# Text Entry in Virtual Reality: A Comparison of 2D and 3D Keyboard Layouts

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**Abstract.** Text entry is an important task in most interactive technologies in use today. Virtual Reality (VR) is becoming increasingly popular and is used in a variety of contexts, including tasks that involve text entry. With this being the case, it has become increasingly important to determine what the best keyboard layout is for text entry tasks in VR environments. To address this need, the current study compared two keyboard layouts, 2D (flat UI) and 3D (curved UI), with respect to text entry performance in VR. Results indicated that, compared to the 3D keyboard layout, using the 2D keyboard layout for the text entry task led to a greater number of words per minute, fewer corrections, and fewer redundant key presses while typing. These results indicate that the 2D keyboard layout was more efficient in VR text entry performance, compared to the 3D keyboard layout. Implications for the design and development of VR text entry tasks are discussed.

**Keywords:** Virtual reality, text entry in VR, 3D text entry, keyboard layout, flat UI, curved UI.

## 1 Introduction

Text entry is an integral task afforded by most of the interactive technologies that users commonly use. As an interaction style, text entry allows the user to perform various tasks: users can look up information, they can communicate with other users, and they can even play games using text entry. Due to the pervasiveness of text entry tasks in modern technologies, text entry has been of particular interest to researchers in human computer interaction (HCI) circles [1-4], partly because of the increasing variety of different devices (e.g., desktop computers, hand-held devices, head-mounted displays, etc.) and input methods (e.g., touch, stylus, swipe, etc.).

While HCI researchers have studied text entry in desktop computers, hand-held mobile devices, and voice-based interfaces, research into text entry in virtual reality (VR) environments is in its infancy [5, 6], which is partly attributable to the recent proliferation of relatively affordable VR headsets and resurgence of academic and industrial interest. VR technology affords the ability to immerse users in computer-generated three-dimensional (3D) environments in which they can control and interact with 3D objects. This also means that 3D user interfaces (UI) can be adopted for interaction purposes. While it would be reasonable to utilize this affordance of 3D UI layouts and metaphors for most VR tasks on the grounds that 3D representations would be perceived as more natural, many existing VR applications rely on 2D UI layouts and interaction metaphors for common interaction tasks, including text entry. Specifically, most VR applications adopt the familiar mental model of 2D keyboards, which are displayed on a flat UI layout in the

VR environment. This begets the question of whether directly appropriating this metaphor for VR tasks is preferable to using a 3D representation of keyboard layouts for text entry tasks.

The current study was designed to address this question and to compare two keyboard layouts, 2D (flat UI) and 3D (curved UI), with respect to text entry performance in VR. We designed two keyboard layouts and conducted a user study in which we evaluated the performance of these two layouts in enabling users to complete text entry tasks. More specifically, we measured text entry performance in terms of words per minute (WPM), number of corrections, and redundant key entry/deletion rate. We found that the 2D keyboard layout significantly outperformed the 3D layout in all these metrics.

With the current study, our goal was to empirically evaluate the performance of two keyboard layouts. Another aim of the current study was to call for future research into the design, implementation, and evaluation of text entry tasks and methods for VR environments. The contributions of the current study are as follows:

- User study of 3D text entry in VR,
- Empirical evaluation of two keyboard layouts for text entry tasks in VR,
- Design guidelines for text entry tasks in VR.

## 2 Related Work

While other forms of text entry in VR (e.g., speech-based) has been of interest to VR researchers [7, 8], in this paper we particularly focus on studies that utilize keyboard-based (either physical or virtual) text entry in VR.

In one such study, Grubert et al. examined the effects of hand representation on text entry performance in VR [9]. Participants used a physical keyboard while typing. The virtual representation of the keyboard was 2D with a flat panel. The researchers were interested in comparing four hand representations: no hand representation, inverse kinematic model (virtual simulation of 3D hand models displayed based on users' hand/finger movements in the physical environment), fingertip visualization using spheres and video inlay of users' own hands in the virtual environment. Text entry speed ranged from 34.4 WPM to 38.7 WPM, with no significant differences among the four groups.

