Preliminary Assessment of Tongue Drive System in Medium Term Usage for Computer Access and Wheelchair Control

Behnaz Yousefi, Xueliang Huo, *Student Member, IEEE*, and Maysam Ghovanloo, *Senior Member, IEEE*

Abstract—**Tongue Drive System (TDS) is a wireless, wearable assistive technology that enables individuals with severe motor impairments access computers, drive wheelchairs, and control their environments using tongue motion. In this paper, we have evaluated the TDS performance as a computer input device using ISO9241-9 standard tasks for pointing and selecting, based on the well known Fitts' Law, and as a powered wheelchair controller through an obstacle course navigation task. Nine able-bodied subjects who already had tongue piercing participated in this trial over 5 sessions during 5 weeks, allowing us to study the TDS learning process and its current limiting factors. Subjects worn tongue rings made of titanium in the form of a barbell with a small rare earth magnetic tracer hermetically sealed inside the upper ball. Comparing the results between 1st and 5th sessions showed that subjects' performance improved in all the measures through 5 sessions, demonstrating the effects of learning.**

I. 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

(a)

(b)
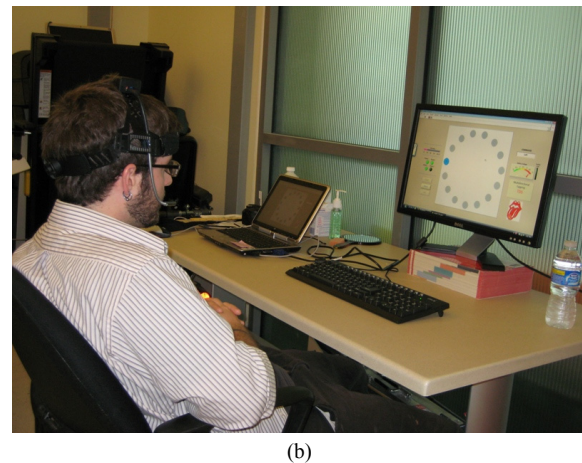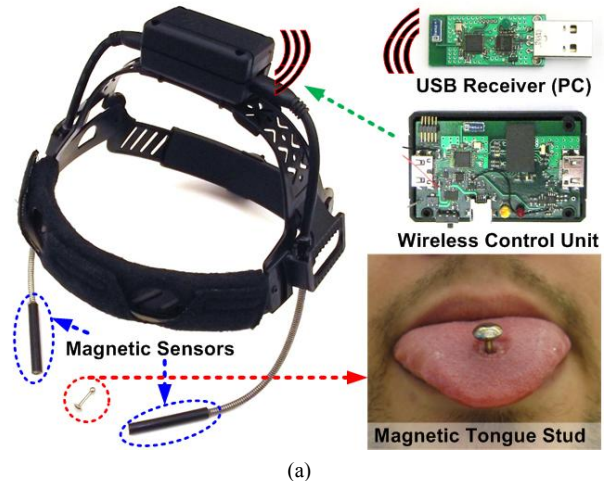
Fig. 1. (a) TDS prototype comprised of a headgear with an array of lateral magnetic sensors, a wireless control unit, a USB receiver dongle, and a small magnetic tracer embedded in a titanium tongue stud with m&m-shaped upper ball. (b) Experimental setup with the subject sitting 1 m away from a 22" LCD monitor, performing the multidirectional tapping task.

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 [7] 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 after each computer access part in each session.

II.   METHODS AND TASKS

A.   Computer Access

Subjects performed four computer tasks including: horizontal and vertical (One-direction) tapping, center-out tapping, and multidirectional tapping. To facilitate learning particularly in the first session, these tasks were arranged from easy to difficult in terms of the required number of TDS commands. The GUI was developed in the LabVIEW environment and presented to the subjects sitting 1 m away from a 22" LCD monitor with 1280 × 800 pixel resolution. The task window was a white 610 × 610 pixel square in the center of the monitor, shown in Fig. 1b.

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:

$$ID = \log_2\left(D/W + 1\right), \qquad (1)$$
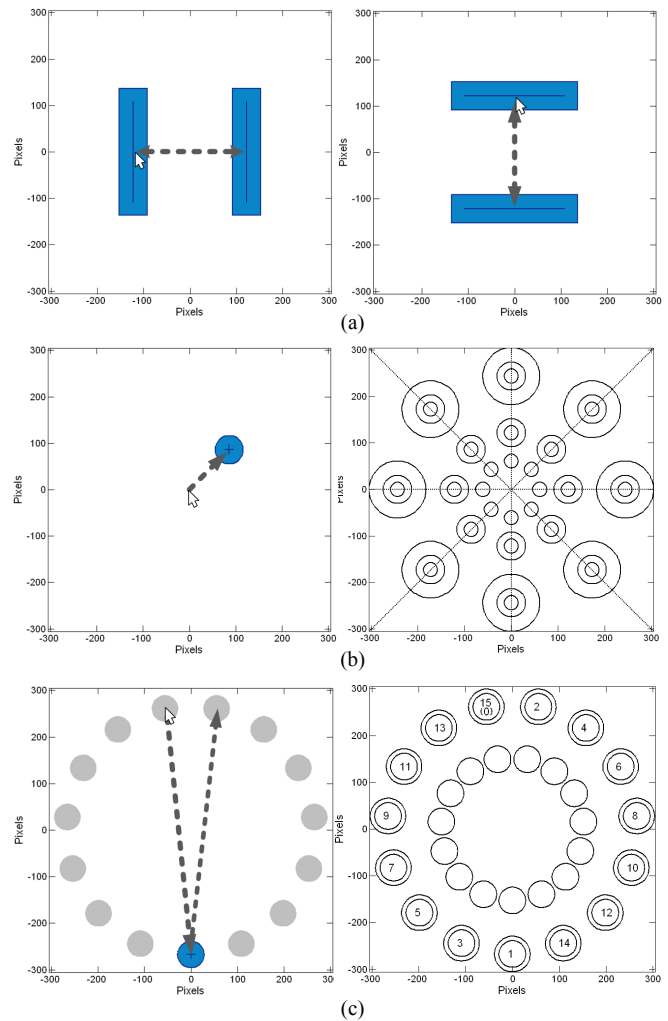
Fig. 2. GUI screen for (a) horizontal and vertical unidirectional tappings, (b) center-out tapping with all 48 possible target conditions on the right panel, and (c) multidirectional tapping with all 45 possible target conditions and their sequential order of tapping on the right panel.

