Improving Two-Thumb Touchpad Typing in Virtual Reality

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ABSTRACT

Two-Thumb Touchpad Typing (4T) using hand-held controllers is one of the common text entry techniques in Virtual Reality (VR). However, its performance is far below that of two-thumb typing on a smartphone. We explored the possibility of improving its performance focusing on the following two factors: the visual feedback of hovering thumbs and the grip stability of the controllers. We examined the effects of these two factors on the performance of 4T in VR in user experiments. Their results show that hover feedback had a significant main effect on the 4T performance, but grip stability did not. We then investigated the achievable performance of the final 4T design in a longitudinal study, and its results show that users could achieve a typing speed over 30 words per minute after two hours of practice.

CCS CONCEPTS

• **Human-centered computing** → **Text input**.

KEYWORDS

two-thumb touchpad typing; virtual reality; text entry

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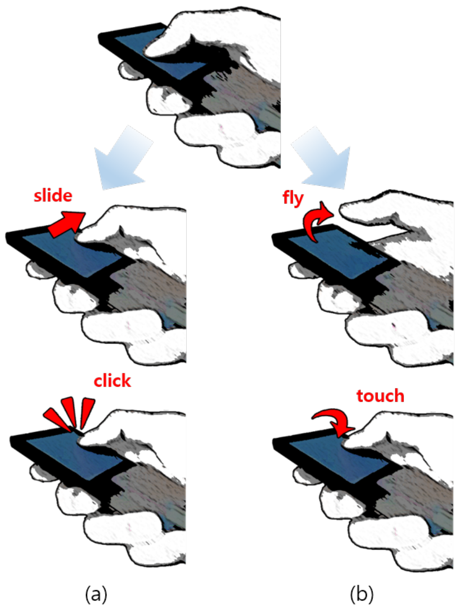

Figure 1: Two typing behaviors for 4T. (a) slide-and-click and (b) fly-and-touch.

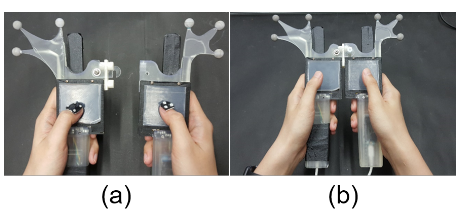

Figure 2: A pair of prototype hand-held touchpad controllers. (a) They may be used separately, or (b) may be combined and used as a single controller.

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INTRODUCTION

Hand-held VR controllers are commonly used in major VR systems, such as HTC Vive, Oculus Go, and Samsung Gear VR, and two-thumb touchpad typing (4T) using hand-held controllers is one of the common text entry techniques in VR [4, 11]. 4T in VR is akin to two-thumb typing on a smartphone, but its performance is far below that of two-thumb typing on a smartphone. Studies showed that two-thumb typing on a smartphone could achieve a typing speed over 50 words per minute (WPM) [1], but 4T in VR could achieve only 8.35 WPM [11]. To improve the performance of 4T in VR, we considered the following two possibilities. First, the visual feedback of hovering thumbs may improve the performance of 4T in VR. Without such hover feedback, users may be obliged to "slide-and-click" on the touchpad as shown in Figure 1a. With effective *hover feedback*, they may be able to "fly-and-touch" on the touchpad as shown in Figure 1b, and may type faster [9]. Second, improving grip stability may improve the performance of 4T in VR. In the current 4T in VR, users type on two separate controllers holding them in each hand. In this case, their grips may not be as stable as when they type on a smartphone holding it in both hands. Improving *grip stability* by combining two controllers physically would improve the performance of 4T in VR. To explore these two possibilities, we conducted two user experiments. In the first, we examined the effects of the two design factors, *hover feedback* and *grip stability*, on the performance of 4T in VR. In the second, we conducted a longitudinal study to evaluate the expert performance of the final 4T design.

TEXT ENTRY WITH HAND-HELD CONTROLLERS IN VR

Speicher et al. [11] compared six representative selection-based text entry methods in VR, and four of them (Controller Pointing, Controller Tapping, Discrete Cursor, and Continuous Cursor) were utilizing hand-held controllers.

The Controller Pointing method is a ray-casting text entry method using hand-held controllers. This method is in fact commonly used in various environments, such as gaming environments [6] and large wall display environments [8], as well as in VR [4, 5]. The Controller Tapping method is analogous to text entry with pen-tapping on a tablet. Users hold the controllers like digital pens and tap on a virtual keyboard to enter text. There are examples using hand-held controllers [2], using a digital pen [3], or using a hand [12]. In the Discrete Cursor method, users use directional pads or thumb-sticks to control one or two cursors on a virtual keyboard and use a trigger button to select the

(a)

(b)

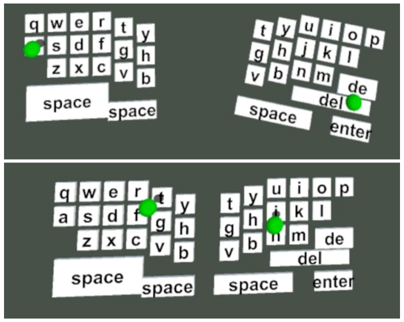

Figure 3: The virtual keyboards designed for Experiment 1. (a) Two split keyboards for the Split conditions, and (b) a combined, whole keyboard for the Combined conditions.