Knierim et al. studied the effect of hand avatars and transparency of these avatars on text entry performance in VR [10]. Participants used a physical keyboard, and both their hands and the keyboard were tracked using special sensors and were simulated in the virtual environment. Compared to no hand visualization, inexperienced typists benefited significantly from having their hands visualized in the virtual environment while typing, which translated into faster text entry. This, however, was not the case for experienced typists. Their performance under the no-hand and hand-avatars conditions was comparable. As for the effect of the realism of hand representations and transparency of these hand models, the researchers found no difference in text entry performance. This study highlights the importance of providing hand visualizations during text entry tasks in VR, especially when a physical keyboard is being used. In another study that utilized a physical keyboard for text entry tasks in VR, Grubert et al. compared touchscreen and standard, desktop keyboards on text entry performance in VR and found that using touchscreen keyboard was slower than using standard, desktop keyboard [11].

In addition to studying the use of physical keyboards for text entry tasks in VR, previous research has also explored the feasibility of using alternate text entry methods in VR. For instance, Rajanna et al. investigated the viability of gaze typing in VR in sitting and biking conditions [6], while examining the effect of selection method (dwelling vs. button click). They utilized a commercial HMD that supported eye-tracking in VR, using which they enabled users to select keys with gaze movements. In Study 1, the researchers used a 2D representation of a virtual QWERTY keyboard and found that gaze typing speed ranged from 8.1 WPM to 10.15 WPM. While the researchers found a significant difference across the four conditions, they failed to follow up the significant result with a post-hoc analysis, which would reveal which conditions were different from which conditions. In Study 2, the researchers used a curved UI for the keyboard layout, which was larger than users' field-of-view (FOV) afforded by the VR headset. With the curved UI, text entry speed went down, ranging from 6.8 WPM to 9.2 WPM. The researchers attributed this performance decrement to the fact that participants needed to make more head movements to see all the keys on the virtual keyboard (because the keyboard was larger than users FOV). Because the researchers did not directly compare the flat UI used in Study 1 to the curved UI used in Study 2, it is not possible to conclude from these two separate studies that the curved UI should lead to slower text entry performance in VR. If the curved UI was within-view as well, the results would probably have been different, for instance. That said, one implication of the Rajanna et al. study is that virtual keyboards, whether 2D or 3D, should be displayed within the FOV of participants, so as to minimize redundant head movements, which might slow the participants down while typing.

In an attempt to develop a set of guidelines for text entry tasks in VR, Speicher et al. [5] investigated selection-based text entry in VR by comparing six different methods of text entry: head pointing, controller pointing, controller tapping, freehand selection, discrete cursor selection, and continuous cursor selection. Participants were presented with a virtual 2D keyboard and were asked to enter short phrases. Text entry speed ranged from 5.3 WPM to 15.4 WPM, with the controller pointing selection method outperforming all the other five methods. This study indicates that for selection-based text entry tasks utilizing a virtual keyboard the best method of key selection is controller pointing, in which a raycasting metaphor is used to enable participants to point to a key and select the key by pressing the trigger or selection button on the controller.

Based on the foregoing review of related work, the comparison of 2D and 3D keyboard layouts on text entry performance in VR still remains understudied, which provided the impetus for the current study. We sought to investigate the effect of keyboard layouts on text entry performance when using native VR controllers that implement a raycasting metaphor for selection tasks. This decision was made on the basis of Speicher et al.'s findings [5], as discussed earlier. We also decided to implement both 2D and 3D virtual keyboard layouts so that both layouts would be displayed within users' FOV. This way the performance of the two layouts could be compared, which was not possible in Rajanna et al [6].

# 3 Method

## 3.1 VR Keyboard

We developed two keyboard layouts in Unity 3D (Fig. 1). The keyboard layouts were identical in that both were built to mimic a virtual representation of standard QWERTY layout. The two layouts were different in that one had was a 2D keyboard using a flat UI, whereas the other one was a 3D keyboard using a curved UI.

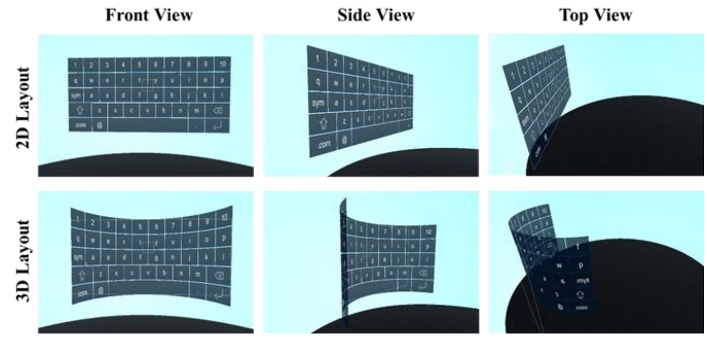


**Fig. 1.** Screenshots of the keyboard layouts from different angles. 2D keyboard layout uses a flat panel, while 3D keyboard layout uses a curved user interface panel.

