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Evaluation of Tooth-Click Triggering and Speech Recognition in Assistive Technology for Computer Access

Tyler Simpson, MSc,[1] Michel Gauthier,[1] and Arthur Prochazka, PhD[1]

Abstract

Background. Computer access can play an important role in employment and leisure activities following spinal cord injury. The authors' prior work has shown that a tooth-click detecting device, when paired with an optical head mouse, may be used by people with tetraplegia for controlling cursor movement and mouse button clicks. *Objective*. To compare the efficacy of tooth clicks to speech recognition and that of an optical head mouse to a gyrometer head mouse for cursor and mouse button control of a computer. *Methods*. Six able-bodied and 3 tetraplegic subjects used the devices listed above to produce cursor movements and mouse clicks in response to a series of prompts displayed on a computer. The time taken to move to and click on each target was recorded. *Results*. The use of tooth clicks in combination with either an optical head mouse or a gyrometer head mouse can provide hands-free cursor movement and mouse button control at a speed of up to 22% of that of a standard mouse. Tooth clicks were significantly faster at generating mouse button clicks than speech recognition when paired with either type of head mouse device. *Conclusions*. Tooth-click detection performed better than speech recognition when paired with both the optical head mouse and the gyrometer head mouse. Such a system may improve computer access for people with tetraplegia.

Keywords

assistive technology, computer access, spinal cord injury, tetraplegia

Introduction

The field of study aimed at providing computer access for individuals with disabilities is as old as the personal computer itself.[1] Computer access provides increasingly important avenues for employment, education, social interaction, and entertainment.[2] For people with upper extremity paralysis, the commercially available technologies that enable computer access are more complex and less efficient than a traditional mouse and keyboard. Closing this gap in performance is one way to provide better productivity and more enjoyment from computer-related activities for people with disabilities affecting hand function.

Numerous systems have been developed to provide computer access to people with disabilities. For cursor control, a few different "head mouse" devices exist that are based on tracking head movements either optically[3-8] or with a head-mounted gyrometer.[3-8] Speech recognition, gaze tracking and the use of brain–computer interfaces,[9,10] mouth joysticks, and vocal joysticks[11] are among other strategies available or under development for cursor control. For mouse button clicks, popular alternatives include enlarged push buttons, voice commands, tongue switches,[12] blink switches, sip-and-puff switches, and dwell selection (mouse clicks generated via software by holding the cursor in place for a brief interval).[13]

In prior work, we found that a tooth-click (TC) activated wireless triggering device, initially developed for neuroprosthetic control,[14] could be used by people with upper limb paralysis as a method of controlling mouse clicks.[13] In that study, we found TCs to be comparable in speed to a sip-and-puff switch and significantly faster than dwell selection for generating mouse clicks. The TC device was paired with an optical head mouse (OHM) to trigger single, double, left, or right mouse clicks and click and drag. Click-type selection was achieved by moving the head quickly in 1 of 4 directions immediately after a TC. In the present study, we were interested in evaluating the TC device when coupled either with the OHM used previously or a gyrometer head mouse (GHM). These hardware configurations are described in further detail below. In a separate

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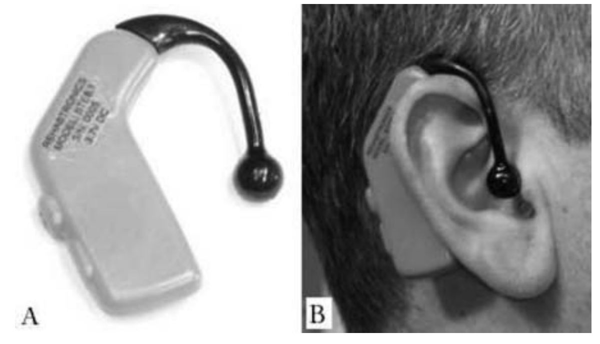


Figure 1. A, The tooth-click detector device. B, The device is properly positioned on the ear, with the sensor (black spherical part) touching the tragus.

experiment, we compared the performance of the TC/OHM and TC/GHM combinations with speech recognition (SR/OHM and SR/GHM). The SR method of generating mouse clicks was chosen for comparison with the TC method because it is already used by a reasonable proportion of people with upper extremity paralysis. We hypothesized that the SR method would be slower than the TC alternative.

