PRELIMINARY ASSESSMENT OF TONGUE DRIVE SYSTEM IN MEDIUM TERM USAGE FOR COMPUTER ACCESS AND WHEELCHAIR CONTROL

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INTRODUCTION

Tongue Drive System (TDS) is an Assistive Technology (AT) designed to enable individuals with severe physical disabilities to access computers or drive powered wheelchairs with their tongue motion. TDS consists of four key components [1]-[3]: a small magnetic tracer fixed on the tongue with tissue adhesives or piercing, a headset with an array of 3-axial magnetic sensors to detect the changes in the magnetic field generated by the tracer, a wireless link established between a control unit on the headset and a receiver on a computer or smartphone to transfer the magnetic sensor data [4], and a sensor signal processing (SSP) algorithm, which recognizes the position of the magnetic tracer, hence, the position of the tongue in real time (see Fig. 1 a). The current TDS prototype has six commands, which are simultaneously available to the user: four directional (LEFT, RIGHT, UP, and DOWN) and two selection commands. When using TDS for computer access, for instance, the directional commands can be used to move the cursor on the screen in four directions and the selection commands can be used to emulate the mouse left- and double-click.

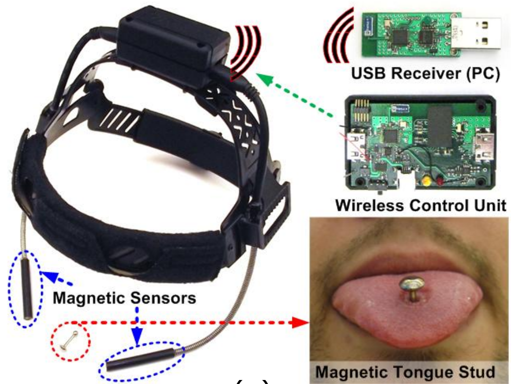
In our earlier studies, to evaluate TDS as a computer input device, we had measured the TDS information transfer rate (ITR), often used in brain computer interfacing (BCI), only in one session, by attaching the TDS magnetic tracer on subjects' tongues using dental adhesives [1]-[4]. In this study, we have evaluated the TDS performance as a computer input device to control the cursor using ISO9241-9 standard tasks for pointing and selecting. ISO9241-9 [5], which is based on the well known *Fitts' Law*, has been widely adopted by the scientific community for evaluating conventional non-keyboard input devices, such as mouse or touchpad [6] as well as novel ATs for motor disabled such as head trackers [6] or voice activated software [8]. The Fitts' Law states that rapid human motor actions convey a finite amount of information, called *throughput* (measured in bits per second, b/s) and there is a tradeoff between speed and accuracy with certain throughput values [9]. ISO9241-9 standard addresses the calculation of throughput in certain simplified tasks of rapid cursor movements over on-screen targets of different widths and distances. The purpose is to emulate and quantify human interactions with real life graphical user interfaces (GUI) via a specific computer input device.

In this study, in order to observe the learning process, which is a key factor in the acceptability and adoption of a new AT, we evaluated the TDS performance over 5 sessions during 5 weeks by 9 able-bodied subjects, 4 males and 5 females, aged 19-28 years, who already had tongue piercing. We embedded the magnetic tracer inside the upper ball of specially designed barbell-shaped titanium tongue studs, worn by the subjects throughout the study. To compare the tongue-TDS performance with that of index finger-keypad, similar computer tasks were performed with both TDS and keypad. Moreover, to validate our experimental methods and data analysis, the study included performing all computer tasks with a standard optical mouse, for which the range of throughput has been well established in the literature [6]. Each trial also included powered wheelchair (PWC) drive by TDS through an obstacle course each computer access part in each session.

