Precision vs. Power Grip: A Comparison of Pen Grip Styles for Selection in Virtual Reality

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ABSTRACT

While commercial Virtual Reality (VR) controllers are mostly designed to be held in a power grip, previous research showed that using pen-like devices with a precision grip can improve user performance for selection in VR, potentially even matching that achievable with a mouse. However, it is not known if the improvement is due to the grip style. In this work, 12 subjects performed a Fitts' task at 3 different depth conditions with a pen-like input device used in both a precision and power grip. Our results identify that the precision grip significantly improves user performance in VR through a significant reduction in error rate, but we did not observe a significant effect of the distance of targets from the user. We believe that our results are useful for designers and researchers to improve the usability of and user performance in VR systems.

Index Terms: Human-centered computing—Human Computer Interaction (HCI); Human-centered computing—Virtual Reality; Human-centered computing—Pointing;

1 INTRODUCTION

Virtual and Augmented Reality (VR/AR) applications have become more popular in several fields, including entertainment, training, research, and education due to recent technology advances. High-resolution head-mounted displays (HMDs), accurate tracking systems, and efficient graphics hardware deliver today a comfortable experience for casual and professional applications. This allows developers to deploy a variety of content in VR and AR systems. However, during the interaction with a virtual environment (VE), commercial systems typically limit user either to handheld devices, e.g., HTC Vive or Oculus Touch controllers, or to the user's fingers, e.g., with the HoloLens or Leap Motion. The implementation of an interaction method then maps real-world user movements or actions into interaction with the VE.

This primary interaction method plays a key role for selecting, creating, and manipulating virtual content and is the main motivation for research on VR/AR selection methods. However, hardware and the software limitations of current interaction devices, such as jitter, thermal noise, and latency, negatively affect interaction methods, e.g., [7, 8]. Also, hand tremor and grip style potentially affect interaction performance, too. The combination of all these issues means that it is currently not possible for VR users to reach a level of input performance comparable to real-life or desktop interaction. There are several approaches to improve user performance in VR. One class proposes novel interaction methods and techniques for existing interaction devices, e.g.. [15, 33, 44]. Another class presents novel interaction devices, e.g., [16, 17]. Recently, several VR/AR pens or stylii, such as Massless[1], Logitech VR Ink (Pilot Edition)[2] and Holo-Stylus[3], have been introduced for interaction and content creation in VR.

The availability of such pen-like controllers and that they involve a different grip style poses the question if pen-based interaction is a better option for efficient and/or precise interaction. Different grips involve different muscle groups, which potentially results in different pointing performance. Due to the involved dynamic tripodal finger configuration, a precision grip affords more precision than a power grip, which is best illustrated by the progression of pen grips observed in children learning to write [40].

Furthermore, unlike in the real world, a precision grip does not always have to be associated with peri-personal space interaction in VR. While a subset of VR applications focuses only on targets within arm's reach, VEs do not have size limitations and virtual objects can thus be far away from the user. Through appropriate VR interaction methods the user can also interact with objects at larger distances in VR. Similarly, augmented content attached to real-world targets in AR might be distant from the user's hands. Thus, most AR systems include methods to interact with objects that are further away. This motivated us to focus on selection methods suitable for both near and distant objects in this work.

Here we explore how selection performance changes when a pen-like hand-held VR controller is held in a power or a precision grip for interaction with objects at different distances. The main outcome is that the precision grip significantly improves user performance compared to the power grip used with current VR controllers.

2 PREVIOUS WORK

2.1 Fitts' Law

Fitts' law [21] models human movement times for pointing tasks. Equation 1 shows the Shannon formulation of Fitts' law [27].

$$MovementTime = a + b * \log_2\left(\frac{A}{W} + 1\right) = a + b * ID \quad (1)$$

In equation 1, the empirical constants a and b are identified by linear regression. A is the amplitude of the movement, which is the distance between two targets, and W is the target width. The logarithmic term in equation 1 represents the task difficulty and is called the *index of difficulty*, *ID*.

