NOTE TAKING IN VR: THE FOREARM KEYBOARD

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ABSTRACT

This work presents and evaluates a forearm keyboard that allows users to enter textual data using a natural full-handed typing mechanism for virtual reality head-mounted display environments. Should the issues noted with the keyboard during the study be solved, the keyboard would compare favourably with others seen in the literature.

KEYWORDS

Virtual reality, head-mounted display, text entry, note taking

1. INTRODUCTION

As virtual reality (VR) technology has advanced and the cost of head-mounted displays (HMDs) has reduced, their use in educational environments has increased [1][2][3]. These applications have demonstrated that VR environments have proven beneficial for training in physical and mental tasks. However, the literature rarely addresses the ability of trainees or pupils to take notes in these environments. As [4], [5], and [6] show, note-taking improves retention of learning; therefore, HMD-based educational applications should provide a fast, accurate, and easy-to-use method for participants to note critical points during their learning. While stylus and wand devices are typical of VR input, they lack the flexibility, accuracy and speed of input of a traditional keyboard or pen [7]. To ensure compatibility with all applications, any suggested input device should be able to move through the virtual environment with the user during their exercise. This design requirement imposes the need for a device that can be utilised without interfering with the natural control flow of the application, meaning that it needs to be tracked and easily portable. As such, the idea of using parts of the body presents itself.

2. PREVIOUS LITERATURE

Numerous attempts have been made to create a keyboard suitable for VR. [8], [9], [7], [10], [11], [12], [13], [14], and [15] used physical keyboards with virtual representations shown allowing participants to see the keys they were pressing. While often proving to be fast and accurate, physical keyboards generally require a fixed physical hard surface on which to place the device and were therefore not suitable for non-static experiences. Alternatively, [16] and [17] considered how ideas from thumbstick-based keyboards could be applied to VR controllers. These were relatively slow but with a low error rate. Furthermore, [18], [19], [20], and [21] attempted text entry using tracked gloves but none undertook a systematic typing test making any comparison impossible. Tracked controllers packaged with consumer VR HMDs have also been tried by [22], [23] and [24]. These demonstrate three entirely different methods with moderate entry speeds and low error rates. Other text entry methods include the use of a smartphone [25] and using gaze to enter text [26].

Dhinaharan Nagamalai (Eds): EDU, SCMC -2023
pp. 55-61, 2023. IJCI – 2023 DOI:10.5121/ijci.2023.120404

3. Study Design

There are two segments in this study which need to be designed, the keyboards to be used and the typing test.

3.1. Keyboard Design

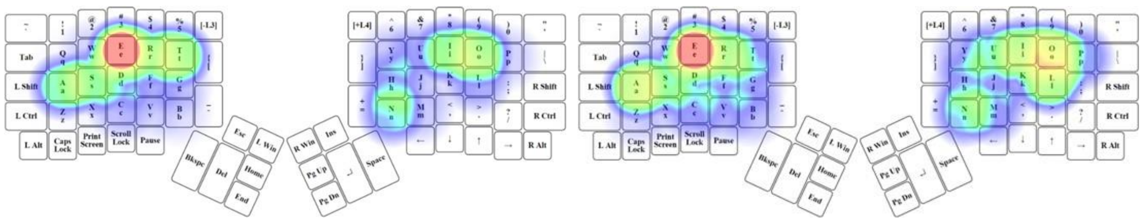
Thumb Keyboard [24] provides the inspiration for the first keyboard but will use consumer controllers. Unlike [24], the consumer controllers cannot be joined together to provide a more stable and comfortable typing experience. However, the similarities between this keyboard and [24] will allow for direct comparison between this work and existing validated results.

Forearm Keyboard The second keyboard will be a purely virtual keyboard visible inHMD above the user's forearm. To give the user visibility and spatial context, an additional tracker will be attached to the participant's forearm directly below the elbow. Combining this tracking point with the tracked controller in the user's hand will allow for the arm to be represented virtually. Tracking of the hand to press the keys will be done using a LEAP Motion device [27] attached to the upper arm such that when the user bends their arm at the elbow, the LEAP Motion is projecting directly down the forearm. The LEAP Motion device will create a hand model in the virtual environment, allowing the participant to visualise the location of their fingers in relation to the virtual keyboard.

3.2. Typing Test Design

Before designing a typing test, [28] was considered but, as can be seen from figure 1a, the phrase set presented has a left-hand bias. With keyboards similar to that presented in [24], a bias will potentially reduce the input speed and result in the test being based on the language of the phrase set rather than allowing understanding of the underlying capability of the text entry device. As such, a new word set will be created for this study and comparisons will be drawn from speed and error rate.

