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Upper Extremity Dynamics during Keying

1 March 2007 to 29 February 2012.

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Abstract

Individuals spending a considerable amount of time working at a computer suffer high rates of upper extremity musculoskeletal disorders (MSDs). Recognizing that deleterious limb positions contribute to the development of MSDs, practitioners empirically recommend changes in workstation arrangements and keyboard design with the goal of reducing static postural loads. Research into these interventions has been limited and often neglects the dynamic task requirements and the interplay with observed static loading of the tissues.

The proposed goal of this research was to determine which ergonomic interventions for computer workers reduce both the static and dynamic biomechanical load of the upper extremity, a critical step for testing their effectiveness. Through a series of musculoskeletal modeling and laboratory experimental procedures we improved current models of passive muscle characteristics of both the intrinsic and extrinsic muscles that articulate the hand. We then applied these models to dynamic tapping and demonstrated that negative tilt keyboards increase the load on the forearm muscles, an unexpected result that is contrary to most practice guidelines. Through inverse dynamic models of the hand, forearm, upper arm we calculated the dynamic torques, testing hypotheses that workstation and individual based interventions change these dynamic torques. Shoulder torques decrease with the use of forearm and palm supports; however, the effects are different for mousing compared to keyboarding. For keyboarding, palm supports also decrease shoulder torques; however, for mousing, palm supports did not reduce shoulder torques significantly. Finally, we found that typing style greatly effects upper extremity torque, specifically two-finger typists (hunt and peck) have large dynamic loading and increased variability in joint torques compared to touch typist who use all eight fingers. In addition to testing these specific hypotheses this work also expanded our capabilities in testing design aspects of mobile computing including developing specific measurement capabilities of the thumb during key activation typical of hand held computers. We successfully completed all aims of the study.

Highlights/Significant Findings:

- Current biomechanical models of the hand and forearm were updated to effectively predict measured passive grip forces.
- Negative tilted, not positive tilted keyboards increase forearm muscle loading during tapping.
- Forearm supports reduce shoulder torques; however, the benefits from palm supports for the mouse are different than for the keyboard.
- Typing style also affects upper extremity dynamic loading with more variability and larger torques observed for the two-fingered hunt-and-peck typists, even when keyboard forces were similar.
- New areas of research are leading to new usage and design guidelines for mobile computing technology

Translation of Findings: We have been and continue to translate these findings to both the research and practice world of ergonomics via our routine peer reviewed publication venue as well as through our network of designers and practitioners. To date, we have 7 peer reviewed journal articles developed that relate directly to this study. We have an additional 8 supported by the study. In addition, we have 16 conference abstracts spanning presentations at both biomechanical research and professional ergonomics meetings. We have several partners in the industry through our relationships with the Office Research Committee (www.oerc.com) where we have regularly discussed and presented these findings. Finally, through our continuing education courses as part of the Harvard Education and Research Center (ERC) we present results to current practitioners.

Outcomes/Relevance/Impact: The primary outcomes of this study are recommendations for workstation configurations and user trainings that reduce the biomechanical load of the upper extremity during computer work. These outcomes inform practice. They also inform future research, specifically intervention studies that hypothesize that decreasing load through a series of workstation and training methods reduce the severity, prevalence, and incidence of musculoskeletal disorders among workers who primarily use the computer.

Scientific Report:

AIM 1 Final Progress – develop a musculoskeletal model to predict the muscle forces of the hand and forearm

The first aim as stated in the grant is to *1) Develop a dynamic, EMG-driven musculoskeletal model of the finger and wrist, to predict the forces of, as well as to elicit the specific coordination of the finger and wrist muscles balancing the wrist and finger joint dynamics. This multi-link inverse dynamic model will incorporate Hill type muscle models to compensate for force-velocity and force-length properties and EMG data to drive the load distribution across muscles to determine static and dynamic loading of the finger and wrist muscles during tapping and typing.* .

