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Side Keyboard – the New Approach for Eye-typing

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Abstract

A novel approach for eye-typing using an on-screen keyboard was proposed in the paper. It was compared with the two applied in the previous studies. All utilized the dwell-time selection for writing letters, set to 1000 ms. This value was chosen due to the planned group of participants. Among 14 engaged people, there were four over the age of 50 and one aged 47.

The text utilized in the research was prepared in two languages – Polish and English. The obtained results showed that the language used had no influence on typing efficiency. Additionally, they revealed the new keyboard layout was more convenient than one of the two chosen for comparison and similar to the second. Such conclusions were based on the experiment duration and the number of errors made. They were confirmed by the users' opinions.

Keywords: man machine interaction, eye tracking, input modality, eye-typing; virtual keyboard;

1. Introduction

Over the last few decades, highly dynamic technology development has been witnessed. Computers and electrical devices dominate professional work, free time, and family life. More and more companies focus on solutions that allow for controlling some processes more accurately and faster, saving time, which is desirable in the modern model of functioning. However, among the consequences of computer technology development, less favorable issues should also be mentioned. The dynamics of progress are mainly aimed at increasing economic efficiency, which leaves certain groups of people with no or very limited access to technology. There are, for example, individuals whose cognitive abilities or physical fitness do not allow them to take full advantage of technological achievements. They are not able to use the most basic forms of control – a mouse and a keyboard, and as a result, they cannot utilize computers. This way, such a person becomes more and more withdrawn from professional, social, or even family life.

The concept of using the eye movement device to control a computer or other devices meets the needs in the mentioned field. It is a form of communication retained in most people with any disabilities, excluding those related to visual impairment or blindness. In addition, controlling the device utilizing eyesight can also be widely used in

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other fields. It may be helpful in many industries when an employee engaged in manual activities will be able to use his eyesight to operate the program simultaneously. This is also advantageous in everyday situations, where an ongoing task requires hand interactions, such as surgery. Moreover, hygienic considerations for public displays have also become crucial since the outbreak of the COVID-19 pandemic.

The keyboard is most often associated with the input modality to the computer. Along with the mouse, it is the most popular device used to work with various types of equipment, and its main task is to control entering characters. Keyboards can take very different forms and have their development cycle. It regards both the shape of the keyboard itself and its buttons, their size, and available functions. The same concerns on-screen keyboards. There is still a necessity to constantly improve them and search for better, more convenient, and user-friendly solutions.

2. Eye-Typing Solutions

Entering text using virtual keyboards controlled by gaze interaction requires some design issues to be considered. Among them, keyboard layout, key size, and the way of its activation can be mentioned. The goal is to develop a simple, efficient, and intuitive keyboard interface. The usability of eye typing solutions mostly depends on the approach for the key selection. It influences, among others, the typing speed, unintended key choice, and learnability. Typing with eyes requires the user to maintain a high cognitive load. Though allowing high-speed typing is undoubtedly an essential factor. Another important concern is optimizing a screen area to ensure a convenient size of keys and a place for displaying a written text. Decreasing the number of keys and distances between them can be used to save screen space, but more actions have to be invoked to access the remaining characters. On the other hand, a bigger key size makes the typing task more straightforward yet limits the typing area. Finding solutions for the aforementioned problems has attracted researchers for many years [3, 6, 7]. During this period, several methods for text writing have been developed, differing mainly in ways of typing letters and key layouts.

When the first element is considered, three approaches can be mentioned. The most common is the letter selection triggered by a predefined dwell time. The main concerns, in this case, are dwell duration, ensuring the trade-off between speed and accuracy, and avoidance of the Midas touch problem, a situation in which commands are activated unintentionally. This solution was utilized among others in [4, 9, 10] and [16], and the dwell time is usually set to between 450-1000ms. The second approach, in which typing is realized by eye gestures meant as a set of fixations and saccades, was applied for example by Isokoski [5]. The technique is based on gazing at off-screen targets placed at the screen edges to form letters based on the MDITIM stroke alphabet. Additionally, Wobbrock et al. in [18] developed a solution in which entering a text requires generating a gesture resembling the letter in a keyboard called EyeWrite. Moreover, the eye gestures were also utilized by Porta and Turina in [15]. The authors proposed the Eye-S Input Modality, in which letters are drawn through sequences of fixations on specific parts of the screen called hotspots. The third group of studies for eye typing utilizes smooth pursuits following clusters of letters or character tiles. Such a solution was applied by Lutz et al. [8] in the form of a gaze speller called SMOOVS in which clusters to pursue move apart from each other. A similar solution was described by Abdrabou et al. [1], with such a difference that groups rotate around a central place. In some works, the authors applied a language model to speed up typing process by predicting both subsequent possible letters and words [1, 17, 19]. In the last-mentioned research, a pre-trained model based on convolutional neural networks (CNNs) was used in the prediction process.

