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Differences in typing forces, muscle activity, comfort, and typing performance among virtual, notebook, and desktop keyboards

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ABSTRACT

The present study investigated whether there were physical exposure and typing productivity differences between a virtual keyboard with no tactile feedback and two conventional keyboards where key travel and tactile feedback are provided by mechanical switches under the keys. The key size and layout were same across all the keyboards. Typing forces; finger and shoulder muscle activity; self-reported comfort; and typing productivity were measured from 19 subjects while typing on a virtual (0 mm key travel), notebook (1.8 mm key travel), and desktop keyboard (4 mm key travel). When typing on the virtual keyboard, subjects typed with less force (p's < 0.0001) and had lower finger flexor/extensor muscle activity (p's < 0.05). However, the lower typing forces and finger muscle activity came at the expense of a 60% reduction in typing productivity ($p < 0.0001$), decreased self-reported comfort (p's < 0.0001), and a trend indicating an increase in shoulder muscle activity (p's < 0.10). Therefore, for long typing sessions or when typing productivity is at a premium, conventional keyboards with tactile feedback may be more suitable interface.

1. Introduction

Computer keyboard characteristics can affect computer users' risks for developing upper extremity musculoskeletal disorders (MSDs). Previous studies have shown that a keyboard's key activation force, travel distance, force-displacement characteristics, and tactile feedback can affect typing forces, muscle activity, muscle fatigue and discomfort in the upper extremities (Gerard et al., 1999; Lee et al., 2009; Marcus et al., 2002; Martin et al., 1996; Radwin and Ruffalo, 1999; Rempel et al., 1997; Rempel et al., 1999). Although the strength of relationships between key activation force and typing force varies across studies (Sommerich et al., 1996a), typing forces have been shown to be directly associated with keyboard key activation force (Armstrong et al., 1994; Lee et al., 2009; Radwin and Jeng, 1997; Radwin and Ruffalo, 1999; Rempel et al., 1999). These previous studies have found that typing forces increase with higher key activation forces and that the higher typing forces resulted in increased muscle activity, muscle fatigue and discomfort in the upper extremities.

As tablet use is becoming increasingly common, conventional keyboards are being replaced by virtual, touchscreen keyboards with no physical key feedback. Due to the increased presence of tablets and the associated increase in virtual keyboard use, it is important to understand how the use of a virtual keyboard may affect typing productivity and the physical risk factors associated with MSDs. A touchscreen keyboard is completely different from conventional physical keyboards in terms of key feedback characteristics. Since most standard physical keyboards have a narrow range of activation forces, typically between 0.5 and 0.8 N, users can rest their fingers on the keyboard keys. However, because keys on a virtual keyboard are activated by any physical contact with the skin, users are unable to rest their fingers on the keyboard and must float their fingers, hands, and wrist to avoid accidental key activation. As this hand and finger floating could lead to prolonged static loading in the finger/forearm extensors and shoulder muscles, the associated risks for MSDs may increase whilst using a virtual keyboard. Furthermore, because a virtual keyboard provides limited tactile

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feedback without key travel and force-displacement characteristics, there may be differences in typing productivity and typing forces relative to conventional keyboards which provide users with some sort of tactile feedback.

With the relatively recent introduction of tablets, there has been very little research on how a touchscreen virtual keyboard may affect typing force exposures, muscle activity, user comfort, and typing performance. Young et al. (2013) examined the wrist posture and forearm muscle activity during touchscreen tablet use and found that a touchscreen table use can increase risks for MSDs. Another study (Shin and Zhu, 2011) evaluated the physical risk factors associated with touchscreen keyboard use in a desktop computer setting. They showed that using a touchscreen increased muscle activity in the shoulder and neck muscles, and increased self-reported discomfort in the fingers, shoulder and neck. However, it is still unknown whether using a virtual keyboard affects typing forces and the load on finger flexor, extensor, and shoulder muscles differently than a conventional computer keyboard. Therefore, the purpose of this study was to determine whether there are differences in typing forces, finger and shoulder muscle activity, self-reported comfort and typing productivity between a virtual keyboard which has no tactile-based switches and physical key travel and conventional computer keyboards with tactile (force–displacement) feedback.

2. Method

2.1. Subjects

A total of 19 subjects (10 male and 9 female) were recruited to participate in the study through e-mail solicitations. Seventeen subjects were right hand dominant and all subjects were experienced touch typists with no history of upper extremity musculoskeletal disorders. The average (SD) age and typing speed for all subjects was 24.3 (6.4) years and 62.7 (9.8) words per minute (WPM), respectively. The typing speed was collected using an online typing test program (http://www.typeonline.co.uk) with subject's own conventional keyboard during subject recruitment. Their average (SD) experience using computer was 14.1 (5.5) years; and all subjects were current virtual keyboard users with either smart phones or tablets. The experimental protocol was approved by the University's Human Subjects Committee and all subjects gave their written consent prior to their participation in the study.

