Investigating the Effects of Position and Angle of Virtual Keyboard on Text Entry Performance and Workload

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ABSTRACT

The Virtual Reality (VR) users suffer from neck and arm fatigue. This is because the VR users are required to wear the heavy head–mounted display (HMD) and keep raising the arms. In particular, the virtual keyboards are frequently used and they are time–consuming interfaces in VR. These virtual keyboards are related to both arm and neck fatigue. We considered that the text entry performance of the virtual keyboard and the workload of the users are affected by the position and angle of the virtual keyboard. To investigate these effects, we conducted experiments to compare the performance and workload by changing the position and the angle of the virtual keyboard, which is operated by mid-air tapping. A result of the user study showed that the higher the display position is, the greater the fatigue will occur in the upper arm, and the lower the display position is, the greater the fatigue will be in the neck.

CCS CONCEPTS

• **Human-centered computing** → **Virtual reality**; **Interaction techniques**; **Empirical studies in HCI**.

KEYWORDS

hand-tacking, text input, touch interaction

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1 INTRODUCTION

Virtual reality (VR) users suffer from neck and arm fatigue because they wear a heavy head–mounted display (HMD) and must constantly raise their arms to operate virtual contents. In particular, the virtual keyboards are frequently used and they are time–consuming interfaces in VR. To enter text in VR, a user operates a virtual keyboard, which is displayed in front of the user, by mid–air tapping with her/his hand(s). However, this method uses mid–air tapping and thus has the problem that the text entry is slower and the workload is higher than those of methods using controllers [10] and physical surfaces [4] because the user must constantly raise their arms. This would be because the user is required to keep raising the arm in the air, as Bachynskyi et al. [2] found that keeping raising the arm requires the user to use a broad area of muscles. In this study, we place a virtual keyboard at various positions and angles, and evaluate text entry performance and the workload. A virtual keyboard is typically displayed in the line of sight. However, a lower keyboard would narrow the play area and thus reduce the workload. Furthermore, this design can contribute to the design of interaction using mid-air tapping.

2 USER STUDY

We conducted a user study to investigate the effects of virtual keyboard position and angle on text entry performance and the workload. In the study, we used HTC VIVE as the HMD and Leap Motion (Ultraleap, LM–010) for mid-air tapping detection, which was mounted on the front of the HMD using a mounter. The application was implemented by Unity and executed on Alienware m15 for Windows 10. 18 participants (14 males; age 18–26 years, M = 21.5 years; three left–handed) were recruited. All transcribed English phrases via mid-air tapping as the declination angle θ and the posture angle ϕ (figure 1) of the virtual keyboard varied. In this setting, we defined θ when the participants were standing upright and facing the front as 0° and ϕ when the virtual keyboard was vertical to the line of sight as 0°. Note that the play area when θ = 0° is the area wherein the participant can reach an arm forward; the play area when θ = 22.5° is 87% of the play area when θ = 0°; and the play area when θ = 45° is 53% of the play area when θ = 0° (figure 2). The virtual keyboard had a QWERTY arrangement,

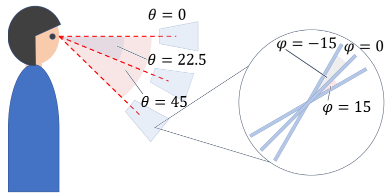

Figure 1: The declination angle θ and posture angle ϕ of the virtual keyboard.

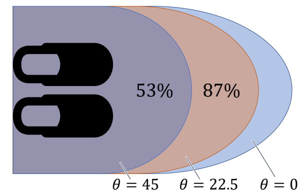

Figure 2: The relationship between the play area and the declination angle θ. Increasing the declination angle θ reduces the play area.

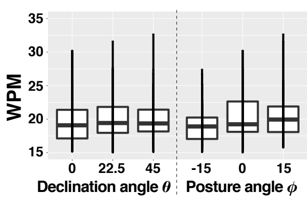

Figure 3: The Word Per Minute (WPM) at a declination angle of $\theta°$ and a posture angle of $\phi°$.

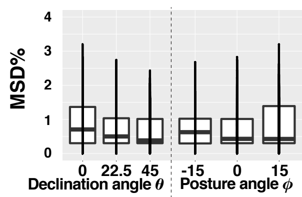

Figure 4: The Minimum String Distance (MSD) error rate at a declination angle of $\theta°$ and a posture angle of $\phi°$.

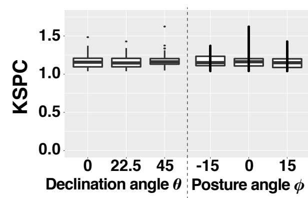

Figure 5: The KeyStrokes Per Character (KSPC) at a declination angle of $\theta°$ and a posture angle of $\phi°$.