To design a word set to be used for this study, two word sets were created by selecting words that are typed exclusively with the left or right side of the keyboard and a third set that utilises both sides equally. These were selected such that the joint set was the same size as the left and right sets combined. To build the collection of words for the user to enter, words were taken randomly from each set proportioned by the set's size. This meant a quarter of the words selected were entered using the right side of the keyboard, a quarter with the left side of the keyboard, and half with the whole keyboard. This list of words was then randomised to force the participant not to use one hand or the other while also ensuring that the keyboard as a whole was used evenly. The comparison of these word sets can be seen by comparing figure 1a and figure 1b.



(a) A heatmap of the phrase set from [28].

(b) A heatmap of the generated phrase set.

Fig.1: Heatmaps of the phrase sets.

3.3. Implementation

Two applications were created to implement the aforementioned designs. Both implementations made use of the default Random library provided by C# through Windows Forms and Unity ensuring the same random number generation algorithm was used in both cases.

3.4. Testing Procedure

Participants undertook the traditional typing test first to create a baseline value for their typing speed and accuracy. Subsequently, participants were given 2 minutes to become familiar with each keyboard layout before the respective typing tests. The 2-minute timing was started when both participant and administrator were sure all keys were accessible.

4. FINDINGS

4.1. Observations During Testing

It should be noted that there were numerous issues with the forearm keyboard experienced by participants. Firstly, there were major issues in getting the virtual arm to align with the participant's physical arm. As such, the two-minute allowance for participants to acclimatise to the keyboard was not started until both participant and test administrator were certain that all keys on the keyboard could be pressed.

Furthermore, there were issues observed with the LEAP Motion sensor. On a number of occasions, the device ceased to track the participant's hand leading to participants spending time making their virtual hand re-appear. As this was a fault of the keyboard, these results were kept as it presents a true representation of the capabilities of the device. The issue was likely caused by the LEAP Motion device being used in a manner for which it was not explicitly designed.

4.2. Data

A total of 17 participants took part in the study. The data produced can be seen in figure 2.

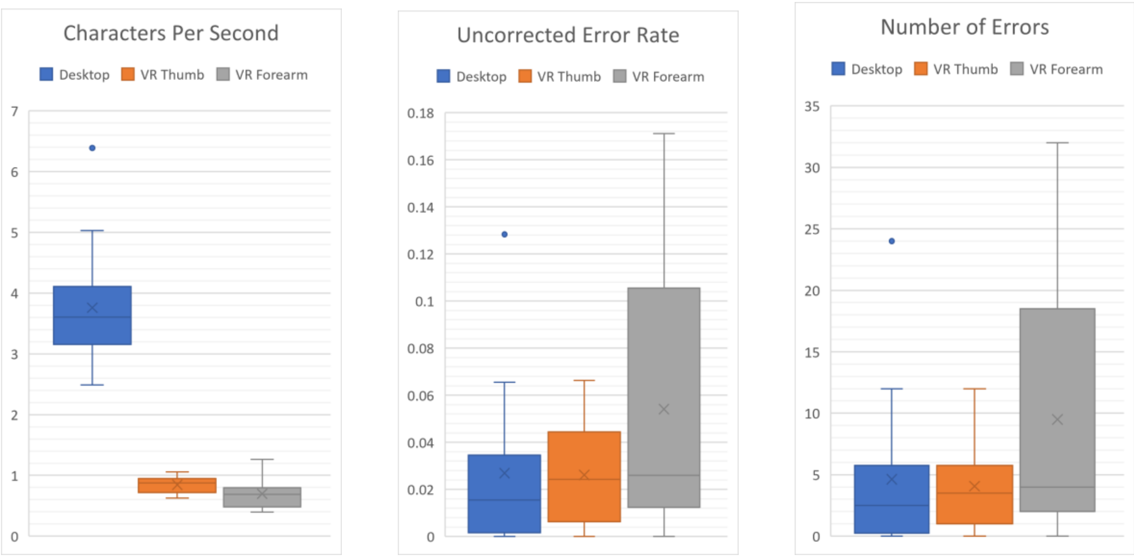
From figure 2a, it can be seen that typing on a physical keyboard is significantly faster than both of the VR keyboards tested in this study; with participants on average achieving approximately four times the speed. Figure 2a also shows that participants were most consistent with the Thumb keyboard as this had the tightest grouping between quartiles.

Figures 2b and 2c demonstrate that both more errors were made on the Forearm keyboard and that these were less likely to be corrected. This implies that participants found the forearm keyboard harder to use than the other two keyboards. On the other hand, figures 2b and 2c demonstrate that participants found the thumb keyboard as easy to use as the physical keyboard as similar levels of uncorrected errors can be seen.

