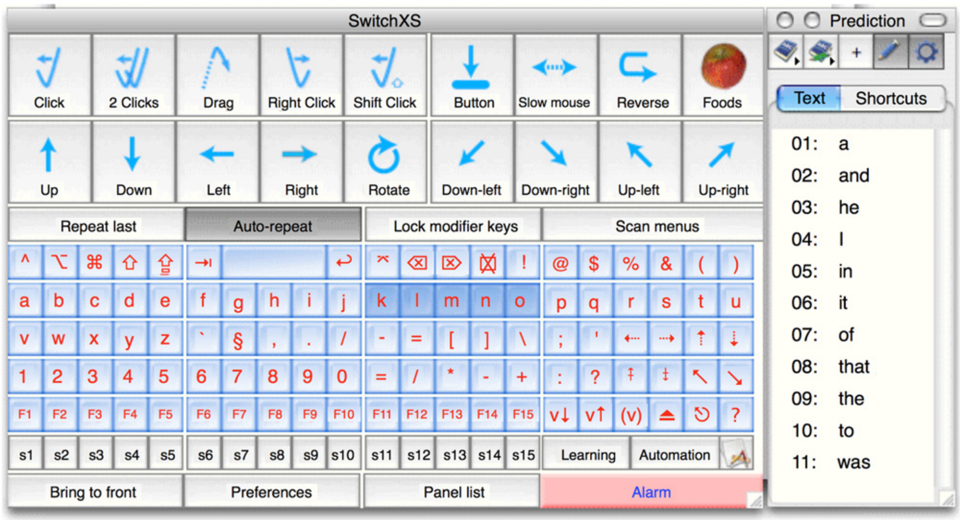

Fig. 1. The SwitchXS keyboard from AssistiveWare includes mouse commands, characters, and specialized function keys. A cursor moves across the keyboard in a specified path and the user triggers a selection when the cursor is on a desired key or set of keys. This selection changes the path of the cursor so that the user and narrow in on a target entry. In the picture the cursor is on the klmno set of keys.

For some people these kinds of keyboards are their only means of communication. Anything that makes such a keyboard faster or more accurate is important for the quality of social communication and for enriching their lives. One method to improve keyboard usability is to modify the layout of items on the keyboard so that commonly used items are located at an early point in the cursor cycle. With this approach it takes fewer steps to reach frequently entered items. This approach is so common that the companies who provide these kinds of keyboard systems also frequently provide software that allows for custom keyboard layouts. A result of this influence on keyboard design is that a keyboard created for a person who writes a blog about computer issues may be quite different from a keyboard created for a person who writes poetry.

A second approach is to adjust the speed of the cursor. Users of these kinds of keyboards are highly practiced and can learn to adequately make selections with cursor durations as short as 50 ms, although this appears to be uncommon. Even at these speeds entry is fairly slow because most characters require several cursor steps before the target can be selected. Thus entry of a single character could take as long as 500 ms, even under quite short cursor durations. (In comparison a person able to ten-finger type at 60 words per minute takes approximately 200 ms to enter a character, assuming 5 characters per word.)

With a faster cursor, it takes less time to reach a desired keyboard entry. However, faster cursor speeds also tend to introduce more errors, as the user may not be able to time their selection and stop the cursor at the location of a desired target. Again, commercial keyboard systems often allow a user to adjust the cursor speed so that it meets the needs and abilities of the user. In general, there is a speed–accuracy trade-off that can only be satisfied by identifying the relative importance of errors and entry speed for a given user. Typing errors in an email may be inconsequential since other parts of the text may resolve any confusion, but errors in a computer program may be more serious and more difficult to resolve.

A third approach is to vary the path of the cursor. A common approach is for the cursor to first cycle through rows of items. When the row containing the target item is covered, the user makes a selection. The cursor then moves across the elements in the selected row and when it is on the target item the user makes another action to select the target. It is easy to imagine variations on this approach. For example, the characters in the keyboard of Fig. 1 are grouped into four sets, and selecting a row first leads to cursor movement across the sets (within the selected row) before then leading to movement within the set toward the final target. The cursor path essentially imposes a hierarchical arrangement on the keyboard, even though all levels of the hierarchy are visible. Hierarchical systems face a depth versus breadth relationship that has been extensively studied for menu systems (Lee and MacGregor, 1985; Fisher et al., 1990). In general, it is not clear what cursor path would promote the fastest entry for these kinds of keyboards; nor is it clear how different cursor paths would influence error probabilities.

The basic idea of optimizing keyboard design has been previously explored and applied to keyboards for locked-in patients. Francis and Rash (2005) showed that optimizing the layout of characters on a keyboard could produce a 33% reduction in entry time for keyboards used by helicopter pilots (who use a single finger to move between keys). Zhai et al. (2002) and Hughes et al. (2002) used an optimization algorithm to identify the optimal position of characters (again for single finger or stylus text entry). Lesher et al. (1998) summarized much of the work on these kinds of keyboards to that date, and systematically investigated a number of issues related to their use and