Auxilio and Beyond: Comparative Evaluation, Usability, and Design Guidelines for Head Movement-based Assistive Mouse Controllers

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vision-based head-tracking AMC developed for similar stakeholders. Furthermore, our study evaluates the usability of Auxilio using the System Usability Scale, supplemented by a qualitative analysis of participant interview transcripts to identify the strengths and weaknesses of both AMCs. Experimental results demonstrate the feasibility and effectiveness of Auxilio, and we summarize our key findings into design guidelines for the development of similar future AMCs.

CCS Concepts: • Human-centered computing → Pointing devices; Accessibility technologies; Accessibility technologies; Pointing; Usability testing; • General and reference → Experimentation; Evaluation; Performance.

Additional Key Words and Phrases: assistive technology, assistive mouse controller, upper limb disability, wearable sensors, pointing device

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1 INTRODUCTION

Upper limb disability refers to the complete or partial loss of motor capability of the upper limb, potentially caused due to — stroke [23, 49, 66, 85], spinal injury [11, 20], cerebral palsy [27, 40, 61, 71], Amyotrophic Lateral Sclerosis (ALS) [28, 73], deformation of limbs at birth [10, 16], amputation [39, 75, 78], etc., significantly reducing the utilization of the upper limbs in various motor tasks. The under-utilized residual capabilities [35] of the disabled upper limb might hamper the lives of those affected in terms of both activity limitations and participation restrictions [58]. For example, in patients with ALS, disability is characterized by motor dysfunctions while the brain and eye functionalities remain preserved [9, 12, 19, 28, 42]. However, the same cannot be said for the motor capabilities of upper limb amputees [78], as they are limited by their amputated body part(s). Research has shown that, unlike a normal person, the residual sensory abilities of disabled individuals intensify over time, compensating for their lost ability [5, 62, 70, 72, 76]. Eventually, they learn to utilize these abilities to accomplish different tasks in their daily lives [33, 55, 65, 86]. Although physically capable individuals can seamlessly use generic handheld pointing devices (e.g. an optical mouse) for interacting with a computer, people with upper limb disability require Assistive Mouse Controllers (AMC) as an alternative input modality for the same [35]. However, the usability and performance of such systems must meet a minimum standard to be suitable for practical, everyday applications.

The ISO 9241-11 states the usability of any system or device as, “the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use” [37]. Researchers have analyzed the feasibility and usability of different gestures and sensor technologies for developing Vision-based [1, 7, 38, 48, 77, 81, 92], Electromyography (EMG)-based [13, 31, 64, 67], Electrooculogram (EOG)-based [12, 17, 42, 80], and Wearables Sensor-based AMCs [25, 30, 67, 84] to make computers accessible to individuals with upper limb disability. However, a particular AMC technology may be convenient for people with a certain disability only. For example, eye movement is one of the residual motor capabilities of patients with ALS [9, 12, 19, 28, 42]. Intuitively, vision-based, EMG-based, or EOG-based AMCs may be more appropriate for them compared to those exploiting head motion sensing technologies [35]. While the existing AMCs try to cater to different needs, they face limitations such as but not limited to — sensitivity to lighting conditions, frequent calibration needs, noise interference, hygiene concerns, and unreliable performance in fluctuating environments, highlighting the need for more user-friendly and robust alternatives. Hence, the design, development, and evaluation of alternative input modalities to facilitate computer interaction for individuals with upper limb disability is still of interest to the research community [58]. Along with that,
the importance of analyzing the comparative performance, usability, and feedback of such an AMC from the users’ point of view cannot be overemphasized [45].

Throughout this study, we conducted a comparative analysis of the performance of Auxilio [35], a prototype of a sensor-based head-mounted wireless AMC for people with upper limb disability that tries to address some of the aforementioned limitations and shortcomings, against Smyle Mouse [1, 48, 77], a commercially available and patented camera-based AMC in similar pointing tasks. Auxilio combines low-cost Commercial Off-The-Shelf (COTS) Inertial Measurement Unit (IMU) for controlling mouse cursor with absolute head movements and infrared sensors for actuating mouse clicks with cheek muscle twitches. On the other hand, Smyle Mouse uses a camera to track head movements to control a mouse cursor and detect a user’s smile to register mouse clicks. Smyle Mouse offers a separate UI that allows the users to choose the type of event to be registered (left-click, right-click, double-click, drag, etc.) with a smile. We acknowledge that comparing Auxilio against another sensor-based head-movement-controlled AMC would have been ideal. However, despite our best efforts, we were unable to procure any such AMC in our locality. Hence, we compared it against the Smyle Mouse, which is similar from the perspective of input modality and is a recognized commercially available, and patented system.

Using these AMCs, a within-subject Point and Click experiment involving 10 participants without any motor impairments was conducted featuring a balloon-popping game, Popper [34]. We believe that since Auxilio is fairly new to the domain of AMC technologies, its performance, usability, and design limitations need to be analyzed before it can be made available to its stakeholders. As evaluation involving individuals with upper limb disability is resource intensive and might have restrictions from legal perspectives, we decided to carry out our initial investigation involving participants without any motor impairment. Furthermore, we investigated the usability of Auxilio in comparison with Smyle Mouse, leveraging the System Usability Scale (SUS) [8, 22, 24, 37, 43, 44]. We followed it up with a qualitative analysis of the interview transcripts of the participants to find strengths, weaknesses, and future directives for similar AMCs. To the best of our knowledge, this work is the first of its kind in the literature.

In summary, the main contributions of this study in the domain of accessibility to computer interaction for the physically disabled community are as follows:

(a) We evaluated the feasibility and performance of Auxilio in comparison to the Smyle Mouse, a patented, camera-based head-tracking AMC, through controlled pointing tasks.
(b) We conducted a comparative usability analysis of both AMC technologies using the System Usability Scale (SUS) to highlight the usability challenges and advantages of each of them.
(c) We carried out a qualitative analysis of user feedback to identify key strengths and limitations of the two AMC types, providing recommendations and distilling design guidelines for similar AMC development.

2 RELATED WORKS

The recent technological advancements have shaped the design, and development of Assistive Mouse Controllers (AMCs) for physically challenged individuals into a prominent research area [38]. Interaction data from such individuals may be recorded either using computer vision, Electromyography (EMG), Electrooculogram (EOG), or wearable sensors. In this section, we elaborate on the existing state-of-the-art AMCs and justify our scope and motivation behind this study.
2.1 Vision-based AMCs

Existing vision-based AMCs in the literature leverage facial or eye gaze features, collected from real-time video feeds using an eye tracker, webcam, or other imaging sensors, and map eye gaze to screen coordinates for cursor control. However, the user’s eye gaze needs to be calibrated before use. For mouse click actuation, dwell-time-based mechanisms or gestures such as — eye wink, blink, or smile are among the common ones. Among the many studied works, researchers have developed Smyle Mouse [1, 48, 77] that uses a generic webcam to register users’ head movement through nose tracking for cursor movement and smile gestures for registering mouse click events. The system offers a calibration phase where a user has to perform a series of gestures as instructed via a UI before actual usage. By default, the smile gesture actuates a left mouse click. However, a user can customize the event (left-click, right-click, double-click, drag, etc.) to be triggered with the gesture from a separate UI. Apart from the smile gesture, the system also offers dwell-time-based click mechanism. Zhang et al. [92] have developed a software-based AMC leveraging eye gaze tracking with an eye tracker to control the mouse cursor movement and dwell-time-based clicking method via a virtual UI for Mouse/Keyboard simulation. The authors have evaluated their works through two experiments, a searching task, and a web browsing task, utilizing Technology Acceptance Model (TAM) and System Usability Scale (SUS). Apart from eye gaze tracking, researchers have also leveraged nose tracking for cursor control [38]. As opposed to eye trackers or webcams, optical mouse or imaging sensors have also been used to track eye gaze for cursor movement [7, 81]. However, a potential drawback of optical mouse sensors is the requirement of an additional light source to work properly, as demonstrated by [7, 81]. Concerning the methods used in the aforementioned works, virtual interface-based methods for making computers accessible to the physically disabled are popular in the literature [26, 36, 83]. Although common, in practice dwell-time-based click actuation suffers from unwanted actuation of mouse clicks due to eye gaze fixation, generally known as the Midas Touch problem [32]. To address this issue, researchers [93] proposed a muscle or eyebrow shrugging-based click actuation technique, implemented through the software packages Camera Mouse [6, 54] and ClickerAid [53]. Furthermore, Rajanna et al. [68, 69] have also developed a system for people with arm or hand impairment that uses eye gaze for pointing at a screen element while selection is actuated by exerting pressure on a pressure sensor-based footwear.

A critical requirement for vision-based AMCs to work properly is to ensure proper lighting conditions for calibration and accurate detection of facial [26, 36, 38, 83] or eye gaze [7, 81, 92] features. For eye gaze-based AMCs, gaze tracking may be challenging due to image resolution, different lighting conditions, the user’s dependency on eyeglasses due to poor eyesight, and even the user’s skin complexion. In addition to that, human eyes are not the most accurate pointing device [4]. Moreover, a human can only gaze at a single point at a given time, preventing the user from looking at another region of interest without moving the mouse cursor. Most importantly, since eyes are used for both cursor movement and click actuation, users might find it difficult to execute both actions simultaneously when required, for example, dragging an item. As stated earlier, a particular problem with dwell-time-based click actuation is the Midas Touch problem [32], resulting in unwanted selection of UI elements. Another disadvantage of vision-based AMCs is that existing eye trackers and webcams can not detect and track a user’s eye gaze beyond a particular distance from the PC or workstation, forcing the user to maintain a particular distance from the PC or workstation.

2.2 Electromyography (EMG)-based AMCs

Electromyography (EMG) signals refer to the measurement of very low electric potentials generated due to muscle contractions with electrodes placed noninvasively on the skin, where the signal amplitudes are proportional to the
exerted muscle force [59]. For people with upper limb disabilities, EMG signals can be retrieved from the contraction of the residual muscles [60], which can then be used to determine the type of intended motion. Researchers have explored the feasibility and performance of a myoelectric cursor control for amputees with the help of a myoelectric armband [31]. However, before the device could be used for mouse cursor control, the users had to go through a training phase for device calibration and preparation for the subsequent test phase, aided by a guided UI-based calibration method.

