PROVIDING EDUCATIONAL ACCESSIBILITY FOR A PARALYZED STUDENT BY EYE-TRACKING TECHNOLOGY: A DESIGN-BASED RESEARCH STUDY

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ABSTRACT

This study explores the development of an eye-tracking solution for paralyzed students, enabling them to access and utilize personal computers for their education. It relies on eye-tracking technology, enabling computer control through eye movements. The study followed four phases: problem analysis, solution development, evaluation, and documentation. In the analysis phase, the problem for developing a solution was defined based on the interviews with the instructor, the paralyzed student, and his parents. The iterative and incremental development process was followed in the development phase with four development cycles. At the end of this phase, an eye-tracking-based computer control system and design principles were obtained to develop such a system. During the evaluation phase, paralyzed student used the system for two semesters. The final phase documented design principles for further eye-tracking systems to support paralyzed individuals' academic lives. By adhering to these design principles, there is a need to develop and adapt more solutions and systems for the benefit of paralyzed people, enabling them to access and maintain their academic lives. The study highlights the potential of eye-tracking technology for paralyzed students and promotes the development of similar solutions.

Keywords: Paralyzed students, educational technology, assistive technology, eye-tracking.

INTRODUCTION

Technological developments encourage researchers to investigate and leverage their advantages in the field of education. Regarding devices, especially mobile devices and multimedia resources, it is essential to utilize them while giving instruction or extracurricular activities (Farkhadov et al., 2017; Sung et al., 2016; Wang et al., 2019). Despite rapid technological enhancements, their usage is very limited for people with special needs. The use of technology for people with special needs is called assistive technology (AT). It is defined as the technology that is used to benefit from assistive technology devices, such as equipment, products, or systems that can be used to enhance the capabilities of disabled people and services that can provide direct assistance or help them use assistive technology devices (Assistive Technology Act of 1998, 1998; Assistive Technology Act of 2004, 2004). Using AT and information and communication technologies (ICT) has great potential for people with various disabilities (Bouck & Long, 2021; Ouherrou et al., 2019; Pasian et al., 2012). When applying ICT to people with disabilities, the essential point to be considered is matching the needs of the users with the potential technology and adapting it according to their differences in learning (Drigas & oannidou, 2013; Heiman et al., 2017; Mandula et al., 2016). Therefore, it is essential to include technology in education by providing adaptive learning environments for people with special needs (Skourlas et al., 2016). People with motor difficulties especially require adapting technology to access educational opportunities.

Despite the importance of technology usage in education, there is a lack of accessibility opportunities for paralyzed students (de Witte et al., 2018; Hersh & Mouroutsou, 2015; Morgado Camacho et al., 2017; Smith & Abrams, 2019). Participating in a class, whether physically or virtually, can be challenging for them. Technology, however, can serve as an invaluable tool, allowing them to attend classes with assistance (Nicolson et al., 2012). For instance, caregivers can facilitate their transport from home to school or university and provide support in note-taking, assignment writing, or reading materials. In the case of online courses, paralyzed students can stay at home, with caregivers helping them connect to the course and providing assistance throughout. While both scenarios for physical and online participation seem reasonable, there is a crucial need for dedicated caregivers to enable paralyzed students to fully engage in lessons. Unfortunately, many parents may face challenges in allocating continuous time to assist their paralyzed children. Another significant consideration in both scenarios is the assumption that students can communicate verbally with people around them and the world. If verbal communication is not possible, both scenarios fall short, making it impossible to fully integrate paralyzed students into the educational environment and provide equal opportunities for education.

At this point, eye-tracking technology emerges as a solution for providing computer input without physical interaction (Donmez, 2023; Donmez & Cagiltay, 2019). Amer, Kamh, Elshahed, and Ramadan (2021) developed an eye-controlled wheelchair using a webcam to capture eye movements. Similarly, Atasoy, Cavusoglu, and Atasoy (2016) developed an eye movement based system that controls a motorized electrical hospital bed using a webcam, while Uslu, Ari, Sumer, and Turker (2017) developed a wearable system for communication and control of peripherals based on pupil positions. Even though the usage of eye-tracking-based technology for enabling human-computer interaction for communication (Blignaut, 2017; Borgestig et al., 2021; Karlsson et al., 2019) or providing rehabilitation is common, its usage for fostering academic skills remains limited.

