The Upper Extremity Loading during Typing Using One, Two and Three Fingers

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Abstract. This study aimed to evaluate the effect of the number of fingers used during typing on the biomechanical loading on the upper extremity. Six subjects typed in phone numbers using their right hand on a stand-alone numeric keypad in three conditions: (1) typing using the index finger; (2) typing using the index and the middle fingers; (3) typing using the index, middle and ring fingers. Typing with three fingers decreased wrist posture deviation, decreased angular velocity at the wrist, elbow and shoulder joints, and decreased peak to peak torques at the wrist and shoulder joints compared to single finger typing, while no difference was found between one and two finger typing. These results demonstrated that different computer keyboarding styles affect the biomechanical loading on the upper extremity.

Keywords: Typing; Upper extremity; Kinematics; Kinetics.

1 Introduction

More than 76 million or 56% of employed people in the US use a computer at work in 2003 [1]. The high prevalence of computer use and its association with upper extremity musculoskeletal disorders (MSDs) have caused a substantial public health burden in the US. Epidemiologic evidence has consistently reported more than 50% of computer users sustain musculoskeletal symptoms and disorders of the upper extremity spanning from the neck and shoulder to the hand and wrist [2,3,4,5]. The biomechanical risk factors, including posture, force, repetition, and dynamic motion affect the loading on the soft tissues, which are related to the injury outcomes for the upper extremity [6].

Studies examining the biomechanics of computer use have focused almost exclusively on the distal joints and segments, and only the kinematics of the movement [7,8,9]. Kuo et al. [10] characterized index finger tapping on a keyswitch in terms of finger joint kinetics, kinematics, muscle activation patterns, and energy profiles. They found that while both potential energy and kinetic energy are large enough to overcome the work necessary to press the key switches, nonetheless, the motor control strategies utilize muscle forces and joint torques to ensure a successful keystroke.

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Dennerlein et al. [11] measured both the kinematic and kinetic characteristics of the whole upper extremity. They suggested that finger, wrist and elbow joints work in synergy to produce fingertip motion, with a majority of the movement being generated by the finger and the wrist joint. However, both of these studies were limited in that subjects were tapping on a single key switch using the index finger only, and the motion occurred mainly in the two-dimensional sagittal plane. The upper extremity movement during keyboard use in reality is more complicated which involves three-dimensional (3-D) motion and multiple fingers.

This study aims to explore the characteristics of the 3-D motion of the wrist, elbow and shoulder joint, and to estimate the joint torques while typing using one, two and three fingers. The force, posture, dynamic motion and joint torque can provide quantitative assessment of the biomechanical loading on the upper extremity musculoskeletal system. This is the first step to study the biomechanical risk of upper extremity MSDs associated with computer use.

2 Methods

2.1 Experimental Setup

Six participants (mean (sd) age 28.3 (2.0) years, mean (sd) height 168.4 (7.4) cm, mean (sd) weight 64.9 (12.7) kg), three women and three men entered phone numbers on a stand-alone numeric keypad with their right hand (Fig. 1). The phone numbers included only numbers randomly generated from zero to nine. The experiment included three conditions: (1) typing using the index finger only; (2) typing using the index and the middle fingers only; (3) typing using the index, middle and ring fingers only. With a repeated measures study design, each participant completed all three conditions with the order of the conditions randomized. The participants were free of upper extremity MSDs at the time of the experiments. All subjects were right-handed. Informed consent was obtained, and all experimental procedures and forms were approved by the Harvard School of Public Health Institutional Review Board.

A stand-alone numeric keypad was used instead of a full-sized keyboard because we wanted participants to perform a less familiar task than typing on a standard keyboard to minimize the effect of typing skills on the performance and potentially on the kinematics and kinetics. All conditions were performed at the participant's own comfortable speed. During the experiment, subjects were instructed to type normally as if on their own computers. For the conditions that required typing with multiple fingers, subjects were not instructed to use a specific finger for a specific column of the keys, however, the numbers of fingers used was monitored to ensure that the required fingers were indeed used. They were instructed to proceed if mistakes were made during typing.

The key switch's activation force was 0.44 N, and the total travel (the maximum distance the key can be pressed down in the vertical direction) was 3.23 mm. The subjects completed the typing tasks while seated in a chair adjusted such that their thighs were parallel to the ground and the height of the typing surface was even with their seated elbow height. No forearm or palm support was provided.