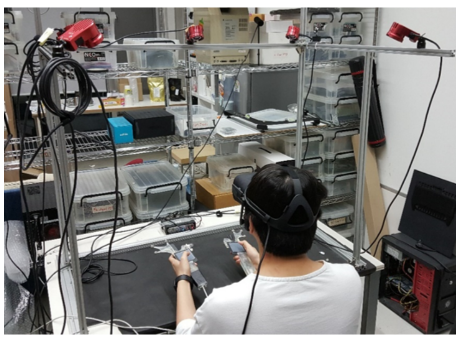

Figure 4: The experiment environment for Experiments 1 and 2. An optical tracking system was used to track the controllers and the thumbs.

current key. The Discrete Cursor method is a common text entry method for a game controller [13]. It may be applied to VR environments with hand-held controllers because most controllers contain a directional pad or a thumb-stick.

The Continuous Cursor method, which is common in VR [4, 11], allows users to set a cursor or cursors on a virtual keyboard using the thumb's position on a touchpad and select a key by pressing the touchpad. With two controllers, users hold them in each hand and type with the two thumbs. The Continuous Cursor method is an example of 4T in VR, and its performance in [11] was 8.35 WPM.

EXPERIMENT 1

The goal of Experiment 1 was to examine the effect of the two design factors, *HoverFeedback* and *GripStability*, on the performance of 4T in VR. Therefore, the experiment was a 2 (*HoverFeedback*) $\times$ 2 (*GripStability*) within-subjects design, where *HoverFeedback* was either Hover Feedback (HF) or No Hover Feedback (NHF), and *GripStability* was either Combined or Split.

Apparatus

Figure 2 shows a pair of hand-held controllers with a touchpad (50mm $\times$ 50mm) that we implemented for this experiment. In the Split conditions, they were used separately in the left and right hands (Figure 2a). In the Combined conditions, they were combined and used as a single controller for better grip stability (Figure 2b).

Figure 3 shows a screen snapshot of the virtual keyboard implemented for the experiment. In the HF conditions, the 3-D positions of the thumbs are represented by green balls over the keyboard in VR. In the NHF conditions, the visual feedback of thumbs appears only when the thumbs are on the touchpad. When the thumb selects a key by pressing it, the key turns red. The layout of the keyboard is based on the keyboard layout in Son and Lee [9], which is a slight variant of the QWERTY layout.

In the Split conditions, the keyboard is divided into the right and left halves, as shown in Figure 3a, at the R-U, F-J, and C-N boundaries considering the reaches of the two thumbs. The T and Y, G and H, and V and B keys are duplicated on both sides because different users use different hands for these keys. The two halves appeared where the two corresponding touchpads were in VR. In the Combined conditions, the two halves were combined as shown in Figure 3b. The combined keyboard appeared where the combined controllers were in VR.

We used an Optitrack system (5 Flex 13 cameras) to track the positions and postures of the two controllers and the user's thumbs as shown in Figure 4. Reflective markers are on the controllers and on the tips of the thumbs. As the positions of the thumbs on the touchpads are available from the tracker, the touchpads needed to sense the touch forces of the thumbs only. The force sensing of the touchpads were done using XactFSR[1]. To provide click haptic feedback, we added a linear resonant actuator under each touchpad.

[1] https://www.sensitronics.com/products-xactfsr.php

Participants and Procedure

Twelve university students (5 female, average age = 20.5) were recruited. Eleven of them were regular users of a QWERTY keyboard on a smartphone, and nine of them were not familiar with VR. Each participant was paid approximately 15 USD.

Participants were seated in front of a desk as shown in Figure 4. They were given a short introduction to 4T in VR including differences among four designs. Participants completed four sessions, one for each of the 2×2 conditions, and the order of the conditions was counterbalanced using a balanced Latin square. They were allowed to practice with each design before each session for up to 5 minutes. They repeated 5 blocks in each session, and in each block, they transcribed 5 sentences selected randomly from MacKenzie and Soukoreff phrase set [7]. They were allowed to utilize any typing skill (slide-and-click or fly-and-touch) which they felt convenient, and were instructed to input as fast and accurately as possible. They were not allowed to rest their arms or hands on the desk or on the chair during a block. However, they were forced to take a break for 1 minute between blocks. After each session, participants were asked to answer a NASA-TLX questionnaire. After finishing all sessions, they answered another questionnaire consisting of two questions about their preference about the two design factors and an open-ended question about their reasons for their preference. The whole experiment took about 90 minutes per participant.

Table 1: The means of WPM, UER, CER, and NASA-TLX scores in Experiment 1. Standard deviations are given in parentheses. A higher value is better for WPM and a lower value is better for the others.