We completed Aim 1 as described below. Some modeling efforts were difficult to complete as the EMG protocols provided a large amount of noise that did not allow us to adequately utilize our developed EMG driven model. Traditional optimization methods proved just as reliable, once we developed better passive force models based on our *in vivo* data.

Developing better passive force models for the finger muscles

Qin J, Lee D, Li Z, Chen H, Dennerlein JT. Estimating in vivo passive forces of the index finger muscles: Exploring model parameters. *J. Biomechanics*. 2010: 7;43(7):1358-63. PMID: 20181338

Background:
When attempting to incorporate current passive muscle-force models into a dynamic model of the finger musculature during tapping on a computer key switch we noticed that the predicted muscle force values in these unpublished results were quite large compared to *in vivo* data.

Methods:
We compared predicted passive finger joint torques from a biomechanical model that includes the exponential passive muscle force-length relationship documented in the literature with finger joint torques estimated from measures in ten adult volunteers. The estimated finger joint torques were calculated from measured right index fingertip force, joint postures, and anthropometry across 18 finger and wrist postures with the forearm muscles relaxed. The biomechanical model predicting passive finger joint torques included three extrinsic and three intrinsic finger muscles.

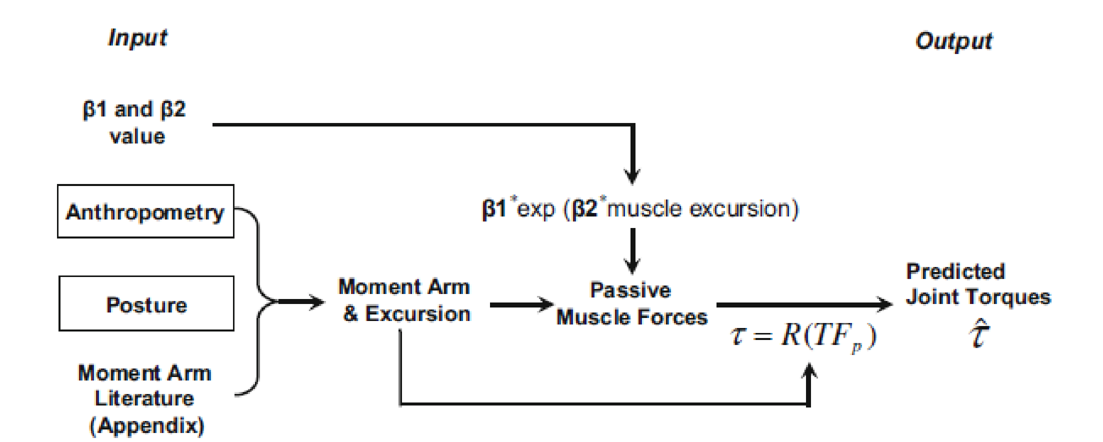

Figure 1: Musculoskeletal model flowchart (boxed parameters are experimental measurements).

Results:
The values for the predicted passive joint torques were much larger than the values calculated from the fingertip force and posture measures with an average RMS error of 7.6 N-cm. Sensitivity analysis indicated that the predicted joint torques were most sensitive to passive force-length model parameters compared to

anthropometric and postural parameters. Using Monte Carlo simulation, we determined a new set of values for the passive force-length model parameters that reduced the differences between the joint torques calculated from the two methods to an average RMS value of 0.5 N-cm; a 94% average improvement of error from the torques predicted using the existing data. These new parameter values did vary across individuals; however, using an average set for the parameter values across subjects still reduced the average RMS difference to 0.8 N-cm.

Table 1: Passive muscle force model parameters (b1 and b2) from existing data and from Monte Carlos simulations that minimized the difference function.