For making computers accessible to people with high-level spinal cord injury, researchers in [64] have proposed two cursor control methods, auto rotate and manual rotate, using a single-site surface EMG sensor. However, the proposed method requires the usage of disposable Ag/AgCl center snap electrodes, which makes it a hindrance for daily tasks. The aforementioned work was evaluated through a pointing task-based experiment utilizing Fitts’ law.

EMG signals are susceptible to external noises and are highly dependent on the exact and accurate placement of electrodes [18] for accurate gesture recognition. One of the inherent problems of EMG technology is that the retrieved signals are typically weaker and vary from person to person [79], thereby, requiring a user-specific device calibration and gesture recognition, every time a user intends to use it as an AMC. Although deep learning techniques [13] have been proposed for mitigating the need for user-specific device calibration and gesture recognition, the computational expense for fulfilling the simple objective of an AMC seems unreasonable.

2.3 Electrooculogram (EOG)-based AMCs

An Electrooculogram (EOG) is used to measure the corneal-retinal Transepithelial Potential Difference (TEPD) with the help of noninvasive electrodes placed around the human eyes. TEPD is produced due to horizontal and vertical movements of an eye [17, 19, 80], which can be utilized to implement mouse control and clicking mechanisms. However, TEPD is likely to fluctuate in different lighting conditions, making light adaptation and training an integral part of EOG-based AMCs. EOG-based AMCs that leverage eye movements to extract relative gaze position on the screen have been proposed [41, 47, 50, 82, 87], facilitating interaction with a computer for people suffering from neurodegenerative disorders. To facilitate typing through recognition of eye movement patterns, real-time EOG-based systems have been developed [12, 21, 29, 42, 63, 89] for people with ALS, which is a neurodegenerative disorder that does not affect the brain functions or the eye movements. Such nature of the disease makes EOG-based systems best suited for people suffering from it [9, 19].

Although EOG is a promising low-cost AMC technology that is still being researched, it is limited by its low spatial resolutions, as it is difficult to estimate the absolute gaze position due to noise from nearby sources of bio-potentials [12, 50, 51]. Apart from the high pre-processing complexities of EOG signals [51], their characteristics vary due to the variation in the number, the type (dry or wet), the material, and the placement of electrodes [29, 42, 46, 50, 51, 63]. Finally, from an ergonomic perspective, it is intuitive that continuous eye movements for controlling a mouse may pose certain health issues, thereby, affecting the user’s performance and comfort.

2.4 Sensor-based Wearable AMCs

Apart from Vision, EOG, and EMG–based AMCs, sensor-based wearable AMC technologies have also been developed for assisting people with upper limb disabilities, leveraging their residual motor functionalities as alternative input modalities. Among these alternatives, head movement is a natural, effective, and the most common modality for moving a cursor [25, 30, 35, 67, 84]. Other alternatives include but are not limited to tongue muscle movement [56], and Brain Computer Interfaces (BCI) [57].
Authors of [35] have developed a head-mounted wireless AMC for people with upper limb disability. The AMC utilizes absolute head movements and cheek muscle twitches for cursor control and mouse click actuation, respectively. Commercially available low-cost Inertial Measurement Unit (IMU) combined with infrared sensors were used for detecting head movements and cheek muscle twitches, respectively. The device was designed to allow the stakeholders to move the cursor around the screen with only $\pm 15^\circ$ head rotations horizontally and vertically from an ergonomic viewpoint. Velasco et al. [84] have developed an AMC for people with cerebral palsy, where the subjects can move the cursor through their head movements. They proposed a pointing facilitation algorithm, MouseField, which allows UI elements to have some sort of gravitational effect on the cursor. They had designed a video game, featuring pointing tasks, which had to be played with and without the MouseField algorithm in action for testing their technology. Most of the studies [25, 67, 84] involving head movement detection for cursor control, have used head-mounted Inertial Measurement Sensors (IMUs) for tracking 3D head movement. However, Gorji et al. [30] have used Infrared (IR) sensors mounted inside a collar, which is wearable on the user’s neck below the chin level, for measuring the user’s range of head tilt motion. For cursor movement, they have designed two separate modes, such as the joystick mode and the direct mapping mode, which require unique calibration phases before the cursor can be controlled. In the joystick mode, the cursor is set to move horizontally and vertically at a specific speed, while the sensor data are used to determine the direction of movement. On the other hand, in the direct mapping mode, the data from the IR sensors are mapped directly to the cursor position on the screen. For both of these modes, they conducted two experiments that involved - 1) moving the cursor following a predefined path on the screen, and 2) guiding the cursor within a predefined location on the screen and evaluating user performance using Fitts’s law. For mouse click actuation using wearables, different approaches that are either dwell-time-based [84], EMG-based [67], or BCI-based [25, 57], have also been explored in the literature. In addition to these approaches, researchers have also leveraged various residual motor capabilities for actuating mouse clicks. For example, authors in [74] have used flex sensors for detecting cheek muscle twitches, whereas tongue muscle was used for clicking a joystick, embedded in a user-specific mouth retainer in [56]. Yamamoto et al. [88] studied the feasibility of a wearable and stretchable strain sensor as a click actuation device through a single case study involving a user with mixed types of cerebral palsy.

Existing state-of-the-art wearable devices suffer from a few limitations. For instance, the device in [56] requires placement of the device inside a user’s mouth through a retainer, raising health and hygiene issues, as well as probable fatigue of tongue muscles from repeated and prolonged usage. Due to the unrealistic setup of the IR sensors [30], the sensor readings are susceptible to fluctuations from changes in lighting conditions, bringing the performance of the device into question. Moreover, the calibration phase in their proposed device requires a user to perform certain training movements, which may compromise the ease of use of the device. Furthermore, in scenarios that require rapid movements of the mouse cursor, their device may not be a viable option. Again, the device proposed by Yamamoto et al. [88] can not be used by individuals with amputated or disabled upper limbs.

In light of the above discussions, a new sensor-based AMC can address several limitations in existing technologies. Vision-based AMCs often face challenges with lighting conditions, calibration, and the “Midas Touch” problem in dwell-time-based click mechanisms. Similarly, EMG and EOG-based systems suffer from external noise, complex calibration, and low spatial resolution. Wearable sensor-based AMCs, while promising, often require intrusive setups or cumbersome calibration processes. A non-intrusive, head-motion-controlled AMC using IR sensors for clicks can offer a more intuitive, less invasive, and less intrusive solution, improving usability and reducing calibration complexity. Taking the aforementioned limitations into account, the helmet-shaped working prototype of Auxilio, as shown in Figure 2, was developed. It is the first of its kind that combines IMU for capturing head motions for controlling a mouse.
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cursor and infrared sensors for detecting cheek muscle twitches for actuating clicks. It aims to resolve some, if not all the limitations of the existing AMC technologies. To the best of our knowledge, no studies have so far conducted a comparative analysis of the user performance in pointing tasks with such a device and its usability in comparison with an existing one, which could lead to the understanding of the requirements and design guidelines for similar devices in the future. In the next section, we elaborate on our methodology, followed by the experimental results and a discussion of our research findings.

Fig. 2. Prototype of Auxilio, a sensor-based head-mounted wireless Assistive Mouse Controller (AMC) that uses absolute head movements for mouse cursor control and cheek muscle twitches for mouse click actuation using an Inertial Measurement Unit (IMU) and infrared sensors.

3 DEVICE WORKFLOW

Based on the working principle proposed in [35], the workflow of Auxilio is summarized in Figure 3. Auxilio is designed for individuals with upper-limb disabilities. It consists of a transmitter unit, resembling a helmet, equipped with motion and IR sensors, a microcontroller, wireless communication, and an adjustable head-strap for comfort. An Inertial Measurement Unit (IMU) detects head movements (yaw and pitch) to control cursor movement within ergonomic limits. Infrared sensors, placed on an adjustable visor, detect cheek twitches for left and right mouse clicks. A receiver unit connects to a PC, mapping transmitted data to system-level calls for controlling the mouse via a driver. The driver is also capable of detecting special gesture messages, which can trigger specific actions like connecting or disconnecting the control of the pointer. Calibration is performed at startup, and gesture controls allow toggling the device’s functionality.

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4 METHOD

In Human-Computer Interaction (HCI), a pointing task is considered as the user interaction for selecting any element on a user interface with any pointing device such as a mouse, stylus, trackpad, finger, or any other wearable device [34]. This study was designed to evaluate and compare users’ interaction in pointing tasks while using Auxilio [35] against a state-of-the-art AMC. As a representative of such systems, we opted for Smyle Mouse [1, 48, 77], a commercially available and patented camera-based head-tracking mouse, as it only requires a generic webcam for interaction and offers a trial version with a validity of 15 days which was sufficient for our objective. Furthermore, we employed the System Usability Scale (SUS) questionnaire [2, 8, 45], a 10-item 5-point Likert scale-based closed-questionnaire, to analyze the usability of Auxilio in comparison with Smyle Mouse. The questionnaire adopted for this study is provided...
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in Appendix B. This section begins with the details of our experimental methodology, followed by results analysis and discussion sections.

Fig. 4. Snapshots of the game Popper – (a) Player registration and game instruction screen, (b) Resting period in the form of a reward screen between levels for reducing fatigue, a particular level with (c) a static balloon of size 128px, and (d) a dynamic balloon of size 32px.

4.1 Participants

The target users for this experiment were individuals without any form of motor impairments of the upper limb. However, all of them were required to have basic computing knowledge. 10 individuals [7 males (70%, Mean Age: 27.71 ± 6.85 years), 3 females (30%, Mean Age: 25.67 ± 2.08 years)] were recruited for this experiment. All of them had adequate experience and knowledge of operating a computer. The participants were recruited from known acquaintances via email. They were notified about the automated data collection before their participation and were assured of no invasion of privacy on our part. Each participant provided written consent before they participated in this study. As a token of appreciation for their time and efforts, a remuneration equivalent to 4.20 USD in local currency was handed over to each of them at the end of the respective data collection session.

4.2 Experimental Design

We conducted a within-subject Point and Click experiment, featuring a balloon popping game, Popper [34], with both Auxilio and Smyle Mouse as AMCs without imposing any interaction constraints such as — extremely accurate, accurate, neutral, fast, and extremely fast [91]. The experiment had only one independent variable, the device being tested — Auxilio and Smyle Mouse. The dependent variables were the different performance metrics — Throughput, Miss Click
Rate, Target Hit/Miss Rate for Dynamic Targets, Mean Target Re-entry, and Mean Path Efficiency. We allotted around 35–50 minutes per participant during which they were briefed about the objective of this experiment, the semantics of the game *Popper*, and the interaction mechanisms of each AMC. They had a few trial runs to familiarize themselves with the respective AMCs, followed by the experiment.