The studies conducted in eye typing can also be differentiated by taking the layout of keys into account. There are works in which the well-known QWERTY layout was used, as in [9, 12, 13]. However, in the Morimoto et al. work [12], characters were organized in one or two lines, and the alphabetical order was additionally tested. Panwar and others in [14] provided the letter arrangement with two zones: the central one with the most frequently occurring letters and the outer, surrounding zone with the next most frequently used characters. On the other hand, Huckauf and Urbina [16] developed a dwell-time-free text entry system pEYEs in which letters are grouped into the sectors of the pie. Furthermore, in [1, 8], hexagonal clusters with hexagonal tiles organized in a circular layout around a central area were applied. In all this research, the two-stage letter choice was utilized: the selection of a letter group and then a particular character within the group. The same method was proposed by Cecotti et al. [2]; however, this time, the virtual keyboard was organized as a set of letter buttons arranged around a rectangular area where the text is written.

Although various studies were conducted, providing various approaches for eye-typing using on-screen keyboards, there is still a place for exploring new solutions, which can be better adjusted to a given group of users or tasks. It was the motivation factor for undertaking studies aimed at finding a new method in the area under consideration.

When analyzing the previously conducted research, it was noticed that participants engaged in the research were young people, probably more often acquainted with new IT technologies. For example, in Huckauf and Urbina work, [4] there were 4 people aged between 23 and 27; 8 participants from 22 to 33 years were recruited by Panwar in [14]; 24 participants (age: M = 25.4, SD = 3.41) by Lutz et al. [8]; 26 participants aged between 16 and 29 (M = 21.6; SD = 2.5) were invited by Abdrabou et al. [1]; 6 people between 23 and 46 years old involved by Morimoto in [11] and 6 with mean age 35 (SD=7) in [12]; 8 volunteers aged between 24 and 38 (28 on average) were engaged by Porta [15].

Based on such a juxtaposition, it was decided to extend the prospective users' age range and invite, for the experiment purpose, people over the age of 50. Additionally, the participants speaking two languages (Polish and English) were involved in the tests to make the study independent of particular language characteristics.

3. The Method

The experiment was conducted with the usage of three keyboard types, two known from the literature and one novel, elaborated during the presented studies. The two chosen solutions represent different dispersion of keyboard keys. In the first of them, keys are centralized close to each other, while in the second one, they are spread around the screen. The approach developed during this research introduces a layout in which the keys cover only the sides of the screen.

All keyboards utilize the dwell selection for typing letters. This choice was made not to force the older participants to memorize eye gestures. Moreover, all keyboards have a similar approach for writing text, consisting of two stages. During the first of them, a user selects a group of letters. In the second step, the choice of a letter within the group is made. There is also an auxiliary "Start/Stop" button in each keyboard window. Its function is to facilitate measuring time during the test.

Nevertheless, the keyboards differed in the design: buttons' shape and arrangement, the layout of the letter within the group, and the place for typing a text. Furthermore, visual feedback for the selected item is given to the user by changing the color of the buttons.

The software implementation was realized in the C# language, and the EyeTribe C# SDK was used to establish a connection between the application and the eye tracker. Apart from the Windows 10 operating system, the application has no other requirements.

3.1. The Pie-based Keyboard

The first keyboard implemented in this study is based on the solution proposed by Huckauf and Urbina [16]. It groups letters into the sectors of the pie. After the defined dwell time, another pie appears on the screen with the chosen group of letters and one sector for a letter. On the right side of the keyboard, a textbox is placed in which a written text is visible. In the middle of the circle for individual characters, a "BACK" button is located, which is used to return to the previous view. The delete action needed for correcting errors is available within the bottom sector as it can be seen in Fig. 1.