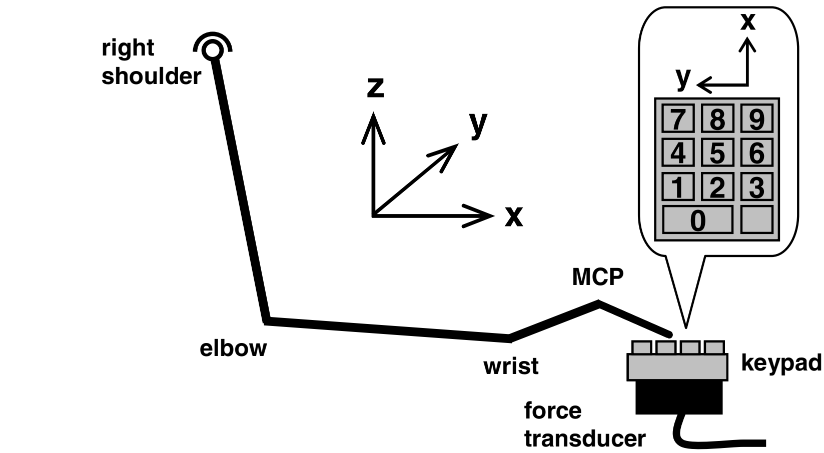

Fig. 1. Schematic view of the sagittal plane of the right upper extremity during experiment defining the global coordinate system

2.2 Experimental Measurements

Force vectors applied by the fingertip to the key and keypad were measured by a 6-axis force-torque transducer (ATI Industrial Automation, model Gamma, SI-65-5.5, Apex, NC, USA). The keypad sat on top of a 3 mm-thick aluminum sheet attached to the force-torque transducer. The amplified signals from the force-torque transducer were recorded onto a personal computer with a National Instruments Board (NI PCI-6040, National Instruments, Austin, TX, USA) at 200 samples per second. The force signal was low pass filtered digitally using a fourth order Butterworth filter with a cutoff frequency of 20 Hz and a zero phase shift.

Three-dimensional kinematics of the upper extremity was recorded using an active-marker infrared motion analysis system (Optotrak Certus System, Northern Digital, Ontario, Canada). Four clusters of three markers secured on a rigid plate were mounted on the hand, forearm, upper arm and torso, each was treated as a rigid body segment. A single marker was attached to the fingertip of the index finger. The 3-D positions of these markers were recorded at 200 samples per second. All kinematic data were low-pass filtered digitally using a fourth order Butterworth filter with a cutoff frequency of 10 Hz and a zero phase shift. Using the relationships of the anatomical landmarks and anthropometrical data, the position of each segment's center of mass, its inertia tensors and orientation were calculated at each instance of time based on the 3-D trajectories of the markers [12,13,14].

From the trajectories of the upper extremity segments we calculated joint angle, angular excursion, and joint torques. Joint angles were calculated using Euler angles with reference to the posture of the forearm fully pronated, the elbow flexed 90 degrees, and the upper arm vertical to the ground. The angular velocity was derived as the derivative of posture and the rectified mean was calculated. For joint posture excursion and torque sign convention, flexion, adduction, supination and internal rotation were positive, and extension, abduction, pronation and external rotation were negative. Angular excursion was calculated as the difference between the 95^{th} and the 5^{th} percentiles of joint angles. A 3-D multi-segment inverse dynamic model [10,15] calculated net reactive joint forces and moments for the wrist, elbow and shoulder joints. Peak-to-peak joint torque was calculated as the difference between the 95^{th} and the 5^{th} percentiles of torques. Participants typed for 20 seconds in each condition, and the mid fifteen seconds of data for each subject in each condition were extracted for analysis. One minute rests were given between conditions.

2.3 Statistical Analysis

The dependent variables were calculated based on each participant's anthropometry. The mean and standard deviation of the dependent variables across participants were presented. To determine the difference of joint loading while using different number of fingers during typing, we compared the kinematics and kinetics across three experimental conditions. We evaluated the effect of typing condition on fingertip force, joint posture, and moment in 3-D coordinates for each joint using a mixed effect model with the condition as the fixed effect and subject as the random effect. If a significant condition effect was found ($P \leq 0.05$), we proceeded with Tukey's post-hoc pairwise comparison between each condition pair.

