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Effects of Virtual Hands on Physical Demands and Task Performance for Typing in Virtual Reality

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Abstract: This study aimed to evaluate the effects of virtual hands in virtual reality (VR) environment on physical demands and task performance during typing tasks. Ten participants (aged 19 to 28; five males) performed typing tasks under three different conditions (typing on a laptop, typing in VR without virtual hands, and typing in VR with virtual hands) in a randomized order. A synchronized virtual keyboard was provided for both VR conditions. The kinematic data of the upper body was measured using an optical motion capture system with eight cameras. For the typing performance, the typing speed (word per minute [WPM]) and accuracy were measured. The results of the upper body angles showed that typing in VR without virtual hands showed lower shoulder adduction (81% decrease) compared to typing on a laptop. Typing in VR with virtual hands did not show significant differences in shoulder flexion/extension and abduction/adduction and wrist flexion/extension compared to typing on a laptop. The results of the hand trajectory showed that typing in VR without virtual hands resulted in significantly lower total distance traveled (49% decrease) and mean hand velocity (47% decrease) relative to typing on a laptop. Typing in VR with virtual hands did not show significant differences in hand coordination compared to typing on a laptop. For the typing performance, both VR without (7.5 WPM) and with virtual hands (19.4 WPM) showed significantly lower performance than typing on a laptop (27 WPM). There was no significant difference in typing accuracy between conditions. The results suggest that the presence of the virtual hands for typing in VR resulted in comparable joint angles of the shoulders and wrists and hand coordination to conventional typing on a laptop. Nonetheless, further design improvement of virtual hands and virtual keyboards would be needed to improve the typing speed.

Keywords: Virtual Reality Typing, Virtual Hands, Hand Kinematics, Joint Angles

1. Introduction

Virtual reality (VR) has emerged as a cutting-edge technology to serve a company's future design, training, and corporate communication demands. Whitman et al. (2004) claimed that VR enables users to mentally fly, swim, run, and walk across various buildings. According to Patel and Cardinali (1994), virtual reality (VR) offers many commercial possibilities, including entertainment, government, education, and practically every other industry.

In recent years, the market for VR is continuously flourishing, especially after the covid 19 breakthrough (Atsiz, (2021); Javaid et al., (2020); Rutkowski, (2021); Sarkady et al., (2021); Singh et al., (2020)). The value of VR device sales, according to 2018 CCS-Insight research, was predicted to be raised from US$1.5 billion in 2017 to US$9.1 billion by 2021, and according to grand view research, the market will develop up to US$28.42 billion in 2022, and $87.0 billion by 2030 (CCSInsight, (2017); Grand view report, (2018)).

With the prevalence of VR use in an office environment, the importance of the text entry method has also become a significant issue. In their research, Bowman et al. (2002) mentioned using gestures and controllers for text entry tasks. However, according to Yu et al. (2017), most past research focused on short text entries. For office utilization of VR, long text input was necessary. VR headset combined with a conventional physical keyboard may create a portable office by allowing users to experience a motion-independent, robust, and immersive virtual office environment that is more suitable for long text entries (Grubert et al., (2018); Knierim et al., (2018)).

One of the primary reasons behind the popularity of VR is the immersive interface. Grubert et al. (2018) experimented with the alphabetic entry on VR in four conditions of hand visibility, i.e., inverse kinematic model, no hand representation, depiction of a fingertip using spheres, and video inlay. According to their study, hand visibility in a virtual environment enhanced performance. Again, Knierim et al. (2018) showed the effect of hand visibility and concluded the avatar hand could improve typing performance. However, these studies did not consider the fluctuation or benefit from the biomechanical perspective due to the visualization of the virtual hand.