Regardless of the keyboard layout, the strings were displayed in one of the horizontal bars placed above the keyboard (Fig. 2). The top bar represented the submit button the users pressed to submit their text entry. The label bar, placed below the top bar, showed the phrase the participants were to enter. The bottom bar was the input field and showed the letters typed as participants selected keys.

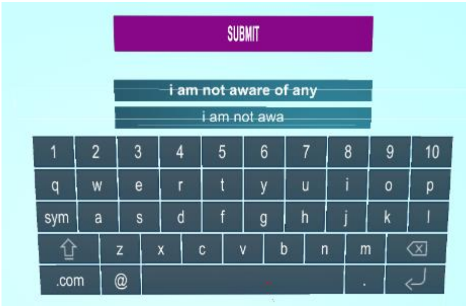


**Fig. 2.** VR Keyboard Screen for 2D Layout

### 3.2 Text Entry Task

Users performed a simple text entry task in which they were asked to enter the short strings (sentences or phrases) presented to them as quickly and accurately as possible. For this purpose, we designed two keyboard layouts, one with a flat UI and another with curved UI. Users were asked to enter five such strings using each of the keyboard layouts. The strings were randomly selected from the memorable mobile emails dataset provided by Vertanen and Kristensson [12]. For key selection, based on [5], we used a raycasting metaphor in which participants used the Oculus Touch controller to point to the key they wanted to select.

### 3.3 Study Design

To examine the effect keyboard layout on text entry performance in VR, we conducted a within-subjects experiment in which users performed the same text entry task (with different strings) using both the 2D keyboard layout and 3D keyboard layout. This was done to eliminate the potential confounding effect of individual differences on the effect of keyboard layout on text entry performance. The order of keyboard layout presentation was counterbalanced to minimize order effects. As such, half of the users first completed the text entry task using the 2D keyboard layout, and then moved on to completing the task using the 3D keyboard layout, whereas half of the users started out with the 3D keyboard layout and then proceeded to the 2D keyboard layout.

The independent variable manipulated in the experiment was the keyboard layout with two levels: 2D keyboard layout, which used a flat UI design, and 3D keyboard layout, which used a curved UI design, as shown in Fig. 1. We hypothesized that the

3D keyboard layout would lead to better text entry performance, because it would provide a more natural representation of the keyboard in a 3D virtual environment.

The dependent variable was text entry performance operationally defined in terms of the average number of words per minute (WPM), average number of corrections, and average redundancy rate. These are described in greater detail below.

#### 3.3.1 Words per Minute

To standardize the WPM metric, we defined one word as a string with five characters. We computed the WPM for each trial by dividing the number of words entered during the trial by the number of seconds taken to enter the string presented in each trial. The average WPM across the five trials was used as the dependent variable for each user.

#### 3.3.2 Number of Corrections

A correction refers to a key press performed to correct a typo during text entry. The number of corrections was defined in terms of the number of key presses required to correct typos during each trial. Again, we used the average number of corrections across all trials.

#### 3.3.3 Redundancy Rate

Redundancy rate was defined by the proportion of the number of redundant key presses performed to the total number of key pressed required, where the number of redundant key presses was computed by subtracting the total number of key pressed required (the length of a given string) from the total number of key pressed actually performed by the user during each trial. Similar to the previous two metrics, we used the average redundancy rate across all trials.

### 3.4 Apparatus

We used the Oculus Rift headset in this experiment. Oculus Rift is a head-mounted display (HMD) that track the users' position around the virtual environment. The HMD features a display with a 1080 x 1200 resolution and a 90hz refresh rate [13]. The HMD also tracks the user's head motion using a gyroscope and an accelerometer. The Oculus Rift also has a field of view (FOV) of 110 degrees [13]. The Oculus Rift comes equipped with two motion controllers, only one of which was used during this experiment, specifically the right Touch controller. The VR Keyboard application was run on a VR-compatible computer with i7 CPU and 16 GB RAM.

### 3.5 Participants

Upon arrival in the experimental room, participants read and signed an informed consent form. Then the experimenter explained the experimental procedures. Specifically, participants were told that they were going to complete the experiment in two parts and that they were going to complete a short text entry task in each part. They were also told that they could take a break at any point, and to take off the headset should they ever feel uncomfortable.

### 3.6 Procedures

Upon arrival in the experiment room, participants read and signed an informed consent form. Then the experimenter explained the experimental procedures. Specifically, participants were told that they were going to complete the experiment in two parts and that they were going to complete a short text entry task in each part. They were also told that they could take a break at any point, and to take off the headset should they ever feel uncomfortable.