Furthermore, eye-tracking systems designed for communication are often prohibitively expensive for many individuals and frequently necessitate extensive customization. The primary objective of this study is to design and develop an affordable eye-tracking system tailored to the unique needs of paralyzed students. This technology enables them to use personal computers independently, ensuring access to educational resources and the ability to maintain their education. The significance of this study lies in its potential to revolutionize the educational experience for paralyzed students, who have long faced significant challenges in accessing and participating in traditional educational settings. Developing an eye-tracking system for controlling computers enables these students to access education independently and reduces their reliance on caregivers. This technology has the power not only to transform their educational experience but also to improve their overall quality of life and foster greater inclusivity in education.

METHODOLOGY

This study employed a design-based research methodology, which integrates design, research, and practical application (Wang & Hannafin, 2005). The research approach followed a systematic process comprising design, development, and evaluation stages, ensuring systematicity by adhering to specific steps (Richey et al., 2004). Design-based research was implemented in four phases: analysis, development, evaluation and testing, and documentation and reflection, as illustrated in Figure 1 (Reeves et al., 2004).

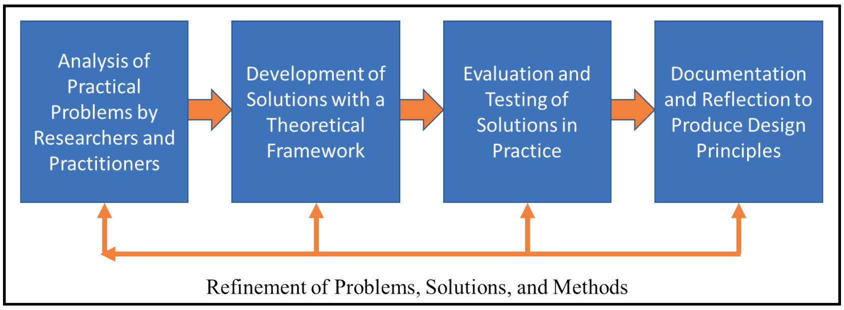

Figure 1. Design-Based Research Model by Reeves et al. (2004)

Participant Information

The study centered around a 23-year-old male participant actively pursuing his academic journey in the Physics Department. It's essential to highlight that his parents have played a crucial role in making his education possible. The participant faces unique challenges due to a diagnosis of Spinal Muscular Atrophy Type II (SMA2), a genetic disorder significantly affecting his control over voluntary muscle movements.

Spinal Muscular Atrophy Type II (SMA2) is a neuromuscular condition characterized by the progressive degeneration of motor neurons, resulting in the weakening of voluntary muscle functions. For our participant, this creates challenges in muscle coordination in his daily life and makes it difficult to engage in academic activities.

Apparatus

The solution developed for this study comprises a computer supported by the Windows operating system, an eye-tracking device, and computer control software, as illustrated in Figure 2. The computer, equipped with a 15.6-inch screen, is operated with an Intel Core i5 processor and 8GB of RAM to meet the minimum requirements of the eye-tracking devices used during this study.

Two low-cost eye-tracking devices, namely the Eye Tribe and Tobii EyeX, were employed throughout the study, maintaining similar sampling rates. The sampling rate defines how frequently the system records eye movement within a specific time frame, typically measured in Hertz (Hz). The Eye Tribe recorded eye movements at a 60 Hz sampling rate, while the Tobii EyeX operated at 70 Hz. During the development phase of this study, the Eye Tribe eye-tracker was utilized to capture eye movements. Subsequently, the Tobii EyeX eye-tracker was employed during the evaluation and testing phase for the same purpose due to its higher sample rate.

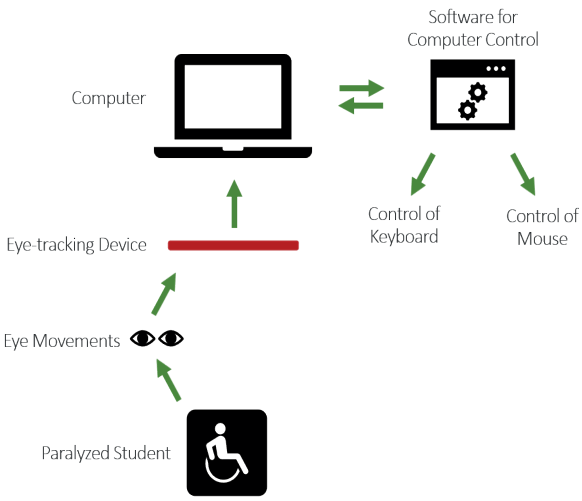

Figure 2. System Flow Diagram

The Procedure of the Study

The initial planning of this study commenced with a help request from the instructor of the paralyzed student, the participant of this study. Following the help request, the first phase of this study started with analyzing the problem. During this phase, interviews with the instructor, the paralyzed student, and his parents were conducted to understand the situation before designing and developing the optimal solution. The interviews aimed to determine the basic needs of the user. Subsequently, a review of existing technologies and current literature was conducted to align the student's needs with the capabilities of available technology. Based on the results of the first phase, the researchers determined to use eye-tracking technology in the solution to be developed for the paralyzed student.

