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Are there differences in muscle activity, subjective discomfort, and typing performance between virtual and conventional keyboards? *

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Abstract— **This study investigated whether muscle activity and fatigue differed between a touchscreen virtual keyboard and two conventional keyboards. Finger flexor, extensor, and shoulder muscle electromyography, subjective discomfort, and typing performance were measured while 19 subjects typed on a virtual keyboard and two conventional keyboards with differing tactile feedback. The results showed that the use of the virtual keyboard resulted in lower muscle activity on the extrinsic finger flexor and extensor muscles ($p < 0.05$), a trend toward higher shoulder muscle activity ($p < 0.10$), higher subjective discomfort ($p < 0.0001$), and lower typing performance ($p < 0.0001$), as compared to the conventional keyboards. The results indicate that the use of a virtual keyboard increases muscle loading and subjective discomfort; therefore, shorter periods of operation may be more appropriate when using a virtual keyboard.**

I. Introduction

Studies have shown associations between computer use and musculoskeletal disorders (MSDs) [1]. Repetitive finger movements, awkward wrist postures, and static loading on the upper extremity muscles during typing are risk factors associated with computer-related MSDs [3].

Previous studies have shown that keyboard characteristics such as key activation force, travel distance, and tactile feedback can affect typing forces and tendon travel while possibly increasing the risk of developing musculoskeletal disorders (MSDs) [2,4]. These studies found that higher activation forces increased muscle activity, muscle fatigue, and discomfort in the upper extremities and that key travel distance and key stiffness affected both muscle activity and upper extremity discomfort.

As smart phones and tablet PCs have become increasingly prevalent, the touchscreen virtual keyboard has become a mainstream interface. Since a virtual keyboard is completely different from conventional keyboards in terms of key travel and tactile feedback, physical exposures and MSD risks may differ from those associated with conventional keyboard use.

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Most conventional keyboards are designed to have an activation force anywhere between 0.5 and 0.8 N [5]. The activation force was likely chosen to support the weight of the finger while preventing accidental key activation [6]. In contrast, since a virtual keyboard simply relies on contact with the fingertip, there is no key travel or force threshold to actuate the keys; consequently, users cannot rest their fingers/hands on the virtual keyboard. The absence of being able to rest the fingers/hands on the virtual keyboard may increase static muscle loading and discomfort in finger/hand and shoulder muscles. Therefore, it would be important to determine whether using a virtual keyboard has any effect on muscle activity and any other physical risk factors in the upper extremities.

There is a lack of research into how virtual keyboards may influence typing performance and muscle activity in the upper extremities. Therefore, the present study compared a virtual keyboard to two conventional keyboards in order to determine whether there were any differences in typing performance, muscle activity and subjective discomfort in the upper extremities and neck/shoulder. Based on previous research [7], it was hypothesized that virtual keyboard use may increase muscle activity and discomfort in the finger extensor and shoulder muscles.

II. Methods

A. Subjects

A total of 19 subjects (10 male and 9 female) were recruited to participate in the study through e-mail solicitations. All 19 subjects were experienced touch typists with no history of upper extremity musculoskeletal disorders and 17 of the subjects were right hand dominant. The average age and typing speed for all subjects was 24.3 (SD 6.4) years and 62.7 (SD 9.8) word per minute (WPM), respectively. Their average years of computer use were 14.1 (SD 5.5) years. The experimental protocol was approved by the Human Subjects Committee of the University of Washington and all subjects gave their written consent prior to their participation in the study.

B. Experiment design

In the repeated-measures laboratory experiment, subjects typed for two five-minute sessions on each of the three keyboards used in the experiment: a detachable 104-key desktop keyboard with 4.0 mm of key travel (SK-8115, Dell Inc., USA), a laptop with a keyboard with 1.6 mm of key travel (Envy14, Hewlett Packard Inc., USA), and a laptop with a dual touch screen interface with 0 mm of key travel (Iconia, Acer Inc., Taiwan). The 1.6 and 4.0 mm keyboards had the same activation force, approximately 0.6 N. During the typing sessions, typing speed and accuracy were measured by a software program (Mavis Beacon Teaches Typing Platinum - 25th Anniversary Edition, Broderbund Software Inc., USA). After typing on each keyboard, based on the ISO keyboard comfort questionnaire [5], subjective discomfort and preference ratings were collected using a questionnaire containing 7-point Likert scales. A 5-minute break was given between each keyboard to minimize residual fatigue effects from the previous condition. Keyboard order was randomized and counterbalanced to minimize potential confounding.