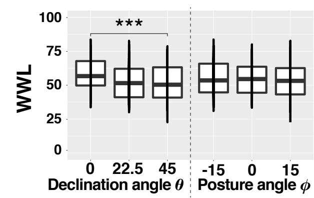

Figure 6: The Weighted Work Load (WWL) at a declination angle of $\theta°$ and a posture angle of $\phi°$.

whose keys were square following previous study [6]. We referred to the previous study using a physical keyboard for the angle [8]. We configured the keyboard to the position where the participants stretched their arms

We employed a within–subject 3×3 factorial design. The two independent variables were the declination angle θ ($0°$, $22.5°$, and $45°$) and the posture angle ϕ ($0°$and $\pm 45°$). The declination angle $45°$ was the chosen maximum value because this is within the range over which the neck can be safely tilted. We held declination angle θ during the task by fixing the standing position and the virtual keyboard in a world coordinate system.

We asked the participants to enter phrases with only the index fingers of both hands to perform best in text entry [4]. We used the phrase set of MacKenzie and Soukoreff [7]. Before commencing the study, all participants practiced phrase entry for 3 min. All participants entered 10 phrases under all of 9 conditions, the order of which was determined using a Latin square. At the end of each condition, the participants answered NASA-TLX [5] and SUS [3] to evaluate subjective Weighted Work Load (WWL) and usability. We used Word Per Minutes [1] (WPM), Minimum String Distance Error Rate [9] (MSD), and KeyStrokes Per Character [9] (KSPC) to evaluate text entry performance. In the statistical analysis, we performed two–way ANOVA with the declination angle θ and the posture angle ϕ as the factors. We used Tukey's multiple comparison method for the post–hoc tests.

3 RESULT

fig. 3–7 show the WPM (M = 19.3, SD = 3.72), MSD error rate (M = 0.77%, SD = 0.73%), KSPC (M = 1.17, SD = 0.09), WWL (M = 54.2, SD = 13.3), and score of SUS (M = 73.7, SD = 12.2) for each declination angle θ and posture angle ϕ. As the WPM, KSPC, WWL, and SUS scores were normally distributed (Shapiro–Wilk test, WPM: p = 0.1915 > 0.05, KSPC: $p = 0.1915 > 0.05$, WWL: $p = 0.881 > 0.05$, SUS: $p = 0.682 > 0.05$), we used ANOVA to perform comparisons. In contrast, the MSD error rate did not exhibit a normal distribution and we thus employed the Kruskal–Wallis test for comparison. For the WPM, the main effect of ϕ was detected ($F_{2,136} = 6.41$, $p = 2.17 \times 10^{-3} < 0.05$), with no interaction ($p = 0.910 > 0.05$); however, a significant difference was not detected in the post–hoc test. For the WWL, the main effect of θ was detected, with no interaction ($p = 0.259 > 0.05$); the post hoc test showed a significant difference between $0°$ and $45°$ ($p = 3.70 \times 10^{-2} < 0.05$). Neither main effects nor interactions of θ and ϕ were detected when evaluating the MSD error rate, the KSPC, or the SUS score. fig. 8 shows the results of the fatigue evaluation (M = 4.11, SD = 1.95). fig. 8 shows that the larger θ is, the smaller the fatigue is. fig. 9 shows the numbers of participants who complained of arm and neck fatigue at each θ. This indicates that when θ is small, the upper arm fatigue is large and when θ is large, the neck fatigue is large.

4 DISCUSSION

We found that neither the declination angle θ nor the posture angle ϕ affected text entry performance (i.e., the WPM, MSD error rate, or the KSPC). However, the WPM of our study was higher than the 9.77 WPM reported earlier [10], which also uses mid-air tapping. This may indicate a learning effect; the text entry amount of our study (10 phrases) were larger than that of the previous study (5 phrases) [10]. This suggests that it is necessary to investigate the effect of θ and ϕ in a longitudinal study.

We are also interested in investigating the text entry performance and workload when neither the upper arms nor the neck

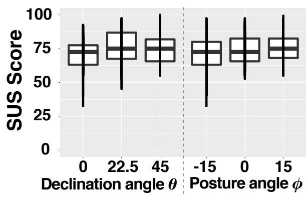

Figure 7: The System Usability Scale (SUS) at a declination angle of θ° and a posture angle of ϕ°.

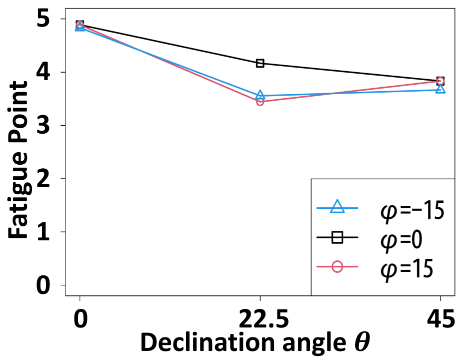

Figure 8: The relationship between the declination angle θ° and fatigue.

