Cursor Click Modality in an Accelerometer-Based Computer Access Device

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***Abstract*—The purpose of this study is to investigate the effects of different cursor click modalities in an alternative computer access device using accelerometry from head tilt to control cursor movement. Eighteen healthy adults performed a target acquisition task using the device with five different cursor click modalities, while maintaining cursor movement control via accelerometry. Three dwell-based click modalities with dwell times of 0.5 s, 1.0 s, and 1.5 s were tested. Two surface electromyography-based click modalities - with the sensor placed next to the eye for a blink and above the eyebrow for a brow raise - were tested. Performance was evaluated using metrics of target selection accuracy, path efficiency, target selection time, and user effort. Surface electromyography-based click modalities were as fast as the shortest dwell time and as accurate as the longest dwell time, and also minimized user effort. Three of the four performance metrics were not affected by sensor location. Future studies will investigate if these results are similar in individuals with neuromuscular disorders.**

***Index Terms*—Surface electromyography, accelerometer, alternative computer access, dwell, cursor click.**

I. INTRODUCTION

CURRENT standard computer access methods such as keyboards, mice, and joysticks are typically controlled through physical contact between the user and a device. These systems require coordinated movements of the upper limbs and hands to achieve precise control, which may be difficult for individuals with severe motor impairments such as those caused by a range of neuromuscular diseases [1]–[3].

Several alternative methods of computer access have been developed to allow computer control with limited physical movements. These include mouth-sticks and tongue-control [4], computer-vision [5]–[8], head-tracking via accelerometer and gyroscope [9]–[12], and surface electromyography (sEMG) using voluntary muscle movements [13]–[16]. These access methods are designed to allow individuals to easily and efficiently make cursor movements without the need for coordinated control of the upper limbs and hands.

Functional alternative computer access also requires an easy and accurate cursor click mechanism. Initial systems using a mechanical switch were bulky and difficult to use for individuals with severe motor impairments [17]–[19]. Since then, many systems with alternate cursor clicking mechanisms have been developed. One such example is dwell-based clicking in which the cursor is moved across the screen via a limited motion access method (e.g., eye-gaze or head tracking) and hovers over a relatively fixed location for a set duration in order to trigger a click [20]–[22]. The duration of the dwell time is crucial for system performance: a shorter dwell time allows the user to make faster clicks at the expense of a greater likelihood of unintentional clicks. A longer dwell time prevents accidental clicks, but decreases the efficiency of the device [23]–[25].

In contrast, sEMG acquired from voluntary and intentional muscle movements such as hard blinks [12], [20], [26], teeth clenching [27], frowning [28], and smiling [29] has been utilized as a click mechanism to provide high accuracy of selection [12], [20]. Magee *et al.* [20] and Vojtech *et al.* [12] each compared performance of a device that uses sEMG-based cursor clicking against Camera Mouse [7], a system that uses computer vision for cursor movement and dwell time for cursor clicking. Both studies found that sEMG selection provided more reliable and intentional clicking when compared to Camera Mouse [30]. Further, participants in Magee *et al.* [20] reported difficulty in maintaining a steady head position when hovering over a target. Vojtech *et al.* [12] demonstrated that their designed system showed a clear speed/accuracy tradeoff when compared to Camera Mouse: while Camera Mouse allowed for faster movement speeds, but had lower target selection accuracies.

Differences in experimental design between Magee *et al.* [20] and Vojtech *et al.* [13] make it difficult to

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compare the two studies. In Magee *et al.* [20], the dwell-based click modality in the Camera Mouse system was replaced with their own sEMG-based click modality. As a result, they were able to observe the effects of changing click modality in a computer vision-based system. In contrast, Vojtech *et al.* [12] used a device that controlled cursor movements with a tri-axial accelerometer (ACC) that mapped slight tilts of the head into cursor movements, thereby comparing click modalities in systems with different cursor movement modalities. It is unclear whether the results of the computer vision-based system from Magee *et al.* [20] could be duplicated with an ACC-based system. Further, both studies used only a single dwell duration and a single sEMG sensor placement (i.e., near the eye to elicit a click via a hard wink or blink). Examining differences in dwell duration and sEMG sensor configuration may result in differences in user performance (movement speed, target selection accuracy), which could inform access method development for individuals with neuromuscular disorders who may have muscle spasms, a reduced range of movement, or weak control of certain muscles.