Before starting the typing task, the chair, table, and monitor were adjusted to match each subject's anthropometry in accordance with standards on computer workstation design [8]. During the typing sessions, muscle activity (raw EMG) was recorded from the right extensor digitorum communis (EDC), flexor digitorum superficialis (FDS), and trapezius (TRAP). The EDC muscle activity was measured by placing the EMG electrodes over the muscle belly one-third of the distance from its origin at the lateral epicondyle [9]. Similarly, the FDS muscle activity was measured by placing the EMG electrodes over the muscle belly one-third of the distance from its origin on the medial epicondyle. The electrodes for the TRAP were placed 1 cm laterally from halfway between C7 and the right acromium process and the ground electrode was placed on C7 [10].

To reduce skin impedance, prior to applying EMG electrodes to the skin, the electrode contact area was prepared by shaving hair with a razor (Medline, USA) and cleaning the skin surface with alcohol prep pads (Dynarex, USA). Then, disposable Ag/AgCl surface electrodes with an 8 mm diameter pick up area (Model: Blue Sensor N; Ambu; Ballerup, Denmark) were placed with a 20 mm inter-electrode spacing on the three muscles. EMG signals were recorded using a digital data logger (Mega ME6000, Mega Electronics, Finland) at a sample rate of 1000 Hz for the entirety of the experiment.

After collecting the raw EMG data, a band pass filter of 10-350 Hz was applied. The filtered EMG data from the EDC, FDS, and TRAP muscles were normalized by Maximum Voluntary Contraction (MVC) to obtain the amplitude probability density function (APDF) for the EMG data expressed as a percentage of the MVC (%MVC). Each contraction time lasted for three seconds and there was a 3-5 second break between contractions. From the three contractions, the maximum RMS signal over a one-second period was identified and used to normalize the EMG data.

Statistical analysis was conducted in JMP (Version 9; SAS Institute Inc., USA). A *mixed model* with *restricted maximum likelihood estimation* (REML) was used to determine whether there were any keyboard-based differences on muscle activity and software-measured typing performance. Any statistical significance was followed by the *Tukey-Kramer* method to determine differences between groups. *Friedman* test and post-hoc multiple comparisons in R (R 2.13.2, Development Core Team) were used to determine the effect of keyboards on subjective comfort, typing performance, and preference. All data are presented as mean and standard error; and significance was noted when Type I error was less than 0.05.

III. Results

Due to technical difficulties, EMG from one subject could not be used; therefore, the EMG results are based on 18 subjects. The normalized $50^{th\%tile}$ (median MVC%) muscle activity are summarized in Table I. Compared to the 4.0 mm travel keyboard, the 0 mm travel virtual keyboard had lower median muscle activity in both the EDC ($p = 0.009$) and FDS ($p = 0.001$) muscles. No differences in EDC muscle activity were found between the virtual and 1.6 mm travel keyboard whereas the 0 mm keyboard had lower FDS muscle activity than 1.6 mm keyboard. In contrast, when TRAP muscle activity was compared between the virtual and 4.0 mm keyboards, there was a trend towards higher median muscle activity with the virtual keyboard ($p = 0.10$). Muscle activity levels when using the 1.6 mm travel keyboard were almost always between the virtual and 4.0 mm travel keyboard activity levels.

TABLE I. NORMALIZED MUSCLE ACTIVITY (±SE) [N = 18]

	Keyboard			
	Virtual	1.6 mm	4.0 mm	p-value
$50^{th\%tile}$ EDC	12.9[a] (±1.1)	13.2[a] (±1.1)	14.1[b] (±1.1)	= 0.009
$50^{th\%tile}$ FDS	5.6[a] (±1.1)	8.2[b] (±1.1)	7.8[b] (±1.1)	= 0.001
$50^{th\%tile}$ TRAP	10.8[a] (±1.1)	10.2[a] (±1.1)	9.3[a] (±1.1)	= 0.10

a. Across rows, different letters indicate significant differences

Subjective discomfort and preference ratings showed that the virtual keyboard consistently received the lowest (least preferable) ratings whereas there were no differences between 1.6 mm and 4.0 mm travel keyboard except for subjective ratings of typing accuracy and speed (Table II). The 1.6 mm travel keyboard received the lowest discomfort rating while 4.0 mm keyboard had the highest subjective ratings for typing

TABLE II. MEAN(±SE) OF SUBJECTIVE COMFORT AND PREFERENCE RATINGS [N = 19]