In the second phase of this study, which is dedicated to developing the solution, the researchers focused on the initial planning of the solution that can help the student provide educational accessibility by using eye-tracking technology. The Eye Tribe eye-tracking device was used in this phase because of its affordable price. An iterative and incremental development process was employed during this study phase, as depicted in Figure 3.

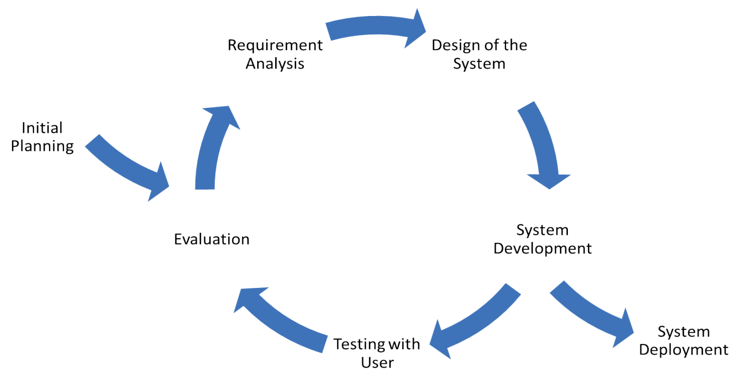

Figure 3. Development Process of the Solution

The iterative and incremental development process was executed in four cycles, outlined in Table 1. The initial cycle spanned seven weeks. In this first cycle, the interview results of the first phase of this study were used to determine system requirements. Then, the design and development of the solution were realized in four weeks. It was followed by a meeting with a paralyzed student to conduct a user test and interview. The researchers then evaluated this user meeting to provide input for the second cycle of the development process.

Table 1. Iterative and Incremental Development Process of the Study

# of the Development Cycle	Process	Duration
Development Cycle 1	Requirement Analysis	1 week
	Design and Development	4 weeks
	User Test and Interview	1 meeting
	Evaluation of the User Meeting	1 meeting
Development Cycle 2	Analysis, Design and Development	2 weeks
	User Test and Interview	1 meeting
	Evaluation of the User Meeting	1 meeting
Development Cycle 3	Analysis, Design and Development	3 weeks
	User Test and Interview	1 meeting
	Evaluation of the User Meeting	1 meeting
Development Cycle 4	Analysis, Design and Development	5 weeks
	User Test and Interview	1 meeting
	Evaluation of the User Meeting	1 meeting

After completing the first cycle of the development process, three additional cycles were implemented by following the stages of analysis, design and development, user test and interview, and user meeting evaluation, as outlined in Table 1. The second cycle spanned four weeks, while the third cycle lasted five weeks. Lastly, the fourth cycle lasted seven weeks. Consequently, the second phase, the development phase, employed an iterative and incremental development process and took fourteen weeks to complete. The outcome of this phase was the identification of design principles for developing an eye-tracking-based system tailored for paralyzed students to enable independent use of their personal computers.

In the third phase of this study (see Table 2), the evaluation and testing phase, the developed solution was used by the paralyzed physics student for two semesters, spring and fall. During these two semesters, he frequently used the developed solution for academic purposes and beyond. Additionally, he used this system for various extracurricular activities, social interactions, leisure activities, and more.

Moreover, four more cycles were deployed to finalize the proposed solution during this phase (see Table 2). The Tobii EyeX eye-tracking device was used in this phase because it was affordable and a widely used brand. The first finalizing cycle started with analyzing individual usage during two semesters. Then, it was followed by design and development, user test and interview, and evaluation of the user meeting. It lasted ten weeks. Following the completion of the initial cycle, three additional cycles were implemented, which involved (1) analysis, design, and development, (2) user testing and interviews, and (3) evaluation of the user meeting. Then, both the second and third finalizing cycles lasted eight weeks. Lastly, the fourth finalizing cycle lasted six weeks. Consequently, during the third phase, the development phase, two main processes were undertaken: testing and finalizing cycles. Testing spanned two semesters, while finalizing cycles took place over a period of thirty-two weeks. As a result of this phase, the proposed solution, an eye-tracking-based system for paralyzed students to enable them to use their personal computers for mainly academic purposes, was finalized.