II. CURRENT INVESTIGATION

The current study adapted the system developed by Vojtech *et al.* [13] (henceforth referred to as the ACC/sEMG system) to function with either a dwell- or sEMG-based click modality. We sought to answer the following research question: using an ACC-based movement modality, how does the target selection modality affect performance? Secondary research questions were (1) what is the effect of different dwell durations?, and (2) does performance differ for different sEMG sensor locations? We hypothesized that increasing dwell time would result in a speed/accuracy trade-off, in which the speed of selecting a target would decrease and the selection accuracy would increase with increased dwell time. We also hypothesized that performance at a group level would not change across sEMG sensor locations.

III. METHODS

A. Participants

Eighteen healthy adults (9 female, 9 male; M = 22.6 years, SD = 3.3 years) with no history of motor impairment or prior experience with computer access research participated in the study. All participants provided a written consent in compliance with Boston University Institutional Review Board.

B. Experimental Design

1) Overview: All participants completed an experimental session that lasted approximately 1.5 hours. Participants were seated directly in front of a computer screen and instructed to avoid talking and reduce extra movements that could affect cursor movement. Participants completed a total of five target acquisition tasks, each with a different click modality. Three dwell times were tested and were always presented in a set order (0.5 s, 1.0 s, and 1.5 s) as a single block for all participants. Two sEMG sensor locations were tested, one for activation via a hard wink or blink and another for activation via an eyebrow raise. These five target acquisition tasks were presented as three blocks in a randomized order such that all dwell times were always presented together in the same order. Randomization and counterbalancing across participants were used to limit the effects of learning. At the start of each block, participants completed an automated calibration. Participants then completed two minutes of free play to gain familiarity with cursor movement and the specific target selection mechanism. Thus, there were a total of three calibrations, five familiarization sessions, and five experimental tasks (Figure 1).

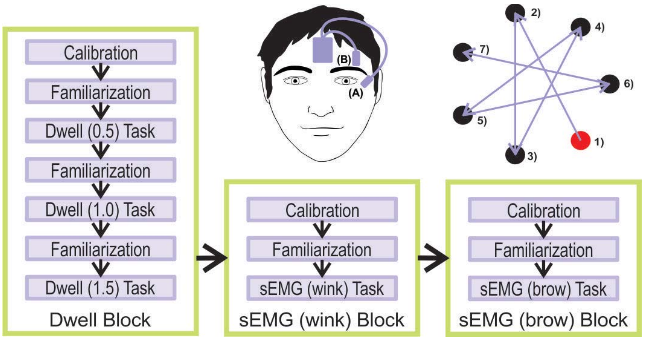

Fig. 1. Schematic showing sensor placement, target acquisition task, and the overall experimental design. The accelerometer sensor was always placed on the glabella. The surface electromyography sensor could be placed over two regions: (A) the risorius and orbicularis oculi for a hard wink or blink, or (B) the frontalis for an eyebrow raise. The target acquisition task consists of seven identical circular targets with one target colored red as the active target. The five experimental tasks were divided into three blocks. Each block started with a calibration session. A familiarization session occurred prior to each click modality.

2) Target Acquisition Task: The target acquisition task consisted of seven identical, equidistant. and evenly-spaced circular targets (Figure 1). Targets had a diameter of 42.4 pixels and an inter-target distance of 437.3 pixels. The task was presented to each participant at a resolution of 1920 × 1080 pixels. The cluster of targets appeared in one of five locations on the screen: at the center, or in one of the four corners. One of the seven targets appeared red in color, whereas the remaining six targets appeared black in color. Participants were instructed to select the active red target (henceforth referred to as a "trial"). Click activation generated a short "click" sound. Upon the activation of a click, regardless of whether the target was successfully selected, the target that was diametrically opposite the previous active target was designated as the new active target. Thus, participants could only click once per trial. This process was repeated for all seven targets (henceforth referred to as a "round"), and all five locations across the screen were covered, resulting in 35 distinct trials per target acquisition task. Target location order was randomized across participants.

3) ACC/sEMG System:

a) Overview: The ACC/sEMG system employs accelerometer inputs for control of cursor movement. Accelerometer and sEMG signals were recorded using the Delsys Trigno™ Wireless EMG System (Delsys, Boston, MA) using factory default settings. The sensor comprises of two components: 1) a single differential MiniHead sensor (25 × 12 × 7 mm) used for sEMG acquisition, and 2) the main sensor body (27 × 37 × 15 mm) used for establishing a local reference to the signals acquired by the MiniHead and for recording a tri-axial accelerometer signal.