The experiments were performed in the same controlled environment for both the devices. Each participant played the entire game in fullscreen mode on a desktop with a screen resolution of $1920 \times 1080$ pixels using either Auxilio first, followed by Smyle Mouse, or vice versa. The sequence of device usage was alternated between every participant to enforce counter balancing. A brief resting period was allocated after each device interaction to reduce fatigue. The participants were presented with only one-at-a-time randomly-appearing 36 static and 36 moving or dynamic balloons of 4 different widths (32 px, 64 px, 96 px, and 128 px) as targets that they had to pop using a left mouse click inside it with respective AMCs. For the dynamic targets, a balloon would float upwards on the screen until it reached several spikes placed on top, causing the balloon to pop if the player failed to do so. We term each pop of a balloon as a *trial*. A *trial* began with the target appearance and ended with a successful pop action. In summary, Each participant was presented with 72 targets of various widths in total, half of which were static and the rest were dynamic. The game ended when all the targets were popped by a participant. The corresponding interaction data were collected for both devices per participant. A few snapshots of *Popper* have been provided in Figure 4. We also collected data on skin conductance, temperature, and heart rate using non-invasive sensors to assess potential physiological stress levels during the experiment. However, since those data did not reveal any significant variation, we did not incorporate their analysis in this article.

Following their interaction with the devices, each participant was asked to share their perceptions of the usability, the pros, and the cons of both AMCs through an unstructured interview, audio recordings of which were collected and analyzed later. Finally, they were asked to complete the SUS questionnaire (as provided in Appendix B) online to rate the various usability aspects of each AMC. Their responses (as provided in Appendix C and Appendix D) were later processed to analyze the usability of Auxilio in comparison with Smyle Mouse. It is important to note that we carried out the usability survey after the interview session to prevent the participants’ open opinions regarding their interaction with the AMCs from being influenced by the SUS questionnaire. This allowed us to get unbiased and natural insights into their experience with the AMCs.

### 4.3 Data Collection and Analysis

The data collected for analysis in this study consists of the participants’ interaction data from the game *Popper* for each AMC (Auxilio and Smyle Mouse) as a pointing device, the audio recordings of their unstructured interviews, and their responses to the SUS questionnaire. The interaction data per participant consists of parameters such as — *movement amplitude* ($A$), *target width* ($W$), *movement time* ($MT$), *cursor on and off count per target*, *straight-line distance* ($SLD$) *between the cursor and the target coordinates*, total mouse clicks, total miss-clicks, total targets hit, and total targets missed. Given a particular type of target, the parameter *cursor on and off count per target* was collected to get a measure of *Target Re-entry* (TRE) for each AMC, which is defined as the event when a mouse cursor enters the target region, then leaves, and re-enters again [52]. The interpretations of the recorded parameters are summarized in Table 1.

For a comparative evaluation of a user’s performance with different AMCs in pointing tasks with different indexes of difficulties ($ID$), the index of performance, also known as throughput ($TP$) [34, 90] is usually considered [14]. Once the data from this experiment for both AMCs were collected, we calculated the IDs for each task using Equation 1, where $A$ is the movement amplitude and $W$ is the target width [34]. The $TP$ of each participant in pointing tasks with
Table 1. Descriptive summary of the parameters collected per participant in the Point and Click experiment using Auxilio [35] and Smyle Mouse [1, 48, 77].

| Parameter                                      | Value(s)/Unit | Interpretation                                                                 |
|------------------------------------------------|---------------|---------------------------------------------------------------------------------|
| Movement Amplitude (A)                         | pixels        | Represents the length of the cursor trajectory as the movement amplitude (A) in Equation 1. |
| Target Width (W)                               | pixels        | Represents the width of a target (W) in Equation 1.                              |
| Movement Time (MT)                             | seconds       | Represents the time (MT) required to hit a target in Equation 2.                 |
| Cursor On and Off Count Per Target             | [I, O]        | The total number of times the cursor moved inside (I) and outside (O) a target’s boundary. |
| Straight-line Distance (SLD) between the Cursor and the Target Coordinates | pixels        | The Euclidean distance between the coordinates of the mouse cursor and the target. |
| Total Mouse Clicks*                            | n             | The total number of mouse clicks.                                                |
| Total Miss Clicks*                             | n             | The total number of mouse clicks outside a target boundary.                      |
| Total Targets Hit*                             | n             | The total number of targets (balloons) that were popped.                         |
| Total Targets Missed*                          | n             | The total number of targets (balloons) that were missed.                         |

* Total value at the end of the entire game Popper.

We then carried out a one-tailed unpaired t-test (α = 0.05, 9) between the users’ throughput with each AMC to analyze if the mean throughput of one AMC is significantly higher than the other given a particular type of target (static or dynamic). We also calculated and analyzed the miss click rates, target hit/miss rates for dynamic targets, mean target re-entry, and mean path efficiency for each pointing device (Auxilio and Smyle Mouse) to get an insight into the individual and/or the combined effect of the precision and stability of the cursor movement, and the effectiveness of the click mechanisms of each AMC on user performance for pointing at a target (static or dynamic) of a particular width (32px, 64px, 96px, and 128px). After analyzing the interaction data of the Point and Click experiment, we analyzed the participants’ responses to the SUS questionnaire [8], followed by transcription of the audio recordings of the unstructured interviews.

Based on the transcription of the interviews, we conducted a simple qualitative analysis to capture the strengths and weaknesses of both the devices from the participants’ point of view. A hybrid coding approach (predefined and emerging codes) was employed, with two raters discussing and reconciling differences in coding. We set some predefined codes based on the interviews and our prior experience. After dividing the transcripts into taggable units, two raters independently coded all the units. While coding, the raters were allowed to create any emerging code if necessary. After all the transcripts had been tagged, reconciliation of emerging codes was performed between the two raters, followed by the calculation of Cohen’s Kappa [15] measure for inter-rater reliability. Finally, based on the agreement of both the
raters, final tagged versions of the transcripts were produced. After that, the codes were merged to find out the major themes for each device based on the frequency of codes. Future suggestions for each device were also extracted from the transcripts.

5 RESULTS AND DISCUSSIONS

5.1 Point and Click Experiment

The analysis of interaction data of 10 participants with the game Popper as part of the within-subject point-and-click experiment offers new insights into the usability and the user performance in pointing tasks with Auxilio and Smyle Mouse as AMCs. Table 2 provides descriptive statistics of the task completion times and mean throughput of each device in pointing tasks for each type of target (static and dynamic) considered in this experiment. A two-tailed $F$-test revealed that the throughput varies insignificantly ($\alpha = 0.05$) for both static and dynamic targets for both devices ($F_{\text{Static}}(9, 9) = 1.9755, p = 0.3250$ and $F_{\text{Dynamic}}(9, 9) = 3.6096, p = 0.0694$). However, the mean throughput of users with Auxilio ($\overline{TP}_{\text{Auxilio}} = 0.9315$ bps) in dynamic targets was found to be significantly higher than that with Smyle Mouse ($\overline{TP}_{\text{Smyle Mouse}} = 0.6654$ bps), as verified by a one-tailed unpaired $t$-test with $\alpha = 0.05$ ($t_{\text{Dynamic}}(9) = 3.3641, p = 0.0024$). The same for the static targets ($\overline{TP}_{\text{Auxilio}} = 0.8671$ bps, $\overline{TP}_{\text{Smyle Mouse}} = 0.7489$ bps) was insignificantly different at the same level of significance ($t_{\text{Static}}(9) = 1.5340, p = 0.0723$).

Table 2. Descriptive statistics of the task completion times and throughput in the Point and Click experiment using different pointing devices.

| Target Category | Pointing Device | Tasks (n) | Task Completion Time (seconds) | TP (bps) |
|-----------------|-----------------|-----------|--------------------------------|----------|
|                 |                 | Mean      | SD    | Min      | Max      | Mean TP | $t(0.05, 9)$ |
| Dynamic         | Auxilio         | 360       | 8.5272 | 9.9313   | 0.7970   | 59.063  | 0.9315  |
|                 | Smyle Mouse     | 360       | 13.0633| 12.2990  | 1.1720   | 60.9690 | 0.6654  |
| Static          | Auxilio         | 360       | 6.4358 | 5.8687   | 0.5780   | 46.5000 | 0.8671  |
|                 | Smyle Mouse     | 360       | 8.3471 | 9.6888   | 1.2820   | 115.063 | 0.7489  |

* $p$-value is significant at $\alpha = 0.05$.

The participants reported that the mouse cursor oscillated in Auxilio even without any head movements, making it difficult to pinpoint and click simultaneously on small targets compared to Smyle Mouse. This oscillation increased their miss-click rates, mean target re-entry, and in some cases their task completion time. No significant inconsistencies in the click detection mechanism of Auxilio were reported. However, they mentioned that although pinpointing was easier with Smyle Mouse due to stable cursor movement, the system failed to recognize mouse click events frequently, inflating their task completion time (both static and dynamic targets) and target miss rates (dynamic targets only). These claims can be verified from the box plots of task completion times with the devices, as shown in Figure 5, and the bar charts of the miss click rates, mean target re-entry, and the target hit/miss rates for dynamic targets grouped by target widths for both devices and targets, as shown in Figure 6a, Figure 6c, and Figure 6b, respectively.