	Keyboard			
	Virtual	1.6 mm	4.0 mm	p-value
Hand/Wrist comfort	2.9 [a] (1.7)	5.5 [b] (1.1)	5.2 [b] (1.0)	<0.0001
Arm/Shoulder comfort	3.4 [a] (1.7)	5.1 [b] (1.2)	5.1 [b] (0.9)	<0.0001
Ease-of-use	1.7 [a] (1.3)	5.7 [b] (0.9)	5.9 [b] (0.7)	<0.0001
Typing accuracy	1.5 [a] (1.0)	5.2 [b] (1.1)	6.1 [c] (0.9)	<0.0001
Typing speed	1.7 [a] (1.3)	5.3 [b] (0.9)	5.7 [c] (0.7)	<0.0001
Activation force	2.4 [a] (1.6)	4.1 [b] (1.8)	4.6 [b] (0.8)	=0.0005
Adjustment speed	2.4 [a] (1.4)	5.3 [b] (1.1)	6.1 [b] (0.8)	<0.0001
Preference	1.6 [a] (1.1)	5.3 [b] (1.1)	5.5 [b] (1.0-)	<0.0001

a. Across rows, different letters indicate significant differences productivity and accuracy, speed, easy-of-use, and the time needed to adjust to using the keyboard ($p < 0.0001$). Similarly, the perceived activation force on virtual keyboard was substantially lower than the other keyboards ($p < 0.0001$) whereas there were no differences in the perceived activation force between 1.6 and 4.0 mm travel keyboards.

As can be seen in Table III, there were significant differences in the objective measures of typing speed and accuracy between the virtual keyboard and conventional keyboards ($p < 0.0001$). Typing speed on virtual keyboard was approximately 60% slower compared to the conventional keyboards ($p < 0.0001$). Accuracy on the virtual keyboard was 84.5% whereas the accuracy on the conventional keyboards averaged 95% ($p < 0.0001$).

TABLE III. MEAN(±SE) TYPING SPEED AND ACCURACY [N = 19]

	Keyboard			
	Virtual	1.6 mm	4.0 mm	p-value
Typing Speed (WPM)	24.3 [a] (±2.0)	63.4 [b] (±2.0)	62.7 [b] (±2.0)	<0.0001
Typing Accuracy (%)	84.4 [a] (±1.0)	95.4 [b] (±1.0)	95.2 [b] (±1.0)	<0.0001

a. Across rows, different letters indicate significant differences

IV. Discussion

The present study investigated whether there were differences between a virtual keyboard and conventional keyboards in terms of muscle activity, subjective discomfort, and typing performance. This study found that the virtual keyboard had lower finger muscle activity and a trend towards higher shoulder muscle activity. The virtual keyboard had higher discomfort ratings, lower typing performance and was subjectively the least preferred keyboard. The results indicate that when high typing throughput or productivity is desired, a conventional keyboard should be used. The slower typing on the virtual keyboard is likely the result of subjects having to view the laptop screen and then switch to viewing the virtual keyboard keys when they typed. The typing speed on the virtual keyboard tested in this study is likely slower than on tablets and smart phones due to the dual viewing demands.

The EMG results indicated that the virtual keyboard had consistently lower muscle activity levels in the finger extensor (EDC) and flexor (FDS) muscles when compared to the 4.0 mm travel keyboard, whereas there were no differences between the virtual and 1.6 mm travel keyboard. This may be explained by the differences in key force-displacement between keyboards. Key activation forces are known to be positively correlated with applied finger forces [2,4]. Positive relationships between force and muscle activity levels have also been found. Thus, the higher activation forces resulted in greater typing forces for the 4.0 mm travel keyboard and may have, in turn, resulted in higher finger muscle activity levels. It is also likely that the higher typing productivity with the 4.0 mm travel keyboard also contributed to the higher finger muscle activity levels; thus, the difference in typing speed between the virtual and conventional keyboards was a study limitation.

Although we hypothesized that finger extensor muscle activity may be higher on the virtual keyboard, the results showed that the conventional keyboards had higher muscle activity. Again, the differences in typing speeds between the virtual and conventional keyboards were a study limitation. In future studies, introducing a condition where subjects type at a fixed speed on all keyboards would minimize this typing speed bias and better enable the comparison of muscle activity levels between keyboards.

Different from EDC and FDS muscles, trapezius (TRAP) muscle activity on the virtual keyboard was marginally higher than on the conventional keyboards. This finding was in line with a previous study [7]. Because a function of trapezius muscle is to support the arm, with the virtual keyboard, floating the hands and forearms while typing may have increased the loading on the trapezius. The higher subjective discomfort from the virtual keyboard may also be the result of higher trapezius muscle activity levels. Since prolonged static muscle loading is a risk factor for musculoskeletal disorders [3], using a virtual keyboard may increase the risk for musculoskeletal discomfort and the subsequent chances for the onset and development of an upper extremity MSD.

In conclusion, the study demonstrated that there were differences between virtual and conventional keyboards in muscle activity, typing productivity, and subjective discomfort. The virtual keyboard did have lower muscle activity levels in the finger flexor and extensor muscles; however, the tradeoff was a trend towards higher shoulder muscle activity, greater subjective discomfort and decreased typing productivity. As a result, when engaging in long typing sessions or when typing productivity is at a premium, conventional keyboards should be used; however, for shorter typing sessions when typing productivity is not at a premium, the virtual keyboard may be a suitable interface.

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