3 Results

The fingertip force magnitudes were 1.5 to 1.6 times of the activation force requirement of the keypad. The average forces on the keyboard were 0.65(0.16) N, 0.65(0.07) N and 0.72(0.08) N when using one, two and three fingers during typing.

The mean wrist abduction (ulnar deviation) posture across six subjects was 6.4 (4.7) degrees (Table 1) during one finger typing, significantly greater than three finger typing (2.3 (4.1) deg). The wrist flexion excursions in one (13.6 (2.2) deg) and two (14.1 (1.1) deg) finger typing conditions were significantly greater than three finger typing (11.6 (1.9) deg). The mean posture of shoulder internal rotation during three finger typing was greater than two finger typing, and there was more forearm supination excursion during three finger typing than one finger typing. The flexion angular velocity of the wrist (22.7 (4.0) deg/s), elbow (7.8 (2.3) deg/s) and shoulder (5.0 (2.0) deg/s) during three finger typing were lower than one finger typing (*P-values* < 0.06). Shoulder internal rotation velocities during one (7.3 (2.2) deg/s) and two (7.3 (3.6) deg/s) finger typing were significantly greater than three finger typing (6.1 (3.0) deg/s). Two finger typing did not differ from one finger typing in terms of joint angles and velocity.

The mean joint torque did not differ across conditions (Table 2), while the peak to peak joint torque of wrist adduction decreased significantly from one (6.7 (1.8) Ncm) to three finger typing (5.6 (1.5) Ncm). Similarly, peak to peak torque of shoulder internal rotation during one finger typing (35.4 (10.5) Ncm) was significantly greater than three finger typing (24.3 (7.6) Ncm). The shoulder adduction peak to peak torque difference between one (25.0 (8.9) Ncm) and three (22.1 (8.9) Ncm) finger typing was marginally significant ($P = 0.06$). No significant difference of joint torque between one and two finger typing was found.

4 Discussion

The goal of this paper was to evaluate the effect of the number of fingers used during typing on the biomechanical loading of the upper extremity. Three dimensional motion of the upper extremity during random phone number typing was tracked and the kinematic and kinetic profile from the shoulder to wrist joint was recorded and computed. The results showed decreased wrist posture deviation, decreased angular velocity at the wrist, elbow and shoulder joints, and decreased peak to peak torques at the wrist and shoulder joints as the number of fingers increased from one to three during typing. This study is among the first few endeavors to quantitatively assess the 3-D kinematics and kinetics of the upper extremity during computer keyboard use. Previous effort on assessing biomechanical loading evaluated the task of single finger tapping on a single key-switch [11]. As the next step, the task in this study was more complicated in that participants were typing on multiple keys using multiple fingers.

This study showed that various typing styles could lead to different biomechanical loading on the upper extremity. However, this is just one piece of a big puzzle. Typing is a complicated motion which can be affected by individual factors, physical work environment, and cognitive and mental load. Future research need to evaluate each of those factors and the associated internal loading on the musculoskeletal system. Duration has been reported to be another risk factor of the upper extremity MSDs related to computer use [16], therefore, the temporal changes over a longer period of time needs to be evaluated. This study is a step stone for designing future research in the real work situations typing on standard QWERT computer keyboard for an extended period of time. Noted that no differences were found between typing using one and two finger, but they are different from typing using three fingers. It is likely that typing with four or five fingers from each hand will lead to even more different biomechanical loading profiles. More markers can be added on all fingers and each finger segment so that the DIP and PIP joint kinematics and kinetics from each finger can be recorded.

In conclusion, the results of this study demonstrated that number of fingers used during keying lead to different biomechanical loading patterns. The biomechanical loading on the wrist and the shoulder during one and two finger typing was higher than three finger typing and no difference was found between one and two finger typing. The results of this study maybe used to design future research to study the association between typing styles and the risks and injury mechanisms of computer use related upper extremity MSDs.

Table 1. Mean (SD) joint posture, excursion and velocity across six subjects for three typing conditions: using one, two or three fingers. Conditions with different superscript letters are significantly different, and the corresponding means are represented by the letters such that A>B. Bold numbers are condition effect with $P \leq 0.05$. Joint angular velocity were mean rectified. Flexion, adduction, supination and internal rotation were positive, and extension, abduction, pronation and external rotation were negative.