Based on Figure 5, Figure 6a and Figure 6c, the wider range of task completion times and the higher values of miss click rates and mean target re-entry with Auxilio for 32-pixels-wide static targets provides substantial evidence of mouse cursor oscillation that made it difficult to pinpoint and click simultaneously within small target boundary. However, a decreasing trend can be observed for all these parameters with increasing target width for both static and dynamic targets. This suggests that the mouse cursor oscillation in Auxilio may be compensated with targets of optimal width,
allowing users to successfully click on a target while reducing the *miss click rates* and *mean target re-entry* with a reasonable task completion time. On the other hand, if we observe the reduced *mean target re-entry* (< 1.5) for Smyle Mouse, as shown in Figure 6c, it may be inferred that the cursor movement in Smyle Mouse was indeed stable, unlike Auxilio. Again, close observation of the box plot of task completion time for static targets using Smyle Mouse, as shown in Figure 5a, reveals that even with a 128-pixels width, it took more than 10 seconds to hit a static target (balloon). In some cases, it took even more than 30 seconds (64px and 96px targets) to pop a target, and 115 seconds (32px targets) in the worst case, without any underlying trend. This validates the anomalies in the click detection mechanism of Smyle Mouse. On the contrary, though the mouse cursor movement in Auxilio exhibited unwanted oscillation, its click detection mechanism was far superior to Smyle Mouse. This can be further validated by the inflated *miss-click rate* for both static and dynamic targets having a decreasing trend with an increase in target width for Auxilio. The qualitative analysis carried out later also supports this claim. Interestingly, the *mean path efficiency* of both AMCs never exceeded 55% regardless of the type of target (static or dynamic) and the target width (32px, 64px, 96px, 128px). Although the cursor movement in Auxilio is sensitive and continuous, as seen from the movement heatmaps in Appendix F, the involuntary oscillations in the cursor’s movement may have contributed to a reduced *mean path efficiency*. However, for Smyle Mouse, this could be due to its discrete cursor movement mechanism, as seen from the movement heatmaps in Appendix F. These findings from the interaction data of this experiment provide substantial evidence of the superior usability of Auxilio compared to Smyle Mouse, which will be further analyzed in the next section using the System Usability Scale (SUS).

### 5.2 System Usability

In this analysis, we investigated the users’ standpoint on the usability of Auxilio, leveraging the System Usability Scale (SUS). SUS employs a 10-item closed-questionnaire-based approach to quantify the subjective assessments of the usability of any system or device on a 5-point Likert scale as a single number between 0 and 100. However, the
degree of usability (poor or good) of a system or a device cannot be interpreted from that score alone [8]. As a solution, letter grades (A+, A, A−, etc.) are assigned to this score based on empirical evaluation of various studies related to SUS [2, 45], A+ being the highest grade of usability. From the user ratings of the devices used in this study, as summarized in Table 3, it was observed that the SUS scores of Auxilio ranged between 70.00 and 92.50, whereas for Smyle Mouse, it ranged between 30 and 92.50. The mean SUS score (out of 100) of Auxilio was about 78.75 and that of Smyle Mouse was 48.75, achieving an overall rating of B+ and F, respectively. According to the literature [3], the overall adjective usability rating of Auxilio is Good and that of Smyle Mouse is Awful.

However, the perception of device usability is subjective, and therefore, not every user will perceive its usability in the same way [45]. For instance, only about 10% of the participants expressed their interest in using Smyle Mouse frequently, whereas 10% expressed their reluctance to use Auxilio frequently. Similarly, while all the participants agreed on the simplicity of the interaction mechanism of Auxilio, 70% of them disagreed on the same for Smyle Mouse. Details of the participants’ responses to the SUS questionnaire have been provided in Appendix C and Appendix D.
Table 3. Results of usability analysis of Auxilio [35] and Smyle Mouse [1, 48, 77] using the System Usability Scale (SUS) [8].

| Respondent | Auxilio | Smyle Mouse |
|------------|----------|-------------|
|            | SUS Score | Grade | SUS Score | Grade |
| R1         | 92.50     | A+     | 92.50      | A+    |
| R2         | 85.00     | A+     | 82.50      | A     |
| R3         | 85.00     | A+     | 40.00      | F     |
| R4         | 87.50     | A+     | 32.50      | F     |
| R5         | 52.50     | D      | 45.00      | F     |
| R6         | 70.00     | C      | 32.50      | F     |
| R7         | 82.50     | A      | 65.00      | C     |
| R8         | 70.00     | C      | 30.00      | F     |
| R9         | 72.50     | C+     | 30.00      | F     |
| R10        | 90.00     | A+     | 37.50      | F     |
| Mean       | 78.75     | B+     | 48.75      | F     |
| SD         | 12.32     |        | 23.01      |       |

5.3 Feedback and Observation

The qualitative analysis of the participant interviews helped us find qualitative insights into each of the devices. After reconciling the emerging codes, Cohen’s Kappa measure was found to be 0.72 for around thirty codes in each category, indicating a substantial inter-rater reliability [15]. Summary of the themes, codes, and their respective frequency is presented in Appendix E. The analysis aimed to complement the experimental findings by identifying key themes related to user experiences, strengths, and weaknesses of each of the devices, followed by potential design directives for similar devices in the future.

In the case of Auxilio, the analysis revealed six prominent themes.

1. **Ease of Use and Deterministic Behavior**: One of the main strengths of Auxilio comes from its ease of use and persistent and easy calibration. One of the participants, P4 reported, “The calibration in Auxilio was easy, user friendly, and consistent throughout the session”. Another major strength is the deterministic behavior of Auxilio, enabling participants to infer the state of the system at any moment and act accordingly, as reported by P2, “Both devices required neck movements. For Auxilio, neck movements are certain, I know exactly how much to move. But I could not map myself in the case of Smyle Mouse”.

2. **Difficult Precise and Static Pointing**: The main weakness of Auxilio comes from perhaps the inability to keep the cursor static at a single point as it is directly bound to the head movements of the user, which results in small oscillations and difficulty while trying to hit small targets. According to P2, “The mouse cursor had jittery movements while trying to pinpoint on the smaller (32px) targets. It was in the periphery, but it was still moving. Pinpointing and clicking on even smaller targets would have been a problem.”

3. **Ergonomics, Cognitive Load, and Comfort**: The overall design of Auxilio was mostly appreciated by the users with a few suggestions discussed later. As stated by P7, “I did not face any strain while moving my head using Auxilio”, and P2, “Mental load was lower in Auxilio, as the pointer movement was bound to exact head movements”.

4. **High Responsiveness**: As indicated by the experimental results, the main reason Auxilio performed better than Smyle Mouse in the dynamic target tasks is due to its high responsiveness for both clicking and mouse cursor
movements. In this regard, participant P8 stated, "In Auxilio, after the mouse calibration, the cursor always returned to the screen center when I wanted to recenter it. The cursor followed whichever direction I intended to move it with my head movement. I never had to move my head to an extreme angle to move the cursor with Auxilio."

(5) **Adaptability:** Based on the interviews of some of the participants, Auxilio, specially for clicking, had some initial learning curves. However, it was easy to adapt as all the participants got accustomed to it by the end of their respective sessions. Based on the statement of P2, "Clicking in Auxilio at the beginning required coping up with cheek muscle movement. I had to practice it a couple of times. After learning, it was ok."

(6) **Discomforts:** Few participants reported some discomfort while using Auxilio. The majority of the comments were about the large visor of the device, which in some cases, obstructed part of their peripheral vision, creating uneasiness. Participant P3 reported, "However, the current design of the device features a visor-like mechanism which I felt blocked my view sometimes".

On the other hand, analysis of the interviews for Smyle Mouse pointed to four prominent themes.

(1) **Performance and Calibration Issues:** The greatest issue of Smyle Mouse was with its inconsistent performance and the requirement of frequent recalibrations. Despite the initial calibration of the mouse cursor, it lost mapping with the face orientation over time and the participants were continuously struggling to make up for that. As a result, patterns of continuously dragging the cursor towards the different screen edges can be seen from the heatmaps in Appendix F. According to P8, "Using the Smyle Mouse was a bit stressful for me because, if I moved my head to extreme left/right, the cursor would not return to the exact center. To recenter the cursor, I had to move my head very fast in the opposite direction." The smile detection algorithm of the Smyle Mouse is also prone to drifts and it is inaccurate. It caused the greatest dissatisfaction among the users and combined with the cursor drift and dynamic targets, it resulted in serious difficulties in detecting clicks after a moment and became almost impossible to invoke clicks from extreme angles. According to P6, "I felt the calibration of the Smyle Mouse drifted overtime during the session; it did not register click events". Another complaint was about dynamic target tracking. Smyle Mouse relies on discrete movements to keep the cursor static at a point, as seen from the movement heatmaps in Appendix F. However, the same design choice made it difficult to continuously track dynamic targets. According to P1, "But it can also become a problem when you are trying to do small movements using your mouse, specially for dynamic target tracking, when you need to make small adjustments to your cursor position. This is difficult to do because of how the cursor moves (discrete movements)". As a whole, it resulted in a non-deterministic and inconsistent system.

(2) **Ergonomic Issues, Cognitive Load, and Physical Discomforts:** The overall performance problems with Smyle Mouse translated to ergonomic issues and higher cognitive load. It required a substantial amount of head and neck (for cursor) and jaw muscle movement (for clicking via smile), resulting in increased physical stress. P8 commented, "Due to the rapid movement of my head, although I did not experience any pain, my neck felt stiff after using the Smyle Mouse for a while which was stressful. Due to the fact that I had to move my head to an extreme angle frequently while using the Smyle Mouse, it was difficult to look at the screen from that angle". Moreover, the continuous struggle to re-calibrate the cursor and make up for inconsistency resulted in a higher cognitive load as well. In this regard, P2 stated, "The problem with the Smyle Mouse was that it required calibration before every click, resulting in higher mental load".

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(3) **Design and Learnability Issues**: Relying on a camera-based setup makes the Smyle Mouse inherently difficult to control at extreme angles and works properly only within a constrained area. However, the issue with drifting makes the mouse continuously succumb to this problem. According to P9, “I had to move my head to an extreme angle when I wanted to move the cursor to an extreme point on the screen occasionally. The Smyle Mouse failed to recognize my smile.” Along with that, the initial calibration of the Smyle Mouse was reported as difficult to understand, resulting in learnability issues. However, few participants did find the clicking and calibration of the Smyle Mouse to be easy.

(4) **Stable Static Pointing**: While the Smyle Mouse suffers from many issues, it has one advantage over Auxilio. Due to the discrete nature of mouse pointer movement, it was easier to hit smaller (32px) static targets with the Smyle Mouse compared to Auxilio as depicted by the lower value of mean task completion time in Figure 5. In this regard, P7 commented, “In the case of the Smyle Mouse, I felt that pinpointing was more accurate as the cursor did not have any jittery movement”.

### 5.4 Design Guidelines

Based on the pointing experiment, system usability, and qualitative analysis of the strengths and weaknesses of both the devices in subsection 5.3, we can recommend some basic guidelines for the design of similar AMCs in the future.

