Impact of Key Shape and Dimension on Text Entry in Virtual Reality

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Abstract

Virtual Qwerty is the most popular method of text entry in virtual reality. Since virtual keyboards are not constrained by the physical limitations of actual keyboards, designers are taking the liberty of designing novelty keys for these keyboards. However, it is unknown whether key design affects text entry performance or user experience. This work presents results of a user study that investigated the effects of different key shapes and dimensions on text entry performance and user experience. Results revealed that key shape affects text entry speed, dimension affects accuracy, while both affect user experience. Overall, square-shaped 3D keys yielded the best actual and perceived performance, also was the most preferred by the users.

Author Keywords

Head-Mounted Display (HMD); Virtual Reality (VR); 3D; 2D; dimension; virtual keyboard.

CCS Concepts

•**Human-centered computing** → **Text input; Empirical studies in interaction design; Virtual reality;** *Usability testing;*

Introduction

The use of virtual reality has significantly grown over the last decade due to the affordability of virtual reality hard-

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Figure 1: A Leap Motion Controller was attached to the front of the Oculus Rift at a 20° down angle to increase its field of view when the user's head is upright.

Figure 2: The setup used in the study. The black material on the desk is duvetyne[4].

Key Design	Reference
Round 3D	[4, 5, 10, 26]
Square 2D	[4, 14, 15, 17, 27, 32, 34, 36]
Square 3D	[6, 11, 16, 24, 29, 32]
Hexagonal 3D	[8]

Table 1: Commonly used key shapes in Qwerty for virtual reality.

ware and its applicability in many areas [28], including office work [13], collaboration and training [21], and social networks [25]. However, text entry in virtual reality remains a challenge [14, 32]. Most works in this domain explore different tracking mechanisms and develop novel input techniques and technologies without much consideration for how the design of the keys (the shape, size, dimension, and color of the keys) affects text entry performance. This has resulted in the emergence of virtual keyboards with a range of key designs (a quick search on the Unity Asset Store[1] can attest to this). This lack of understanding can slow down the progress in optimizing text entry in virtual reality. To address this, we conducted a comparative study to evaluate the performance of six different key designs (3 shapes × 2 dimensions) on text entry performance and user experience in virtual reality.

Related Work

Recently, researchers have been tackling the text entry challenge in virtual reality. Although a range of novel techniques and technologies have been proposed, the most popular solution is still virtual Qwerty (see a recent review [12]). These keyboards use the the standard Qwerty layout, but the design of the base and the keys vary (Table 1). Rajana and Hansen [27] studied flat and curved keyboard bases in virtual reality. They found out that entry speed with a flat base is significantly faster than with a curved base. Outside virtual reality, the effects of keyboard shape [22], size [31], and background [35], and key size [7, 18] and spacing [7] on text entry performance have been explored. However, to our knowledge no work has explored whether key shape and dimension affect text entry performance and user experience in the context of virtual reality.

Experiment

This study investigated the effects of key shape and dimension on text entry performance and user experience.

Apparatus

We developed a custom system with Unity3D 2017.14.17 and Orion 4.4.0 SDKs. It ran on a Windows 10 HP OMEN desktop computer with an AMD Ryzen 5 2500X Quad-Core processor, 8 GB RAM, and an Nvidia GeForce GTX 1060 graphics card. It used an Oculus Rift[2] Head-Mounted Display (HMD). It also used a Leap Motion Controller[3] to track hands, which was attached to the front of the HMD at a 20° down angle to increase its field of view when the user's head is upright (Figure 1). We covered the base with a duvetyne[4] fabric (Figure 2) to absorb light since reflective surfaces affect Leap Motion's tracking ability [9]. We used Leap Motion regardless of its limitations [16, 23, 33] due to its availability and affordability.

Design

The study used a within-subjects design with two independent variables: *key shape* and *key dimension*. Key shape had three levels: round, square, and hexagonal. Key dimension had two levels: 2D and 3D. In each condition par-

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[1] Unity Asset Store https://assetstore.unity.com

[2] Oculus Rift https://www.oculus.com

[3] Leap Motion Controller https://www.leapmotion.com

[4] Duvetyne https://en.wikipedia.org/wiki/duvetyne

Figure 3: The abstract hand representation used in the study.