Before participants donned the Oculus Rift headset, the experimenter explained and demonstrated how to use the right-handed motion controller to perform a selection by pressing the trigger key on the controller. After the experimenter ensured the participant was comfortable with how to use the controller, the participant put on the VR headset. When the headset was donned properly and comfortably, the experimenter opened up the tutorial file where the participant would get an opportunity to practice inputting a phrase and understanding how the keyboard was laid out. When the participant indicated that they felt comfortable, the experimenter had them begin the first part of the experiment in their randomly assigned starting condition, which was the 2D keyboard layout for half of the participants and the 3D keyboard layout for the other half. When the participants were done with all the five phrases in the starting condition, the instructions panel in the virtual environment indicated that the first part was completed and that they should remove the headset.

Following the completion of the first part, participants took a five-minute break. After the break, they were told that they were going to perform the same text entry task (with different strings) again. In this second part, those participants who started with the 2D layout used the 3D layout, and those who started with the 3D layout used the 2D layout. Once the second part was completed, participants were debriefed about the study and were encouraged to ask any questions they may have.

## 4 Results

To compare the two keyboard layouts on the performance metrics described earlier, we conducted several descriptive and inferential statistics tests. Table 1 presents a summary of these tests for each of the dependent variables of the experiment.

The assumption of normality, as assessed by Shapiro-Wilk's test, ($p > .05$) was met for the average WPM and average number of corrections variables, but not for the redundancy rate variable. Therefore, a paired-samples $t$ test was conducted to compare the average WPM and number of corrections between the 2D and 3D keyboard layouts, and a Wilcoxon rank test was conducted for the average redundancy rate variable.

As seen in Table 1, results revealed a significant difference between the 2D keyboard layout and 3D keyboard layout in the average number of WPM, with a greater number of average WPM in the 2D keyboard layout (Fig. 3).

**Table 1.** Summary of Descriptive and Inferential Statistics

| | *M* (*SD*) | |
|---|---|---|
| **WPM** | | $t(31) = 11.57$, $p < .001$ |
| 2D Layout | 17.35 (.59) | Cohen's $d = 2.05$ |
| 3D Layout | 11.81 (.45) | |
| **Corrections** | | $t(31) = 4.14$, $p < .001$ |
| 2D Layout | 6.30 (1.11) | Cohen's $d = .73$ |
| 3D Layout | 12.34 (1.55) | |
| **Redundancy Rate** | | $W = 128$, $p = .01$ |
| 2D Layout | 14.99 (3.05) | Cohen's $d = .41$ |
| 3D Layout | 23.88 (2.91) | |

Alpha level set at .05 for all hypothesis tests.

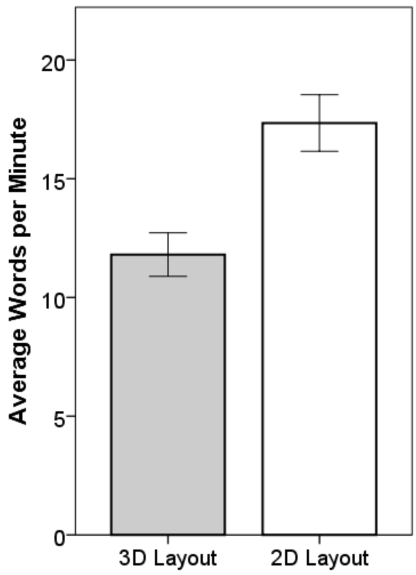


**Fig. 3.** Average WPM as a function of keyboard layout

Regarding the effect of keyboard layout on the number of corrections made during text entry, results showed that participants made more corrections in the 3D keyboard layout compared to the 2D keyboard layout (Fig. 4).

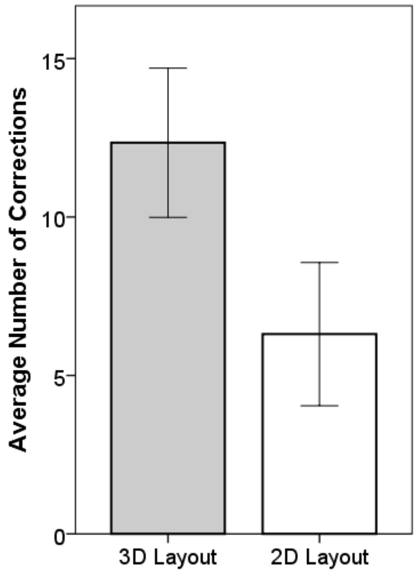


**Fig. 4.** Average number of corrections as a function of keyboard layout

As for the effect of keyboard layout on redundancy rates, results revealed a statistically significant difference between the two keyboard layouts, with increased redundancy rates in the 3D keyboard layout (Fig. 5).