1. When an AMC is being designed, it must be easy to use and learn. The device should have an easy, consistent, and persistent calibration. Along with that, the calibration should never drift with time or position.
2. One pivotal factor for creating an easy-to-use device is to have a highly responsive and deterministic behavior for the device. The clicks and movements of the device should register quickly without miss, and must not cause fatigue over time.
3. The device should not have any severe restrictive constraints, both environmental and user action-wise. For instance, a device that fails to work under low light, or requires the user to sit in a specific posture or at a specific distance, or restricts limb movement within a certain range can result in user dissatisfaction and stress.
4. Moreover, the designers need to be careful about the ergonomic factors and cognitive load of the device. It should not require movements that humans are either not used to or might cause stress in the long run.
5. Designing a pointing system that can both be static while required, and be highly responsive and continuous when tracking moving targets is crucial to a good AMC design. While there is a trade-off between these two based on whether absolute or relative movement is being used and the algorithm employed for smoothing, the designers should strive to create a balance which is suitable for the intended users.
6. It also brings to the point that the UI of an operating system or application can be improved to make it further accessible by avoiding small buttons and introducing accessibility features like gravitational fields and control snapping [84].
7. Finally, the physical design of the device must not be obtrusive or bulky, and the users should not feel discomfort from prolonged usage.

Along with the guidelines derived from the device analysis, we also received some valuable feedback from the users about device improvements. Focusing on users suffering from neck pain, P2 suggested, “Another possible area of improvement can be for people suffering from neck pain or disabilities, such as cervical disk prolapse. Their movement can be stiff in a specific direction. So, personalization or adaptation in the very beginning with the help of a training can be used to map the cursor. It can be adjusted and learned to improve based on performance. Having an adjustment factor...
could be helpful. After the initial adjustment, there could be further adjustments on-the-fly, while using the device." Another common suggestion was to test the devices in prolonged use cases. During the interview, P1 emphasized, "Having a longer session spanning hours might be more accurate to test out whether it would be viable for prolonged use or not".

One more suggestion for such devices would be to introduce different gestures as shortcuts for commonly used actions, such as connecting or disconnecting the device. Furthermore, the drivers for the software should have customization options to tune the cursor speed, swapping left and right clicks, etc. While Auxilio has these abilities, the Smyle Mouse could not support such features properly because of its design.

6 LIMITATIONS AND FUTURE WORKS

This study involved a small sample of 10 participants, which provided valuable insights but may limit the ability to generalize the findings. Expanding the study to include a larger and more diverse group of participants in the future could offer a deeper and broader understanding of user experiences and improve the reliability of the results.

Moreover, the study was limited to basic pointing and clicking tasks, which, while important, represent only a part of the full functionality of a modern computer mouse. Tasks like dragging, dropping, scrolling, and zooming were not evaluated but are key to understanding the overall capability of these devices. Future research should explore these additional tasks and how they impact user experience. Additionally, an AMC might require specialized gestures as shortcuts for common activities to improve the overall user experience. Design and evaluation of such gestures can be a significant topic of study.

Furthermore, we did not assess the long-term and extensive use of the devices. Understanding how these AMCs perform over extended periods, including their impact on learnability, memorability, and user comfort and fatigue, is crucial. Longitudinal studies would help reveal how well the devices hold up under prolonged use and whether any issues arise over time.

Additionally, our study focused only on AMCs developed for users with upper limb disabilities. However, many users may have multiple or coexisting disabilities that could affect how the device is used. Future studies should consider users with other disabilities, such as visual or cognitive impairments, to ensure the design of AMCs is more inclusive and accessible to a wider range of users.

Finally, as assistive technologies evolve, there is an opportunity to explore how AMCs could use artificial intelligence or machine learning to adapt to individual user preferences. Future work could investigate how these devices might personalize their functions over time, improving both user satisfaction and performance.

Addressing these limitations will help develop more comprehensive design guidelines for Auxilio and similar head-mounted AMCs, making them more effective and accessible for a diverse range of users in everyday contexts.

7 CONCLUSION

In this study, we compared the performance of Auxilio, a sensor-based head-mounted mouse, with Smyle Mouse, a commercially available, patented vision-based device. Both devices offer similar input modalities and are designed for individuals with upper limb disabilities. Our pointing experiment showed that Auxilio generally outperformed Smyle Mouse, except when targeting the smallest static objects, proving its feasibility and highlighting the areas for improvement in Auxilio’s design. Auxilio also received a higher score on the System Usability Scale (SUS), suggesting greater practical usability. Finally, both of these analyses combined with the qualitative study of the participant interview transcripts allowed us to find out the strengths and weaknesses of the devices from the perspective of the users. By
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further distilling this knowledge, we were able to propose potential design guidelines and future directives for creating better AMCs for the upper limb disabled community. We believe that our effort would inspire and assist further research and innovation in developing more effective and inclusive assistive devices for this community.

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REFERENCES

[1] Jeffrey P. Bakken, Nivee Varidireddy, and Vladimir L. Uskov. 2019. Smart University: Software/Hardware Systems for College Students with Severe Motion/Mobility Issues. In Smart Education and e-Learning 2019. Vladimir L. Uskov, Robert J. Howlett, and Lakhmi C. Jain (Eds.). Springer Singapore, Singapore, 471–487.

[2] Aaron Bangor, Philip Kortum, and James Miller. 2009. Determining what individual SUS scores mean: Adding an adjective rating scale. Journal of usability studies 4, 3 (2009), 114–123.

[3] Aaron Bangor, Philip Kortum, and James Miller. 2009. Determining what individual SUS scores mean: Adding an adjective rating scale. J. Usability Studies 4, 3 (2009), 114–123.

[4] Richard Bates and Howell O Istance. 2003. Why are eye mice unpopular? A detailed comparison of head and eye controlled assistive technology pointing devices. Universal Access in the Information Society 2, 3 (2003), 280–290.

[5] Ceren Battal, Valeria Occelli, Giorgia Bertonti, Federica Falagardi, and Oliver Collignon. 2020. General enhancement of spatial hearing in congenitally blind people. Psychological science 51, 9 (2020), 1129–1139.

[6] Margrit Betke, James Gips, and Peter Fleming. 2002. The Camera Mouse: Visual Tracking of Body Features to Provide Computer Access for People with Severe Disabilities. IEEE transactions on neural systems and rehabilitation engineering : a publication of the IEEE Engineering in Medicine and Biology Society 10 (04 2002), 1–10. https://doi.org/10.1109/TNSRE.2002.1021581

[7] Frank H. Borsato and Carlos H. Morimoto. 2016. Episcleral surface tracking: challenges and possibilities for using mice sensors for wearable eye tracking. In Proceedings of the Ninth Biennial ACM Symposium on Eye Tracking Research & Applications (Charleston, South Carolina) (ETRA ’16). Association for Computing Machinery, New York, NY, USA, 39–46. https://doi.org/10.1145/2857491.2857496

[8] John Brooke. 1996. SUS: a ‘Quick and Dirty’ usability scale. Taylor and Francis. 207–212 pages. https://doi.org/10.1201/9781498710411-35

[9] Marco Caligari, Marco Gidi, Simone Guglielmetti, Franco Franchignoni, and Antonio Nardone. 2013. Eye tracking communication devices in amyotrophic lateral sclerosis: impact on disability and quality of life. Amyotrophic Lateral Sclerosis and Frontotemporal Degeneration 14, 7–8 (2013), 546–552.

[10] Richard H Carmona. 2005. The global challenges of birth defects and disabilities. The lancet 366, 9492 (2005), 1142–1144.

[11] Shahrokh Yousefzadeh Chubok, Mohammad Safaei, Ahmad Alizadeh, Masouneh Alamdar Dafshahi, Omad Taghinnejad, and Leila Koochakinejad. 2011. Epidemiology of traumatic spinal injury: a descriptive study. PubMed 13, 52 (2011), 308–11. https://pubmed.ncbi.nlm.nih.gov/21257463

[12] Won-Du Chang, Ho-Seung Cha, Do Yeon Kim, Seung Hyun Kim, and Chang-Hwan Im. 2017. Development of an electrooculogram-based eye-computer interface for communication of individuals with amyotrophic lateral sclerosis. Journal of neuroengineering and rehabilitation 14, 1 (2017), 1–13.

[13] Edison A. Chung and Marco E. Benalcázar. 2019. Real-Time Hand Gesture Recognition Model Using Deep Learning Techniques and EMG Signals. In 2019 27th European Signal Processing Conference (EUSIPCO). European Signal Processing Conference (EUSIPCO), 1–5. https://doi.org/10.23919/EUSIPCO.2019.8903136

[14] Muratcan Cicek, Ankit Dave, Wexin Feng, Michael Xuelin Huang, Julia Katherine Haines, and Jeffry Nichols. 2020. Designing and Evaluating Head-based Pointing on Smartphones for People with Motor Impairments. In Proceedings of the 22nd International ACM SIGACCESS Conference on Computers and Accessibility (Virtual Event, Greece) (ASSETS ’20). Association for Computing Machinery, New York, NY, USA, Article 14, 12 pages. https://doi.org/10.1145/3373625.3416994

[15] Jacob Cohen. 1960. A coefficient of agreement for nominal scales. Educational and psychological measurement 20, 1 (1960), 37–46.

[16] Aurora Adina Colomeischi et al. 2018. Center for Parent Information and Resources: Book Chapters-Educational Sciences, sports and psychology 1 (2018), 227–228.

[17] Donnell J Creed. 2019. The electrooculogram. Handbook of Clinical Neurology 160 (2019), 495–499.

[18] Carlo De Luca. 2006. Electromyography. John Wiley & Sons, Ltd. https://doi.org/10.1002/0471732877.emd097

[19] Lawrence Y. Deng, Chun-Liang Hsu, Tzu-Ching Lin, Jui-Sen Tian, and Yung-Hui Chen. 2009. EOG-based signal detection and verification for HCI. In 2009 International Conference on Machine Learning and Cybernetics, Vol. 6. International Conference on Machine Learning and Cybernetics, Singapore, Singapore, 471–487.

Manuscript submitted to ACM
[20] Michael C. Dewan, Abbas Rattani, Ronnie E Baticulon, Serena Faruque, Walter D Johnson, Robert J Dempsey, Michael M Haglund, Blake C Alkire, Kee B Park, Benjamin C Warf, et al. 2018. Operative and consultative proportions of neurosurgical disease worldwide: estimation from the surgeon perspective. Journal of Neurosurgery 130, 4 (2018), 1098–1106.