We also use throughput (based of effective measures), as defined in the ISO 9241-411:2012 standard [23].

$$Throughput = \left(\frac{ID_e}{MovementTime}\right) \quad (2)$$

In Equation 2, movement time is the time between initiation of the movement and the selection of the target. The effective index of difficulty (ID_e) incorporates the user accuracy in the task [23]:

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[1] https://massless.io/

[2] https://www.logitech.com/en-roeu/promo/vr-ink.html

[3] https://www.holo-light.com/solutions/products/holo-stylus.html

$$ID_e = \log_2\left(\frac{A_e}{W_e}+1\right) \tag{3}$$

In Equation 3, A_e is the effective distance, the actual movement distance to the target, and W_e is the effective target width, the distribution of selection coordinates, calculated as $W_e = 4.133 \times SD_x$, where SD_x is the standard deviation of selection coordinates along the task axis. SD_x represents the precision of the task performance [28, 29].

2.2 3D Pointing in Virtual Environments

Pointing is a fundamental task while users interact with a VE [19]. Various studies in the literature have explored pointing tasks in VE, see, e.g., a recent survey of devices and techniques for 3D pointing [1] or evaluations of different mid-air selection methods, e.g., [29]. More recent work has directly compared different interaction styles for 3D pointing [14, 36].

2.3 Peri-personal Space 3D Object Selection

To interact with 3D objects in peri-personal space, which is defined as the immediate space around the body, research has previously proposed several different mappings between real and virtual hand motion [1, 37]. The most well-known technique is the "Virtual Hand", where the position, rotation, and velocity of the user's hand is directly mapped to the virtual one. This allows users to intuitively interact with the 3D environment, including grabbing and touching objects [11]. Yet, recent research showed that even with this direct mapping, user performance significantly differs in VR for object interaction in peri-personal space [3, 4].

2.4 Ray Casting

While selection with a virtual hand metaphor is easy in VR, it is challenging to select targets that are further away with this technique [25]. Ray casting, a vector based technique, is the preferred choice of interaction technique for the selection of distant objects in many VR scenarios [19]. Still, as it requires accurate pointing, ray casting does not perform well for small and/or distant targets [38], similar to a laser pointer in the real world. Thus, new techniques or combinations of existing techniques have been introduced to improve ray casting, e.g., [13]. Recent research has shown that, even though ray casting is the preferred interaction method for further away targets, it is negatively affected by rotational jitter in VR controllers [7, 8].

2.5 Grip Styles for Handheld VR Controllers

Current VR controllers are still undergoing rapid development. It seems that almost every week a new controller is proposed, each of which aims to increase user performance and experience in VR/AR. Previous studies on tool design and human anatomy showed that arm, elbow, forearm, wrist, hand, finger, and fingertip position and rotation all can effect the user performance [18, 26, 41, 42, 48]. Moreover, even the physical attributes of a tool, such as changing the size of the handle, can affect user performance [32, 43]. This also applies to VR controllers: the ergonomics, grip strength, and hand posture are some of the factors that influence VR controller design, that might also affect user performance. A recent VR study by Batmaz et al. [10] demonstrated that grip style can negatively affect the interaction with the VE and thus affect performance.

The type of movement that describes interaction with current VR controllers best is *prehensile movements*, which are movements of the hand when it positions an object, while that object is being held securely fully or partially in the hand [20]. While there are diverse and extensive prehensile movement types, Napier [35] suggested two major grip styles that categorize these grips anatomically and functionally. The first one is the *precision grip* where the object is pinched between multiple fingertips and the opposing thumb. This is shown in Fig. 1(a). Recent VR pen/stylus controllers use this grip style. The second one is the *power grip*: the object is held while fingers form a clamp position, with the palm touching the object and where the thumb applies pressure counter to the fingers. This is shown in Fig. 1(b). HTC Vive and Oculus controllers are examples of controllers designed to be used in a power grip.

3 MOTIVATION & HYPOTHESES

Previous research showed that performance varies between different input devices in VR [45, 47]. A recent study by Pham and Stuerzlinger [36] demonstrated that interacting with a pen-like controller in VR increases user interaction performance to the same level as that of a 2D mouse. They hypothesized that the precision grip (instead of a power grip) was the reason behind the observed increase in user performance.

One of the limitations of their work was they explored different input devices only for ray-casting and only for targets at 1 and 1.5 meters. Thus, their results do not cover peri-personal space. Yet, new pen-like VR interaction devices, such as the Logitech VR Ink (Pilot Edition) are clearly designed to be used in peri-personal space.


(a) (b)

Figure 1: A participant holding the input device with (a) a precision grip and (b) a power grip. Subjects pressed the space bar on the keyboard on their lap with their non-dominant hand to select targets.