METHODS AND TASKS

<u>Computer Access</u>

Subjects performed four computer tasks in the following order: horizontal and vertical (One-direction) tapping, center-out tapping,



(a)

(b)

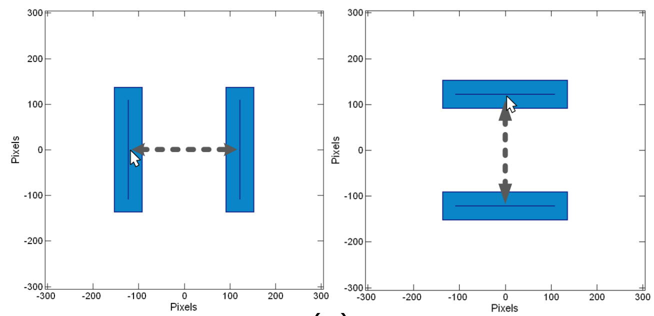
Figure 1: (a) TDS prototype and its elements (b) Experimental setup with the subject sitting 1 m away from a 22" LCD monitor, performing the multidirectional tapping task.

and multidirectional tapping. Unidirectional tapping required subjects to move the cursor between a pair of vertically or horizontally oriented bars with randomized thicknesses and separations (Fig. 2a). Center-out tapping required subjects to move the cursor towards circular targets which appeared one at a time with randomized widths, distances and angles (Fig. 2b). Multidirectional tapping required subjects to move the cursor between two circular targets located across the diameter of a large circle, and the target orientation rotated around that circle after each tap (Fig. 2c). In all the tasks, the subjects were required to move the cursor as fast and as close to the target centers as possible, i.e. maximizing the speed and accuracy as much as possible.

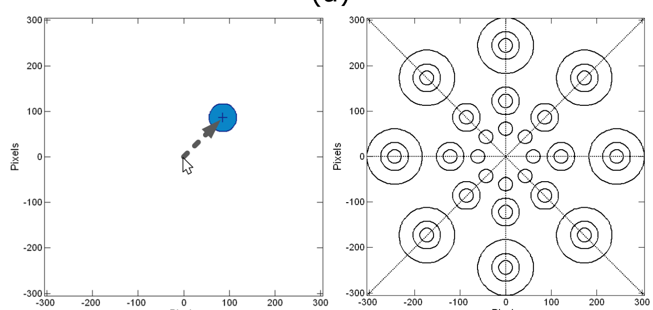
The performance measures consisted of 3 items: *Throughput (TP)*, *Outside Hit percentage (OH%)* and *Reaction Time (RT)*. *TP*, as mentioned earlier, shows the amount of information that users can deliver to the computer via an input device within a specific time period in a certain cursor movement task. According to the Fitts's law, *TP* is defined as the ratio between the *Index of Difficulty*, *ID*, of a certain target and the time it takes to reach that target (measured in bits/s). *ID* is measured in bits and is defined by:

$$ID=log_2(D/W+1) \qquad (1)$$

Where *W* and *D* are the target width and distance [10]. *OH%* is the percentage of the taps outside the targets vs. the total number of taps and shows whether the targets are actually selected or not. *RT* in the center-out tapping is defined as the elapsed time between the new target appearing on the screen and the initiation of cursor movement.



(a)



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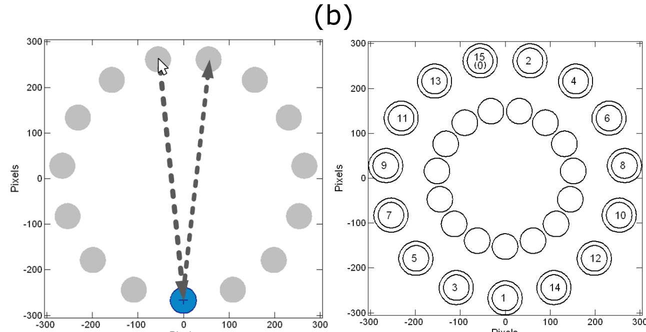
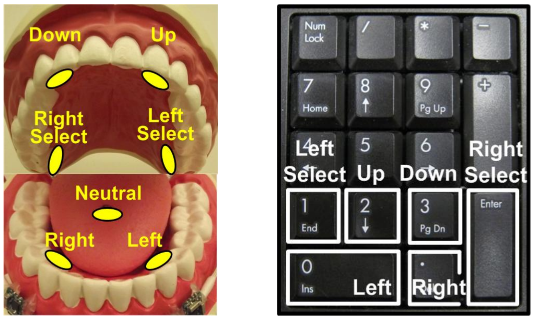


(c)

Figure 2: Graphical user interface screen for (a) horizontal and vertical tapping, (b) center-out tapping with all 48 possible targets and (c) multidirectional tapping with all 45 possible targets and their sequential order.