[21] Xiao Juan Ding and Zhao Lv. 2020. Design and development of an EOG-based simplified Chinese eye-writing system. Biomedical Signal Processing and Control 57 (mar 2020), 101767. https://doi.org/10.1016/j.bspc.2019.101767

[22] Mandy R. Drew, Brooke Falcone, and Wendy L. Baccus. 2018. What does the system usability scale (SUS) measure?: Validation using think aloud verbalization and behavioral metrics. In Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), Vol. 10918 LNCs. Springer, Cham, 356–366. https://doi.org/10.1007/978-3-319-91797-9_25

[23] Nancy E. Mayo, Sharon Wood-Dauphinee, Sara Ahamed, Gordon Carron, Johanne Higgins, Sara Mcewen, and Nancy Sallbach. 1999. Disablement following stroke. Disability and rehabilitation 21, 5-6 (1999), 258–268.

[24] Jan Ehlers, Christoph Strausch, and Anle Huckauf. 2018. A view to a click: Pupil size changes as input command in eyes-only human-computer interaction. International Journal of Human Computer Studies 119 (2018), 28–34. https://doi.org/10.1016/j.ijhcs.2018.06.003

[25] RC Fouche. 2017. Head mouse: generalisability of research focused on the disabled to able bodied users. In Proceedings of the South African Institute of Computer Scientists and Information Technologists (Thaba ‘Nchu, South Africa) (SAICSIT ’17). Association for Computing Machinery, New York, NY, USA, Article 14, 10 pages. https://doi.org/10.1145/3129416.3129442

[26] Dmitry O. Gorodnichy and Gerhard Roth. 2004. Nose ‘use your nose as a mouse’ perceptual vision technology for hands-free games and interfaces. Image and Vision Computing 22, 12 (2004), 931–942. https://doi.org/10.1016/j.imavis.2004.03.021

[27] H Kerr Graham and P Selber. 2003. Musculoskeletal aspects of cerebral palsy. The Journal of bone and joint surgery. British volume 85, 2 (2003), 157–166.

[28] Orla Hardiman, Ammar Al-Chalabi, Adrianio Chio, Emma M Corr, Giancarlo Logroscino, Wim Robberecht, Pamela J Shaw, Zachary Simmons, and Leonard H Van Den Berg. 2017. Amyotrophic lateral sclerosis. Nature reviews Disease primers 3, 1 (2017), 1–19.

[29] Jeong Heo, Heenaam Yoon, and Kwang Suk Park. 2017. A novel wearable forehead EOG measurement system for human computer interfaces. Sensors (Switzerland) 17, 7 (jun 2017), 1485. https://doi.org/10.3390/s17071485

[30] Ali Heydarigorji, S. M. Safari, Ch. T. Lee, and P. H. Chou. 2017. Head-mouse: A simple cursor controller based on optical measurement of head tilt. In 2017 IEEE Signal Processing in Medicine and Biology Symposium (SPMB). Institute of Electrical and Electronics Engineers Inc., 1–5. https://doi.org/10.1109/SPMB.2017.8275058

[31] Carles Igual, Jorge Igual, Janne M Hahne, and Lucas C Parra. 2019. Adaptive auto-regressive proportional myoelectric control. IEEE Transactions on Neural Systems and Rehabilitation Engineering 27, 2 (2019), 314–322.

[32] Robert J.K. Jacob. 1990. What you look at is what you get: Eye movement-based interaction techniques. In Conference on Human Factors in Computing Systems - Proceedings. Association for Computing Machinery, 11–18. https://doi.org/10.1145/97243.97246

[33] Theresa A Jones. 2017. Motor compensation and its effects on neural reorganization after stroke. Nature Reviews Neuroscience 18, 5 (2017), 267–280.

[34] Mohammad Ridwan Kabir, Mohammad Ishrak Abedin, Rizvi Ahmed, Hasan Mahmud, and Md Kamrul Hasan. 2022. Antasid: A novel temporal adjustment to Shannon’s index of difficulty for quantifying the perceived difficulty of uncontrolled pointing tasks. IEEE Access 10 (2022), 21774–21786.

[35] Mohammad Ridwan Kabir, Hasan Mahmud, and Md Kamrul Hasan. 2023. Acceptability of a head-mounted assistive mouse controller for people with upper limb disability: An empirical study using the technology acceptance model. PloS one 18, 10 (2023), e0293608.

[36] Avnish Kabra, Chandan Agrawal, H Pallab Jyoti Dutta, M.K. Bhuyan, and R.H. Laskar. 2020. Vision Based Communicator. In 2020 IEEE Applied Signal Processing Conference (ASAPCON). Institute of Electrical and Electronics Engineers Inc., 293–297. https://doi.org/10.1109/ASPCON49795.2020.9276644

[37] Aycan Kaya, Reha Ozturk, and Cigdem Altin Gumussoy. 2019. Usability Measurement of Mobile Applications with System Usability Scale (SUS). In Industrial Engineering in the Big Data Era, Fethi Calsir, Emre Cevlikcan, and Hatic Camgoz Akdag (Eds.). Springer International Publishing, Cham, 389–400.

[38] Shadman Sakib Khan, Md. Samim Haque Sunny, M. Shifat Hossain, Eklas Hossain, and Mohiuddin Ahmad. 2017. Nose tracking cursor control for the people with disabilities: An improved HCI. In 2017 3rd International Conference on Electrical Information and Communication Technology (EICT). Institute of Electrical and Electronics Engineers Inc., 1–5. https://doi.org/10.1109/EICT.2017.8275178

[39] John Kirkup. 2007. A history of limb amputation. Springer. https://doi.org/10.1016/j.bspc.2018.03.021

[40] Karen W Krigger. 2006. Cerebral palsy: an overview. American family physician 73, 1 (2006), 91–100.

[41] Alex Larson, Joshua Herrera, Kiran George, and Aaron Matthews. 2017. Electrooculography based electronic communication device for individuals with ALS. In 2017 IEEE Sensors Applications Symposium (SAS). Institute of Electrical and Electronics Engineers Inc., 1–5. https://doi.org/10.1109/ S17.7894082

[42] K Lee, W Chang, and S Kim. 2016. Im C. Real-time ‘eye-writing’ recognition using electrooculogram (EOG). Trans Neural Syst Rehabil Eng 2, 1 (2016), 37–48.

[43] James R Lewis. 2018. The system usability scale: past, present, and future. International Journal of Human–Computer Interaction 34, 7 (2018), 577–590.

Manuscript submitted to ACM
Auxilio and Beyond: Comparative Evaluation, Usability, and Design Guidelines for Head Movement-based Assistive Mouse Controllers

[44] James R. Lewis and Jeff Sauro. 2009. The factor structure of the system usability scale. In Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics). Vol. 5619 LNCS. Springer, Berlin, Heidelberg, 94–103. https://doi.org/10.1007/978-3-642-02806-9_12

[45] James R. Lewis and Jeff Sauro. 2018. Item benchmarks for the system usability scale. Journal of Usability Studies archive 13, 3 (5 2018), 158–167. https://doi.org/10.5555/3294033.3294037

[46] Chiu Teng Lin, Juang Tai King, Priyanka Bharadwaj, Chih Hao Chen, Akshansh Gupta, Weiping Ding, and Mukesh Prasad. 2019. EOG-Based Eye Movement Classification and Application on HCI Baseball Game. IEEE Access 7 (2019), 96166–96176. https://doi.org/10.1109/ACCESS.2019.2977755

[47] Dhamush Roopa Lingegowda, Karan Amrutesh, and Srikanth Ramanujam. 2018. Electrococulography based assistive technology for ALS patients. In 2017 IEEE International Conference on Consumer Electronics-Asia, ICCE-Asia 2017, Vol. 2018-Jana. Institute of Electrical and Electronics Engineers Inc., 36–40. https://doi.org/10.1109/ICCE-ASIA.2018.8307837

[48] Perceptive Devices LLC. 2024. Downloadable Head Mouse: Hands-Free control via Webcam. https://smylemouse.com/ Accessed on 2024-09-07.

[49] Eng H Lo, Turgay Dalkara, and Michael A Moskowitz. 2003. Mechanics, challenges and opportunities in stroke. Nature reviews neuroscience 4, 5 (2003), 399–414.

[50] A. López, P. J. Arévalo, F. J. Ferrero, M. Valledor, and J. C. Campo. 2014. EOG-based system for mouse control. In Proceedings of IEEE Sensors, Vol. 2014-Decem. Institute of Electrical and Electronics Engineers Inc., 1264–1267. https://doi.org/10.1109/ICSENS.2014.6985240

[51] Alberto López, Marta Fernández, Héctor Rodríguez, Francisco Ferrero, and Octavian Postolache. 2018. Development of an EOG-based system to control a serious game. Measurement: Journal of the International Measurement Confederation 127 (oct 2018), 481–488. https://doi.org/10.1016/j.measurement.2018.06.017

[52] I. Scott MacKenzie, Tatu Kauppinen, and Miika Sillverberg. 2001. Accuracy measures for evaluating computing pointing devices. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (Seattle, Washington, USA) (CHI ’01). Association for Computing Machinery, New York, NY, USA, 9–16. https://doi.org/10.1145/365024.365028

[53] John Magee, Torsten Felzer, and I. Scott MacKenzie. 2015. Camera Mouse + ClickerAID: Dwell vs. Single-Muscle Click Actuation in Mouse-Replacement Interfaces. In Universal Access in Human-Computer Interaction. Access to Today’s Technologies, Margherita Antonia and Constantine Stephanidis (Eds.). Springer International Publishing, Cham, 74–84.

[54] John J. Magee, Samuel Epstein, Eric S. Missimer, Christopher Kwan, and Margrit Betke. 2011. Adaptive Mouse-Replacement Interface Control Functions for Users with Disabilities. In Universal Access in Human-Computer Interaction. Users Diversity, Constantine Stephanidis (Ed.). Springer Berlin Heidelberg, Berlin, Heidelberg, 332–341.

[55] Hiroshi Mano, Sayaka Fujiwara, and Nobuhiro Haga. 2018. Adaptive behaviour and motor skills in children with upper limb deficiency. Prosthetics and Orthotics International 42, 2 (2018), 236–240.

[56] Nicholas Marjanovic, Kevin Kerr, Ricardo Aranda, Richard Hickey, and Hananeh Esmailbeigi. 2017. Wearable wireless User Interface Cursor-Controller (UIC-C). In 2017 39th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC). Institute of Electrical and Electronics Engineers Inc., 3852–3855. https://doi.org/10.1109/EMBC.2017.8037697

[57] Dennis J. McFarland, Dean J. Krusienski, William A. Sarnacki, and Jonathan R. Wolpaw. 2008. Emulation of computer mouse control with a noninvasive brain-computer interface. Journal of Neural Engineering 5, 2 (2008), 101–110. https://doi.org/10.1088/1741-2560/5/2/001

[58] Nathan W Moon, Paul MA Baker, and Kenneth Goughnour. 2019. Designing wearable technologies for users with disabilities: Accessibility, usability, and connectivity factors. Journal of Rehabilitation and Assistive Technologies Engineering 6 (2019), 2056665319862137.