5. DISCUSSION

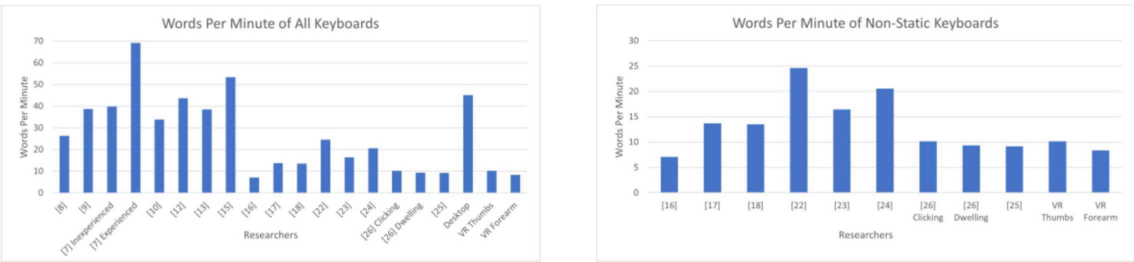
Using the calculation provided in [29], we can convert our CPS measurements into wordsper-minute (WPM) measurements to allow for comparisons to other results. In doing this, we can produce the charts seen in figure whatever.

Using figure 3a, we can determine that the results obtained on our Desktop Keyboard lie between experienced and inexperienced users. Therefore, our results represent that of an average typist, meaning that we can do deeper comparisons to other studies.



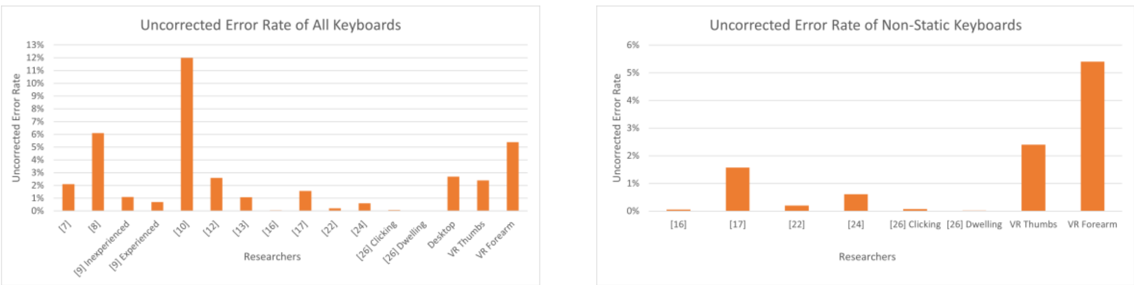
(a) The characters per second of each keyboard. (b) The uncorrected error rate of each keyboard. (c) The number of errors made on each keyboard.

Fig.2: Box and whisker plots showing the results of the keyboards.



(a) WPM all Keyboards

(b) WPM portable Keyboards



(c) UER all Keyboards

(d) UER portable Keyboards

Fig.3: Comparison to other keyboards.

Another key comparison can be made between the thumb keyboard implemented in this study and the keyboard created by [24]. [24] achieved a WPM approximately double the observed values in this study. Therefore, giving participants further experience with each of the keyboards created here could lead to an increase in observed typing speeds.

With this in mind, from figure 3b it can be determined that both the thumb keyboard and the forearm keyboard stack up relatively well against keyboards seen in the literature. On the other hand, a consideration of figure 3d shows the keyboards created for this study have a higher error rate that those seen in the literature.

Although some achievements have been made with these keyboards, the overall picture must still be considered. Figure 3a shows that compared to the physical keyboards, portable keyboards demonstrate a significant disadvantage in terms of speed. Therefore, we recommend that all seated applications look to use a physical keyboard wherever possible.

Further to this, figure 3c demonstrates how some visually occluded keyboards have fewer errors than the keyboards for this study. This implies that participants were getting particularly frustrated with the keyboards created such that they did not wish to interact with the keyboard further to fix their errors.

6. Conclusion

This work demonstrates the advantages of creating a keyboard suitable for use anywhere within a virtual environment. The forearm keyboard presents a way of entering textual data into a VR HMD-based environment, allowing users to take notes as part of a learning experience. Furthermore, by mounting the device on a part of the user, the forearm keyboard can be integrated into existing applications with minimal interference with other interface elements; allowing for robust if slow input. While the keyboard performed worse than some seen in literature, an improvement in performance would be observed with an increased acclimatisation period for users. However, if additional familiarisation with the keyboard does not improve these then the use of context-dependent interfaces providing specific words or phrases may be beneficial. These could be implemented in a way similar to a Japanese Kana keyboard [30], allowing fast and efficient selection of subject-appropriate verbiage. Further improvement could be achieved with an evolution in the design through better placement of the LEAP motion controller to improve the accuracy of typing. In this study, the LEAP Motion device was being used out of specification with custom hand-model transforms having to be implemented to use the device as per our design. If mounted directly on the arm, the forearm keyboard could be combined with [31] which demonstrated how LEAP Motion could be used for text entry purposes. For future developments of the keyboard, it may be beneficial to consider the addition of auto-correction technologies to increase text entry speed and reduce error rates. Alternatively, a swipebased input system on the user's forearm could be investigated as the tactile feedback of the arm would allow for non-line-of-sight typing [32], though the multi-finger input that the forearm keyboard allows would be lost, which may reduce input speed.

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