The keyboard is light violet. It changes to a darker one when the eyesight is focused on the given item. The selection of the element entails triggering the action. When the letter is chosen, the pie is closed.

3.2. The Tree-based Keyboard

As the second solution utilized in the research, the keyboard type proposed by Cecotti et al. in [2] was chosen. It was designed as a multimodal virtual keyboard recognizing eye and hand gestures in a tree selection mode. The tree has two levels and allows the user to select any character with two commands. The virtual keyboard has two main components: the first one is the center of the screen, where the user's input text is displayed. It is surrounded by different command buttons constituting the second part (Fig. 2). At first, they show character groups, and after selecting a letter set, buttons display their members.

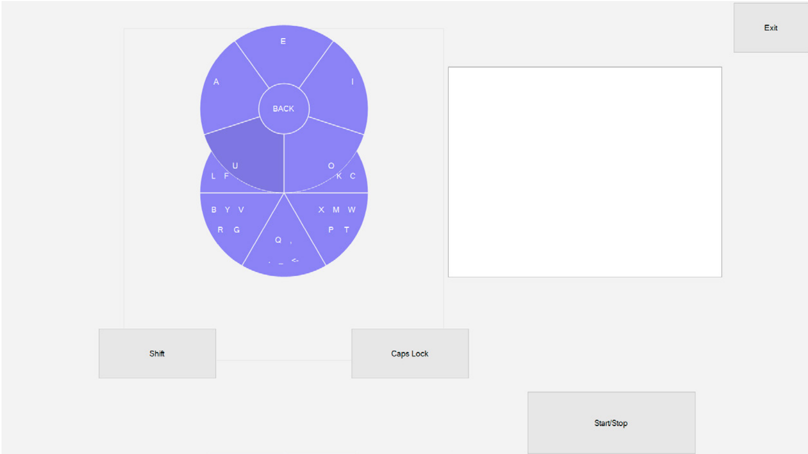

Fig. 1. The Pie-based keyboard used in the research.

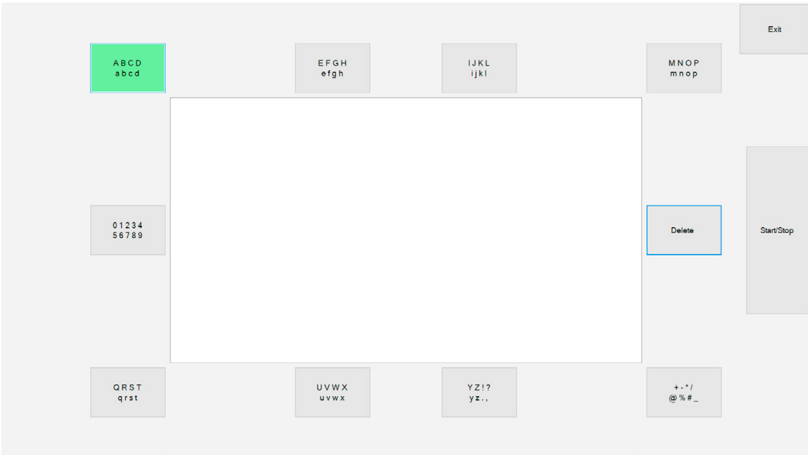

Fig. 2. The Tree-based selection keyboard applied in the study

The letters are organized in alphabetical order on grey elements, changing to light green when a user focuses on them. Further, when the selection is made, it becomes dark green for 0.5 sec.

3.3. The Side Keyboard

The Side Keyboard presented in Fig. 3 is a novel approach. When designing its layout, two issues were considered: an intuitive choice of the desired letter and removing the necessity of using the BACK key in the case of selecting the wrong group of letters. This keyboard, similar to the previous one, includes a text box in the screen center, yet buttons were placed on the left and right sides of the screen. Those on the right are shown or hidden depending on the current state of the keyboard. The buttons are triangle-shaped due to the optimization of the space – to fit as many groups of letters as possible in the smallest possible plane while, at the same time, maintaining a large area for easy viewing. The buttons on the right have only one letter. They are arranged in the same order as in the group on the left. The letters were divided according to the frequency of their usage. The vowels were grouped together; special signs were located in the first and last triangles, starting from the top left, and most often used consonants in the middle of the keyboard.