Methods

Equipment

Tooth-click detector. The TC detector device used in this study was originally developed to act as a hands-free remote switch.[14] Shown in Figure 1, it is a lightweight device with a contoured arm that wraps around the ear. At the tip of the arm is a 3-axis accelerometer sensor that detects the jaw vibrations elicited during TCs. The device's onboard microprocessor runs a software program that differentiates TCs from speech-related and movement-related transients. The device is sufficiently sensitive that even small TCs (inaudible and scarcely noticeable to a human observer) can be detected with high reliability. Once a TC is detected, the device transmits a 433.92-MHz wireless signal to a remote receiver that is connected via a universal serial bus to the host computer.

In our study, custom software running on the host computer acknowledged a TC event by displaying a popup radial menu on the screen, centered on the mouse cursor. The menu, shown in Figure 2, allowed users to produce a left click, right click, double click, or click and drag. These clicks were selected from the menu by making a brief cursor movement to the left in the case of a left click, to the right for a right click, or down to begin a click and drag. Double clicks were produced when the user clicked his or her teeth a second time without making a menu selection.

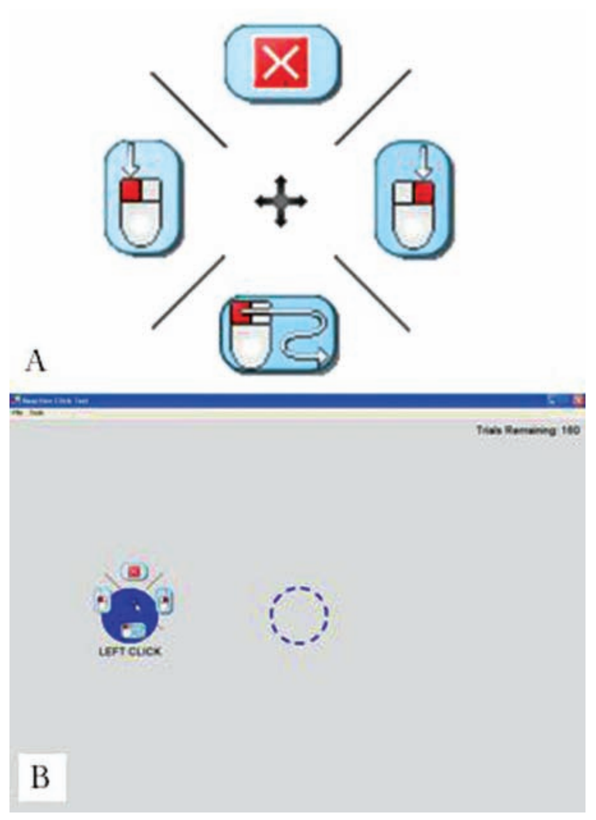


Figure 2. A, The radial menu used for accessing different click types. The menu appeared when triggered by a tooth click and was centered on the cursor's position. Subjects then made a small, rapid head movement to the left to produce a left mouse click, to the right for a right mouse click, down to begin a click and drag, or they held the cursor stationary and clicked their teeth a second time for a double mouse click. B, The cursor and radial menu are shown correctly positioned on a target, just prior to click-type selection, in the Index of Performance task. A dashed circle was added to the image to show the cursor's starting position, before the target was revealed. The combination of target diameter and distance shown here produced an Index of Difficulty value of 2 bits (the maximum difficulty used was 4 bits).

Head mouse. The OHM device used in this study was the TrackIR (NaturalPoint Inc, Corvallis, OR). The TrackIR, much like the HeadMouse Extreme (Origin Instruments Corp, Grand Prairie, TX) or the TrackerPro (Madentec Ltd, Edmonton, Alberta, Canada), is an infrared camera that tracks the movement of a reflective sticker worn on the user's head. It was selected over the alternatives due to its lower price. The device was positioned on top of the computer monitor and was 1 of the 2 methods tested for cursor control.