Accelerometer signals were recorded at 148 Hz. sEMG was recorded at 2000 Hz and band-pass filtered (20–450 Hz), and amplified by a gain of 300. Signals in the range of 0–20 Hz are generally due to movement artifacts, whereas the upper cut-off point of 450 Hz eliminated high-frequency noise [31], [32]. Accelerometer and sEMG signals were time-aligned using the Trigno™ Wireless Biofeedback System [33]. Signal recording and post-processing were conducted using PyGesture [34] and custom Python scripts.

b) Sensor preparation and placement: A single sEMG sensor was used during the experimental session. Prior to placing the sensor, the participant's skin was abraded using alcohol wipes, and exfoliated using tape to remove dead skin and oils [35]. The main sensor component of the ACC/sEMG system was then placed on the glabella with the y-axis of the accelerometer in the sensor parallel to the sagittal plane of the user. The MiniHead sensor was configured in one of two regions: the risorius and orbicularis oculi for hard wink or blink, or the frontalis for eyebrow raise (see Figure 1). The sEMG sensor was placed on the left or right side of the face based on each participant's personal preference.

c) Cursor movement modality: Across all click modalities, participants controlled the cursor by tilting their head in the direction of the intended cursor movement. The tilt angle, which related to the angle of head tilt in the x-y plane to acceleration in each axis was computed by converting the tri-axial acceleration signal from rectangular (x, y, z) to spherical (ρ, θ, φ) coordinates. Head roll and head pitch were then computed (Eq. 1 & 2) and mapped to moving the cursor up or down and left or right, respectively. A combination of these two measures enabled two-dimensional movement within the screen.

$$\text{Head Roll}\,(\theta, \text{deg}) = \frac{360}{2\pi} \times \text{atan2}\left(\frac{\mathrm{y}}{\mathrm{z}}\right) \tag{1}$$

$$\text{Head Pitch}(\rho, \text{deg}) = \frac{360}{2\pi} \times \text{atan2}\left(\frac{-\mathrm{x}}{\sqrt{\mathrm{y}^2 + \mathrm{z}^2}}\right) \tag{2}$$

The root-mean-square (RMS) values corresponding to head roll and pitch tilt were computed over windows of 54-ms and normalized by the RMS values obtained during system calibration (see *Calibration*). The minimum (i.e., for left or down movements) and maximum (i.e., for right or up movements) RMS values from calibration data produced a scalar multiplier from −1 to 1 to be multiplied by the RMS of the accelerometer. Consequently, larger head movements resulted in faster cursor movements. Movements with RMS values exceeding calibration values were scaled to the limits defined by calibration.

d) Cursor click modality: Cursor clicking was performed via five different modalities across the five target acquisition tasks. For dwell-based clicking, three different dwell times were tested: 0.5 s, 1.0 s, and 1.5 s, in which a click was registered if the cursor remained within a prescribed region for a fixed duration of time (henceforth referred to as dwell (0.5), dwell (1.0), and dwell (1.5), respectively). For sEMG-based activation, two different sEMG sensor locations were tested: hard wink/blink, in which the sEMG sensor was placed over the risorius and orbicularis oculi, and eyebrow raise, in which the sEMG sensor was placed over the frontalis, (henceforth referred to as sEMG (wink) and sEMG (brow) respectively).

The cursor was considered to be "dwelling" if it remained within a radius of 21.2 pixels (equal to the size of the targets in the target acquisition task) from a fixed point for a pre-set duration (i.e. 0.5 s, 1.0 s or 1.5 s). If the cursor moved more than 21.2 pixels in radius from the fixed point, a new fixed point was set and the dwell time was reset.

For sEMG-based clicking, the system identified muscle activity as an intentional click using high and low thresholds. Specifically, a cursor click was registered when the RMS of the sEMG exceeded the high threshold, and remained in the "selected" position until the RMS of the signal fell below the low threshold. These thresholds were determined by multiplying the maximum RMS of the sEMG signal obtained during calibration by scalar factors. The first threshold multiplier was adopted from Cler and Stepp [36] as 0.7, and the second threshold multiplier was adopted from Vojtech *et al.* [12] as 0.4.

e) Calibration: The ACC/sEMG system was calibrated prior to each block of target acquisition tasks. Based on the target selection mechanism, participants were asked to tilt their head along roll and pitch axes for cursor movements, as well as to complete a set of click movements when appropriate (i.e. a blink/wink or eyebrow raise). In total, the system was calibrated three times throughout the experiment session. Each calibration took approximately fifteen seconds. To ensure that calibration provided sufficient cursor control, a brief cursor control task was presented to participants after acquiring calibration data. In this task, a target first appeared in one of four corners of the computer screen. Participants were instructed to guide the cursor to the target through appropriate head movements, and click via the given click modality. Upon selection, the target sequentially changed its position to the remaining three corners of the screen. If the experimenter observed poor control or if the participant failed to select a target in under 15 seconds, the ACC/sEMG system was recalibrated and all previous calibration data was replaced. Recalibration was common across all participants, with almost all participants needing at least two calibrations for one or more of the click modalities.