	Fitted from Ranney et al. (1987)	Individual subject values										Averaged across subjects	Average subject
		01	*02*	*03*	*04*	*05*	*06*	*07*	*08*	*09*	*10*		
Beta1 (N)													
FDP	2.921	1.873	3.181	2.619	4.783	1.712	1.623	0.348	2.083	2.343	0.057	2.062	2.556
FDS	4.681	1.546	0.292	0.709	0.053	0.160	1.705	0.011	1.276	0.277	0.302	0.633	0.834
RI	2.391	0.307	0.700	1.342	1.837	0.806	0.195	0.380	1.710	3.694	2.455	1.343	0.187
LU	0.191	0.180	0.199	0.168	0.367	0.341	0.306	0.459	0.330	0.518	0.003	0.287	0.302
UI	1.899	0.641	0.800	1.316	0.037	0.735	0.721	0.806	0.933	0.451	0.109	0.654	1.261
LE	1.203	1.591	2.250	2.559	1.707	1.188	1.867	0.905	2.007	2.921	1.147	1.814	1.504
Beta2 (1/mm)													
FDP	0.102	0.130	0.168	0.176	0.232	0.247	0.105	0.096	0.213	0.130	0.008	0.151	0.230
FDS	0.084	0.262	0.080	0.096	0.048	0.123	0.229	0.027	0.241	0.096	0.186	0.139	0.321
RI	0.295	0.397	0.273	0.100	0.222	0.327	0.501	0.290	0.189	0.108	0.104	0.251	0.607
LU	0.209	0.149	0.065	0.163	0.148	0.171	0.336	0.412	0.353	0.447	0.060	0.230	0.383
UI	0.334	0.034	0.333	0.360	0.354	0.048	0.136	0.482	0.040	0.096	0.249	0.213	0.004
LE	0.105	0.030	0.012	0.009	0.052	0.107	0.029	0.049	0.024	0.010	0.073	0.039	0.003

Conclusions:

These new parameters may improve dynamic modeling of the finger during sub-maximal force activities and are based on in vivo data rather than traditional in vitro data.

Model predicts larger muscle forces for non-neutral wrist postures during keying.

Qin J, Chen H, Dennerlein JT. Flexed wrist posture increases hand and forearm muscle stress during tapping on a computer key switch. In Review, Ergonomics.

[1]Chen H, Asundi K, Dennerlein, JT. Changes in Muscle Stresses during Tapping across Four Wrist Postures. *AIHce2010*, Denver, CO. 22-27 May 2010

Background:

Ergonomic guidelines for computing encourage straight and slightly flexed wrist postures to prevent hand and arm symptoms and disorders. This study aimed to quantify the effect of wrist posture during tapping on resulting finger and wrist muscle stress predicted from the combination of kinematic and kinetic experimental data and a musculoskeletal model of the fingers, hand, and wrist and the muscles that articulate their joints.

Methods:

Ten healthy subjects tapped on a keypad using their index finger in four wrist postures: straight, adducted (ulnar deviation), flexed and extended. Torque at the finger and wrist joints were calculated from measured joint postures and fingertip force using a 3-D segmental model of the finger and hand. Muscle stresses (including both the active and passive components) of the six finger muscles and four wrist muscles that balanced the calculated external 3-D joint torques at the 3 index finger joints and the wrist joint were calculated using classic optimization techniques that minimized the squared sum of muscle stress.

[1] Won Best Student Poster – AIHA Ergonomics Working Group

Results:
Flexed wrist resulted in greater total muscle stresses than other wrist postures and the extensors exhibited higher muscle stresses compared to the flexors. While the finger muscle stress showed an expected alternating peaking pattern between the flexor and extensors during a typical tap, the stress of the wrist extensors remained higher than 4.5 N/cm^2 and wrist flexor stresses remained below 0.5 N/cm^2 during the cyclic pattern.