Gyro mouse. The GHM used in this study was derived from a Gyration GyroTransport (Movea, Inc, Grenoble, France), a wireless handheld mouse intended for use as a presentation pointer. We removed the device's enclosure and attached the circuitry to a headband to achieve hands-free cursor control. Using this GHM, head rotations in the up-down and left-right directions produced corresponding cursor movements on the computer screen. The "Tracer" (Boost Technology, Redwood City, CA) is a commercially available head-mounted gyro mouse that achieves the same functionality as our modified GyroTransport. We chose to modify an existing GyroTransport device instead of purchasing a Tracer as this was more cost effective, and we discovered that the 2 devices share the same gyrometer sensor technology and software.

Speech recognition. The SR software used in this study was Dragon NaturallySpeaking 9.5 (Nuance Communications Inc, Burlington, MA). To "train" the SR program, each user read aloud several sentences displayed by the software for 5 to 10 minutes. Prolonged use would be required to bring the software's recognition accuracy up to advertised levels, but for this study it was only practical to have subjects train for up to 10 minutes as recommended by the manufacturer for first-time users.

The software allowed users to activate left and right mouse buttons by speaking the phrases "left mouse click" and "right mouse click." On initial assessment, these default voice commands were found to be slow, unreliable, and, in the case of click and drag, incompatible with the OHM and GHM systems. To improve functionality, we used a single voice command (the word "click") to trigger a macro that displayed our radial click menu. From the menu, the different click types were selected by small cursor movements as in the TC strategy. The use of the radial menu allowed subjects to complete the experiment within a reasonable time, without requiring extensive prior training with the software. This addition to the base software differentiated it from the commercially available version but increased the speed with which users could generate different types of mouse clicks. We felt that the improvement was justified as our interest was to test the feasibility of SR in general rather than the approach used by a specific manufacturer.

Experiments and Interface Software

Four pairings of cursor control and mouse-click control were tested: TC/OHM, TC/GHM, SR/OHM, and SR/GHM. Subjects used these device combinations to perform specific tasks involving cursor movement and mouse clicks.

Randomized click-type task. The first program recorded the total time taken by the subject to react and move the cursor from the center of the screen to a randomly positioned circular target and perform 1 of the 4 different types of mouse clicks (left click, right click, double click, or click and drag). The click types performed in this task represent the range of clicks commonly used on a personal computer.

Subjects began each trial of this task by positioning the cursor on a button located at the center of the screen and then performing a left click. The center button disappeared, and after a randomized 1 to 3 second delay, a target button appeared in 1 of 16 other locations on the screen. Target sizes were randomized to either 66 or 99 pixels in diameter. The type of click required to complete the trial was also randomized and displayed in text below the target. Subjects completed trials by performing the correct mouse click on the target, causing the center button to reappear so that the next trial could be initiated. The software recorded trial parameters and reaction time data.

Eighty trials were performed using each of the 4 device pairings, which were presented in a pseudo-random fashion between subjects to minimize training effects in the group data.

Simple single-click reaction-time task. In a separate set of experiments, the target location and click type were held constant. Subjects performed left clicks on a fixed target at the center of the screen. Cursor movement was thus eliminated for this experiment, except when making selections from the click menu.

Index of performance task. These trials were designed to gather click time data necessary for determining a device's Index of Performance (IP). IP values provide a framework for comparison between devices across different studies, because they take task difficulty into account. The IP calculation is described below. The software in this case prompted for left clicks only, and the size and positions of the target areas were adjusted to achieve 4 specific distance-to-diameter ratios for the IP calculation. The diameter and distance pairs used were the following: 100-pixel-diameter targets at distances of 100 and 300 pixels from the screen's center (ID = 1 and 2 bits) and 20-pixel-diameter targets at distances of 140 and 300 pixels (ID = 3 and 4 bits). Subjects performed 80 trials per device in this experiment. Able-bodied subjects used a regular mouse and TC/OHM and TC/OGM combinations. Spinal cord injured subjects with varying degrees of tetraplegia used the same TC device combinations, as well as a trackball instead of the standard mouse.