TABLE I
INDICES OF DIFFICULTY IN UNIDIRECTIONAL
(*U*) AND CENTER-OUT (*C*) TASKS

Pixels		*D1C*	*D1U* *D2C* *D2U*	*D2U* *D3C* *D3U*	*D3U*
		61	122	244	488
W1	30	1.60	2.34	3.19	4.11
W2	61		1.59	2.32	3.17
W3	122		1.00	1.59	2.32

TABLE II
INDICES OF DIFFICULTY IN MULTIDIRECTIONAL (M) TASK

Pixels		*D1M* 305	*D2M* 534
W1	57	2.67	3.37
W2	76		3.00

Where *W* and *D* are the target width and distance [10]. Tables I and II show the *ID*s for different *D-W* pair conditions in our tapping tasks. *OH%* is the percentage of the taps outside the targets to the total number of taps. While *TP* does not reflect whether the targets were eventually selected or not, *OH%* reveals the subjects' accuracy in using the computer

Fig. 3. (a) Recommended tongue positions for six TDS tongue commands plus the tongue resting position, which is considered neutral. (b) Designated keys on the keypad to resemble the TDS commands' positions.

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

input device for pointing and selecting the targets [6], [11]. We asked the subjects to focus on accuracy as opposed to speed if their *OH%* tends to be growing. *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. It includes subjects' decision time to which direction to move, which tongue position or key to select, physical movement of the tongue or finger, and the system latency (including the GUI) in detecting and applying subjects' commands to cursor movements.

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. Subjects were allowed to rest up to 1 min between consecutive rounds.

B. 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.

III. RESULTS AND DISCUSSION

Table III shows the tapping task results along with key statistical values. The 3rd column shows the subjects' performance measures with mouse, which was only measured in the first session to generate a reference point. Mouse TPs for all the tasks were within the acceptable range of 3.7-4.9 b/s [6], which validates our methodology, GUI functionality, and data analysis.

The 4th and 5th columns in Table III show the TDS performance measures in the 1st and 5th sessions, respectively, which are used in paired t-tests with the resulted p values in the 6th column indicating their significant difference (when $p < 0.05$). These comparisons show that subjects' performances have been significantly improved over 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 5th 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 5th and 1st sessions. Pair-wise comparison with Bonferroni adjustments followed by RM-ANOVA 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 ($p = 0.334$).

TABLE III. 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

(a)

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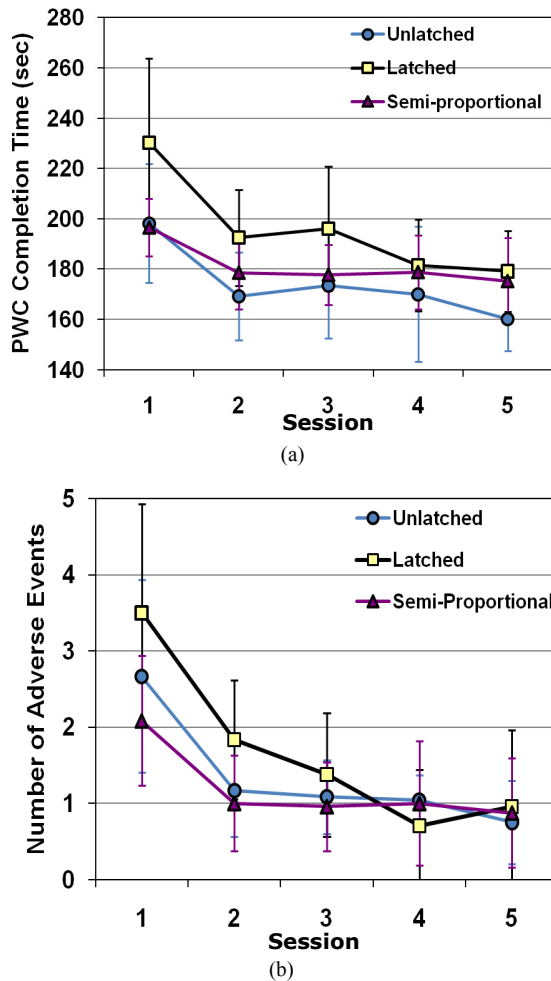
Fig. 5. PWC control session (a) Completion time and (b) Number of events.

IV. CONCLUSION

We have evaluated the Tongue Drive System (TDS) both as a computer input device and PWC controller over 5 sessions during 5 weeks with 9 able-bodied subjects, who already had tongue piercing, wore the TDS magnetic tongue studs over the course of this study. Nearly all TDS performance measures improved significantly from the first to the last session. We expect the further detailed comparison between subjects' performance with TDS and keypad will provide valuable insights about the human factors of the tongue motion and a few limiting factors of the current TDS, which can lead the way in improving future revisions of the TDS as well as other similar devices that can also be used as assistive technologies.

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