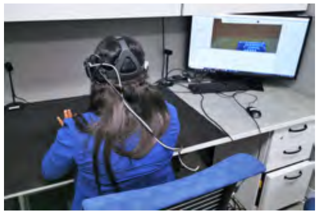

Figure 4: A volunteer participating in the user study.

Key Design	Area
2D Round	19.63 cm^2
3D Round	70.69 cm^2
2D Square	25 cm^2
3D Square	150 cm^2
2D Hexagonal	16.24 cm^2
3D Hexagonal	62.48 cm^2

Table 2: Each key was designed to fit a 5×5 cm square, which acted as the active touch area for the keys. The height of the 3D keys were 2 cm.

ticipants transcribed five random English phrases from a corpus [19]. The conditions were counterbalanced using a Latin square. The dependent variables were the performance metrics. In summary, the design was: 12 participants × 6 conditions × 5 phrases = 360 phrases in total.

Metrics
The study recorded the standard words per minute (wpm), error rate, and corrected error rate performance metrics. Words per minute is the average number of words entered in one minute, where a "word" is measured as five characters [2]. Error rate is the average percentage (%) of incorrect characters remained in the final text. Corrected error rate is the average percentage (%) of incorrect characters corrected by the user (which are not in the final text).

Virtual Keyboard
We developed a custom virtual Qwerty that used round, square, and hexagonal keys in both 2D and 3D (Figure 6). These shapes was chosen since these are commonly used in Qwerty for virtual reality (Table 1). Table 2 displays the area covered by each key. All keys were positioned in a 5×5 cm active area with a 7 mm padding between the keys to facilitate comfortable 3D pointing [3]. Users saw a virtual representation of their hands (Figure 3). The keyboard provided visual feedback on each key press. The 2D keys were highlighted in a different color [34] and the 3D keys played a key-down animation mimicking actual keys [32]. The keyboard used a dark-blue background with light-grey keys and black font for better contrast. All keys used the same font and font size. Neutral colors were used as bright colors can cause visual fatigue [20]. Abstract hands were used to avoid the effect of gender and the "uncanny valley" [1, 30].

Virtual Environment
The virtual environment had a desk, the custom virtual Qwerty on the desk, and a text input area floating above the desk (Figure 5). When participants entered the virtual environment, they felt like they were sitting in a chair facing the desk. We used a minimalistic approach to design the environment to ensure that it did not distract the participants.

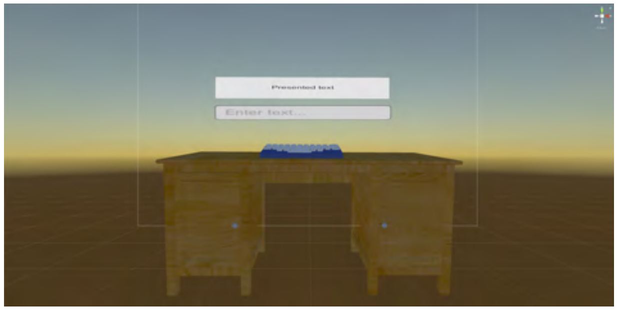

Figure 5: The virtual environment used in the study. It had a wooden desk, the virtual keyboard on the desk, and a text input area floating above the desk.

Participants
Twelve participants voluntarily took part in the study (Figure 4). Eight of them were female and four were male. Their age ranged from 19 to 32 years (M = 22.9, SD = 3.5). They all identified themselves as native or bilingual speaker of the English language. Three of them wore eyeglasses. They all were experienced Qwerty users. Four of them had used an HMD before, but none had experience typing in virtual reality.

Procedure
The study was conducted in a quiet room. Upon arrival, we explained the study procedure to all participants, collected their consents, and asked them to complete a demographics and experience questionnaire. They then participated in two 10-minute practice sessions. In the first session, they

Figure 6: The six key designs used in the study, from left: 2D round, 3D round, 2D square, 3D square, 2D hexagonal, and 3D hexagonal.

played around with their hands to get a feel of the virtual hands. In the second session, they typed the *"The quick brown fox jumps over the lazy dog"* pangram with either of the six key designs (Figure 6) in a counterbalanced order. These sessions were necessary since most participants were unfamiliar with virtual reality. Besides, these enabled us to observe any symptoms of virtual reality sickness[5] (none recorded in this study), adjust the headset, and calibrate the keyboard position for each user.