	Flexion			Adduction			Internal rotation (Supination)		
	One	Two	Three	One	Two	Three	One	Two	Three
Posture mean (deg)									
Wrist	-10.7 (14.3)	-11.9 (15.5)	-11.7 (15.9)	**-6.4 (4.7)**^{B}	**-4.5 (3.2)**^{AB}	**-2.3 (4.1)**^{A}			
Forearm							25.1 (4.0)	24.8 (3.6)	24.5 (3.7)
Elbow	4.9 (8.9)	4.7 (8.4)	2.7 (8.0)						
Shoulder	4.5 (9.9)	3.2 (8.8)	6.1 (7.4)	-17.7 (2.8)	-16.9 (2.3)	-16.7 (2.6)	**10.4 (8.4)**^{AB}	**9.9 (8.9)**^{B}	**12.7 (8.2)**^{A}
Posture excursion (deg)									
Wrist	**13.6 (2.2)**^{A}	**14.1 (1.1)**^{A}	**11.6 (1.9)**^{B}	5.2 (1.9)	5.8 (0.8)	6.1 (1.4)			
Forearm							**3.5 (1.1)**^{B}	**3.8 (1.2)**^{AB}	**4.9 (1.7)**^{A}
Elbow	3.6 (1.7)	3.6 (2.0)	3.5 (1.3)						
Shoulder	5.3 (0.8)	5.9 (1.2)	5.1 (1.9)	1.6 (0.9)	1.7 (1.1)	1.3 (0.6)	3.8 (0.8)	4.0 (1.7)	3.8 (1.9)
Angular velocity (deg/s)									
Wrist	**30.4 (3.8)**^{A}	**27.0 (3.9)**^{AB}	**22.7 (4.0)**^{B}	12.1 (2.9)	11.8 (3.2)	11.1 (3.8)			
Forearm							10.7 (2.7)	10.6 (3.3)	10.8 (2.9)
Elbow	**9.4 (3.7)**^{A}	**9.1 (3.5)**^{AB}	**7.8 (2.3)**^{B}						
Shoulder	6.0 (2.0)	6.1 (2.7)	5.0 (2.0)	2.9 (1.1)	2.7 (1.7)	2.3 (0.9)	**7.3 (2.2)**^{A}	**7.3 (3.6)**^{A}	**6.1 (3.0)**^{B}

Table 2. Mean (SD) of joint torque (Ncm) statistics across six subjects for three typing conditions: using one, two or three fingers. Conditions with different superscript letters are significantly different, and the corresponding means are represented by the letters such that A>B. **Bold** numbers are condition effect with $P \leq 0.05$. Flexion, adduction, supination and internal rotation were positive, and extension, abduction, pronation and external rotation were negative.

	Flexion			Adduction			Internal rotation (Supination)		
	One	Two	Three	One	Two	Three	One	Two	Three
Mean joint torque (Ncm)									
Wrist	-26.2 (9.4)	-26.1 (8.6)	-26.4 (8.9)	3.5 (2.0)	3.4 (1.9)	3.1 (2.3)			
Forearm							-17.2 (30.6)	-16.8 (29.7)	-20.7 (32.9)
Elbow	-200 (74)	-200 (70)	-200 (71)						
Shoulder	-266 (157)	-255 (147)	-284 (154)	-164 (44)	-158 (67)	-154 (52)	1.8 (2.7)	2.4 (4.2)	0.4 (2.1)
Peak to peak joint torque (Ncm)									
Wrist	11.4 (1.9)	10.3 (1.4)	10.3 (1.2)	**6.7 (1.8)**^{A}	**5.9 (1.2)**^{AB}	**5.6 (1.5)**^{B}			
Forearm							11.7 (2.6)	12.0 (3.4)	11.4 (4.2)
Elbow	30.5 (5.7)	28.8 (6.4)	28.2 (5.5)						
Shoulder	60.6 (12.3)	61.0 (21.1)	56.1 (18.2)	25.0 (8.9)	27.6 (12.9)	22.1 (8.9)	**35.4 (10.5)**^{A}	**31.3 (10.4)**^{A}	**24.3 (7.6)**^{B}

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