Index of Performance and the Fitts's Law Model

The IP is a standardized measure used to compare computer input devices. The International Organization for Standardization (ISO) describes in the ISO 9241-9 standard a method for deriving the IP of a pointing device by measuring the time required to move the cursor a specified distance, from the starting point to a target area.[15] IP is measured in bits per second. The relationship between these terms is described in Fitts's Law,[16] which states the following:

$$\mathrm{MT} = a + b\mathrm{ID}, \quad (1)$$

where ID is the Index of Difficulty, MT is the movement time, and a and b are coefficients that may be determined experimentally. As recommended by MacKenzie,[17] the ID value was calculated as follows:

$$ID = \log_2(A/W + 1), \qquad (2)$$

where A is the amplitude of the movement (distance to target) and W is the target width (diameter). From Equation (2), trials with small A and large W values would result in low ID values, whereas trials with large A and small W values would have high ID values.

From Equation (1), the IP is defined as follows:

$$IP = 1/b. \quad (3)$$

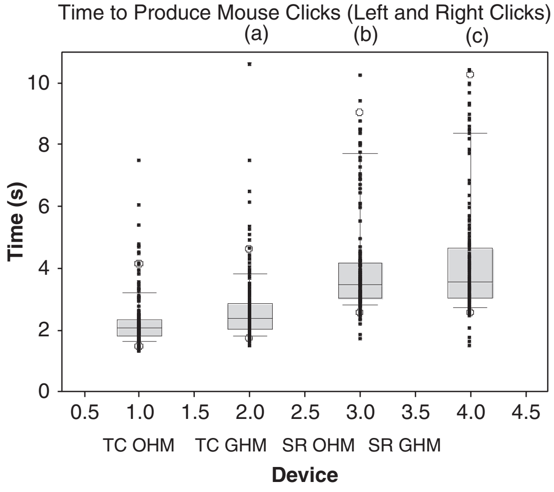
The IP value represents the information-dependent aspect of the movement time. Zhai[18] suggests that a fully comprehensive representation of device performance should include both the IP value and the a coefficient. High IP and low a values are indicative of good device performance. A high IP value corresponds to a low slope in the plot of MT versus ID. The coefficient a corresponds to the MT value for a 0-ID value, that is, the click reaction time to the appearance of a large target at the current cursor position.

Subjects

The study was performed with the approval of the University of Alberta Human Research Ethics Board. For the experiments comparing TC and SR methods of click generation, data were collected from 5 able-bodied subjects. In previous work,[13] we found that there was no significant difference in click times obtained by able-bodied and tetraplegic subjects performing a similar task. Subjects were between 25 and 30 years of age, and 4 were male. All subjects were familiar with computers but none had prior proficiency with the combinations of devices evaluated in this study. For the experiments comparing the IP of the OHM and GHM systems, 6 able-bodied subjects between the ages of 25 and 46 (4 were male) and 3 tetraplegic subjects between the ages of 30 and 50 (2 males and 1 female) took part. Two of the tetraplegic subjects primarily used a trackball device for computer access, whereas the third used a standard mouse in a manner that mimicked the functionality of a trackball. None of the tetraplegic subjects had previously used a GHM device, though 2 had limited prior experience using an OHM device.

Statistical Analysis

The data collected during our experiments were not normally distributed. For the first task, median click time values were compared using the nonparametric Kruskal–Wallis 1-way analysis of variance. Multiple comparisons were performed using a Dunn's posttest, and results are reported as being significant at $P < .05$. Linear regressions were performed on the MT/ID data. Pairwise comparisons between regression lines were performed using multiple regression analysis, with significance tested at $P < .05$.



Extra Outliers for Figure 3 (beyond 11 seconds):	
TC GHM	11.77
SR OHM	11.48, 12.63, 14.00, 14.61, 15.47, 21.91, 22.70, 38.31
SR GHM	11.14, 11.22, 12.23, 16.20, 19.33, 23.63, 49.02

Figure 3. Box plot representation of the median click times obtained from the 4 device combinations (tooth-click[TC]/optical head mouse [OHM], toothclick/gyrometer head mouse[GHM], speech recognition [SR]/optical head mouse, speech recognition/gyrometer head mouse). The line in the center of the box denotes the median. Box edges are the 25th and 75th percentiles. Whiskers (horizontal lines) are the 10th and 90th percentiles, and empty circles are the 5th and 95th percentiles. Original data points are overlaid on top of the box plot. Note: extra outliers at (a), (b), and (c) are shown in the table below the figure.

