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Neural Signal Based Control of the Dasher Writing System

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***Abstract*— Integration of the Dasher text-entry program with a brain-computer interface (BCI) system may give individuals with severe motor disabilities the ability to write using their neural signals. Five able-bodied participants previously trained to control their neural signals using motor imagery in an electroencephalogram-based BCI study were trained to control the Dasher program using similar methods. The time to write simple phrases in Dasher using BCI and standard mouse inputs were compared. To compare with existing technology, four disabled participants wrote the same phrases using their own augmentative communication input. The time to input phrases with Dasher-BCI was greater than that for Dasher-mouse and other alternative inputs. However, as Dasher is optimized for BCI control, it will become increasingly useful for people with severe motor and speech disabilities.**

I. Introduction

BRAIN-computer interface (BCI) technology, which links neural signal based commands to computer based outputs, has advanced significantly over the past decade. The BCI research community aims to give people with motor disabilities the ability to use their neural signals to control devices ranging from computers to wheelchairs to prosthetic limbs. A major advantage of BCIs over other augmentative communication methods is its independence from muscle movement, which is required for all other devices. Many BCI studies have demonstrated that people can move a computer cursor to a target using neural signals collected from the scalp (electroencephalogram - EEG) [1-3], surface of the brain (electrocorticogram - ECoG) [4, 5], or within the brain (local field potential and action potential recordings) [6, 7]. This is typically accomplished by training the user to modulate their neural signals by performing motor imagery [1, 4, 5, 8]. However, with few exceptions [9, 10], even very simple computer based applications controlled with neural signals are not available for people with motor disabilities.

Individuals with disabilities that severely limit both speech and movement (e.g. locked-in syndrome or advanced amyotrophic lateral sclerosis) would benefit from a simple text entry program that allows them to communicate requests to their caretakers, express their thoughts, and record their experiences. Frequently people who have difficulty with oral and written communication let go important, but nonessential, requests (e.g. turning the television off, feeling cold) due to the excessive burden it takes to relay the message [11]. While some text entry programs are available for people with severe disabilities, they all require residual muscle movement. Often, even if the movement is possible, it may require significant effort, evoke pain, or lack precision and accuracy. The ability to use a simple text entry system that does not require physical effort can improve the quality and enjoyment of life for people with disabilities affecting speech and motor control.

This work explores the potential of interfacing Dasher, a text entry program, with an EEG based BCI system. Time comparisons are made between the Dasher-BCI system and other methods of text entry. Able-bodied participants trained to use their neural signals to perform a BCI cursor movement task applied the same cursor control strategies to write simple phrases in Dasher. For comparison with existing augmentative communication devices, disabled participants input the same phrases using their own alternative communication method (e.g. head mouse). This information can inform further development of a BCI-based writing system.

II. Dasher Writing System

Dasher is a user interface for computer text entry intended for situations when a keyboard cannot be used.[1] The program uses a language model to predict the probabilities of characters that come next, making more likely text easier to write. The alphabet can be set to appear at either the right-hand or bottom edge of the screen. When the program is started the letters move towards the center of the screen at a pre-determined speed. The user controls the movement of a cursor in either one- or two-dimensions (1-D or 2-D) to zoom in on a sequence of letters. For example, to write the word "hello," the user aims the cursor to zoom in on the letter "h." As "h" approaches, the size of its box becomes larger and another alphabet appears within it to allow selection of the second letter, with the most probable letters appearing larger. Fig. 1 shows an example of writing the phrase "good morning." The predicted sequences of letters are determined by preloaded alphabet and training texts, which initialize the language model. These can be enhanced

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[1]Dasher is free, open-source software that can be downloaded from http://www.inference.phy.cam.ac.uk/dasher/

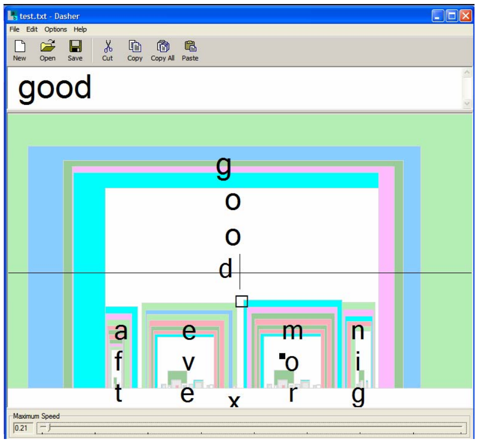

Fig. 1: Writing "good morning" in Dasher's phrase mode. Words that commonly come after "good" are easiest to navigate to. The Dasher cursor is the small black square.