[59] T. Montani, D. Stegeman, and R. Merletti. 2004. Basic Physiology and Biophysics of EMG Signal Generation. John Wiley & Sons, Ltd, Chapter 1, 1–25. https://doi.org/10.1002/0471678384.ch1 arXiv:https://onlinelibrary.wiley.com/doi/pdf/10.1002/0471678384.ch1

[60] Ashok Muzumdar. 2004. Powered upper limb prostheses: control, implementation and clinical application. Vol. 1. Springer.

[61] Karen B Nelson and Judith K Grether. 1999. Causes of cerebellar palsy: Current opinion in pediatrics 11, 6 (1999), 487–491.

[62] Mats E Nilsson and Bo N Schenkman. 2016. Blind people are more sensitive than sighted people to binaural sound-location cues, particularly inter-aural level differences. Hearing research 332 (2016), 223–232.

[63] Bryce Obard, Alex Larson, Joshua Herrera, Dominic Nega, and Kiran George. 2017. Electrococulography Based IOS Controller for Individuals with Quadriplegia or Neurodegenerative Disease. In Proceedings - 2017 IEEE International Conference on Healthcare Informatics, ICHI 2017. Institute of Electrical and Electronics Engineers Inc., 101–106. https://doi.org/10.1109/ICHI.2017.90

[64] Sarah M. O’Meara, Megan C. Shyr, Kenneth R. Lyons, and Sanjay S. Joshi. 2019. Comparing Two Different Cursor Control Methods which Use Single-Site Surface Electromyography. In 2019 9th International IEEE/EMBS Conference on Neural Engineering (NER). Institute of Electrical and Electronics Engineers Inc., 1163–1166. https://doi.org/10.1109/NER.2019.8716903

[65] Camilla Pierella, Farnaz Abboli, Ali Farschianasadegh, Jessica Pedersen, Elias B Thorp, Ferdinando A Mussa-Ivaldi, and Maura Casadio. 2015. Remapping residual coordination for controlling assistive devices and recovering motor functions. Neuropsychologia 79 (2015), 364–376.

[66] Preeti Raghavan. 2015. Upper limb motor impairment after stroke. Physical Medicine and Rehabilitation Clinics 26, 3 (2015), 599–610.

[67] Md. Rokib Raihan, Abdullah Bin Shams, and Mohiuddin Ahmad. 2020. Wearable Multifunctional Computer Mouse Based on EMG and Gyro for Amputees. In 2020 2nd International Conference on Advanced Information and Communication Technology (ICAIT). Institute of Electrical and Electronics Engineers Inc., 129–134. https://doi.org/10.1109/ICAIT51786.2020.9333476

[68] Vijay Rajanna. 2016. Gaze typing through foot-operated wearable device. In ASSETS 2016 - Proceedings of the 18th International ACM SIGACCESS Conference on Computers and Accessibility. Association for Computing Machinery, Inc, 345–346. https://doi.org/10.1145/2982142.2982145

Manuscript submitted to ACM
Vijay Rajanna and Tracy Hammond. 2016. GAWSCHI: gaze-augmented, wearable-supplemented computer-human interaction. In Proceedings of the Ninth Biennial ACM Symposium on Eye Tracking Research & Applications (Charleston, South Carolina) (ETRA '16). Association for Computing Machinery, New York, NY, USA, 233–236. https://doi.org/10.1145/2857491.2857499

Noa Raz, Ella Striem, Golan Pundak, Tanya Orlov, and Ehud Zohary. 2007. Superior serial memory in the blind: a case of cognitive compensatory adjustment. Current Biology 17, 13 (2007), 1129–1133.

Dinah S Reddihough and Kevin J Collins. 2003. The epidemiology and causes of cerebral palsy. Australian Journal of physiotherapy 49, 1 (2003), 7–12.

Heiner Rindermann, A Laura Ackermann, and Jan Te Nijenhuis. 2020. Does blindness boost working memory? A natural experiment and cross-cultural study. Frontiers in psychology 11 (2020), 1571.

Neal W Roller, Adrian Garfunkel, Chris Nichols, and Irwin I Ship. 1974. Amyotrophic lateral sclerosis. Oral Surgery, Oral Medicine, Oral Pathology 37, 1 (1974), 46–52.

Khushal Sancheti, Sridhar Krishnan K, Suhas A, and Suresh P. 2018. Hands-free Cursor Control using Intuitive Head Movements and Cheek Muscle Twitches. In TENCON 2018 - 2018 IEEE Region 10 Conference. Institute of Electrical and Electronics Engineers Inc., 0356–0361. https://doi.org/10.1109/TENCON.2018.8650532

Amene Sabzi Sarvestani and Afshin Taheri Azam. 2013. Amputation: a ten-year survey. Trauma monthly 18, 3 (2013), 126.

Bo N Schenkenman and Mats E Nilsson. 2010. Human echolocation: Blind and sighted persons' ability to detect sounds recorded in the presence of a reflecting object. Perception 39, 4 (2010), 483–501.

Aman Sharma and Sakhsham Chaturvedi. 2021. Mouse-Less cursor control for quadriplegic and autistic patients using artificial intelligence. In Advances in medical diagnosis, treatment, and care (AMDTC) book series, IGI Global, 105–137. https://doi.org/10.4018/978-1-7998-7460-7.ch008

Tully-Valary Steinbach. 1979. Upper Limb Amputation. In The War Injuries of the Upper Extremity. Vol. 16. S.Karger AG, 224–248. https://doi.org/10.1159/0004002266 arXiv:https://karger.com/book/chapter-pdf/2029365/0004002266.pdf

M. Suresh, P.G. Krishnamohan, and Mallikarjun S. Holi. 2011. GMM modeling of person information from EMG signals. In 2011 IEEE Recent Advances in Intelligent Computational Systems, Institute of Electrical and Electronics Engineers Inc., 712–717. https://doi.org/10.1109/RAACS.2011.6069403

Geer Teng, Yue He, Hengjun Zhao, Dunhu Liu, Jin Xiao, and S Ramkumar. 2020. Design and development of human computer interface using electrooculogram with deep learning. Artificial intelligence in medicine 102 (2020), 101765.

Marcel Tresanchez, Tomás Palleja, and Jordi Palacin. 2019. Optical Mouse Sensor for Eye Blink Detection and Pupil Tracking: Application in a Low-Cost Eye-Controlled Pointing Device. Journal of Sensors 19, 1 (2019), 3931713. https://doi.org/10.1155/2019/3931713 arXiv:https://onlinelibrary.wiley.com/doi/pdf/10.1155/2019/3931713

Triadi Triadi, Inung Wijayanto, and Sugondo Hadiyoso. 2021. Electrooculogram (EOG) based Mouse Controller Using the Continuous Wavelet Transform and Statistic Features. Lontar Computer: Jurnal Ilmiah Teknologi Informasi 12, 1 (2021), 53. https://doi.org/10.24843/Ikijit.2021.v12.i01.p06

Javier Varona, Cristina Manresa-Yee, and Francisco J Perales. 2008. Hands-free vision-based interface for computer accessibility. Journal of Network and Computer Applications 31, 4 (2008), 357–374.

Miguel A Velasco, Alejandro Clemotte, Rafael Ray, Ramón Ceres, and Eduardo Rocon. 2017. A novel head cursor facilitation technique for cerebral palsy: Functional and clinical implications. Interacting with Computers 29, 5 (2017), 755–766.

Charles DA Wolfe. 2000. The impact of stroke. British medical bulletin 56, 2 (2000), 275–286.

Wan-wa Wong, Yuqi Fang, Winnie CW Chu, Lin Shi, and Kai-yu Tong. 2019. What kind of brain structural connectivity remodeling can relate to residual motor function after stroke? Frontiers in neurology 10 (2019), 1111.

Jing Xiao, Jun Qu, and Yuanqing Li. 2019. An Electrooculogram-Based Interaction Method and Its Music-on-Demand Application in a Virtual Reality Environment. IEEE Access 7 (2019), 22059–22070. https://doi.org/10.1109/ACCESS.2019.2908324

Akio Yamamoto, Kenji Kihara, Mariko Yagi, Yoko Matsumoto, Shuichi Tsuneishi, Hideo Otaka, Masaya Yonezawa, and Satoshi Takada. 2020. Application of a wearable switch to perform a mouse left click for a child with mix type of cerebral palsy: a single case study. Disability and Rehabilitation: Assistive Technology 15, 1 (Jan 2020), 54–59. https://doi.org/10.1080/17483410.2018.1520309

Metin Yildiz and Hessa Ozbek Ulkuayt. 2018. A New PC-Based Text Entry System Based on EOG Coding. Advances in Human-Computer Interaction 2018, 1 (2018), 8528176 arXiv:https://onlinelibrary.wiley.com/doi/pdf/10.1155/2018/8528176

Shumin Zhai. 2004. Characterizing computer input with Fitts’ law parameters—the information and non-information aspects of pointing. International Journal of Human-Computer Studies 61, 6 (2004), 791–809.

Shumin Zhai, Jing Kong, and Xiangshi Ren. 2004. Speed–accuracy tradeoff in Fitts’ law tasks—on the equivalency of actual and nominal pointing precision. International journal of human-computer studies 61, 6 (2004), 823–856.

Xuebai Zhang, Xiaolong Liu, Shyan-Ming Yuan, and Shu-Fan Lin. 2017. Camera Mouse: Dwell vs. Computer Vision-Based Intentional Click Activation. In Universal Access in Human–Computer Interaction. Designing Novel Interactions, Margherita Antonia and Constantine Stephanidis (Eds.). Springer International Publishing, Cham, 455–464.

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A CONSENT FORM

Informed Consent Form — Auxilio

STUDY TITLE
Point–and–Click Experiment to Compare Auxilio with other input device(s)

PRINCIPAL INVESTIGATORS
- ANONYMIZED FOR REVIEW

INSTITUTION
ANONYMIZED FOR REVIEW

CONTACT INFORMATION
- ANONYMIZED FOR REVIEW

PURPOSE OF THE STUDY
You are invited to participate in a research study aimed at comparing Auxilio against different input device(s) through a point-and-click experiment. As part of this study, we will also collect data on skin conductance, temperature, and heart rate to assess potential stress levels during the experiment.