Results

Randomized Click-Type Task

The subject group's median click times from the randomized click-type task (for left and right mouse clicks) are shown in Figure 3, with additional outlier data points listed in the table below the figure. The TC/OHM and TC/GHM combinations were much faster than the SR/OHM and SR/GHM combinations, so it is clear that the button-clicking component of the tasks had a bigger impact on performance

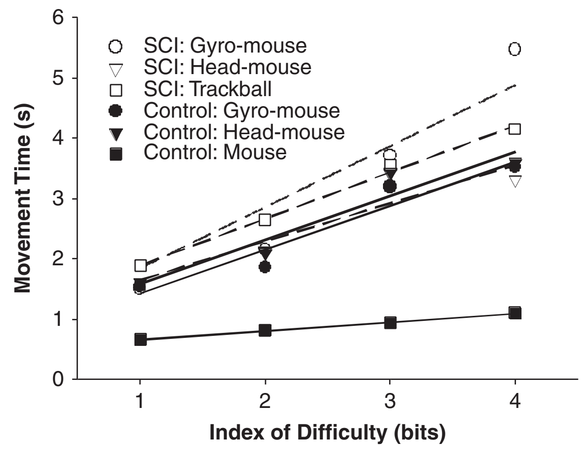


Figure 4. Linear regression of mean movement time versus index of difficulty for the device combinations used in the Index of Performance task. SCI = spinal cord injured group.

than the cursor movement component. Median click times were slightly lower with the TC/OHM than the TC/GHM combination (2.06 vs 2.37 seconds, $P < .05$). The SR/OHM combination was likewise slightly faster than the SR/GHM combination (3.47 vs 3.55 seconds), though in this case the difference did not reach significance. Additionally, all subjects reported preferring the TC/OHM, followed by the TC/GHM, the SR/OHM, and the SR/GHM.

We also eliminated the cursor movement component of the task and measured the time required to produce clicks on a large, fixed target that suddenly appeared. The median click times under these conditions were 0.84 seconds when using TCs and 2.66 seconds when using SR. These values were determined to be significantly different in a Mann–Whitney rank sum test at $P < .01$.

Index of Performance Experiments

In the second experiment, data were collected for tasks with 4 distinct ID values. The median MT values are plotted against the ID values in Figure 4. Coefficients *a* and *b* for the TC/OHM and TC/GHM combinations were determined by linear regression (see Table 1). The unadjusted regression line for the tetraplegic subjects' TC/GHM data had a negative *y*-intercept value. This was likely due to a few large click time values obtained during trials with the highest ID value. As the *y*-intercept corresponds to the click reaction time without cursor movement, we repeated the linear regression analysis in this case with the restriction of a *y*-intercept of 0.84 seconds (the median time to produce clicks on a large, fixed target that suddenly appeared, that is, a task with an ID value of 0).

Table 1. Regression Coefficients for the Devices Used in the Index of Performance (IP) Task[a] for Spinal Cord Injured (SCI) and Control Groups

	a	*b*	IP = 1/*b*	Relative IP
SCI: Gyro mouse	0.84	1.01	0.99	0.14
SCI: Head mouse	0.98	0.66	1.52	0.22
SCI: Trackball	1.13	0.77	1.29	0.19
Control: Gyro mouse	0.74	0.72	1.39	0.20
Control: Head mouse	0.84	0.74	1.35	0.20
Control: Mouse	0.51	0.15	6.90	1.00

[a] Higher IP (or relative IP) indicates faster cursor control and mouse clicking performance.

IP values, calculated as 1/*b*, are listed in Table 1 as raw values and as fractions of the median IP value obtained when performing the task with a standard mouse (6.90 bits/s). This standard mouse IP value fell within the range reported in previous similar studies.[11,17,19,20] The TC/GHM pairing yielded a relative IP value of 0.20 for the able-bodied subjects and 0.14 for the tetraplegic subjects (absolute IP values were 1.39 and 0.99 bits/s, respectively). For the TC/OHM combination, relative IP values were 0.20 (1.35 bits/s absolute) for the able-bodied group and 0.22 (1.52 bits/s absolute) for the tetraplegic group, which compares favorably with a relative IP of 0.19 (1.29 bits/s absolute) when the tetraplegic group used the trackball, a device with which they were already familiar. Not surprisingly, the conventional mouse was the fastest device for the control group. The control group did not show a difference in IP between the TC/OHM and TC/GHM combinations, whereas the tetraplegic subjects had a significantly lower performance with the TC/GHM.