(a) (b)

Figure 3: (a) Recommended tongue positions for six TDS commands (b) Designated keys on the keypad to resemble the TDS commands.

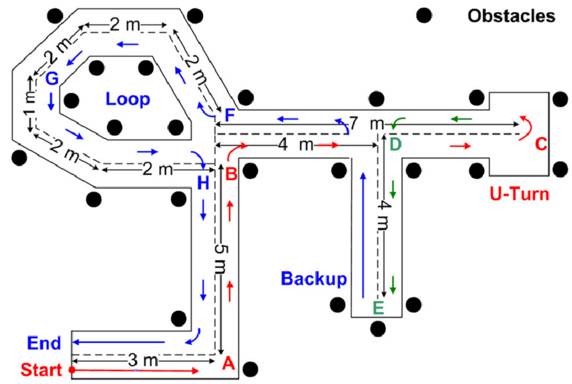


Figure 4: Obstacle course used in the powered wheelchair control tests, with its dimensions, obstacles locations, and driving trajectory.

Within each task, device order (TDS, keypad, mouse) was randomized. Fig. 3 shows the recommended tongue positions for the six TDS commands and the keys on a standard keypad designated to the same commands. These are selected in a way that they resemble their positions in the mouth. Each task with each device was performed in four rounds, with the first round considered as practice.

Powered Wheelchair (PWC) Navigation

The PWC session consisted of navigating a Quantum Q6000 electric-powered wheelchair from Pride Mobility (Exeter, PA) using the TDS, through a ~50 m obstacle course that had 1 loop, 1 backup, 6 turns, and 24 obstacles (Fig. 4). Subjects were required to navigate the PWC through the course as fast as possible and try to avoid events, such as hitting the obstacles or driving outside the track, as much as possible. The PWC control session was always conducted after the computer access session when the subjects had gained more experience with TDS.

Following are the 3 strategies tested for wheelchair control with TDS: 1) *Unlatched Mode*, for which UP and DOWN TDS commands were used to accelerate the PWC forward and backward and LEFT and RIGHT commands were used to turn to left and right. In this mode, the PWC only moved as long as a command was being issued. 2) *Latched Mode* was similar to the unlatched, except for the ability to lock the PWC onto a certain command, such as moving forward, and allowing subjects to return their tongue to the resting position until there was a need for a new command. 3) *Semi-proportional Mode*, in which steering of the PWC was proportional to the deviation of the tongue position from the center line over the lips. Each strategy in each session was repeated four times, the first of which was for practice.

RESULTS AND DISCUSSION

Table 1 shows the tapping task results along with key statistical values. Mouse *TP*s for all the tasks were within the acceptable range of 3.7-4.9 b/s [6], which validates our methodology and data analysis. Comparing TDS 1^{st} and 5^{th} sessions shows improvements in all performance measures throughout 5 sessions.

The purpose of including keypad in our trials was to explore the limiting factors in the current TDS prototype by having another switch-based computer input device, operated by a dexterous body part such as the index finger, for the exact same tasks and number of commands. Comparing TDS and keypad 5^{th} sessions showed that in all of the performance measures TDS was inferior to keypad. Detailed comparison (not mentioned here) revealed valuable insights for improving the TDS. For instance, one reason for higher TDS *OH%* is lacking visual feedback and less distinct tactile feedback compared to keypad (pointing to a specific tooth with the tongue and bringing it back to its resting position vs. pressing a button and releasing it).