Entering letters in the Side keyboard is realized in two steps. The first is needed to select the group of characters on the left screen side, which triggers opening the right panel with letters placed on separate buttons. During the second

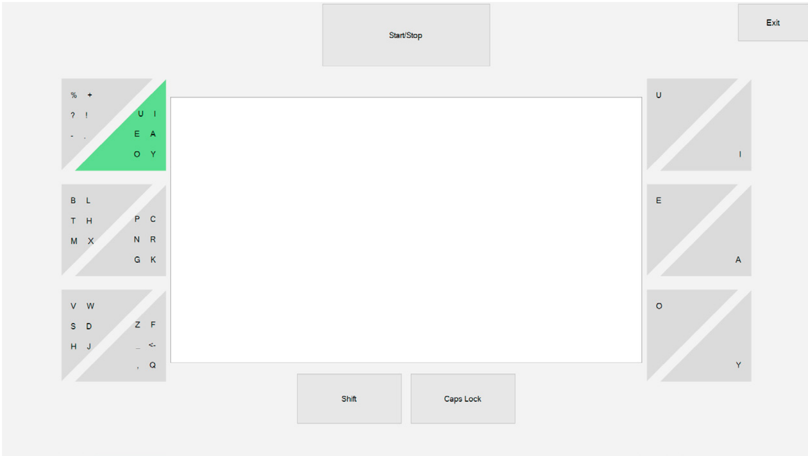

Fig. 3. The introduced Side keyboard

phase, a user points out the letter they are interested in. When a character is selected, it is entered into the text field, and the entire right side panel is hidden to give a clear indication that the letter or symbol has been entered. The keyboard also has a graphical help when selecting buttons. When the gaze moves over a given triangle, it is highlighted in light green (Fig. 3) as in the case of the Tree-based keyboard. After selecting this button by staring at it for a set duration, the triangle turns dark green.

4. The Experiments

14 unpaid volunteers took part in the conducted experiments. The subjects' age ranged from 24 to 58, with an average of 37.38 years. There was one person aged 47 and four aged above 50. Four people wore glasses, and no one had contact lenses during the experiment. 7 out of 14 participants were English speaking, on the advanced level, using the English language on a daily basis. Moreover, all participants had no experience in eye typing, and only one was acquainted with eye-tracking technology.

The experiments were carried out for each participant according to a set pattern. The only changing element was the sequence of screen keyboards used to enter text by means of eyesight. At the very beginning of the session, each participant became familiar with the program. All the necessary information related to the conducted test and the calibration were provided. Each keyboard was described in detail, and the way how to enter characters on each of them was demonstrated.

In the beginning, the participant went through the calibration process. During it, the subjects follow the point appearing within ten locations. When the calibration error was too large, it was repeated until a satisfactory result was obtained. In order to get a well-prepared environment, the calibration result was accepted when a value was lower than 0.5 degrees. Then the user was given simple training to become familiar with each keyboard. The exercise was to write the name and surname and the current month's name. The dwell time was set to 1000ms.

After that, the main stage of the research began, in which the participant's task was to write a text consisting of 11 words and 76 chars in the Polish language and 11 words and 71 letters in English. This setup required the user to enter the text three times, once for each keyboard. Before each trial, the calibration was repeated. In order to eliminate possible difficulties associated with transcribing the text and looking away from the keyboard, the text was read word by word each time to allow the subject to focus only on the task. Every attempt started and ended with the "Start/Stop" button press, triggering the experiment duration measurement. The eye movement data was collected using the Eye Tribe eye tracker, working with the 60Hz sampling rate.

When all the trials were completed, participants filled out a questionnaire. They rated each keyboard for ease of usage and shared their opinion on the experiment in which they participated.