In this study, we aim to evaluate the hand motion trajectory and shoulder and wrist joint angles along with the performance of VR typing, considering the effect of hand visibility. We analyzed three different typing conditions, i.e., no VR, VR with and without virtual hand. We hypothesized that hand visibility would have a positive biomechanical effect as well as performance improvement. This study used a laptop screen as a control condition to compare the VR screen with the same paired-up keyboard. From this research, the significance of hand visibility for VR typing would be assessed, which will be a pioneer in designing a keyboard for VR typing and reduce the physical discomfort of typing in VR using a keyboard.

2. Method

2.1 Participants

Ten young adult participants (five males and five females), Northern Illinois University graduate students within the 19 to 28 age limits, were recruited for the study. None of the subjects had a history of musculoskeletal diseases in the upper extremity or musculoskeletal pain in the upper extremity during or within seven days before the study. The Institutional Review Board of the university approved the experimental methodology, and all subjects provided written consent before taking part in the study.

2.2 Experimental Protocol

Oculus Quest 2 (1832x1920 resolution per eye, 72 - 120 Hz refresh rate, 6 degree of freedom) and Logitech K830 keyboard (2.4 GHz Wireless Technology and Bluetooth Smart), BlueTooth pairable with a laptop, and the VR were provided to conduct the typing tasks.

In randomized order, typing tasks were performed. The typing tests were performed on the TypingTest online platform for a 5-minute medium test for each task condition (2022 Cloud Kayak Labs, Inc, n.d.). Hence, each participant typed for 15 minutes and was provided 5 minutes break after typing in each condition. Same keyboard and sitting arrangement was used for all task conditions. Task conditions:

1. No VR: On a laptop, the keyboard paired with the laptop (figure 1-a)
2. VR with hand visible: On a VR, the keyboard paired with the VR and hand tracking turned on (figure 1-b)
3. VR without hand visible: On a VR, the keyboard paired with the VR and hand tracking were turned off (figure 1-b)

Figure 1. Typing task on (a) laptop (b) VR using keyboard

2.3 Kinematic Data

An eight-camera optical motion capture system (Flex 13; Optitrack; Natural Point, OR) with reflective markers (14 mm) was used to sample kinematic data of the upper extremity at 120 Hz throughout the tasks and marker set used was conventional upper extremity with 27 markers. A digital zero-phase 4th order Butterworth filter with a cutoff frequency of 6 Hz was used to filter the raw kinematic data (Motive; Optitrack; Natural Point, OR). The trajectory of the hand movements for the right-hand finger (RFIN) and left-hand finger (LFIN) were collected from marker data in the comma-separated value file saved from the Motive software synchronized with the Motive software. The overall mean distance, total length or total distance, mean velocity, and sway area were measured as trajectory parameters similar to postural steadiness (Prieto et al., 1996). All the calculations were conducted on MatLab matrix-based software after modifying the positions with respect to the initial position.

The wrist and shoulder flexion/extension angles and the abduction/adduction angle were computed using biomechanical analysis software (Visual3D; C-Motion Inc., Germantown, MD). The instantaneous orientations of the anatomical axes in the upper arms and the trunk were used to compute shoulder angles. The wrist angles were calculated using instantaneous orientations of the anatomical axes in the forearms and hands. Using the Amplitude Probability Density Function, these kinematic variables were condensed into 10th, 50th, and 90th percentile values (Jonsson, 1982).

2.4 Subjective data

A widely used standardized test for evaluating perceived usability was the System Usability Scale (SUS) used for this study. According to Sauro and Lewis (2009), in industrial usability studies, the SUS accounted for 43% of post-study questionnaire usage. Conceptually, the first step in scoring was to translate raw item scores into adjusted scores, which are also referred to as "score contributions" and range from 0 (the worst rating) to 5 (the best rating).

2.5 Data Analysis

Using the amplitude probability density function (APDF), the 10th, 50th, and 90th percentiles of the shoulder and wrist joint angles were summarized. Univariate General Linear Model was used for statistical analysis of joint angle data, trajectory parameter data, performance data with task condition as a fixed factor, subject number as a random factor, and post hoc Tukey's honestly significant difference (HSD) test showed the significance of task condition. The model was built with the main effect of task condition and subject information, including an interception in models. Task condition significance was evaluated from the SPSS software statistical result and was considered statistically significant when the p-value was less than 0.05.