C. Data Analysis

1) Performance Metrics: Four outcome measures were used to assess user performance across different click modalities: target selection accuracy, path efficiency, target selection time, and user effort. Target selection accuracy was treated as a binary parameter, set to 1 when participants correctly selected an active target, and 0 otherwise. To ensure that the same distance is travelled between each trial, the first trial of each round was excluded from analysis, resulting in a total of 30 trials. An average target selection accuracy was calculated for each target selection modality. Trials marked as inaccurate were omitted from calculations of path efficiency and target selection time.

Path efficiency was calculated as the ratio of the ideal Euclidean path between targets to the actual path trajectory taken by the user. It is a measure of the straightness of the cursor path trajectory. The coordinates where participants selected the previously active target were designated as (x_0, y_0), and the coordinates of the new active target as (x_n, y_n). The Euclidean distance between these two coordinates divided by the actual distance traveled gave the path efficiency (See Eq. 3).

$$\text{Path Efficiency}(\%) = \frac{\sqrt{(x_n - x_0)^2 + (y_n - y_0)^2}}{\sum_{i=1}^{n} \sqrt{(x_i - x_{i-1})^2 + (y_i - y_{i-1})^2}} \quad (3)$$

Target selection time was the amount of time the user took to navigate from the previously active target to the next active target and select it. This includes the reaction time needed to identify the active target, though reaction time should not vary across modality. Following each target acquisition task, participants assessed their effort level needed to control the device using that click modality with a visual analog scale from the NASA Task Load Index [37] using anchors of very low to very high effort. It is important to consider user effort, because individuals will often prefer a simple and comfortable computer access device despite objectively poor performance [38].

2) Supplementary Analyses: Supplementary analyses were performed to further investigate the results of the study, though *a priori* hypotheses were not made. In order to further investigate accuracy, the average distance between the location of inaccurate clicks and the location of the desired target (i.e., the error distance) was calculated. In order to investigate the potential for motor learning within individual sessions, each session was separated into halves. Target selection accuracy, path efficiency, and target selection time were calculated separately for the first and second half of each session.

3) Statistical Analysis: Statistical analysis was performed with Minitab 18 [39], with significance set *a priori* at $p < .05$. Ryan-Joiner tests were used to test the normality of data for each performance metric. Only target selection accuracy failed the test of normality. As a result, an arcsine transformation was used on target selection accuracy prior to parametric testing. Repeated measures analyses of variance (ANOVAs) were used for each performance metric with participant as a random factor and click modality as a fixed factor. Partial eta-squared (η_p^2) values were calculated to determine the effect size for significant factors [40]. *Post hoc* Tukey simultaneous tests were used to evaluate significant differences between click modalities.

An additional repeated measures ANOVA was used for error distance with participant as a random factor and click modality as a fixed factor. Three repeated measures ANOVAs were used to compare performance metrics at the start and end of each session with participant as a random factor, and click modality and session half (first/second) as fixed factors. *Post hoc*

TABLE I
ANALYSIS OF VARIANCE RESULTS FOR EACH PERFORMANCE METRIC

Factor	*df*	*F*-value	*p*-value	$\eta_p{}^2$	Effect Size
Target Selection Accuracy					
Modality	4	50.30	< 0.01	0.75	Large
Path Efficiency					
Modality	4	2.13	0.09	--	--
Target Selection Time					
Modality	4	16.87	< 0.01	0.50	Large
User Effort					
Modality	4	7.51	< 0.01	0.31	Large

IV. RESULTS

All participants were able to complete the target acquisition task in its entirety. Table I shows the results of each ANOVA for user performance. Click modality had a significant effect on target selection accuracy, target selection time, target entry, and user effort (all with $p < .01$) with partial eta squared values of $\eta_p^2 = 0.75$, $\eta_p^2 = 0.50$, $\eta_p^2 = 0.34$, and $\eta_p^2 = 0.31$, respectively, all indicating large effect sizes [40]. Target selection modality did not have a significant effect on path efficiency. Mean values and 95% confidence intervals for all performance metrics across click modality are plotted in Figure 2, with black bars indicating significant differences.