In this work, we investigate the following two hypotheses:

H1. Holding a VR controller with a precision grip significantly increases user performance, compared to a power grip: The effects of wrist, hand, and fingertip positions on user performance for human computer interaction has been previously studied for a 2D mouse [2], which identified that user performance can increase if thumb and index finger works in unison. In this study, and to resolve questions raised by previous work [36], we explore how a precision grip, which is used for pen-like devices, e.g., during drawing, affects user performance in comparison to a power grip, which is how current VR controllers are typically held.

H2. User performance does not vary with different target depths while holding a VR controller with a precision or power grip: The limitations of depth perception in VR systems have been previously studied, e.g., [24, 39]. In our context, user performance in VR systems has shown to be negatively affected by stereo deficiencies, such as the vergence-accommodation conflict [4, 5]. These previous studies already showed that different depth distances affect user performance. Here, we investigate if the grip style has an effect on user performance at different target distances.

4 USER STUDY

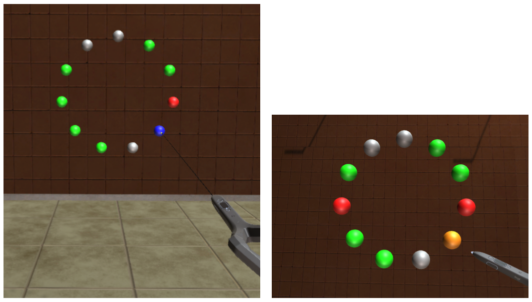
4.1 Subjects

We recruited twelve subjects (7 female; average age 26.67 ± 3.60 years; 1 left-handed) from the local university to take part in the study. Every subject used their dominant hand to do the task in both conditions, i.e., with the two grip styles. The inter-pupillary distance of the HMD was adjusted for each participant.

4.2 Apparatus

A computer with i7-4790 processor, 16 GB RAM, and GTX 1060 graphics card was used for the experiment, programmed with

Unity3D. We used a HTC Vive Pro headset for display and a Logitech VR Ink (Pilot Edition) for input, all with V2 Lighthouses.



(a) (b)

Figure 2: (a) For targets further away, subjects used fixed-length ray casting, while (b) for targets in peri-personal space subjects had to place the cursor inside the targets, similar to a virtual hand method.

4.3 Procedure

At the start, participants signed a consent form. An experimenter then explained through demonstration the entire experimental procedure to the participant, after which they were asked to fill out a demographic questionnaire. Then, subjects performed an ISO 9241-411 pointing task [23] with 11 targets (see Fig. 2). In this task, targets were distributed at equal distances in a circular arrangement, with targets alternating across the circle center. The first target was chosen randomly and subjects performed the ISO task either in a clockwise or counter-clockwise direction, randomly determined by the software. At the end of the experiment, subjects filled a short questionnaire where they shared their observations. The study lasted about 25 minutes.

The pen-like input device was used by the participants in two different conditions, i.e., two different **Grip styles** – a precision grip (holding the device like a pen; Fig. 1(a)) and a power grip (holding the device like a stick; Fig. 1(b)).

Also, participants performed the task with the circular target arrangement at three different **Depth distances**: 0.4, 1, and 1.6 m away from the user. In pilots, we first tested 0.5 m as the closest distance, but some subjects were not able to reach the targets comfortably and had to overly extend their arms. We also tried 0.3 m, but then subjects were not able to see all targets at the same time. Hence, we chose the shortest depth distance as 0.4 m, i.e., well within peri-personal space, where subjects were easily able to reach all targets. This was not possible in the other target distance conditions. We increased the depth distance linearly, based on the results of previous work [22], while still keeping the distance conditions comparable to previous work (1 and 1.5 meters in [36]).

Participants were seated in a chair at the center of the tracking area with a keyboard on their lap (see Fig. 1), which they used to select the targets by hitting the space bar with their non-dominant hand. This allowed us to avoid the "Heisenberg effect" [12] that occurs when the user physically interacts with the input device, which affects cursor position or ray rotation. Beyond the different target depth distances, the targets also appeared at three different **Target sizes:** 1.5, 2.5 and 3.5 cm and at three different **Target distances:** 15, 25 and 35 cm, i.e., different target circle diameters.

We used a 1 cm diameter yellow sphere as cursor. For the smallest target depth condition (0.4 m), where targets were within the subjects' peri-personal space, we attached a floating cursor 4 cm above the tip of the 3D model of the pen. For the other two conditions (1 and 1.6 m), we used standard ray casting, where the cursor was attached to the end of a ray starting from the center of the pen, aligned with the pen direction. We positioned the cursor at the first object that the ray hits, either on one of the targets or the back wall. Participants used this cursor to interact with targets in the VE beyond arm's reach. For the precision grip condition, the cursor and the ray was positioned at the tip of the pen device, as in Fig. 2. For the power grip condition, the ray and cursor were placed on the opposite side, i.e., the other end of the pen device.