3. Result

3.1 Performance

The typing speeds were significantly affected by the task condition, and no VR, VR with and without hand conditions were all significantly different from each other (p's <0.01), where typing accuracy did not show a significant difference in any task condition comparison (p's>0.05). In VR with visible hand typing, the mean typing actual and net speed was acquired at 69% and 66.4% of no VR condition, respectively. However, in VR without visible hand typing, the mean typing actual and net speed was acquired at 30% and 29.5% of no VR condition, respectively (table 1).

Table 1. Mean (standard error) of performance

Performance parameters	No VR	VR Without Hand Visible	VR With Hand Visible	p-value
Actual Speed, WPM	29.132 (6.510)	8.732 (4.500)	20.000 (4.54)	<0.001*
Accuracy, %	98.270 (2.657)	93.870 (13.121)	95.400 (8.091)	0.391
Net Speed, WPM	28.800 (6.720)	8.470 (4.501)	19.131 (4.630)	<0.001*

Note: *: p < 0.05

3.2 Kinematic data

From table 2, in hand movement, the total distance or movement of the left hand was significantly different no VR and VR without visible typing conditions (p's <0.001). On the other hand, the sway area of the left hand was significantly affected by hand visibility for VR task conditions (p's < 0.001). Additionally, the left hand's mean velocity for typing showed a significant difference for no VR, VR with and with visible hand conditions (p's = 0.026). For the right hand, only the mean distance or mean of hand movement in the trajectory was significantly different for hand visibility with the VR typing conditions (p's =0.048).

Table 2. Mean (standard error) of hand motion parameters

Motion Measurement Parameters	No VR	VR Without Hand Visible	VR With Hand Visible	p-value
Left Mean Distance	0.013 (0.001)	0.015 (0.002)	0.015 (0.002)	0.423
Left Total Length	5.114 (0.376)	2.599 (0.213)	4.361 (0.493)	<0.001*
Left Mean Velocity	0.017 (0.001)	0.009 (0.001)	0.015 (0.002)	<0.001*
Left Sway Area	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.026*
Right Mean Distance	0.019 (0.001)	0.023 (0.002)	0.021 (0.002)	0.048*
Right Total Length	8.980 (0.637)	7.427 (0.905)	8.131 (0.754)	0.230
Right Mean Velocity	0.030 (0.002)	0.025 (0.003)	0.028 (0.003)	0.165
Right Sway Area	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.707

Note: *: $p < 0.05$

The hand motion trajectory plot (figure 2) for subjects portrayed the movement of the right and left hand based on the tracking data of right finger (RFIN) and left finger (LFIN) markers, respectively, in the two-dimensional plane. The area of hand movement was found different depending on the typing conditions. The density of right-hand trajectory points was found more to the top right side of the plane (lowest right shoulder and wrist adduction angle) for VR without hand visible condition than in the other two conditions. The left-hand trajectory points were less scattered, indicating slower hand motion (highest left wrist adduction angle) for VR without virtual hand VR typing.

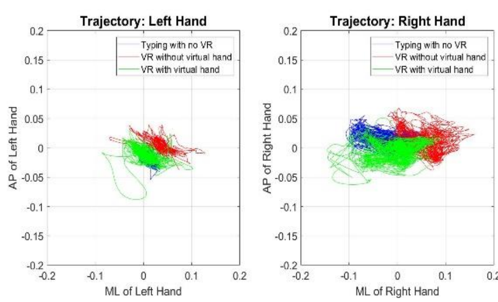

Figure 2. Hand motion trajectory plot for left-hand (left) and right-hand (right)

The joint angles were segmented into the shoulder and wrist angles (Table 3). Right shoulder adduction angles significantly decreased for VR without hand visible condition than the no VR condition (p's < 0.035). The right wrist's flexion angles were significantly lower for VR hand visible condition than for VR without visible hand condition (p's = 0.025). Additionally, the right wrist's adduction angles were significantly lower for VR without visible hand condition than the no VR condition (p's <0.05). For the left wrist, the adduction angles were significantly higher for VR without a virtual hand than for VR with visible hand condition (p's = 0.028).