In the main study, participants transcribed five short phrases from a corpus [19] with each key design in a counterbalanced order. A random phrase was presented above the input area. Participants were instructed to read, understand, and memorize the phrase before transcribing it *as fast and accurate as possible*, then press the ENTER key to see the next phrase. Error correction was encouraged, but not enforced. There were 2-minute breaks between the conditions, where participants were instructed to remove the HMD. Upon completion of the study, participants ranked the key designs in terms of how natural they felt, speed, accuracy, and their overall preference.

Results

For statistical tests, we removed all instances where the user's hands were not visible due to tracking issues (7% of the data). We used repeated-measures ANOVA for all analysis as a Shapiro-Wilk test and a Mauchly's test confirmed that the filtered data did not violate its normality and sphericity assumptions, respectively.

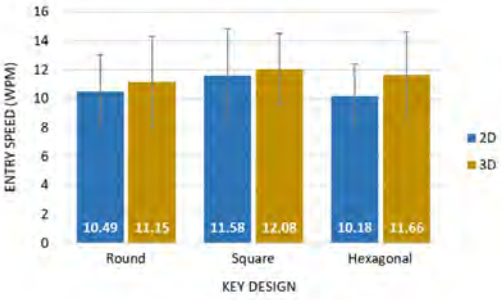

Figure 7: Average entry speed for the six different keys explored in the study. Error bars represent ±1 standard deviation.

Entry Speed

An ANOVA identified a significant effect of shape on entry speed ($F_{2,11}$ = 3.64, $p < .05$). The average entry speed with round, square, and hexagonal keys were 10.82 wpm (SD = 2.9), 11.83 wpm (SD = 2.9), and 10.92 wpm (SD = 2.7), respectively. A Duncan's test revealed that entry speed with square keys was significantly faster than with round keys. An ANOVA failed to identify a significant effect of dimension ($F_{1,11}$ = 2.16, p = .2). The average entry speed with 2D and 3D keys were 10.75 wpm (SD = 4.4) and 11.63 wpm (SD = 2.6), respectively. There was also no significant ef-

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[5] Virtual Reality Sickness https://en.wikipedia.org/wiki/virtual_reality_sickness

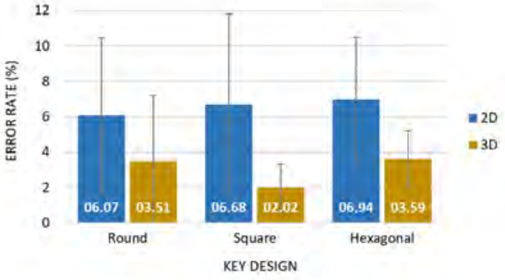

Figure 8: Average error rate for the six different keys explored in the study. Error bars represent ±1 standard deviation.

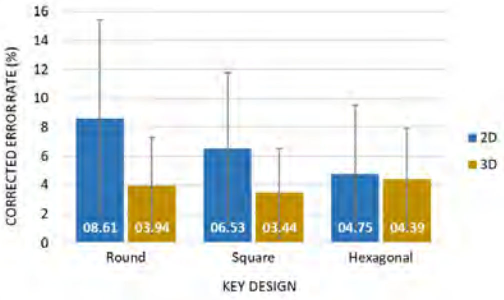

Figure 9: Average corrected error rate for the six different keys explored in the study. Error bars represent ±1 standard deviation.

fect of shape × dimension ($F_{2,11}$ = 0.84, p = .4). Figure 7 illustrates average entry speed with all key designs.

Error Rate (%)

An ANOVA failed to identify a significant effect of shape on error rate ($F_{2,11}$ = 0.61, p = .5). The average error rate with round, square, and hexagonal keys were 4.79% (SD = 4.2), 4.35% (SD = 4.4), and 5.27% (SD = 3.2), respectively. However, there was a significant effect of dimension ($F_{1,11}$ = 10.03, p < .01). The average error rate with 2D and 3D keys were 6.56% (SD = 4.4) and 3.04% (SD = 2.5), respectively. A Duncan's test revealed that error rate with 2D and 3D keys were significantly different. However, an ANOVA failed to identify a significant effect of shape × dimension ($F_{2,11}$ = 0.80, p = .5). Figure 8 illustrates average error rate for all key designs.