Post hoc Tukey simultaneous tests for target selection accuracy showed that sEMG (wink) was significantly more accurate than sEMG (brow), dwell (1.0), and dwell (0.5), but there was no difference when compared to dwell (1.5). Dwell (1.5) was significantly more accurate than other dwell times, but there was no significant difference when compared to sEMG (wink) or sEMG (brow). sEMG (brow) was significantly more accurate than dwell (1.0) and dwell (0.5). Dwell (0.5) was significantly less accurate than all other modalities.

Post hoc testing for target selection time showed that sEMG (wink) was significantly faster than dwell (1.0) and dwell (1.5), but that there was no difference when compared to dwell (0.5) or sEMG (brow). Dwell (0.5) was significantly faster than all modalities except sEMG (wink), whereas dwell (1.5) was significantly slower than all other modalities. There was no significant difference in target selection time between sEMG sensor locations.

Post hoc testing for user effort showed that sEMG (wink) was statistically less effortful than dwell (0.5) and dwell (1.0), but that there was no difference when compared to dwell (1.5) or sEMG (brow). sEMG (brow) was found to be statistically less effortful than dwell (0.5). There was no statistically significant difference in effort level within dwell durations or sEMG sensor locations.

Supplementary analysis comparing error distance across click modalities revealed that click modality had a significant effect on the error distance (with $p < .01$) with a partial eta squared of $\eta_p^2 = 0.45$, indicating a large effect size [40]. Tukey simultaneous tests revealed that the error distance was

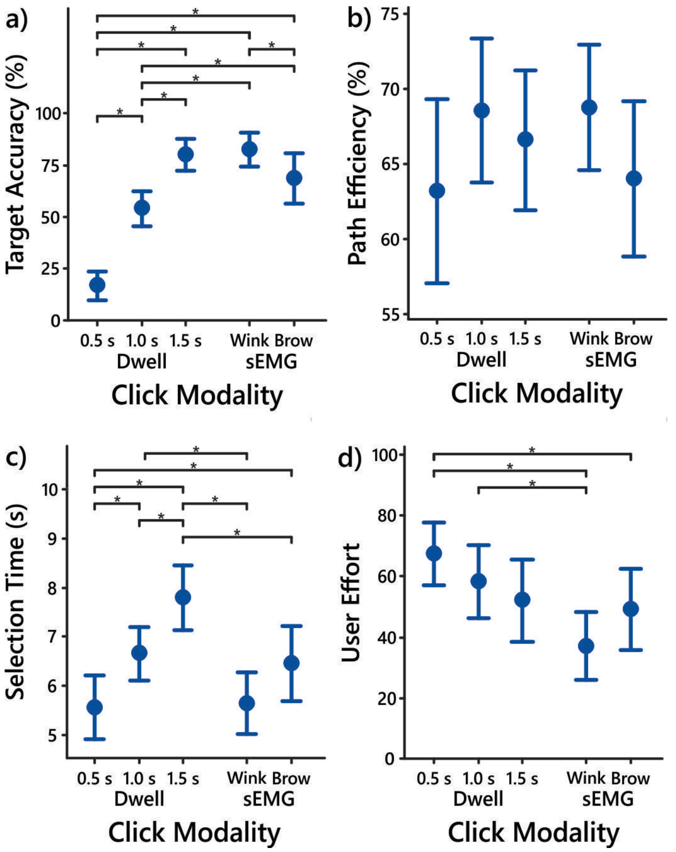

Fig. 2. Means and 95% confidence intervals per click modality for each performance metric: a) target selection accuracy, b) path efficiency, c) selection time, d) user effort. Black bars indicate significant differences in mean values ($p < .05$).

significantly larger for sEMG (brow) than all other modalities. Supplementary analysis comparing performance metrics between the first and second half of each session showed that session half did not have a significant effect on target accuracy, path efficiency, or target selection time.

V. DISCUSSION

Path efficiency was the only performance metric that was not significantly affected by click modality. This was expected since this metric should only be sensitive to differences in cursor movement modality, which was identical across all click modalities in the study.