Table 3. Mean (standard error) of shoulder and wrist joint angles

Joint Angles	Percentile	No VR	VR Without Hand Visible	VR With Hand Visible	p-value
Left Shoulder Flexion (+)/	10 th	38.900 (6.080)	42.690 (5.970)	42.270 (5.660)	0.691

Extension (-)					
	50 th	42.630 (5.720)	46.510 (5.540)	49.620 (4.580)	0.381
	90 th	46.410 (5.360)	49.580 (5.220)	52.310 (4.430)	0.437
Left Shoulder Abduction (+) /Adduction (-)	10 th	3.730 (1.780)	3.920 (2.370)	2.910 (1.470)	0.802
	50 th	6.090 (1.920)	6.030 (2.380)	6.010 (2.160)	0.999
	90 th	8.090 (2.020)	8.000 (2.390)	8.710 (2.270)	0.909
Right Shoulder Flexion (+)/ Extension (-)	10 th	34.180 (8.090)	46.840 (3.990)	43.000 (4.730)	0.068
	50 th	39.500 (7.160)	50.180 (3.620)	48.010 (3.800)	0.080
	90 th	44.520 (6.660)	53.510 (3.380)	51.720 (3.720)	0.139
Right Shoulder Abduction (+) /Adduction (-)	10 th	-13.020 (3.500)	-6.200 (2.170)	-11.860 (3.070)	0.106
	50 th	-9.250 (3.250)	-1.780 (1.990)	-6.710 (2.240)	0.035*
	90 th	-4.510 (2.300)	1.580 (2.060)	-2.970 (2.060)	0.011*
Left Wrist Flexion (+)/ Extension (-)	10 th	-23.340 (3.330)	-21.250 (3.740)	-22.150 (3.540)	0.399
	50 th	-19.140 (3.070)	-17.150 (3.380)	-17.280 (2.940)	0.339
	90 th	-15.100 (2.930)	-12.460 (3.310)	-12.560 (2.650)	0.204
Left Wrist Abduction (+) /Adduction (-)	10 th	-28.480 (5.520)	-34.410 (4.450)	-33.130 (6.300)	0.467
	50 th	-19.090 (6.780)	-27.180 (4.780)	-24.250 (6.480)	0.447
	90 th	-10.450 (6.270)	-19.910 (4.660)	-9.160 (6.670)	0.028*
Right Wrist Flexion (+)/ Extension (-)	10 th	9.390 (2.070)	11.270 (1.390)	8.290 (2.710)	0.266
	50 th	14.460 (1.790)	18.230 (1.800)	13.320 (2.430)	0.089
	90 th	21.160 (2.020)	25.630 (2.320)	19.860 (2.320)	0.025*
Right Wrist Abduction (+) /Adduction (-)	10 th	-38.460 (2.610)	-32.640 (2.090)	-35.980 (2.030)	0.051
	50 th	-30.820 (2.870)	-24.420 (2.270)	-27.660 (2.050)	0.008*
	90 th	-21.660 (2.940)	-16.180 (2.150)	-18.650 (1.980)	0.011*

Note: *: $p < 0.05$

3.3 Subjective Measure

The mean value of the SUS scores for no VR (on average 88), VR with virtual hand (on average 62) decreased significantly for VR without virtual hand typing (on average 44) (p's <0.05). Participants rated the hand visible typing 71%

higher than without hand visible VR typing condition. In short, Participants preferred the VR with hand visible conditions over without hand visible conditions.