Corrected Error Rate (%)

An ANOVA failed to identify a significant effect of shape on corrected error rate ($F_{2,11}$ = 3.26, p = .05). The average corrected error rate with round, square, and hexagonal keys were 6.28% (SD = 5.8), 4.98% (SD = 4.6), and 4.57% (SD = 4.2), respectively. There was also no significant effect of dimension ($F_{1,11}$ = 4.54, p = .05). The average corrected error rate with 2D and 3D keys were 6.63% (SD = 5.9) and 3.92 (SD = 3.3), respectively. An ANOVA failed to identify a significant effect of shape × dimension as well ($F_{2,11}$ = 3.05, p = .06). Figure 9 illustrates average corrected error rate for all key designs.

Qualitative Data

Table 3 presents all user responses, where one can see that most participants found the square 3D keys the most natural. They also felt that square 3D keys enhanced their text entry speed and accuracy, thus wanted to use it in virtual reality. The square 2D keys were the second most preferred, followed by the round 3D keys. Participants were in agreement that the hexagonal keys were not natural and affected their entry speed and accuracy. Yet, one participant wanted to keep using the 3D hexagonal keys, because they *"looked cool"*.

Key Design	*Natural*	*Speed*	*Accuracy*	*Preference*
Round 2D	0	0	0	0
Round 3D	0	**2**	**2**	**1**
Square 2D	0	**2**	**2**	**2**
Square 3D	**12**	**8**	**8**	**8**
Hexagonal 2D	0	0	0	0
Hexagonal 3D	0	0	0	**1**

Table 3: User responses to the key designs they found the most natural, enhance entry speed and accuracy, and their overall design preference. The study involved 12 participants ($N = 12$).

Most participants preferred the 3D keys since they thought they imitated the behavior of an actual key the best. One participant commented that he liked the 3D keys because he is *"used to them from the real world"*. Participants who preferred 2D keys stated that they found the visual feedback on 3D keystrokes distracting (the key-down animation). One participant commented that she kept looking at the animation, which *"disturbed"* her typing.

Discussion

Results showed that entry speed with different key shapes were significantly different. Square keys yielded about 8% faster entry speed than round and hexagonal keys. Participant responses also corroborate this. Most participants (83%, $N = 10$) felt that their entry speed was much faster with square keys (Table 3) compared to the other keys. Text entry speed with 3D keys were also about 8% faster than 2D keys. This effect was not statistically significant. However, it appears that participants picked up on this behavior since most of them (83%, $N = 10$) responded that 3D keys enhanced their entry speed (Table 3). Although there was no significant effect of key shape on error rate, most participants (83%, $N = 10$) felt that square keys were more accurate than the other keys (Table 3). They were not totally amiss since round and hexagonal keys were 9% and 17% more error prone than square keys. There was a significant effect of key dimension on error rate. 3D keys were 54% more accurate than the other keys. Participants noticed this too, as most of them (83%, $N = 10$) responded that they were more accurate with 3D keys than 2D keys (Table 3). There was no significant effect of key size or shape on corrected error rate. This suggests that participants did not face any major difficulties in correcting errors with any of the keys.

Overall, 3D square keys yielded the best actual and perceived performance. These findings suggest that imitating the design and behavior of real world objects in the virtual world is a good idea, especially at the infancy of the technology. Further qualitative research in needed to find out whether this finding can be generalized to a larger sample. We also stress the importance of revisiting this in the future since the need for imitating physical objects in the digital world often diminishes as technologies become ubiquitous.

Conclusion and Future Work

We presented a study that investigated the effects of different key shapes and dimensions on text entry performance and user experience. Results revealed that key shape affects text entry speed, dimension affects accuracy, and both affect user experience. These findings will aid in designing keyboards that can facilitate faster, more accurate, and pleasant text entry experience in virtual reality. In the future, we will investigate the effects of different types of visual, auditory, haptic feedback on text entry performance and user experience. Further, we will replicate this study in the future to find out if the behaviors observed in this study recurs when the technology matures.