At the start of each trial, all the target spheres were grey except for the current target which was orange (see Fig. 2). When the cursor was in contact with the target, the color of the target was changed to blue. If the subject made a correct selection, i.e., hit the space bar when the cursor was in contact with the target, we recorded a "hit" and the color of the sphere was changed to green. Otherwise, subjects "missed" the target, the color of the target was changed to red and an error sound was played.

4.4 Experimental Design

Twelve subjects performed the task in six experimental conditions: two grip styles (2_{GS} =power grip and precision grip) and at three different depth distances (3_{Depth} =0.4, 1 and 1.6 m). We counterbalanced these conditions across subjects to avoid learning effects. We collected movement time (s), error rate (%), and effective throughput (bits/s, [23]) data as dependent variables. To vary the index of difficulty *ID*, we used three target sizes (3_{TS} =1.5, 2.5 and 3.5 cm) and three target distances (3_{TD} =15, 25 and 35 cm), which created 7 unique *IDs* between 2.4 and 4.6. Each subject performed 2_{GS} x 3_{Depth} x 3_{TS} x 3_{TD} x 11 repetitions=594 trials.

5 RESULTS

To assess the effect of the factors on user performance we used Repeated Measures (RM) ANOVA in SPSS 24.0. As in previous work [10, 30, 31], we used Skewness (S) and Kurtosis (K) to determine the normality and considered that the data is normally distributed if Skewness and Kurtosis are between ± 1.5. While throughput had a normal distribution (S=0.63, K=0.33), time (S=0.217, K=-0.09) and error rate (S=1.16, K=0.99) were only normally distributed after log-transformation. We used the Sidak method for post-hoc analysis. To show different levels of significance below, we use *** for p<0.001, ** p<0.01, * p<0.05, and n.s. for non significant results. Here, we only focus on significant interactions.

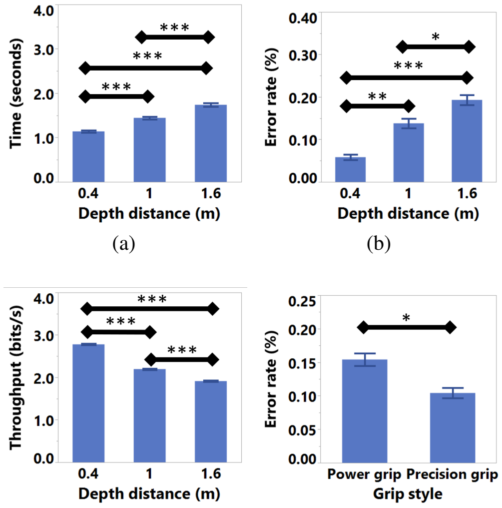
5.1 One-way RM ANOVA results

For the **Grip styles**, Mauchly's sphericity test was not violated for the independent variables. For the **Depth distances**, Mauchly's sphericity test was violated for time ($\chi^2(2)$=10.419, p<0.01, ε=0.642) and throughput ($\chi^2(2)$=12.957, p<0.01, ε=0.605). For the *ID*, Mauchly's sphericity test was only violated for throughput ($\chi^2(35)$=69.562, p<0.01, ε=0.441). For the RM ANOVA, we used Huynn-Feldt correction, since all ε values were less than 0.75. The one-way ANOVA results are shown in Table 1 and Fig. 3.

Table 1: RM ANOVA results

	Depth Distance	Grip Style	ID
Time	F(1.285,14.913)=79.333 *** η^2=0.878	F(1,11)=1.729 n.s.	F(8,80)=132.094 *** η^2 =0.923
Error rate	F(2,22)=24.321 *** η^2=0.689	F(1,11)=6.742 * η^2=0.380	F(8,88)=13.36 *** η^2=0.548
Throughput	F(1.209,13.304)=68.192 *** η^2=0.861	F(1,11)=0.069, n.s.	F(3.532,38.85)=34.48 *** η^2=0.758

According to the results in Fig. 3(a), Fig. 3(b), Fig. 3(c), and Table 1, subjects were faster, made fewer errors, and their throughput increased when targets were closer and vice versa. Moreover, the error rate results in Fig. 3(d) and Table 1 show that subjects made fewer errors with the precision grip.