Table 2. Evaluation and Testing Phase of the Study

Cycle of the Phase	Process	Duration
Testing	Individual Usage	2 semesters
Finalizing Cycle 1	Analysis of Individual Usage	2 weeks
	Design and Development	6 weeks
	User Test and Interview	1 meeting
	Evaluation of the User Meeting	1 meeting
Finalizing Cycle 2	Analysis, Design and Development	6 weeks
	User Test and Interview	1 meeting
	Evaluation of the User Meeting	1 meeting
Finalizing Cycle 3	Analysis, Design and Development	6 weeks
	User Test and Interview	1 meeting
	Evaluation of the User Meeting	1 meeting
Finalizing Cycle 4	Analysis, Design and Development	4 weeks
	User Test and Interview	1 meeting
	Evaluation of the User Meeting	1 meeting

In the fourth phase, the documentation and reflection phase, design principles obtained at the end of the second phase were finalized and documented according to the results of the third phase, the evaluation and testing phase.

FINDINGS

The design and development of the solution in this study progressed through four phases: analysis, development, evaluation and testing, and documentation and reflection.

Analysis Phase

At the outset of the analysis phase, interviews with the paralyzed student, his instructor, and his parents were conducted to understand the basic needs of our target user, the optimal requirements for the solution to encourage academic achievements, and the role of the caregivers in our participant's academic life. According to the interview with our target user, a paralyzed student, it was noted that he participates in face-to-face courses with the help of his parents by using his wheelchair. He does not have any problems with hearing or vision. He could participate in classes and follow the lessons. He has a room in the department to rest and study between his courses. He stays in a dormitory with his mother. Based on the interview with his instructor, we discerned that there are two sides to taking a course: following the lesson in class, watching video-based lessons, and using supplementary course materials provided by the university's Learning Management System (LMS). According to the interview with his parents, we gathered that her mother helps our student study using both printed materials and personal computers. The student instructs his mother on what to do, and she executes the tasks.

Moreover, the fundamental usage of a computer was analyzed during this phase. A computer has two primary input devices. One of them is a mouse that enables users to reflect the up, down, left, and right moves as the cursor moves on the computer screen. In other words, by using a mouse device, users can move the cursor on the screen wherever they want. For example, they can move the cursor on an icon of an application. Then, they need to use the click function or the double-click function on the mouse device to open the application. In addition, one of the most commonly used functions of a mouse device is the right-click option, which enables users to see preferences based on the cursor's position on the screen.

In conclusion, the mouse serves as a compulsory input device for a computer, offering functionalities such as up, down, right, and left movements of the cursor and click, double-click, and right-click functions. The other compulsory input device of a computer is the keyboard, which enables users to write letters, numbers, and symbols or to use keys or combinations of keys by pressing simultaneously to send different commands to the computer. In simple terms, it requires pressing one or more keys to use the keyboard as the input device of a computer. Therefore, our focus during solution development was to simulate the actions of two key input devices, namely the mouse and keyboard, solely through the user's eye movements.

As a result, the researchers of this study decided to concentrate on after-class activities and provide a solution for our participant to use in both of his rooms, at the department and dormitory. The solution was built on eye-tracking technology, creating a computer-based system solely controlled by the user's eye movements. It provided an opportunity for paralyzed students by enabling them to use all of the functions of a computer with eye movements using the developed system, which consisted of an eye tracker device, a laptop, and software.

Development Phase

In this phase, the iterative and incremental development process was applied in four cycles. At the beginning of the first cycle, the requirement analysis was employed based on the results of the first phase. It was decided to develop a solution for our participant that includes a laptop, an eye-tracking device, and software. The eye-tracking device, the Eye Tribe, was chosen as an input source to collect the eye movements of the user as x and y coordinates on the screen. Its sampling rate is 60 Hz, and nine-point calibration was applied before using the system. Subsequently, the system responds to the user according to his eye movements. For the first cycle of the development phase, an application was developed with limited features. The application enabled the user to move the cursor on the screen using eye movements. Additionally, buttons for numerical and alphabetical keys were present on the screen. Throughout the user testing and interview process, the goal was to observe and confirm that the user could manipulate the cursor with their eye movements and accurately position it over the buttons.