REFERENCES

[1] Ferran Argelaguet, Ludovic Hoyet, Michael Trico, and Anatole Lecuyer. 2016. The Role of Interaction in Virtual Embodiment: Effects of the Virtual Hand Representation. In *2016 IEEE Virtual Reality (VR)*. 3–10. DOI: `http://dx.doi.org/10.1109/VR.2016.7504682` ISSN: 2375-5334.

[2] Ahmed Sabbir Arif and Wolfgang Stuerzlinger. 2009. Analysis of Text Entry Performance Metrics. In *2009 IEEE Toronto International Conference Science and Technology for Humanity (TIC-STH)*. 100–105. DOI: `http://dx.doi.org/10.1109/TIC-STH.2009.5444533`

[3] Myroslav Bachynskyi, Gregorio Palmas, Antti Oulasvirta, and Tino Weinkauf. 2015. Informing the Design of Novel Input Methods with Muscle Coactivation Clustering. *ACM Transactions on Computer-Human Interaction* 21, 6 (Jan. 2015), 1–25. DOI:`http://dx.doi.org/10.1145/2687921`

[4] Costas Boletsis and Stian Kongsvik. 2019a. Controller-Based Text-Input Techniques for Virtual Reality: An Empirical Comparison. *International Journal of Virtual Reality* 19, 3 (Oct. 2019), 2–15. DOI: `http://dx.doi.org/10.20870/IJVR.2019.19.3.2917`

[5] Costas Boletsis and Stian Kongsvik. 2019b. Text Input in Virtual Reality: A Preliminary Evaluation of the Drum-Like VR Keyboard. *Technologies* 7, 2 (June 2019), 31. DOI: `http://dx.doi.org/10.3390/technologies7020031`

[6] Sidney Bovet, Aidan Kehoe, Katie Crowley, Noirin Curran, Mario Gutierrez, Mathieu Meisser, Damien O Sullivan, and Thomas Rouvinez. 2018. Using Traditional Keyboards in VR: SteamVR Developer Kit and Pilot Game User Study. In *2018 IEEE Games, Entertainment, Media Conference (GEM)*. 1–9. DOI: `http://dx.doi.org/10.1109/GEM.2018.8516449` ISSN: null.

[7] Herbert A. Colle and Keith J. Hiszem. 2004. Standing at a Kiosk: Effects of Key Size and Spacing on Touch Screen Numeric Keypad Performance and User Preference. *Ergonomics* 47, 13 (Oct. 2004), 1406–1423. DOI: `http://dx.doi.org/10.1080/00140130410001724228`

[8] Joshua Corvinus. 2016. VR Keyboard: Demonstration of a Touch-Type Virtual Keyboard in VR. (Feb. 2016). `https://developer-archive.leapmotion.com/gallery/vr-keyboard`

[9] Alan Davis. 2014. How to Build Your Own Leap Motion Art Installation. (July 2014). `http://blog.leapmotion.com/how-to-build-your-own-leap-motion-art-installation/`

[10] Andrey Doronichev. 2016. Daydream Labs: Exploring and Sharing VR's Possibilities. (May 2016). `https://blog.google/products/daydream/daydream-labs-exploring-and-sharing-vrs/`

[11] Ruofei Du, David Li, and Amitabh Varshney. 2019. Geollery: A Mixed Reality Social Media Platform. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems - CHI '19*. ACM Press, Glasgow, Scotland Uk, 1–13. DOI: `http://dx.doi.org/10.1145/3290605.3300915`

[12] Tafadzwa Joseph Dube and Ahmed Sabbir Arif. 2019. Text Entry in Virtual Reality: A Comprehensive Review of the Literature. In *Human-Computer Interaction. Recognition and Interaction Technologies (Lecture Notes in Computer Science)*, Masaaki Kurosu (Ed.). Springer International Publishing, Cham, 419–437. `DOI:` `http://dx.doi.org/10.1007/978-3-030-22643-5_33`

[13] Jens Grubert, Eyal Ofek, Michel Pahud, and Per Ola Kristensson. 2018a. The Office of the Future: Virtual, Portable, and Global. *IEEE Computer Graphics and Applications* 38, 6 (Nov. 2018), 125–133. `DOI:` `http://dx.doi.org/10.1109/MCG.2018.2875609`

[14] Jens Grubert, Lukas Witzani, Eyal Ofek, Michel Pahud, Matthias Kranz, and Per Ola Kristensson. 2018b. Text Entry in Immersive Head-Mounted Display-Based Virtual Reality Using Standard Keyboards. In *2018 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*. 159–166. `DOI:` `http://dx.doi.org/10.1109/VR.2018.8446059` ISSN: null.