PROCEDURES
If you agree to participate in this study, you will be asked to perform a series of tasks using different input devices. Your age and sex will be recorded for understanding the participant demographics. During the experiment, we will record your performance data as well as your skin conductance, temperature, and heart rate using non-invasive sensors.

DURATION
The experiment will take approximately 35–50 minutes to complete.

VOLUNTARY PARTICIPATION
Your participation in this study is entirely voluntary. You may withdraw from the study at any time without any penalty or loss of benefits to which you are otherwise entitled.

CONFIDENTIALITY
All data collected during this study will be kept anonymous. Your personal identity will not be linked to the data in any way, and only aggregated data will be used for analysis and publication.

POTENTIAL RISKS AND DISCOMFORTS
The risks associated with this study are minimal and are comparable to those encountered in everyday use of computer input devices. The sensors used to monitor your skin conductance, temperature, and heart rate are non-invasive and should not cause any discomfort.
POTENTIAL BENEFITS
While there may be no direct benefits to you, your participation will contribute to a better understanding of the effectiveness and stress implications of different input devices.

COMPENSATION
Each participant will be paid [CURRENCY ANONYMIZED FOR REVIEW] for their participation in this study.

QUESTIONS
If you have any questions about the study, you may contact any of the principal investigators at the contact information provided above.

CONSENT
By signing below, you acknowledge that you have read and understood the information provided above, and you agree to participate in this study. You also understand that you can withdraw your consent at any time without penalty.

Participant’s Name: ________________________________

Participant’s Signature: ________________________________

Date: ________________________________

B SYSTEM USABILITY SCALE (SUS) QUESTIONNAIRE ITEMS

| Item | Description |
|------|-------------|
| SUS 1 | I think that I would like to use this system frequently. |
| SUS 2 | I found the system unnecessarily complex. |
| SUS 3 | I thought the system was easy to use. |
| SUS 4 | I think that I would need the support of a technical person to be able to use this system. |
| SUS 5 | I found the various functions in this system were well integrated. |
| SUS 6 | I thought there was too much inconsistency in this system. |
| SUS 7 | I would imagine that most people would learn to use this system very quickly. |
| SUS 8 | I found the system very cumbersome to use. |
| SUS 9 | I felt very confident using the system. |
| SUS 10 | I needed to learn a lot of things before I could get going with this system. |
C  SYSTEM USABILITY SCALE (SUS) QUESTIONNAIRE RESPONSES FOR AUXILIO

| Respondent | SUS1 | SUS2 | SUS3 | SUS4 | SUS5 | SUS6 | SUS7 | SUS8 | SUS9 | SUS10 | SUS Score | Grade |
|------------|------|------|------|------|------|------|------|------|------|-------|-----------|-------|
| R1         | 5    | 1    | 4    | 2    | 5    | 1    | 5    | 2    | 5    | 1     | 92.50     | A+     |
| R2         | 3    | 1    | 5    | 2    | 5    | 2    | 5    | 2    | 4    | 1     | 85.00     | A+     |
| R3         | 5    | 2    | 4    | 1    | 5    | 2    | 4    | 2    | 4    | 1     | 85.00     | A+     |
| R4         | 3    | 1    | 5    | 2    | 5    | 1    | 4    | 2    | 5    | 1     | 87.50     | A+     |
| R5         | 1    | 2    | 2    | 2    | 4    | 2    | 3    | 4    | 2    | 1     | 52.50     | D      |
| R6         | 3    | 2    | 3    | 2    | 4    | 2    | 3    | 2    | 4    | 1     | 70.00     | C      |
| R7         | 2    | 2    | 5    | 2    | 4    | 1    | 5    | 1    | 5    | 1     | 82.50     | A      |
| R8         | 2    | 1    | 4    | 1    | 3    | 2    | 2    | 4    | 2    | 1     | 70.00     | C      |
| R9         | 4    | 2    | 4    | 1    | 5    | 1    | 4    | 2    | 4    | 1     | 72.50     | C+     |
| R10        | 4    | 1    | 5    | 1    | 4    | 1    | 5    | 1    | 4    | 2     | 90.00     | A+     |

**Mean**: 3.20 1.50 4.10 2.10 4.40 1.60 4.30 2.00 4.00 1.30 78.75  B+  

**SD**: 1.32 0.53 0.99 1.10 0.70 0.52 0.82 0.82 0.94 0.48  12.32

D  SYSTEM USABILITY SCALE (SUS) QUESTIONNAIRE RESPONSES FOR SMYLE MOUSE

| Respondent | SUS1 | SUS2 | SUS3 | SUS4 | SUS5 | SUS6 | SUS7 | SUS8 | SUS9 | SUS10 | SUS Score | Grade |
|------------|------|------|------|------|------|------|------|------|------|-------|-----------|-------|
| R1         | 5    | 1    | 5    | 1    | 5    | 1    | 5    | 1    | 2    | 1     | 92.50     | A+     |
| R2         | 2    | 1    | 4    | 2    | 5    | 1    | 5    | 2    | 4    | 1     | 85.00     | A      |
| R3         | 1    | 2    | 2    | 2    | 3    | 1    | 3    | 2    | 2    | 2     | 40.00     | F      |
| R4         | 1    | 2    | 2    | 3    | 1    | 5    | 4    | 5    | 2    | 2     | 32.50     | F      |
| R5         | 1    | 2    | 2    | 3    | 4    | 5    | 3    | 3    | 2    | 2     | 45.00     | F      |
| R6         | 2    | 4    | 1    | 2    | 2    | 4    | 2    | 4    | 3    | 3     | 32.50     | F      |
| R7         | 1    | 1    | 4    | 2    | 5    | 3    | 4    | 3    | 3    | 2     | 65.00     | C      |
| R8         | 1    | 2    | 3    | 2    | 5    | 2    | 5    | 1    | 3    | 3     | 30.00     | F      |
| R9         | 2    | 4    | 2    | 4    | 2    | 3    | 3    | 5    | 2    | 3     | 30.00     | F      |
| R10        | 2    | 3    | 3    | 2    | 2    | 5    | 3    | 4    | 2    | 3     | 37.50     | F      |

**Mean**: 1.80 2.20 2.80 3.00 3.50 3.20 3.50 2.30 2.20 48.75  F  

**SD**: 1.23 1.14 1.23 0.79 1.56 1.58 1.32 1.35 0.82 0.79  23.01
### THEMES AND CODES SUMMARY

Table 4. Themes and Codes summary of qualitative analysis of Auxilio

| Themes/Codes                                      | Frequency |
|---------------------------------------------------|-----------|
| **Ease of Use and Deterministic Behavior**         | 29        |
| Easy Click Mechanisms (LMB+RMB)                    | 9         |
| Persistent Calibration                            | 6         |
| Easy Device Calibration                           | 5         |
| Easy Pointer Movement                             | 5         |
| Deterministic Device Behavior                      | 4         |
| **Difficult Precise and Static Pointing**         | 21        |
| Oscillating Pointer Movement                      | 8         |
| Difficult Small Target Clicking                   | 7         |
| Difficult Static Targeting                        | 5         |
| Unrecognized Clicks                               | 1         |
| **Ergonomics, Cognitive Load, and Comfort**        | 12        |
| Less Head Movement                                | 3         |
| No/Minimal Strain from Head Movements             | 3         |
| Comfortable Design                                | 3         |
| No/Minimal Muscle Fatigue                         | 2         |
| Lower Cognitive Load                              | 1         |
| **High Responsiveness**                           | 7         |
| Easy Dynamic Target Tracking                      | 3         |
| Easy Large/Non-Small Target Hitting               | 2         |
| Easy Cursor Control at Extreme Angles             | 1         |
| Faster Task Completion                            | 1         |
| **Adaptability**                                  | 6         |
| Positive/Easy Adaptation                          | 4         |
| Initial Learning Phase                            | 2         |
| **Discomforts**                                   | 5         |
| Visual Obstruction from Device                    | 3         |
| Problem for Special Cases/Disabilities            | 1         |
| Uncomfortable Design                              | 1         |
| **Additional Features**                           | 1         |
| Extra Controls and Features                       | 1         |
| Themes/Codes                                           | Frequency |
|-------------------------------------------------------|-----------|
| **Performance and Calibration Issues**                 | 51        |
| Unrecognized Clicks                                   | 18        |
| Frequent Recalibration                                 | 13        |
| Cursor Drift Over Time                                 | 8         |
| Click Mechanism Drift Over Time                        | 6         |
| Non-deterministic Device Behavior                      | 2         |
| Discrete Pointer Movement                              | 2         |
| Difficult Dynamic Target Tracking                      | 2         |
| **Ergonomic Issues, Cognitive Load, and Physical Discomforts** | 23        |
| Neck Strain from Head Movements                        | 8         |
| More Head Movement                                     | 4         |
| Visual Discomfort                                      | 4         |
| Discomfort from Prolonged Use                          | 3         |
| Higher Cognitive Load                                  | 2         |
| Jaw Muscle Fatigue                                     | 2         |
| **Design and Learnability Issues**                     | 14        |
| Difficult Cursor Control at Extreme Angles             | 6         |
| Difficult Click Mechanisms (LMB+RMB)                   | 4         |
| Difficult Device Calibration                           | 2         |
| Constrained Performance                                | 1         |
| Difficult Pointer Movement                             | 1         |
| **Stable Static Pointing**                             | 5         |
| Stable Pointer Movement                                | 3         |
| Easy Static Targeting                                  | 2         |
| **Ease of Use**                                        | 3         |
| Easy Click Mechanisms (LMB+RMB)                        | 1         |
| Easy Device Calibration                                | 1         |
| Easy Small Target Clicking                             | 1         |

F HEATMAPS OF AUXILIO AND SMYLE MOUSE CURSOR MOVEMENTS OF THE PARTICIPANTS
### Continuation of the Heatmap Table

| ID | Auxilio | Smyle Mouse |
|----|---------|-------------|
| 6  | ![Heatmap Image](image1) | ![Heatmap Image](image2) |
| 7  | ![Heatmap Image](image3) | ![Heatmap Image](image4) |
| 8  | ![Heatmap Image](image5) | ![Heatmap Image](image6) |
| 9  | ![Heatmap Image](image7) | ![Heatmap Image](image8) |
| 10 | ![Heatmap Image](image9) | ![Heatmap Image](image10) |