In the second cycle, the utilization of eye movements to emulate both keyboard and mouse functions was established. While replicating keyboard functions, smartphone and MS Windows on-screen keyboards were combined based on the user's needs. For instance, two tabs, one for alphabetical and MS Windows-based keys and the other for numerical and frequently used symbol keys, including a key (named ABC/.?123) to switch between tabs, were included in the design. A suitable and practical design was made by having a limited number of keys in the keyboard in order not to reduce the size of the keys and not to take up too much space on the screen. Three options were identified to replicate the mouse's click function, drawn from current literature and technology. The first was to set a focus duration on a key to run the click function. The click function would be called if the user focused on the key and kept his focus for a specific time. The second one was based on voice commands, where the user needed to speak a predefined word for the click function. The third one relies on intentional blinking rather than a reflex. To execute a click, the user needs to close their eye for a specific duration and then reopen it. All three options were reviewed and tested by considering the user's needs. Then, it was decided to use the third option, blinking, because it resulted in better and quicker user performance. Initially, an attempt was made to execute a click by blinking one eye, with one eye open while the other remained closed. In essence, the eye-tracking data from the eye tracker would gather data from either the left or right eye for a specific duration, resulting in a click. During the trials, it was detected that if the user closes one of his eyes, the eye movement data from the other eye could be corrupted by the user's eyelashes. Thus, it negatively affected the effectiveness of the click function. As a result, it was decided to use blink for both eyes to perform a click by adding a function to distinguish it from blinking as a reflex. The user test was applied at the end of this cycle, followed by an interview. By using the results of the user test and interview, the third development cycle was planned.

In the third cycle, various mouse functions were on the target based on the user's needs. New gestures were designed to be tested with the user's eye movements. At first, a replication of the mouse drag function was designed to move the keyboard on the screen, providing flexibility for the user. A key to move the keyboard was added to the on-screen virtual keyboard, and then two functions were assigned to this key. When the user clicks on this key for the first time, the first function starts, and the on-screen virtual keyboard starts moving in line with the mouse cursor, with eye movements. Therefore, the user could move the on-screen virtual keyboard on the screen. Then, the user could do another click to release the on-screen virtual keyboard wherever s/he wants on the screen as the second function of the move keyboard key. Similarly, a key for enabling a right click was added to the on-screen virtual keyboard. After clicking on this key, the following first click would function as a right click. After that, the double-click function was planned in a similar way to the click function. As we designed and developed a function for clicking in the second phase, the user could blink both of his eyes to click. In other words, the click function runs if the user closes his eyes and opens after a specific time. In addition to this function, the mouse double-click function was designed to activate if the user keeps his eyes closed for twice the duration needed for the regular click function. Moreover, sound notifications were identified for click and double-click to indicate that the time needed for the click had elapsed. Three sound notifications were incorporated to provide auditory guidance for click and double-click functions. A trigger monitored the eye movement data, initiating a countdown if the data flow ceased. The first sound is played when the time reaches the predetermined duration, for example, two seconds. The trigger runs the click function if the user opens his eyes after hearing this sound. If the user keeps his eye closed until hearing the second sound played after a certain time, for example, two more seconds later and opens his eyes. Then, the trigger runs the double-click function. If the user keeps his eye closed two more seconds after hearing the second sound, the third sound is played to indicate that there was no data flow for a long time, the trigger would stop running, and no action would be taken, like a click or double-click. Moreover, before the user closed his eyes, the screen coordinates were recorded to execute click functions after he opened his eyes. This approach accounted for potential differences in the user's eye movements before and after closing his eyes. Therefore, the x and y coordinates on the screen before closing his eyes were kept and used while performing the click function, even though he looked at different positions on the screen after opening his eyes.

In addition to click and double-click functions, the mouse scroll functions (up and down) were also assigned to the keys, which were added to the on-screen virtual keyboard. Furthermore, the print screen key function was modified to exclude the on-screen virtual keyboard from the screenshot. When the user clicks on the print-screen key, these three functions run sequentially: a function to minimize the on-screen virtual keyboard window, a function to take a screenshot, and a function to restore the minimized keyboard window.

At the end of this cycle, a user test with a working on-screen virtual keyboard (see Figure 4) was applied, followed by an interview. The fourth and last development cycle was planned using the user test and interview results.