[15] Jan Gugenheimer, David Dobbelstein, Christian Winkler, Gabriel Haas, and Enrico Rukzio. 2016. FaceTouch: Enabling Touch Interaction in Display Fixed UIs for Mobile Virtual Reality. In *Proceedings of the 29th Annual Symposium on User Interface Software and Technology - UIST '16*. ACM Press, Tokyo, Japan, 49–60. `DOI:` `http://dx.doi.org/10.1145/2984511.2984576`

[16] Adrian H. Hoppe, Leonard Otto, Florian van de Camp, Rainer Stiefelhagen, and Gabriel Unmüßig. 2018. qVRty: Virtual Keyboard with a Haptic, Real-World Representation. In *HCI International 2018 – Posters' Extended Abstracts (Communications in Computer and Information Science)*, Constantine Stephanidis (Ed.). Springer International Publishing, Cham, 266–272. `DOI:` `http://dx.doi.org/10.1007/978-3-319-92279-9_36`

[17] Janis G. Jimenez and Jürgen P. Schulze. 2018. Continuous-Motion Text Input in Virtual Reality. *Electronic Imaging* 2018, 3 (2018), 450–1–450–6. `DOI:http://dx.doi.org/10.2352/ISSN.2470-1173.2018.03.ERVR-450`

[18] Jeong Ho Kim, Lovenoor S. Aulck, Ornwipa Thamsuwan, Michael C. Bartha, Christy A. Harper, and Peter W. Johnson. 2013. The Effects of Touch Screen Virtual Keyboard Key Sizes on Typing Performance, Typing Biomechanics and Muscle Activity. In *Digital Human Modeling and Applications in Health, Safety, Ergonomics, and Risk Management. Human Body Modeling and Ergonomics (Lecture Notes in Computer Science)*, Vincent G. Duffy (Ed.). Springer, Berlin, Heidelberg, 239–244. `DOI:` `http://dx.doi.org/10.1007/978-3-642-39182-8_28`

[19] I. Scott MacKenzie and R. William Soukoreff. 2003. Phrase Sets for Evaluating Text Entry Techniques. In *CHI '03 Extended Abstracts on Human Factors in Computing Systems (CHI EA '03)*. ACM, New York, NY, USA, 754–755. `DOI:` `http://dx.doi.org/10.1145/765891.765971`

[20] Gerald M. Murch. 1984. Physiological Principles for the Effective Use of Color. *IEEE Computer Graphics and Applications* 4, 11 (Nov. 1984), 48–55. `DOI:` `http://dx.doi.org/10.1109/MCG.1984.6429356`

[21] Cuong Nguyen, Stephen DiVerdi, Aaron Hertzmann, and Feng Liu. 2017. CollaVR: Collaborative In-Headset Review for VR Video. In *Proceedings of the 30th Annual ACM Symposium on User Interface Software and Technology (UIST '17)*. Association for Computing Machinery, New York, NY, USA, 267–277. DOI:http://dx.doi.org/10.1145/3126594.3126659 event-place: Québec City, QC, Canada.

[22] Marita A. O'Brien, Wendy Rogers, Arthur D. Fisk, and Mark Richman. 2008. Assessing Design Features of Virtual Keyboards for Text Entry. *Human Factors* 50, 4 (Aug. 2008), 680–698. DOI: http://dx.doi.org/10.1518/001872008X312279

[23] Fábio Henrique M. Oliveira and Adriano O. Andrade. 2015. Preliminary Evaluation of Leap Motion Controller as a Human Tremor Record Device. *An. do VII Simpósio em Eng. Biomédica* (2015), 241–245.