Discussion

The goal of this study was to compare optical head mouse and gyrometer head mouse means of cursor control combined with 1 of 2 means of producing mouse clicks (TC triggering and SR).

In terms of performance, we found that TC triggering of mouse clicks was significantly better than triggering with the SR system. The important difference between TC and SR was the delay between the user's intention to produce a click and the click actually being generated on the computer. For the TC device, there was a delay of 150 to 300 milliseconds between a TC and the appearance of the popup menu on the computer monitor. This delay represents the processing time required to distinguish TC transients from other signals and to transmit a trigger signal to the host computer. In the case of the SR software, the delay was in the order of 1 to 2 seconds. This included the time required to vocalize the word "click" as well as the processing time needed to recognize the word from a large library of words. The extra delay time caused the SR device combinations to be noticeably slower than the TC device combinations, especially in the case of double clicks.

The processing delay (for both TC and SR methods) was also responsible for some inaccuracy when clicking, as it was possible to move the cursor after initiating a click but before the menu appeared. Although the proportion of such misclicks was not recorded, we found that users learned to adjust their clicking strategy to compensate during the allotted training period when using the TC device. However, when using SR, users often performed misclicks due to the recognition delay, even after the training period.

Previous studies that compared IP values of different mouse devices did not include the mouse-click component of cursor control. We expect that as cursor-pointing devices mature further, improvements to the response time of clicking strategies will be of increasing importance.

The SR software tested in this study, despite being very popular commercially, was frustrating to our subjects when used to generate mouse clicks. Any improvement to the recognition speed would likely translate directly into an improvement in clicking speed. It may be possible to improve the speed of SR methods with specialized applications that respond only to a small set of voice commands. Also, the small-window voice analysis described in Harada et al[11] may provide better response times than can be attained by software that specializes in full word recognition.

The tetraplegic subjects in our study did not perform quite as well with the TC/GHM as with the TC/OHM. The difference can be partially attributed to a small number of large outlier click times that occurred in the most difficult trials (ie, those with the highest ID values). In the able-bodied subjects, we did not find any significant difference between the 2 methods in this regard. It is unclear why it occurred in the tetraplegic subjects.

The main motivation for considering a gyro head mouse system was that the components could be packaged together with those of the TC detector within a single small earpiece. The subject would no longer be required to face a camera at a fixed location, the basis of current head-mouse systems. This in turn would allow the device to be used on different computers without the need to relocate a head-mouse camera. An all-in-one device would likely achieve wider user acceptance, an important facet of assistive technology design.

Additionally, a GHM can detect directional gestures without requiring the user to be positioned in front of a camera. With a TC/GHM device, a subject could perform a TC followed by a small head movement in one of several directions to select from a group of options to control a variety of applications, without the visual feedback of a popup menu on a computer screen. This would allow the TC/GHM to be used as a multimodal switch for applications beyond computer access. Example applications, with immediate relevance to people with spinal cord injury, include the control of a neuroprosthetic device, a motorized wheelchair, a telephone, or other devices that interact with the subject's environment.

Conclusion

We compared the use of TCs and SR for generating mouse clicks when paired with an OHM or a GHM to move the cursor. Either method provided hands-free mouse control for people with upper limb paralysis. However, subjects performed mouse clicks significantly faster using TCs than SR. The IP analysis indicated that with only 5 minutes of training, people with tetraplegia using TC detection paired with either an OHM or a GHM could achieve 14% to 22% of the cursor movement and button-clicking speed of an able-bodied person using a standard mouse.

Acknowledgement

We thank Colin Broughton for his help in developing the tooth-click detector device.

Declaration of Conflicting Interests

Arthur Prochazka has a commercial interest in the development of the tooth-click detector device.

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