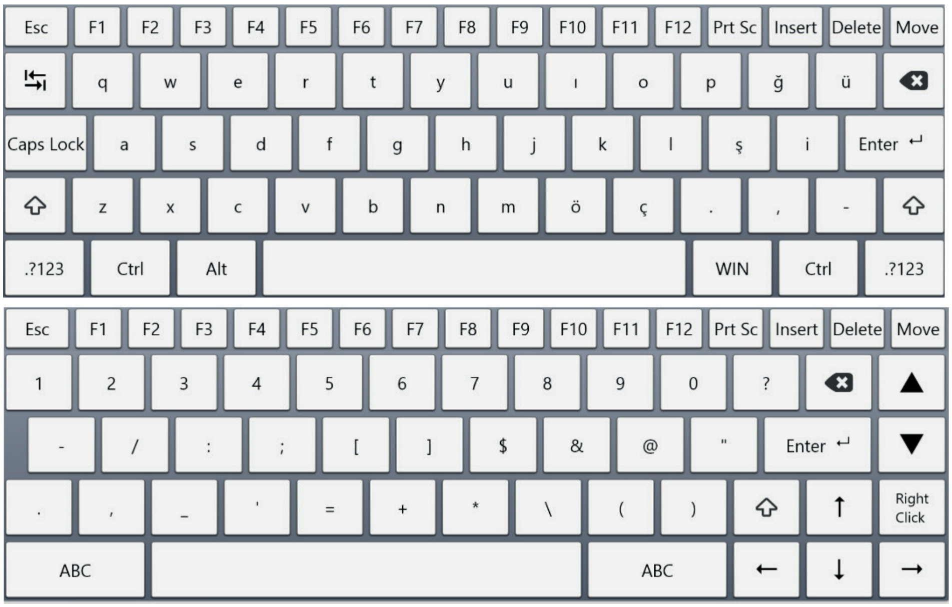

Figure 4. On-screen Virtual Keyboard Developed During the Third Cycle

In the fourth cycle, the overall design of the keyboard was revised to enhance effectiveness and efficiency for the user. To this end, one more line of keys was added at the top of the on-screen virtual keyboard. On this line, there were four groups of keys to provide more comfort.

In the first group, three options were provided for the user to change the duration to keep his eyes closed to perform mouse functions such as click and double-click. By providing this option, it was assumed to give him a chance to use the system quicker as he gained experience. Alternatively, he could use it more slowly when he is a beginner. So he could adjust the duration to click or double-click, depending on his own pace.

In the second group, five options, namely select all, cut, copy, paste, and undo, which require two simultaneous key presses to perform, were added to the on-screen virtual keyboard. This addition aimed to simplify the user process of selecting these functions.

In the third group, two keys were added to increase and decrease the opacity of the on-screen virtual keyboard to make it possible to see the area behind the keyboard. In the fourth and last group, two keys were added, one to minimize the on-screen virtual keyboard and the other to exit, which were not used at first to save space.

Additionally, numeric keys were placed on both tabs for ease of use by putting function keys (F1, F2, F3, etc.) only in the tab consisting of keys for symbols. In parallel to this change, the name of the ".?123" key was replaced with ".+?@". At the end of this cycle, a user test with the developed on-screen virtual keyboard (see Figure 5) was applied, followed by an interview to observe and examine the changes made during this cycle.

Figure 5. On-Screen Virtual Keyboard Developed During the Fourth Cycle

Evaluation and Testing Phase

The developed solution tracks the eye movements of the user and turns them into mouse cursor movements. Moreover, it provides an on-screen virtual keyboard with easy-to-use functions for enhancing interactivity by enabling key press events with the combination of eye movements and eye blinking. This study demonstrated that our target user could successfully engage in computer-based activities to meet his course requirements. The solution not only facilitated independent task performance but also boosted the user's motivation by empowering him to carry out activities autonomously.

During this phase, the paralyzed Physics Department student used the system (see Figure 5) for two consecutive semesters (spring and fall). In the first semester, he registered for three courses, all of which were must-courses. Two were departmental courses, while one was a language course from the foreign languages department. In the second semester, he registered for three must courses again. Two were departmental courses, while one was from the mathematics department. He used the developed solution during these two semesters while actively pursuing his education. He used his computer by himself and did anything that could be done with a computer, such as doing homework or searching for online course materials. Besides, he can easily follow e-mails and class discussions related to his courses, research via the Internet, and reach resources for his personal development. He stated that this solution provided him motivation and a chance to self-control his education by saying: "I can use my computer without the help of my mother.", "I can do anything that can be done on the computer. Awesome!" and "I could write pages of codes with this system in the programming course that I will take next semester."

Figure 6. Solution Developed for the Paralyzed Student

Furthermore, an additional four finalizing cycles were conducted over two semesters, each tailored to the individual use of the proposed solution. In the first cycle, the number of frequently used keys increased based on the user's needs by altering numeric keys on the symbols tab of the on-screen virtual keyboard. Besides, two more keys, one for starting the task manager and the other for performing the function of the "ALT+F4" key combination, a shortcut to close the currently active window, were defined in the symbols tab. At the end of this cycle, a user test was applied, followed by an interview to observe and examine the changes made during this cycle.