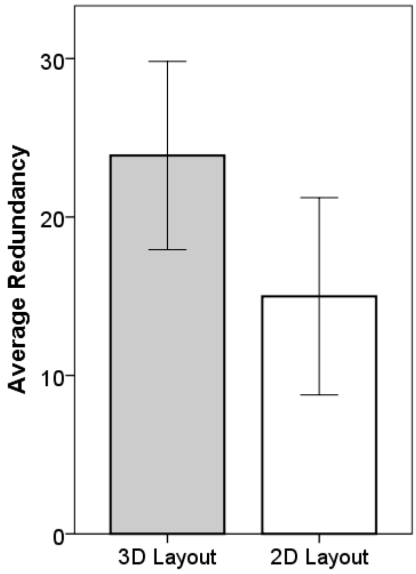


**Fig. 5.** Average redundancy rate as a function of keyboard layout

## 5 Discussion

The purpose of the current study was to investigate the effect of keyboard layout on text entry performance in VR. We set out to compare a 2D keyboard layout with flat UI to a 3D keyboard layout with curved UI with respect to efficiency. More specifically, we focused on the average WPM, a standard metric to evaluate text entry speed, average number of corrections made to edit/correct the text entry, and averaged redundancy rate.

In relation to task entry speed, our results indicate that compared to the 3D layout, the 2D keyboard layout was more efficient in terms of enabling users to enter text faster in VR. In fact, users entered an average of 17.4 WPM using the 2D keyboard layout, in contrast to an average of 11.8 WPM using the 3D keyboard layout. The stark difference between two keyboard layouts was unexpected because we hypothesized the 3D keyboard layout would be a more natural choice in a 3D virtual environment, compared to the 2D keyboard layout. One potential explanation for this finding is that users' familiarity with flat UIs might be the reason why their performance was better in the 2D keyboard layout. Due to the purported novelty of curved UI, the users might have found it more challenging to adjust to this new layout, resulting in slower text entry. While this finding is inconsistent with our initial prediction, the average WPM using the 2D keyboard layout is congruent with a prior study on text entry in VR [5]. In comparing multiple input methods, Speicher et al. found that participants could enter an average of 15.4 WPM (SD = 2.7) on a 2D keyboard layout, using a controller with the same raycasting metaphor as used in our study.

Regarding the number of corrections made during text entry, results indicated that the 3D keyboard layout led to an increased number of corrections than did the 2D keyboard layout, a finding incongruent with our initial prediction. This means that users made a greater number of key selection errors in the 3D keyboard layout condition than in the 2D keyboard layout condition. The increased number of corrections in the 3D keyboard layout condition could also partially explain why users were slower in this condition: The greater the number of corrections made during text entry, the longer it takes to complete the text entry task, leading to fewer WPM in the 3D keyboard layout condition. Closely tied to the number of corrections is the redundancy rate, because an increase in the number of corrections translates to increases in the redundancy rate. Results indicated users needed to make more redundant key selections in the 3D keyboard layout, compared to the 2D keyboard layout.

Given the nascent nature of the literature on VR interaction techniques, it is important to develop empirically-driven guidelines for the design, development, and implementation of effective, efficient, and satisfactory VR systems. One direct implication of the current findings is that a 2D keyboard layout should be used for text entry tasks in VR if task performance and efficiency are prioritized over the visual aesthetics and cohesiveness of the environment. It can be argued that flat UI panels hovering in the virtual environment are not as natural and well-integrated as curved UIs, the difference in performance levels is too stark to overlook.

While the current study provides a first step in the direction of better understanding the effectiveness and efficiency of 2D and 3D layouts for VR interaction tasks, future studies are warranted to corroborate, challenge, and/or expand on the findings from the current study. To the best of our knowledge, the current study is the first to compare 2D and 3D keyboard layouts on text entry performance in VR. Therefore, future research should attempt to replicate the findings from the current study. It would also be particularly useful to extend the current study to investigations of menu design for VR environments and examine the effect of layout on menu selection tasks. Furthermore, in the current study, we focused on objective, task-based metrics when comparing the 2D and 3D layouts, but it would be useful to incorporate user preference as a metric into the comparison of these two layouts.

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