Fig. 5 shows the PWC completion time and the number of adverse events, both of which have statistically improved when comparing 5^{th} and 1^{st} sessions. Pair-wise comparison with *Bonferroni* adjustments followed by RM-ANOVA

Table 1: Tapping Tasks Results

Task	Performance Measures	Mouse	TDS 1st session	TDS 5th session	TDS 1st and 5th session *p*-value	Keypad 5th session	TDS-Keypad 5th session *p*-value
Horizontal tapping	*TP* (b/s)	4.2 ± 1.3	2.1 ± 0.3	2.5 ± 0.4	0.011	3.3 ± 0.2	< 0.001
	OH %	15.4 ± 21.6	24.7 ± 8.6	15.8 ± 7.4	0.004	5.4 ± 3.0	0.002
Vertical tapping	*TP* (b/s)	4.7 ± 1.2	2.2 ± 0.4	2.7 ± 0.2	0.002	3.2 ± 0.3	< 0.001
	OH %	11.4 ± 17.9	23.0 ± 8.8	13.3 ± 4.8	0.004	4.5 ± 3.7	0.014
Center-out tapping	*TP* (b/s)	3.7 ± 0.6	0.7 ± 0.2	1.5 ± 0.2	< 0.001	2.0 ± 0.2	0.001
	OH %	5.1 ± 5.5	33.5 ± 9.1	14.8 ± 7.0	0.003	4.9 ± 2.7	0.003
	RT (sec)	0.1 ± 0.04	0.8 ± 0.1	0.7 ± 0.1	0.027	0.6 ± 0.1	0.035
Multidirectional tapping	*TP* (b/s)	4.5 ± 0.7	0.4 ± 0.1	1.0 ± 0.2	< 0.001	1.2 ± 0.2	0.009
	OH %	3.5 ± 3.3	22.7 ± 8.2	6.9 ± 5.2	< 0.001	2.0 ± 2.1	0.007

applied to the last session PWC completion time shows latched and semi-proportional strategies were not significantly different (p=0.333) but unlatched was significantly lower than both of them (p=0.038). Also, there was no significant difference between 3 strategies in term of the number of events in the 5th session (p=0.334).

CONCLUSION

TDS functionality as a computer input device and PWC controller was tested through 5 sessions. Our results showed significant improvements in all performance measures.

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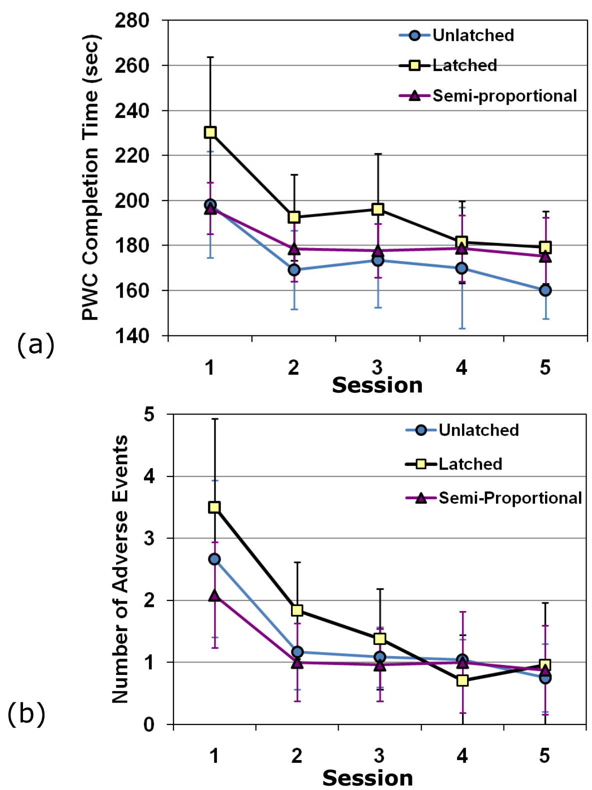

Figure 5: PWC control session (a) Completion time and (b) Number of events.