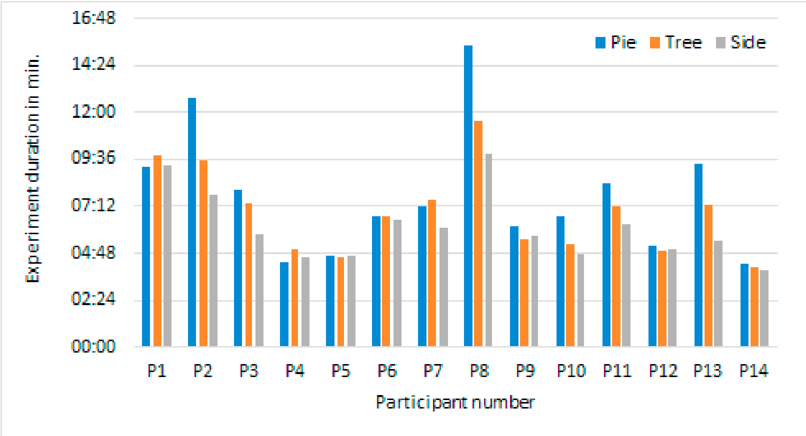

Fig. 4. The experiment's duration for each participant and keyboard. The participants from P1 to P7 entered the Polish text. Participants in the group from P8 to P14 typed text in English.

5. The Results and Discussion

The keyboard assessment was done taking four factors into account: the experiment duration – the time spent on the experiment realisation, the number of errors made, typing speed – the number of words written per minute, and the user's grade.

5.1. The Analysis of The Experiment Duration

The values of the time metric were obtained through Start/Stop button usage. The experiment duration shown for each participant in Fig. 4 was registered for each keyboard independently.

The first seven participants entered the Polish text, while the remaining group the English one. As it can be observed, the experiment duration did not depend on the text language. There were people for whom eye-typing was easier than for others in each subject set. Table 1 shows the average duration estimated for each group and keyboard. For the Pie-based keyboard, a slightly higher outcome was obtained for English-speaking people, who, on the other hand, were quicker in the two remaining approaches. It also seems that the letter arrangement on the Side keyboard could be more adjusted to the English language. However, the differences were minimal, and this fact confirmation needs further studies.

When exploring experiment duration in terms of the keyboard type, the most challenging turned out to be the Pie-based one. The participants utilizing it spent more time on text writing, while the two remaining keyboards were comparable in this aspect.

And finally, if the age is taken into consideration, more extended typing times were acquired for three out of five participants over the age of 45 (P7, P11, and P13). Nevertheless, some younger subjects needed more time (P1, P2), and the longest experiment was conducted for the participant aged 31 (P8). Thus, expectations that subjects over 50 could perform slower were not met.

Table 1. The average duration, in minutes, of typing text for Polish and English groups, and all subjects, and for each keyboard. The standard deviation is provided in brackets.

Keyboard	Polish (SD)	English (SD)	All languages (SD)
Pie-based keyboard	07:33 (0.11)	07:55 (0.14)	07:44:09 (0.13)
Tree-based keyboard	07:12 (0.08)	06:32 (0.09)	06:52:21 (0.09)
Side keyboard	06:23 (0.07)	05:50 (0.07)	06:06:47 (0.71)

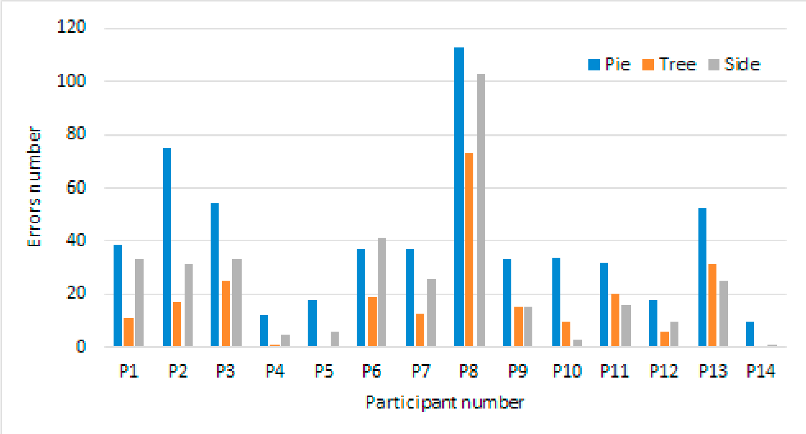

Fig. 5. The error numbers for each participant and keyboard. The participants from P1 to P7 entered the Polish text. Participants in the group from P8 to P14 typed text in English.