[24] Alexander Otte, Tim Menzner, Travis Gesslein, Philipp Gagel, Daniel Schneider, and Jens Grubert. 2019. Towards Utilizing Touch-sensitive Physical Keyboards for Text Entry in Virtual Reality. In *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*. 1729–1732. DOI: http://dx.doi.org/10.1109/VR.2019.8797740 ISSN: 2642-5246.

[25] Tekla S. Perry. 2016. Virtual Reality Goes Social. *IEEE Spectrum* 53, 1 (Jan. 2016), 56–57. DOI: http://dx.doi.org/10.1109/MSPEC.2016.7367470

[26] Duc-Minh Pham and Wolfgang Stuerzlinger. 2019. HawKEY: Efficient and Versatile Text Entry for Virtual Reality. In *25th ACM Symposium on Virtual Reality Software and Technology on - VRST '19*. ACM Press, Parramatta, NSW, Australia, 1–11. DOI: http://dx.doi.org/10.1145/3359996.3364265

[27] Vijay Rajanna and John Paulin Hansen. 2018. Gaze Typing in Virtual Reality: Impact of Keyboard Design, Selection Method, and Motion. In *ETRA*. DOI: http://dx.doi.org/10.1145/3204493.3204541

[28] Grand View Research. 2017. *Virtual Reality Market Size, Industry Growth Analysis Report, 2025*. Technical Report GVR-1-68038-831-2. 125 pages. https://www.grandviewresearch.com/industry-analysis/virtual-reality-vr-market

[29] Daniel Schneider, Alexander Otte, Travis Gesslein, Philipp Gagel, Bastian Kuth, Mohamad Shahm Damlakhi, Oliver Dietz, Eyal Ofek, Michel Pahud, Per Ola Kristensson, Jörg Müller, and Jens Grubert. 2019. ReconViguRation: Reconfiguring Physical Keyboards in Virtual Reality. *IEEE Transactions on Visualization and Computer Graphics* 25, 11 (Nov. 2019), 3190–3201. DOI: http://dx.doi.org/10.1109/TVCG.2019.2932239

[30] Valentin Schwind, Pascal Knierim, Cagri Tasci, Patrick Franczak, Nico Haas, and Niels Henze. 2017. "These are not my hands!": Effect of Gender on the Perception of Avatar Hands in Virtual Reality. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems - CHI '17*. ACM Press, Denver, Colorado, USA, 1577–1582. DOI: http://dx.doi.org/10.1145/3025453.3025602

[31] Andrew Sears, Doreen Revis, Janet Swatski, Rob Crittenden, and Ben Shneiderman. 1993. Investigating Touchscreen Typing: The Effect of Keyboard Size on Typing Speed. *Behaviour & Information Technology* 12, 1 (Jan. 1993), 17–22. DOI: http://dx.doi.org/10.1080/01449299308924362

[32] Marco Speicher, Anna Maria Feit, Pascal Ziegler, and Antonio 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 Press, Montreal QC, Canada, 1–13. DOI: `http://dx.doi.org/10.1145/3173574.3174221`

[33] Frank Weichert, Daniel Bachmann, Bartholomäus Rudak, and Denis Fisseler. 2013. Analysis of the Accuracy and Robustness of the Leap Motion Controller. *Sensors* 13, 5 (May 2013), 6380–6393. DOI: `http://dx.doi.org/10.3390/s130506380`

[34] Chris Wrenar. 2014. AR/VR User Interface Prototyping. (2014). `https://www.wrenar.com/avar-ui-prototyping`

[35] Ashish Yadav and Ahmed Sabbir Arif. 2018. Effects of Keyboard Background on Mobile Text Entry. In *Proceedings of the 17th International Conference on Mobile and Ubiquitous Multimedia (MUM 2018)*. Association for Computing Machinery, Cairo, Egypt, 109–114. DOI: `http://dx.doi.org/10.1145/3282894.3282905`

[36] Chun Yu, Yizheng Gu, Zhican Yang, Xin Yi, Hengliang Luo, and Yuanchun Shi. 2017. Tap, Dwell or Gesture?: Exploring Head-Based Text Entry Techniques for HMDs. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems - CHI '17*. ACM Press, Denver, Colorado, USA, 4479–4488. DOI: `http://dx.doi.org/10.1145/3025453.3025964`