Increasing dwell times showed an expected speed/accuracy tradeoff, supporting our hypothesis. Dwell (1.5) had an average target selection time of 7.8 s, whereas dwell (0.5) had an average target selection time of 5.5 s, a 40.5% decrease. However, dwell (1.5) had a better average accuracy of 82.8% when compared to the average accuracy of dwell (0.5) of 16.9%.

sEMG (wink) was not significantly different from dwell (0.5) in target selection time nor from dwell (1.5) in target accuracy. This indicates that using sEMG (wink) as a click modality preserves both speed and accuracy when compared to dwell-based cursor clicking. This is in contrast to the results seen in Vojtech *et al.* [12] in which the dwell-based Camera Mouse system and the ACC/sEMG system demonstrated a speed/accuracy tradeoff. This discrepancy in results may be due to differences in the cursor movement modality rather than click modality. Furthermore, sEMG (wink) resulted in the best average user effort rating, with ratings that were significantly lower than dwell (0.5) and dwell (1.0), indicating that the combination of discrete control via sEMG and continuous control via accelerometer signals may provide a greater ease of access for the individual. Though sEMG (wink) preserved speed and accuracy when compared to dwell (0.5) and dwell (1.5), it is important to consider that sEMG control is still affected by the speed/accuracy tradeoff. In a study that investigated head and neck sEMG as an input modality for cursor movement, cursor speed was limited to a maximum speed in order to improve accuracy [41]. Future studies should investigate the effect of this speed/accuracy tradeoff in the current device.

sEMG sensor location had varying effects on performance metrics. Target selection time and user effort were maintained across the two sEMG sensor locations, supporting our hypothesis that performance at a group level would not change across sensor locations. Target accuracy, however, was significantly lower when using sEMG (brow) than when using sEMG (wink), indicating that the location of the sensor is important for accurate selection of the target. Additionally, the error distance when using sEMG (brow) was significantly larger than all other modalities, indicating that sEMG (brow) resulted in the largest magnitude of errors.

Differences between sEMG sensor locations could be because raising an eyebrow may be less natural than a wink or a blink. Qualitatively, several participants commented that they were not confident that they could reliably raise their eyebrow. Furthermore, when the sEMG sensor was placed above the eyebrow it was close to the ACC sensor base. Raising an eyebrow could have caused an involuntary upward cursor movement, resulting in incorrect selections and larger error distances. In future implementations, it may be beneficial to place the ACC sensor in a different location further away from the eyebrow (such as on the mastoid). Given that the ACC signal is determined axially, this should have little impact on cursor movement. Alternatively, though the current system integrates the sEMG and accelerometer sensor into a single device in order to limit the amount of external equipment needed, it is possible to decouple the two sensors. This would create less interference between the two sensors as well as provide a cheaper alternative to the current integrated device.

There appeared to be a preference between the two sEMG sensor locations across individual participants. Of the 18 participants, 5 individuals showed equal or better target selection accuracy using sEMG (brow) when compared to sEMG (wink). The individualized improvement in performance between an eyebrow raise and a wink has been observed in previous literature, indicating that there may be an optimal location for the sEMG sensor on an individual basis [42]. This is important when considering user performance in those who may have limited and varied control of facial muscles [1], [3]. Future studies will investigate optimizing sEMG sensor location on an individual basis in a patient population.

In contrast to healthy individuals, those with neuromuscular disorders may find it more beneficial to use a dwell-based click modality. These individuals may be prone to involuntary muscle spasms [3], [43] or muscular weakness may make it difficult to consistently and reliably make voluntary muscle contractions. Thus, future studies are necessary to compare dwell-based clicking to sEMG-based clicking in a patient population with a wide range of neuromuscular disorders.

The current study did not consider the ability of the individual to adapt to the device. Individuals often show significant improvements following extended use of computer access devices [44] and even over short time periods [45]. It is possible that after a prolonged period of using the ACC/sEMG device, many performance metrics would level out regardless of click modality. Additionally, in the current study, there was no difference in performance metrics when comparing the first half of sessions to the second half. This is likely because sessions were at most a few minutes in length. However, it is possible that longer sessions may result in improved performance metrics towards the end of individual sessions as a result of motor learning. In contrast, prolonged use of head movements to control the device may lead to fatigue that would lower performance metrics. Future studies should investigate how performance metrics differ across click modalities at different points in the learning process and within prolonged sessions in order to determine the importance of click modality and how performance metrics may differ over time.

VI. Conclusion

This study showed that within a population of healthy individuals, sEMG-based clicking optimizes both speed and accuracy when compared to dwell-based clicking. Three of the four performance metrics were unaffected by sensor location, indicating feasibility at various sensor locations. Future studies will explore if similar results are observed in individuals with a range of neuromuscular disorders.

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