2.2. Experimental design

Before evaluating the various keyboards, the chair and work surface was adjusted to match each subject's anthropometry in accordance with ANSI/HFES standards (2007). In addition, subjects were allowed to familiarize themselves with the typing software used in the experiment (Mavis Beacon Teaches Typing Platinum – 25th Anniversary Edition; Broderbund Software Inc.; Eugene, OR, USA) using a non-test virtual keyboard. Twelve randomly-selected chapters from a Grimm's Fairy Tales were used as the text for the typing. This text had a Flesch-Kincaid grade level of 5.1–5.7 indicating the text would easily be understandable by an average twelve year old.

In the repeated-measures laboratory experiment, participants typed for two five-minute sessions on each of the three keyboards used in the experiment. As shown in Fig. 1, two conventional keyboards were tested: a desktop keyboard with 4.0 mm of key travel (DT528AT; Hewlett Packard Inc.; Houston, TX, USA) and a notebook computer with a keyboard with 2.0 mm of key travel (Envy; Hewlett Packard Inc.; Houston, TX, USA); along with a notebook computer with a touch screen interface with 0 mm of key travel (Iconia; Acer Inc.; Taiwan). The force-displacement characteristics of the two conventional keyboards are shown in Fig. 1. The key spacing (center-to-center distance) was approximately 19 mm on all the keyboards and all conformed ANSI (ANSI/HFES 100, 2007) and ISO standards (ISO9241-410, 2008).

During the typing sessions, typing accuracy and adjusted typing speed (the product of gross typing speed and accuracy) were recorded by the typing software program. The order of the keyboards used was randomized and counterbalanced to minimize any potential confounding due to keyboard testing order. The various sections of the text used for the typing tasks were also randomized and counterbalanced. Finally, between the use of each keyboard, a 5-min break was provided to reduce any residual fatigue effects of the previous condition. The duration of the typing task was determined based on previous studies that evaluated typing exposures on various keyboards (Gerard et al., 1999; Gerard et al., 2002; Pereira et al., 2013a).

2.3. Typing forces

During keyboard use, typing forces were measured using a force platform (Fig. 2). The force platform consisted of a 36 cm × 18 cm × 0.64 cm (14.17 in × 7.09 in × 0.25 in) aluminum plate mounted to six degree of freedom force/torque load cell (Mini40E; ATI Inc.; Apex, NC, USA) which allowed detection of forces in three dimensions (Kim and Johnson, 2012). A previous study validated the accuracy of the force platform and showed the absolute mean force measurement errors over a 0–4 N range were less than 10% over the full area of the force platform (Kim and Johnson, 2012). The devices were placed on the force platform such that the "H" key of each keyboard was positioned in the center of the force platform. Only the downward, *z*-axis (i.e. perpendicular to the face of the keyboard being tested) were analyzed. To create a flat, continuous work surface, a polyoxymethylene frame which matched the height of the force platform was constructed to surround the force plate. Subjects were also instructed to type without resting their hands or wrists on either the device being tested or the force platform since these resting forces would artificially increase the measured typing forces. The experimenter observed the subjects to ensure they did not rest their hands and wrists on the devices or force platform when typing. Subsequent analysis of the typing force data (forces returning to near zero Newtons between keystrokes) verified that subject did not rest their hand on the device and/or force platform.

A LabVIEW program (Version 2009; National Instruments; Austin, TX, USA) was used to record force data at a rate of 500 Hz (Kim and Johnson, 2012). Prior to each typing task, the force platform was zeroed to offset the weight of the device being tested. The program also simultaneously recorded the digital signals from the keyboard. These digital signals were used by a subsequent LabVIEW-based typing force analysis program to identify individual keystroke force profiles. Only keystroke force profiles associated with the alphanumeric and punctuation portions of the keyboard were evaluated; keystrokes associated with Caps Lock Shift, Ctrl, Alt and Windows keys were not evaluated. The typing force program categorized typing forces as individual keystrokes when the force profile identified by the keyboard digital signal rose above, peaked and then descended below 0.4 N; the force profile had to be between 16 and 250 ms (ms) long, and the peak force had to occur in the first half of the force profile (Rempel et al., 1994). An upper limit of 250 ms was used for keystroke duration, as key rollover (where the letter is repeatedly typed when the key is held down) occurs at durations greater than 250 ms. Over the entire duration of each typing session, median (50th percentile) and peak (90th percentile) typing forces were calculated. In addition, from the individual

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