TABLE I
PARTICIPANT DEMOGRAPHICS

#	Able-Bodied or Description of Disability	Gender, Age	Typical Computer Input Method
1	Able-bodied	M, 20	Standard keyboard and mouse
2	Able-bodied	M, 26	Standard keyboard and mouse
3	Able-bodied	M, 30	Standard keyboard and mouse
4	Able-bodied	F, 22	Standard keyboard and mouse
5	Able-bodied	F, 21	Standard keyboard and mouse
6	Locked-in syndrome	M, 60	Person says letters; an eye blink indicates a selection
7	Amyotrophic lateral sclerosis	M, 50	ASYST 3000 communication program operated by sound from tooth grinding
8	Amyotrophic lateral sclerosis	F, 46	Head mouse with Keystrokes® onscreen keyboard
9	Muscular dystrophy	M, 54	Trackball mouse interfaced with an onscreen keyboard. The mouse is operated by using a pencil held with the right hand to move the ball, and fingers on the left hand to click.

by the user's own writing style, which the program learns every time text is entered. Dasher can also be initialized with a training text of common English language phrases a person with limited communication may want to express to family and caretakers (Fig. 1). Although the training texts make it easier for some words or phrases to be entered, any sequence of letters can be input; it will just take longer.

Dasher's 2-D mode allows the user to select the direction of zooming with one dimension and control the speed using the other. This mode has been interfaced with a standard mouse, head mouse, and eye tracker [12-15]. Experienced users can write at speeds of 35 words/min using a mouse and 25 words/min using an eye tracker.

Since many devices, including a BCI, can be difficult to accurately control in 2-D, Dasher also has a 1-D mode. The 1-D input is mapped onto a continuous curve within the normal 2-D space. Midrange values of the input control the zooming direction, and values at the extremes allow the user to zoom out (reverse). Zooming speed (when pointing straight ahead) is specified in advance by the user. 1-D mode has been interfaced with a breath mouse, which measures the movement of a belt worn by the user as they breathe in and out. Experienced breath mouse users can write at speeds up to 16 words/min [12].

III. METHODS

A. Study Participants

Five able-bodied and four disabled participants (Table I) were chosen based on the following criteria: (1) Participation in a BCI study involving 1-D and 2-D target acquisition tasks for at least six 1-hour sessions, (2) Able-bodied subjects performed the 1-D task using brain control with ≥90% accuracy for three consecutive sessions, (3) Able-bodied subjects had ≥2-hours of practice using Dasher (15 minutes with a mouse and 105 minutes with BCI), (4) Disabled subjects had difficulty with both upper body movement and speech and used an alternative input modality for communication. The disabled subjects did not fulfill criteria #2, so they did not perform the Dasher-BCI task. However, they completed the writing tasks using their own alternative input. Subjects participated with informed consent and this study was approved by the University of Wisconsin-Madison Health Sciences Institutional Review Board.