5.2. Examination of Typing Mistakes

The errors were recognized if the users entered an invalid character or chose an undesirable letter group, which forced them to apply the return button. Counting mistakes, corresponding to deleting the last character, or making an unwanted selection, was performed for all keyboards. In the case of the Pie- and Tree-based keyboards, calculating errors strictly reflected the problems that occurred during the use of these systems. In the case of the Side keyboard, the situation was different because it has been designed so that there is no need to use the Back button to save typing time. Nonetheless, invoking the wrong section of the letter group was treated as a mistake, even if changing the choice was more straightforward – it required just pointing out the right triangle with letters again.

The numbers of mistakes made by each participant for each keyboard are juxtaposed in Figure 5. As can be expected, people with a more extended experiment duration made more mistakes, for example, participants P8 and P13. However, it was not always the case. Taking participants P2, P4, and P12 into account, it can be noticed that all of them made fewer errors for the Tree-based keyboard than for the Side one. However, they realized the experiments longer in the first case than in the second one. It stems from the fact that when pointing out unwanted parts on the Tree-based keyboard, a user had to perform another selection (BACK key) to return to the previous keyboard view. For the Side one, there was no need to use such a button when the wrong letter group was chosen.

In the case of the Pie-based keyboard, the number of errors made with its usage is, in most cases, the highest. These problems may result from the too close proximity to the adjacent circle parts and too small buttons. The least number of mistakes was made when exploiting the Tree-based keyboard, which can be related to the alphabetical order of letters being more intuitive for novices.

Considering the text language, the analysis of the results shown in Table 2 indicates that it had no influence on keyboard usage. The same dependencies among approaches are visible for all groups. The only difference regards the Tree-based keyboard, which had more errors for English than for the Polish text. It is related to the very poor performance of subject P8.

Table 2. The averaged mistake numbers for Polish and English groups, and all subjects, and for each keyboard. The standard deviation is provided in brackets.

Keyboard	Polish	English	All
Pie-based keyboard	38.85 (19.63)	41.71 (31.58)	40.28 (26.33)
Tree-based keyboard	12.28 (08.53)	22.14 (22.73)	17.21 (17.86)
Side keyboard	25.00 (12.99)	24.86 (32.84)	24.86 (24.97)

5.3. Typing Speed

One of the metrics used for virtual keyboard assessment is the typing speed measured as the number of words per minute (WPM), where one word is considered as a sequence of 5 characters, including white spaces [12]. The reliable values for such a metric should be calculated when a user had enough practice time to be fully acquainted with the keyboard layout and the eyes control. Nevertheless, although the above conditions were not met in these studies, such a metric was also determined for the conducted research. The purpose of such calculations was to evaluate the newly developed keyboard compared to the previous solutions. The obtained results are presented in Table 3. Once again, the Pie-based keyboard turned out to be slightly worse than the other two, which means that it was more difficult for new users to control. It has to be emphasized that the typing speed acquired in these studies was much lower than in other works such as [12] or [4]. However, it was achieved after short introductory trials. It can be expected that with more training sessions, outcomes would be better.

Table 3. The averaged, min and max typing speed in WPM for each keyboard. The standard deviation is provided in brackets.

Keyboard	Mean (SD)	Min	Max
Pie-based keyboard	2.18 (0.76)	0.92	3.48
Tree-based keyboard	2.33 (0.66)	1.23	3.48
Side keyboard	2.56 (0.61)	1.44	3.64

5.4. Statistical Analysis

The purpose of the statistical analysis was to verify the significance of differences in the obtained results. At first, the equality of variances (the Levene test) and normality of distribution (the Shapiro-Wilk test) were checked in the groups divided based on languages used (Polish and English) and participants' age (below or equal to 35 and above). The aim was to check how both factors influence the typing speed and error number for a given keyboard type. Because in all the aforementioned tests realized in Python, the null hypothesis could not be rejected, the t-test was applied to ascertain the statistical significance of the outcome differences. As can be noticed in Table 4, no such cases were revealed in both verified factors -– language and age.

Table 4. The t-test outcomes verifying the significance of the differences in the results obtained for language and age subgroups for each keyboard.