In the second cycle, the mouse-over function was defined for the keys of the on-screen virtual keyboard to highlight the key the user is looking at. Moreover, the keyboard move function was limited to two predetermined positions on the screen, one at the center top and the other at the center bottom, to prevent accidentally moving the on-screen virtual keyboard to the unwanted positions. In parallel to this, the keys for increasing and decreasing the opacity of the keyboard were combined, and it was assigned to set the opacity to four predefined values at every click. Furthermore, a key was defined to execute the drag function of the mouse. Upon activation of this key by the user through a click, the subsequent two clicks would execute the mouse's left button down and up actions sequentially. At the end of this cycle, a user test with the final version of the on-screen virtual keyboard (see Figure 6) was conducted, followed by an interview.

In the third cycle, improvements were made to enhance the precision of moving the mouse cursor on the screen using eye movements. Cursor movements were executed based on the average eye positions obtained from the eye-tracking device. For instance, the Tobii EyeX eye-tracking device has a frequency of 70 Hz, indicating how many times per second the eye tracker registers the position of the eyes, and nine-point calibration was applied before using the system. For this device, the average of the last thirty eye positions was used to move the mouse cursor on the screen. In this cycle, the number of eye positions used to calculate the average to move the mouse cursor was defined to be updated automatically depending on the saccades in the eye movement. When the user attempted to fixate on the screen and their eye movements were concentrated in a narrow space, the value utilized to compute the average of eye positions was elevated to facilitate smoother cursor movements on the screen. Conversely, if the saccade's amplitude was longer, the value used to calculate the average of eye positions was decreased to facilitate more rapid cursor movements on the screen. This adaptive approach aimed to optimize cursor control based on the user's specific eye movement patterns.

Figure 7. On-screen Virtual Keyboard

In the fourth cycle, the focus shifted towards enhancing comfort during reading or watching activities, where cursor movement or clicking is not required, and even the on-screen virtual keyboard might be unnecessary. It was resolved by adding a function to pause mouse functions by eye movements and removing the on-screen virtual keyboard from the screen by deactivating the eye-tracking feature. This function had two consecutive steps: the first was to minimize the on-screen virtual keyboard using the minimize key, and the second was to stop the flow of eye movement data for three seconds by consciously closing the eyes. To activate the eye-tracking feature, the user needs to close his eyes for three seconds again. Then, the eye-tracking feature could be used with all of its functions.

At the conclusion of this cycle, a user test with the finalized on-screen virtual keyboard was applied, followed by an interview to observe and examine the final version of the on-screen virtual keyboard.

Documentation and Reflection Phase

In the documentation and reflection phase, design principles obtained at the end of the second phase were finalized and documented according to the results of the third phase, the evaluation and testing phase. The finalized design principles were addressed in the discussion. The design principles that emerged during this study are listed below.

The eye movement-based computer control system should:

Be designed to move the mouse cursor based on the user's eye movements.

- Set the speed of mouse cursor movements based on the saccade's amplitude of eye movements adaptively instead of straightforward mouse cursor movements.
- Have various options to perform mouse functions, such as click and double-click, depending on the user's needs and capabilities. Mouse functions can be performed by using the following:
  - Option 1: focus duration of the user's eye movements for a specific time
  - Option 2: predetermined voice commands
  - Option 3: eye blink for a specific time as it is decided to prefer while developing the solution during this study
- Have easy-to-use methods for frequently used mouse functions such as click and double-click, as it is implemented by closing eyes for one second for click and two for double-click during this study.

- Provide relative flexibility for the user to select the best duration to close their eyes for a click or double-click based on their own pace.
- Provide feedback with sound notifications to guide the user when their eyes are closed while performing specific functions, such as clicking or double-clicking.
- Keep the eye positions of the user before closing the eyes and perform the intended functions based on these eye positions; even the eye positions change while blinking the eyes.
- Include on-screen virtual keyboard keys for various mouse functions, such as right-click, scroll, and drag-and-drop.
- Offer shortcuts on the on-screen virtual keyboard for frequently used functions that require multiple key presses or mouse clicks, such as select all, cut, copy, paste, task manager, and close the currently active window (ALT+F4).
- Have a simple design and easy-to-use on-screen virtual keyboard to ease and enable the user to move eye positions to intended positions on the screen without taking up too much space.
- Enable the user to change the position of the on-screen virtual keyboard around the screen between predefined positions.
- Have options to change the on-screen virtual keyboard's opacity and minimize the keyboard if more space is needed on the screen.
- Enhance user-friendliness, visibility, and focusability by implementing a color-coded system for key groups on the on-screen virtual keyboard. Additionally, employ a feature that highlights keys when the user's eye movements hover over them.
- Provide an option to enable and disable the on-screen virtual keyboard and eye-tracking-based mouse control when necessary.