4. Discussion

This study evaluated the effects of hand visibility on joint angles, hand motion trajectory parameters, systems usability, and performance on VR typing using a conventional keyboard and compared the effects with laptop screen typing using the same keyboard. The overall result showed a positive effect of hand visibility on VR typing. The findings of the hand trajectory demonstrated that, compared to typing on a laptop, typing in VR without virtual hands resulted in a significant reduction in the total path of hand movement (49% decrease) and mean hand velocity (47% decrease) (p's < 0.05). Compared to typing on a laptop versus typing in VR with virtual hands, no significant variations in hand coordination were identified ($p> 0.05$). According to the result, hand visibility significantly reduced the mean path or distance for the right hand ($p = 0.048$). Similarly, the total distance and mean velocity was the lowest without visible hand typing. The typing task did not provide an autocorrect system, and hand coordination indicated the repeated hand movement towards one direction (backspace key). For the left hand, the total length and mean velocity were significantly lower without hand visibility for VR typing because the participants experienced difficulty finding the desired key during typing and significantly showed down their hand movement resulting in the hand staying in the same position for more time than other two conditions. This movement reduction of the left hand and repeated motion toward the top right side of the trajectory of the right hand was also evident in figure 2 of the hand trajectory diagram.

The findings of the upper body angles demonstrated that typing in virtual reality without the use of virtual hands resulted in right lower shoulder adduction than typing on a laptop (81% decrease). The right wrist flexion angle was found highest for without hand visible VR typing, and this result supported the trend of repetitive backspace key use at the top right corner of the keyboard. Theoretically, distal upper-extremity musculoskeletal disorders are less likely to occur when wrist flexion/extension angles are close to the anatomically neutral position (as opposed to large wrist flexion/ extension angles) as it would cause lower carpal tunnel pressure and forces acting on the median nerve and flexor tendons (Rempel et al., 1997; Simoneau et al., 2003). The higher value of the wrist flexion could increase the risk of musculoskeletal disorder and wrist pain in the long run. According to the finding, hand visibility reduced the right flexion angle and thus reduced the risk of musculoskeletal disorders (MSDs) and wrist pain.

The result also showed a significantly lower value for left wrist adduction for hand visibility ($p< 0.05$). This indicated the participants were less engaged in typing when they did not see their virtual hands (figure 2). This trend was similar to the typing performance. The net typing speed of VR conditions was 66.5% and 29.4% compared to no VR typing for hand visible and not visible conditions, respectively. The actual typing speed showed a similar trend. However, the accuracy percentage of the typing tasks did not show any significant difference. In their study, Knierim et al. (2018) mentioned the participants' error correcting frequency was higher when the avatar hand was not visible. A similar observation was found in our study, and the participants corrected the texts as much as possible when they typed wrong. A higher accuracy level was acquired due to the tendency of the participants to correct the text when they detected they typed wrong in all three conditions, which affected the typing speed significantly as they were clicking the wrong key repetitively without hand visible VR typing. For subjective measure (SUS), the participants preferred hand-visible VR typing. As a result, their typing speed and subjective scoring significantly decreased from no VR, VR with hand visible to without virtual hand typing (p’s < 0.05).

This study would help to design a user-friendly typing setup for VR. Moreover, it would provide an insight into the physical benefits of hand visibility in VR typing. This study did not consider the muscular demand and cognitive demand for evaluating the effect of hand visibility in VR typing. Hence, further study is needed to evaluate the effect of hand visibility on the muscular and cognitive demands for VR-keyboard typing. The experiment was also carried out in laboratory settings with the participation of university students. For better evolution, the study should be replicated in an office environment.

5. Conclusion

Given the highest wrist angles, lowest typing speed, and participants' preference in SUS rating, the hand visibility impacted the typing result physically and performance-wise. The presence of a virtual hand for VR typing improved the overall performance of VR typing and reduced the risk of MSDs. With a virtual hand, typing on a VR-keyboard setting allowed improved posture and hand motion coordination and made the typing condition comparable to non-virtual screen typing. This study will help to improve the keyboard's design and will guide to lessen the physical discomfort of VR typing. It will also help to clarify the significance of virtual hand representation for VR typing.

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