	HF		NHF	
	Split	Comb.	Split	Comb.
WPM	19.19 (3.13)	20.56 (4.09)	16.53 (2.70)	17.62 (4.57)
UER	0.83 (0.83)	0.61 (0.45)	0.68 (0.63)	0.65 (0.59)
CER	8.51 (3.90)	8.81 (3.03)	10.26 (3.49)	10.12 (4.35)
TLX	57.75 (16.74)	58.64 (14.98)	66.50 (10.49)	65.94 (10.84)

Results

To compare text entry performances, we measured words per minute (WPM), uncorrected error rate (UER), and corrected error rate (CER) [10], and their averages in the four conditions are shown in Table 1. A mixed-effects model ANOVA showed that *HoverFeedback* had a significant main effect on WPM ($F(1, 33) = 9.52, p = 0.004$), and on CER ($F(1, 33) = 4.56, p = 0.040$), but not on UER ($F(1, 33) = 0.34, p = 0.565$). A mixed-effects model ANOVA showed that *GripStability* did not have a significant main effect on any of WPM, UER, and CER. There was no *HoverFeedback* $\times$ *GripStability* interaction on any of WPM, UER, and CER.

Table 1 also shows the average NASA-TLX scores. A mixed-effects model ANOVA showed that *HoverFeedback* had a significant main effect on NASA-TLX score ($F(1, 33) = 7.98, p = 0.008$), but *GripStability* did not. There was no *HoverFeedback* $\times$ *GripStability* interaction on NASA-TLX.

Regarding preferences, HF and NHF received 11 and 1 vote, respectively, and both Split and Combined received 6 votes. One participant said that mistake possibility was felt lower in NHF because a key selection was done in two steps, entering and clicking a key. Others said that HF required less force and fatigue for key selection, and some said that HF allowed a smartphone-like text entry. Six participants who preferred Combined said that it supports a more stable grip like the grip of a smartphone and text entry without confirming the location of a target key. The other six

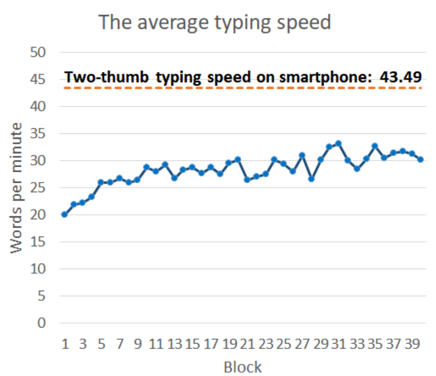

Figure 5: The means of typing speed of the final 4T design over the 40 blocks in Experiment 2.

participants who preferred Split said that it supports a more comfortable movement of thumbs and more localized perception of the haptic feedback of a key selection.

EXPERIMENT 2

The goal of Experiment 2 was to investigate the achievable performance of the final 4T design in a longitudinal study. Since *HoverFeedback* turned out to be effective whereas *GripStability* did not, we chose the HF & Split design as our final 4T design. Five university students (1 female, average age = 22.0) were recruited. All participants had participated in the previous experiments. Each participant was paid approximately 25 USD.

Participants were seated in front of a desk as shown in Figure 4. They took a brief text entry performance test with a smartphone (landscape mode). After the test, they were given a short introduction to the final 4T design. They then completed two sessions over two days. They repeated 20 blocks in each session. The experiment task and procedure in each block was the same as in Experiment 1. They took a 1-minute break between blocks. Each session took about 60 minutes.

Figure 5 shows the average WPM in the experiment. The average WPM, UER, and CER in the second session were 29.91 WPM (SD: 1.97), 0.40% (SD: 0.26), and 9.75% (SD: 1.63), respectively. The achieved speed was a clear improvement, but was still far below their smartphone text entry speeds, which was 43.49 WPM.

DISCUSSION

In summary, Experiment 1 showed that *HoverFeedback* had a significant main effect on the 4T performance, whereas *GripStability* did not, and Experiment 2 showed that the final 4T design could achieve a typing speed over 30 WPM after two hours of practice. Our goal in the future is to improve 4T in VR further to approach two-thumb typing on a smartphone.

We expected users would "fly-and-touch" when the visual feedback of hovering thumbs was provided, whereas they would have to "slide-and-click" otherwise, i.e., when they could see their thumbs only when the thumbs were in contact with the keypads. This expectation was confirmed in Experiment 1. All twelve participants used the fly-and-touch skill in the HF conditions regardless of *GripStability*. On the other hand, in the NHF conditions, 11 participants used the slide-and-click skill regardless of *GripStability*. They were not either forced or advised to use a specific typing skill. The performance difference between the HF and NHF conditions may be attributed to the difference in the typing skill. The advantage of the fly-and-touch skill over the slide-and-click was also shown in the context of 4T in a TV remote control environment [9]. Their analysis showed the fly-and-touch skill supported a more ballistic, concurrent, and integrated motor skill than the slide-and-click skill. A similar analysis on 4T in VR may shed light on our future efforts to improve 4T in VR further in the future.

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