DISCUSSIONS

This study focused on designing and developing a solution that enables complete computer control solely through eye movements, providing an opportunity for physically disabled individuals, such as paralyzed students, to participate in courses with minimal external assistance. The aim was to offer comprehensive educational accessibility for paralyzed students, allowing them to engage in both in-class and online activities independently.

The participant in this study, a paralyzed student from the Physics Department, was able to pursue his undergraduate education with the help of his parents. The participant joined his courses, including both in-class and online activities via the Learning Management System (LMS). Before this study, he was joining in-class activities by wheelchair with the help of his parents, and he was getting help from his parents for online activities like reaching online sources to study, doing homework, typing, taking exams, joining class discussions, etc. During this study, he was asked to use the eye-tracking-based solution for course activities such as preparing homework and accessing/using internet resources. Additionally, he willingly chose to use the system.

When compared to existing systems like Tobii Dynavox (https://www.tobiidynavox.com), the solution developed during this study offers a cost-effective means of communication with the computer. Moreover, the system was tailored and individualized during the study to meet the participant's specific needs, ensuring a perfect fit.

This study has uncovered design principles that facilitate paralyzed students in taking courses through the developed solution. In this study, mouse and keyboard functions were simulated to provide paralyzed users with a solution that does not require physical interaction with these input devices. People with physical impairments can have difficulties properly interacting with input devices, so they need alternative ways to use these devices to control computers (Abiyev & Arslan, 2020; Borgestig et al., 2021; Hemmingsson & Borgestig, 2020; Lupu & Ungureanu, 2014; Raya et al., 2010)what reduces their possibilities to communicate and improve their cognitive and physical skills through computers. This paper proposes a head control mouse based on a triaxial inertial sensor particularly focused on infants with cerebral palsy (CP.

As demonstrated by Galante and Menezes (2012), it is possible to provide digital communication boards consisting of symbols to identify words or ideas to provide a communication method for physically disabled people. It is essential to offer preferences depending on their abilities and habits while developing an eye gaze solution for paralyzed students. In this study, complete control of a computer-based communication solution was developed by simulating mouse and keyboard functions via eye movements.

According to Lin et al. (2011), mouse movements could be provided in line with the eye movements, and various options such as duration to click, eye-movement-based, and voice-controlled options can be offered in an eye-controlled system. In parallel to the study of Zhang et al. (2017), the current study identified mouse functions that require two steps to complete, such as right-click, drag-and-drop, and scroll, as a keyboard key's function, while single-click (left-click) and double-click functions were performed by using only eye gaze.

During the design of the on-screen virtual keyboard in this study, it was imperative to incorporate shortcuts for frequently used functions and to maintain a simple design for the on-screen virtual keyboard, aligning with the approach described in Blignaut (2017) for easy accessibility. According to Caligari et al. (2021), setting the appropriate duration to select a key press is one of the most critical considerations in using an on-screen virtual keyboard with eye movements. In parallel to this finding, the current study offered options to set the duration of the dwell click time for pressing the keys of the on-screen virtual keyboard using eye gaze.

CONCLUSION

This study has demonstrated that the system has the potential to elevate the accessibility of both face-to-face and online education to a new level, particularly benefiting paralyzed students. Online education provides opportunities for students who may not be able to attend classes physically. Even the description of online education fits the paralyzed students; in reality, it is not possible for these students to reach online courses. Therefore, this study showed that eye-tracking technology could help fill the missing part of face-to-face and distance education for paralyzed students.

By leveraging eye-tracking technology, paralyzed students can overcome physical barriers and actively engage in online courses, interact with peers and instructors, and independently pursue learning through Internet services. The system's potential extends beyond the confines of traditional education, offering a transformative solution for paralyzed students to participate in various educational activities.

It's important to note that this study is limited to one participant with SMA2, and students with different needs may require individualized modifications to the developed system. Consequently, the design principles uncovered in this study can serve as a valuable guide for the development of systems tailored to the specific needs of paralyzed individuals, ensuring a more inclusive and adaptive approach to education technology.

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