Feature	**Keyboard**	**Language** p_value (t_value)	**Age** p_value (t_value)
Experiment Duration	Pye	0.840 (0.206)	0.637 (0.483)
	Tree	0.591 (0.551)	0.469 (0.748)
	Side	0.575 (0.576)	0.196 (1.367)
Number of Errors	Pye	0.854 (0.188)	0.479 (0.730)
	Tree	0.340 (0.994)	0.732 (0.351)
	Side	0.984(0.019)	0.268 (1.162)

The similar outputs were obtained when analyzing the experiment duration for each keyboard, independently of the language and age of the participants. The differences were statistically insignificant. However, when the number of errors made by the participants was taken into consideration, it turned out that the data was not normally distributed. For this reason, the Kruskal test was applied in further studies. Because the results were compared in keyboard pairs, the Benjamini-Hochberg correction was also utilized. As a result, no statistically significant difference between the Tree and Side keyboards was revealed. The opposite situation was obtained for the pairs Pye-Tree (corrected p_value=0.012) and Pye-Side (corrected p_value=0.04) – in both cases, outcomes differed significantly.

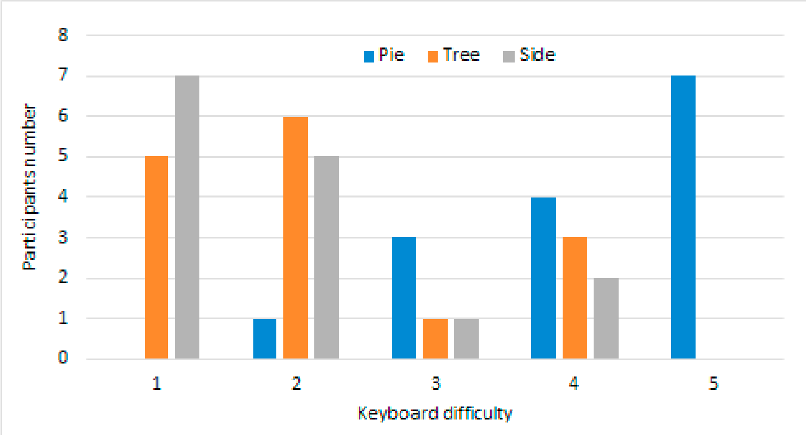

Fig. 6. The users' assessment of keyboards: 1 corresponds to the easiest one, 5 to the most difficult.

5.5. *User's assessment*

The last analysed factor was the users' opinion on each environment used. The participants were asked to assess them using a scale from 1 (the most straightforward keyboard) to 5 (the most difficult). The evaluation was collected on the chart visible in Fig. 6.

When asked for their opinion, the respondents indicated that the Tree-based keyboard and Side keyboard are similar in the ease of entering characters. In this comparison, the Pie-based system turned out to be the worst, which was closely related to a large number of errors and the frequent selection of undesirable sections with characters. The subjects were also very positive about the Side keyboard, as causing the least eye strain, which allows using this system for a longer period. The arrangement of the buttons on both screen sides was invoking only side movements. It probably translates into less fatigue than moving the eyes around the entire monitor or when there is a need to keep eyes constantly focused on a small area of the screen, as in the Pie-based keyboard.

6. Conclusions

The novel approach presented in this paper turned out to be a convenient solution for writing text with the usage of eyesight. When compared to two other solutions, it was indicated as more straightforward and eye-friendly. An important element of text typing systems is the psychological aspect of being rewarded by a fast and seamless text entry. During the experiments, it was noticeable, especially when using the Pie-based keyboard, that many errors frustrated the subjects. Problems with inserting letters kept accumulating, which resulted in a reluctance to continue using this system and making more errors. Considering this aspect, the participants appreciated the Tree-based and Side keyboards solution. In the first of them, distances between the buttons worked to the advantage, which allowed to avoid many errors, while in the latter one, it was the lack of the "BACK" button. The possibility of multiple selections of a letter group meant that the user could focus mainly on entering the correct letters without constant return to the previous view to select the right sector with characters was mentioned as valuable.

The participants also pointed out some disadvantages of both approaches. In the case of the Tree-based one, they were buttons placed in the corners, which were more difficult to select than others. When assessing the Side keyboard, suggestions were made that the applied arrangement of letters made finding the required group more challenging. Some of the participants claimed that alphabetical order would be more convenient. Thus, further experiments are planned to provide more trials allowing for better adjustments to each keyboard and, if necessary, introducing participants' recommendations.

Acknowledgements

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