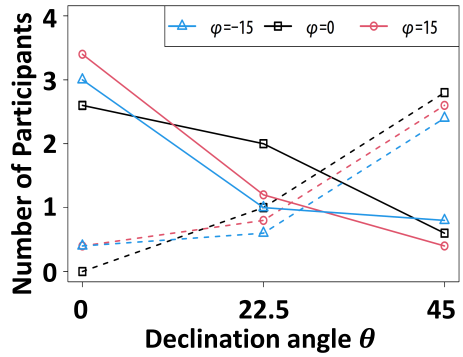

Figure 9: The declination angle θ° by the changes in fatigue points (solid line: upper arm; dotted line: neck).

is fatigued. A lower virtual keyboard (thus with a large declination angle) prevents arm fatigue. However, given the narrow HMD viewing angle, the user must tilt the head downwards, triggering neck fatigue. To do this, we developed a text entry method whereby text can be entered by lowering the arms without lowering the line of sight. We have attached a Leap Motion device to the bottom of the HMD and modified our software. We then performed a small text entry task with the arm lowered and a declination angle θ of 0°. As a result, although the previous study that used the same setting in a pointing task reported almost no fatigue on the upper arm and neck [11], entering text was difficult because the play area and display area differed. The feasibility of our new design must be studied longitudinally; subjects must become familiar with the novel concept.

5 CONCLUSION

We investigated the effects of virtual keyboard position and angle on text entry performance and fatigue. At a declination angle of θ and a posture angle of ϕ, the workload was greater at $\theta = 0°$ than 45°; however ϕ did not affect text entry performance or the workload. The relationship between θ and fatigue site showed that the smaller θ is, the greater the fatigue in the upper arm is, and the larger θ is, the greater the fatigue in the neck is. We plan to measure text entry performance and workload with the arms lowered and θ set to 0°.

REFERENCES

[1] A. S. Arif and W. Stuerzlinger. 2009. Analysis of Text Entry Performance Metrics. In *IEEE Toronto International Conference Science and Technology for Humanity (TIC-STH '09)*. IEEE, 100–105. https://doi.org/10.1109/TIC-STH.2009.5444533

[2] M. Bachynskyi, G. Palmas, A. Oulasvirta, and T. Weinkauf. 2015. Informing the Design of Novel Input Methods with Muscle Coactivation Clustering. *ACM Trans. Comput.-Hum. Interact.* 21, 6, Article 30 (jan 2015), 25 pages. https://doi.org/10.1145/2687921

[3] J. BROOKE. 1996. SUS : A Quick and Dirty Usability Scale. *Usability Evaluation in Industry* (1996), 189–194. https://ci.nii.ac.jp/naid/10024892921/

[4] J. Dudley, H. Benko, D. Wigdor, and P. O. Kristensson. 2019. Performance Envelopes of Virtual Keyboard Text Input Strategies in Virtual Reality. In *2019 IEEE International Symposium on Mixed and Augmented Reality (ISMAR 2019)*. IEEE, 289–300. https://doi.org/10.1109/ISMAR.2019.00027

[5] S. G. Hart and L. E. Staveland. 1988. Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research. In *Human Mental Workload*, P. A. Hancock and N. Meshkati (Eds.). Advances in Psychology, Vol. 52. North-Holland, 139–183. https://doi.org/10.1016/S0166-4115(08)62386-9

[6] D. T. Joseph and A. A. Sabbir. 2020. Impact of Key Shape and Dimension on Text Entry in Virtual Reality. In *Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI EA '20)*. ACM, New York, NY, USA, 1–10. https://doi.org/10.1145/3334480.3382882

[7] I. S. MacKenzie and R. W. Soukoreff. 2003. Phrase Sets for Evaluating Text Entry Techniques. In *CHI '03 Extended Abstracts on Human Factors in Computing Systems* (Ft. Lauderdale, Florida, USA) *(CHI EA '03)*. ACM, New York, NY, USA, 754–755. https://doi.org/10.1145/765891.765971

[8] G G. Simoneau and R W. Marklin. 2003. Effect of Computer Keyboard Slope on Wrist Position and Forearm Electromyography of Typists Without Musculoskeletal Disorders. *Physical Therapy* 83, 9 (sep 2003), 816–830. https://doi.org/10.1093/ptj/83.9.816 arXiv:https://academic.oup.com/ptj/article-pdf/83/9/816/31666530/ptj0816.pdf

[9] R. W. Soukoreff and I. S. MacKenzie. 2003. Metrics for Text Entry Research: An Evaluation of MSD and KSPC, and a New Unified Error Metric. In *SIGCHI Conference on Human Factors in Computing Systems* (Ft. Lauderdale, Florida, USA) *(CHI '03)*. ACM, New York, NY, USA, 113–120. https://doi.org/10.1145/642611.642632

[10] M. Speicher, A. M. Feit, P. Ziegler, and A. Krüger. 2018. Selection-based Text Entry in Virtual Reality. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI '18)*. ACM, Montreal Quebec, Canada, 647:1–647:13. https://doi.org/10.1145/3173574.3174221

[11] F. Tiare and M. Jörg. 2018. Ownershift: Facilitating Overhead Interaction in Virtual Reality with an Ownership-Preserving Hand Space Shift. In *Proceedings of the 31st Annual ACM Symposium on User Interface Software and Technology* (Berlin, Germany) *(UIST '18)*. Association for Computing Machinery, New York, NY, USA, 31–43. https://doi.org/10.1145/3242587.3242594