B. Brain-Computer Interface Training

Participants wore a 16-channel electrode cap (Electro-Cap International Inc., Eaton, OH), which recorded and transmitted their EEG signals to a computer via an amplifier (Guger Technologies, Graz, Austria). A screening procedure was performed to determine the frequency components of specific electrodes that subjects could self-modulate using motor imagery. Recordings from all electrodes were made during screening and assessed in the offline analysis. Subjects imagined different types of movements (e.g. clenching their right or left hand, tapping their feet, etc.) in response to visual cues presented on a computer screen. A set consisted of two cues appearing in random order for two seconds each with two seconds of blank screen in between, for a total of three minutes. Subjects were instructed to perform imagery during the cue and cease imagery when the screen was blank. Two movements were evaluated at a time (e.g. left vs. right hand imagery) and each set was performed twice. These data were processed in the frequency domain using autoregressive spectral analysis to find frequency bands of specific electrodes that changed in power between the imagery (active) and blank screen (rest) time segments. If a high correlation ($r^2 > 0.3$) was found between the power change and active response time segment, the subject could use that imagery to self-modulate the specific signal component. Based on the analysis, 3-5 Hz wide frequency bands (e.g. 12-15 Hz) of specific electrodes were assigned a preferred cursor movement direction (e.g. left or right). Subjects were then trained to use motor imagery to acquire onscreen targets with a computer cursor controlled by their neural signals. During BCI tasks the power content of the chosen signals was measured continuously, and the signal

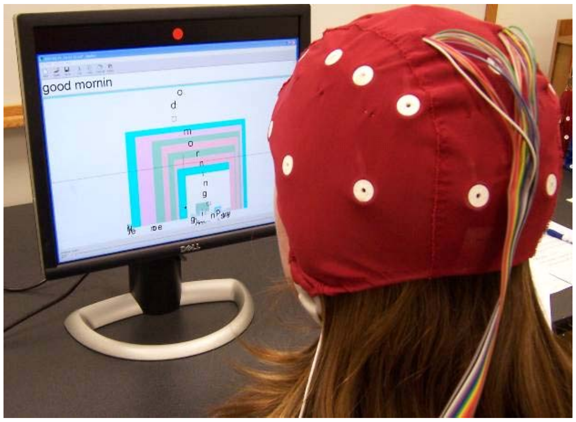

Fig. 2: An able-bodied subject wearing an electrode cap and writing "good morning" in Dasher. The subject is using motor imagery to control the movement of the cursor. The BCI2000 cursor (red ball) feedback is shown at the top.

magnitude was the independent variable in a linear equation that controlled cursor motion in real time. The BCI2000 software (Wadsworth Center, Albany, NY) was modified with in-house software routines for these experiments [16].

C. *Dasher-BCI*

The Dasher-BCI tasks used the direction (horizontal or vertical) of cursor movement most accurately controlled by the subject. For example, if a subject was able to best control horizontal cursor movement using left and right hand motor imagery, they used the same motor imagery and screen orientation for Dasher-BCI tasks. In Dasher, the letters could be setup to appear at the right side or bottom of the screen, requiring 1-D vertical or horizontal cursor movement, respectively.

A TCP/IP connection between BCI2000 (version 1.4.1) and Dasher (version 4.1.1), which were both running on the same personal computer, sent the 1-D BCI2000 cursor position to Dasher, where it was mapped onto the corresponding point along the continuous 1-D curve. This curve allowed the user to zoom in or out on letters with only 1-D control. However, the cursor differed in appearance from the BCI2000 cursor and followed a curve instead of a straight line. In order to provide familiar feedback, a thin window showing the 1-D BCI2000 cursor position (but no targets) appeared at the top or left side of the screen (depending on the Dasher orientation). Subjects could see how the BCI2000 and Dasher cursor positions corresponded and refer back to the more familiar feedback when needed. The Dasher window occupied the remainder of the screen and is where the phrase spelling tasks were performed. Fig. 2 shows a subject wearing an electrode cap and using motor imagery to control the Dasher cursor movement.

D. *Design*

Six phrases ("good morning," "turn tv on," "clean glasses," "too cold," "lights off," and "head hurts") were selected for participants to input. Able-bodied subjects input the phrases using Dasher-BCI in 1-D mode with the Dasher speed set to 0.21 bits/sec. This was performed with a training text consisting of over 200 common short phrases ("phrase mode"), including those selected for this study. Able-bodied subjects also input the phrases using Dasher controlled by a standard computer mouse in 1-D mode at Dasher speed of 1.0 bits/sec. The speed settings controlled how fast Dasher zoomed into the letters, and put a limit on how fast the phrases could be input. However, they were selected based upon previous user feedback for Dasher-BCI and a typical beginner's speed for Dasher-mouse.