(a) (b)

(c) (d)

Figure 3: Significant ANOVA results for (a) depth distance on movement time, (b) depth distance on error rate, (c) depth distance on throughput, and (d) grip style on error rate.

In further RM ANOVA, we were unable to identify significant interactions between **Depth distances** and **Grip styles**.

5.2 Subjective results

In the post-study questionnaire, 9 out of the 12 subjects preferred the precision over the power grip. Also, 10 subjects preferred the precision grip when the targets appeared in their peri-personal space, while 6 subjects preferred to use the power grip when they needed to select further away targets. Two-thirds of the subjects (8 out of 12) reported that the precision grip with targets further away was the physically more fatiguing condition, while the remainder felt it was the power grip with further away targets. 4 subjects felt all of the techniques were equally mentally fatiguing, whereas 4, 3, and 1 subject(s) respectively reported that the power grip with further away targets, precision grip with further away targets, and precision grip with closer targets was the most mentally fatiguing.

Reasons given by participants as to why they chose the precision grip were that it "felt more natural", was "easy to adjust", had "better performance", and was "better to aim". Subjects who chose the power grip mentioned that it was "more comfortable", the "precision grip had far too much jitter and instability", and the "hand shakes too much in precision grip". One also mentioned "When the targets were small and very far away, the power grip was easier to use for a longer period of time. For short, precise selections, precision grip was easier." Another participant also shared a similar point of view.

6 DISCUSSION

In this work, we investigated the effect of VR controller grip styles on interaction in VEs with a pen-like input device. For this, we extended the work of Pham and Stuerzlinger [36] by including peri-personal space targets and different grip styles for a pen-like device.

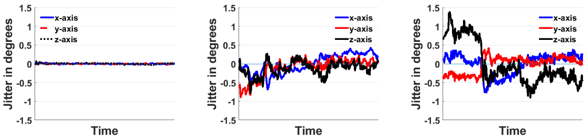
The results demonstrate that subjects made fewer errors with the precision grip. Moreover, the majority of subjects (9 out of 12) preferred the precision grip. Using multiple fingers and rotating the wrist to control the input device made it easier for users to select targets efficiently, as in related previous work [2, 36]. On the other hand, with the power grip subjects had to potentially move their whole arm to point at targets in 3D space. This involves a larger movement compared to the fine adjustments with the finger(tip)s. Thus, our results support hypothesis **H1**, i.e., that holding a VR controller with a precision grip significantly increases user performance compared to a power grip. Our results also confirm and extend the results of Pham and Stuerzlinger's work [36] for grip style.

Our second hypothesis, **H2**, which predicts that user performance does not vary with different target depths for different grip styles, is also supported. While target distance affects results, i.e., for closer targets, subjects were faster, made fewer errors, and their throughput was higher compared to further away targets, we did not see a significant interaction between **Target distance** and **Grip style**, which supports **H2**. We have four potential explanations for this result. The first one is that subjects (somewhat unsurprisingly) continued to use their fingers to fine-adjust the pen position even for close targets, i.e., in peri-personal space.

Our second explanation is that peri-personal space target selection was easier compared to further away target selection in VR, which is why we did not observe any difference in performance for different grip styles for close targets. Subjects might have been able to perform the experiment without small adjustments. Yet, reliably distinguishing between these two potential explanations requires additional hardware, e.g., to track finger movements.

Our third potential explanation concerns the design of the controller. In contrast to Pham and Stuerzlinger's work [36], movement time and throughput were not significantly different in this work. Due to the responses of participants in the free-form part of our questionnaire, we believe that design features of the pen-like device might have affected the user performance. Depending on the details, these might enlarge or reduce the effects of different grip styles for controllers. We discuss this further in the following paragraphs.

There are some differences between our and Pham and Stuerzlinger's work [36] in the outcomes in terms of time and throughput. The error rate for the pen was also much higher in our study. Many of our subjects reported that they felt their hand was shaking, i.e., they felt that they experienced "hand tremors" during the experiment. Yet we made sure to charge the pen-like VR controller fully before experiments and placed the Bluetooth dongle on the wall next to participants, which rules out the most obvious technical explanations. Based on the results of our study and participants' observations, we decided to measure the jitter of the pen-like VR controller, see Fig. 4, and to compare it with the results for VR controllers from previous work on the effect of jitter [7, 8]. Compared to their results [7, 8], the pen-like device has less jitter when it is immobile, see Fig. 4(a). Yet, compared to jitter in a hand-held VR controller [7, 8], when subjects are holding the pen-like device in their hand in a precision grip, a higher level of high-frequency jitter is notable, see Fig. 4(b) and Fig. 4(c). We thus believe that this high-frequency rotational jitter decreased the accuracy of target selection, which increased the error rate and also decreased the throughput. After all, an increase in the spread of the hit locations decreases throughput, as shown in previous work [28]. Further, more than ±0.5 degrees of rotational jitter negatively affects user performance [8], which could also explain our outcomes. Directly comparable work that identified