For comparison with existing devices, disabled subjects input the phrases using their own communication method (listed in Table I). In addition, the communication device of participant #9 was interfaced with Dasher. The disabled subjects were trained on the BCI target acquisition tasks, but their cursor control did not meet the criteria of ≥90% accuracy for three consecutive sessions. Therefore, they did not perform the Dasher-BCI task because it requires precise cursor control. Reasons for their lower degree of cursor control compared with able-bodied subjects include fewer BCI training sessions, sessions occurring in their home (where environmental variables are more difficult to control), and the BCI screening procedure indicating a smaller change in power during imagery.

All tasks were performed in three 60-90 minute sessions. Session duration was determined by the subject's ability to perform the tasks without becoming fatigued. Subjects doing the Dasher-BCI tasks first performed 5 minutes each of BCI target acquisition tasks and Dasher-BCI tasks. The 10 minutes of practice gave subjects a chance to reacquaint themselves with the tasks and the experimenter a chance to verify settings and make adjustments. The time limit for each Dasher-BCI phrase writing attempt was 10 minutes, and subjects were given two minute breaks between each attempt. Subjects were allowed three attempts per session for each Dasher-BCI phrase. The additional attempts were used if they wanted to start over due to difficulty erasing incorrect strings of letters or to improve their time after completing each phrase once. The time to input the phrases for each phrase writing task was measured.

IV. RESULTS

The average time (SD) to input the phrases to Dasher using a BCI, mouse, or alternative device is shown in Fig. 3. All able-bodied subjects completed all Dasher-BCI phrases. The time to input the phrases using Dasher-BCI was significantly greater ($p<.05$) than the other input modalities. In general, the time to input different phrases using Dasher varied due to their length, starting letter (the cursor starts in the center of the screen, in line with the letter "m"), and number of competing phrases (see example in Fig. 1). Participant #4 is included in the average for able-bodied subjects, but is also shown separately in Fig. 3 because #4 had ~25 combined hours of Dasher-BCI practice compared with ~2 hours for other subjects.

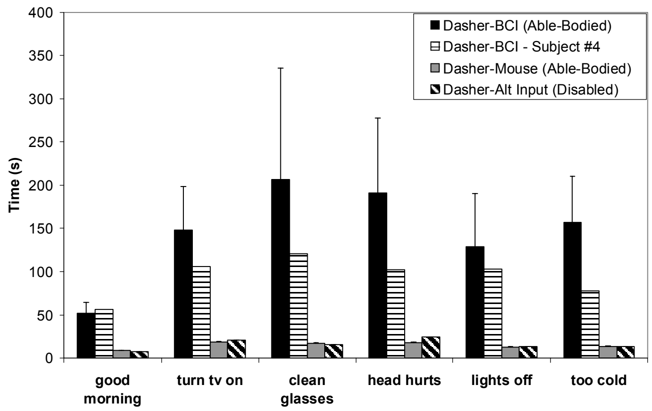

Fig. 3: Average phrase completion time (SD) for: able-bodied subjects (N=5) using Dasher-BCI (black) and Dasher-mouse (gray), a well-trained subject (N=1)using Dasher-BCI (horizontal stripes), and a disabled subject (N=1) using Dasher-alternative input (diagonal stripes).

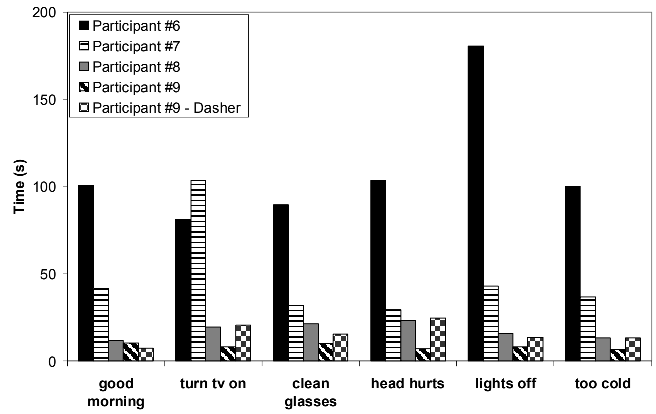

Fig. 4: Disabled subjects (N=4) using their own alternative input (listed in Table I) to write the phrases (without Dasher). The checkered bar is Participant #9 inputting the phrases to Dasher using his altenative input.

Fig. 4 shows the time for the disabled subjects to input phrases using their own alternative communication method (listed in Table I). These were not averaged across subjects because the input modalities and ability level of each subject differed. Participant #9, who wrote with a non-standard mouse setup, interfaced his device with Dasher and used the same speed setting as the able-bodied subjects doing Dasher-mouse tasks. This Dasher-alternative input time is shown in Figs. 3 and 4. There was no significant difference ($p>.05$) between the time for the disabled subject to input the phrases when compared to the able-bodied subjects using a mouse.

V. Discussion

Dasher text-entry using a non-invasive EEG-based BCI input can be achieved by able-bodied individuals previously trained to control a computer cursor using motor imagery. On average, able-bodied subjects had 15 hours of BCI training and 2 hours of Dasher-BCI training (with the exception of participant #4, who had ~25 hours of Dasher-BCI training). This demonstrates that a non-invasive BCI modality can give users enough cursor movement precision to control an off-the-shelf text entry program.

Like any user interface, it takes time to become accustomed to Dasher, whether using a standard mouse or alternative input [15, 17]. In general, people are very familiar with the QWERTY layout used on standard and on-screen keyboards, but do not have the equivalent years of exposure to Dasher. Although subjects were given time to become familiar with Dasher using mouse and brain control, they did not have years or even weeks of continued practice with Dasher. Similarly, they did not have years of training on using motor imagery to control a cursor (as most of them have had with a standard mouse). These two factors will lead to a learning curve that shows sustained improvement in ease and speed of writing, given long-term practice using Dasher and BCI (independently and together). This is demonstrated with participant #4, who had more practice, so her writing speed was faster than average for five out of six phrases.

Some of the difficulty using Dasher-BCI despite excellent performance on BCI target acquisition tasks stems from the sustained attention and control that is required. Although the phrases seem fairly easy to complete once the first couple of letters are written (Fig. 1), finishing the phrase requires holding the cursor still or making movements to compensate for any accidental movement from the desired position. The subjects were trained on target acquisition tasks that required only a 500 ms dwell time, so they were not accustomed to holding a cursor steady for the duration required with Dasher. In addition, while all of the phrases are in the Dasher training text, they were only 6 out of 200+ phrases. Some of the other phrases were similar, which sometimes made the phrase of interest more difficult to choose. For example, there was an easier path to write “headache” than “head hurts,” which was one of the phrases selected for this task.

The similar performance of Dasher-mouse and Dasher-alternative input is another example of long-term learning. Although it could not be evaluated here, it is unlikely that able-bodied subjects could use a head mouse or modified trackball mouse with the same ease and speed as the disabled subjects who have used those devices on a daily basis for years. Therefore, if a disabled subject were using Dasher-BCI as their only means of communication, significant improvement over the long term is very probable.

In addition to evaluating learning over time, it is also important to make objective and subjective comparisons of performance and mental effort between BCI controlled applications and currently available devices requiring muscle control. This information can inform further improvements of BCI controlled applications. User feedback can also aid in matching the needs of disabled individuals to the application. For this reason, it also must be determined if disabled and able-bodied individuals will be able to use brain-control applications in the same way. All of these areas of investigation are currently being explored.

VI. Conclusion

More applications of BCI technology for people with disabilities are needed. Although able-bodied subjects were able to write phrases in Dasher using EEG based BCI control, Dasher-BCI is not yet ready to replace the current devices disabled individuals have access to. However, based on this evaluation of the interface, software and signal processing improvements can be made to increase speed and ease of operation. As Dasher is optimized for BCI control, it will become increasingly useful for people with severe motor and speech disabilities. With further advances Dasher-BCI may also become competitive with devices (e.g. eye tracker, breath mouse) used by people with less severe disabilities. It is also probable that implanted electrodes (ECoG strips/grids or microelectrodes) will lead to improved control and stability of BCI controlled applications.

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