(a) (b) (c)

Figure 4: Rotational jitter observed in the pen-like device in different situations: (a) controller stably positioned on a desk, (b) user holding the device in a power grip, (c) user holding the device in a precision grip. Results are shown for all three Cartesian axes.

much higher throughput [36] used an Opti-Track system, which can provide sub-millimeter precision [45,46] and also exhibits (usually) a much smaller level of rotational jitter.

A final explanation is that we used a ray with infinite length, while [36] used a fixed ray length where the cursor was projected onto the 2D target plane, which also could have affected the results [9].

Based on the subjective responses, we also believe that the design of the pen controller might have affected user performance negatively. For instance, subjects shared their observations about the weight distribution of the controller for different grip styles in the subjective comments section. Moreover, one subject commented that the width of the device was not sufficient to comfortably perform the experiment with a precision grip. Three participants stated it was harder to hold the controller in the precision grip and one participant felt it was more like holding a long stick than a pen. While Pham and Stuerzlinger [36] used a regular whiteboard pen with markers on it, the relatively larger weight of the pen-like controller we used and how its weight is distributed might also have affected user performance.

We chose to conduct our study with the Logitech VR Ink pen-like device since, to the best of our knowledge, it is currently the only pen-like device that is directly compatible with a Lighthouse-based VR setup, which allows us to use this precise tracking technology. While Pham and Stuerzlinger [36] had already tried using a normal HTC VR controller held in a precision grip, they discovered that due to the controller weight, participants were not able to move the device with their fingertips and started to use their wrist. Thus, for us the Logitech VR Ink was the best option for conducting this study. Taking all this information into account, we still believe that the tracking accuracy of the device was sufficient to conduct this study.

6.1 Limitations

Even though we used a state-of-the art tracking technology in this work, based on HTC Vive V2 Lighthouses, the pen-like device we used, the Logitech VR Ink, is still a “Pilot Edition”. We have only limited knowledge on how well the HTC Vive Lighthouse and VR Ink systems work together. Although we analyzed the jitter of the VR Ink, we do not have a strong explanation for the outcomes of our technical jitter evaluation.

We also did not include the HTC VIVE Pro controller in our comparison, since the different physical and technical properties impose a strong confound. For example, unlike the HTC Vive Pro controller, the VR Ink is connected to the computer through a separate USB dongle, which means differences in wireless transmission could also affect the comparison. Thus we decided to focus *solely* on grip style (and not different controllers) to explore the hypothesis of Pham and Stuerzlinger [36].

We also used the HTC Vive Pro headset to make the outcomes of our work directly comparable with previous work [36]. However, we acknowledge that the screen-door effect in these headsets can decrease the performance of the participants for further-away targets, especially for small ones.

7 CONCLUSION AND FUTURE WORK

In this work, we evaluated the effect of different grip styles for a pen-like controller device for targets at different distances in VR. Results showed that user performance increases when a precision grip is used, both for targets in peri-personal space and further away. Based on our results, we suggest that hardware makers investigate controllers that enable a precision grip and also that practitioners and software developers choose the precision grip for more precise and accurate interaction with virtual objects in VE.

In the future, we plan to extend our research of comparing different input devices with different grip styles to identify optimal combinations in terms of user performance in VR, with an eye towards the scenario when a variety of pen-like controllers are easily available and more commonly used. We also plan to further investigate different input devices to reveal the most accurate and precise interaction style. A recent study showed that there is no significant difference between passive haptic feedback and mid-air interaction while a user selects targets in VR [6,34]. While commercial pen-like devices support interacting with hard surfaces, such as tables, and can detect different pressure levels applied to that surface, we can thus also to explore user preferences for interaction in mid-air and with passive haptic feedback.

Moreover, since pen-like devices are relatively new and subject to active development, the interaction with such pens opens additional research questions, such as how people with motor difficulties interact with such devices.

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