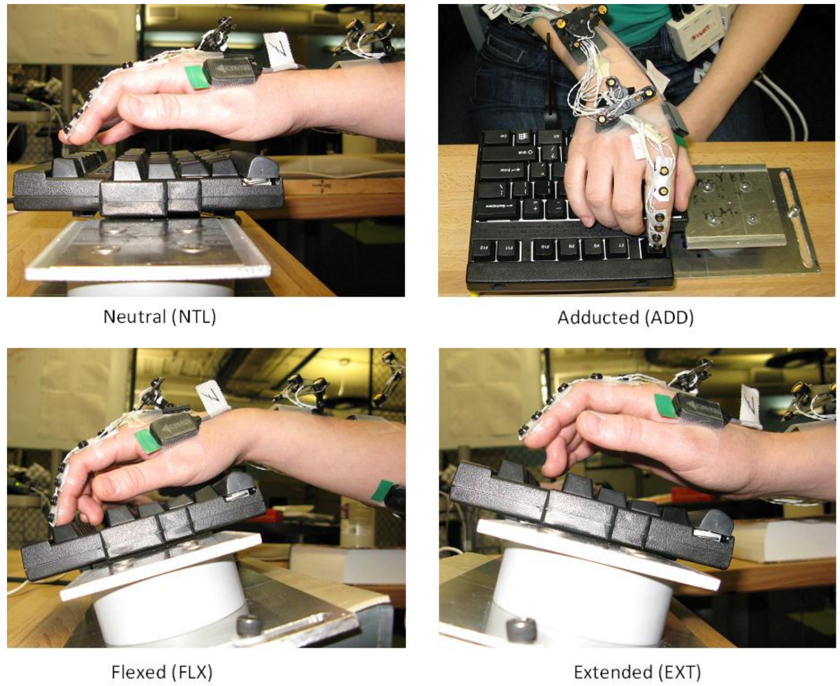

Figure 2. Testing for different muscle loads with angled keyboards.

Discussion and Conclusions:
We tested the hypothesis that non-neutral wrist postures increase extrinsic finger muscle forces and joint stiffness. Wrist posture affects the finger muscle lengths and hence passive tension and strength characteristics. To overcome these different passive forces, finger muscles must compensate through increased activation, increasing the mechanical joint stiffness. While many guidelines suggest neutral or slightly flexed wrist angles during keyboarding, the internal stresses calculated here suggest flexed posture increases the load on muscles and tendons.

New Activity: Minimally obstructive method to measure thumb kinematics during mobile device use

[2]Trudeau, M., Young, J.G., Jindrich, D.L., Dennerlein, J.T. (2012). Motor Performance Varies with Thumb Posture for Single-Handed Mobile Phone Use. Proceedings of the Canadian Society of Biomechanics annual meeting. Vancouver, BC, Canada. June.

Trudeau, M., Young, J.G., Jindrich, D.L., Dennerlein, J.T. (2012, upcoming). Thumb Motor Performance is Greater for Two-Handed Grip Compared to Single-Handed Grip on a Mobile Phone. Proceedings of the Human Factors and Ergonomics Society 56th Annual Meeting. Boston, MA, USA. October.

[3]Trudeau, M., Dennerlein, J.T. (2011). Thumb Motor Performance Varies According to Thumb and Wrist Posture during Single-Handed Mobile Phone Use. (presentation) Human Factors and Ergonomics - New England Chapter. Boston, MA, USA. November.

Trudeau, M., Udtamadilok, T., Karlson, K.A., Dennerlein, J.T. (2010). Thumb Motor Performance Varies by Movement Orientation, Direction, and Device Size during Single-Handed Mobile Phone Use. (poster) 34th Annual Meeting of the American Society of Biomechanics, Providence, RI, USA. August.

Background:
Several studies have developed kinematic models of the thumb but these models either involve inaccurate instrumentation, too few markers, or obstructive marker placements for measuring 3D kinematics of the thumb for precise motions such as tapping and typing on a mobile phone. This study addresses these limitations by proposing an accurate and minimally obstructive method for measuring thumb kinematics during mobile phone interaction.

[2] Finalist for the CSB2012 NDI Young Investigator Award PhD Category competition
[3] Awarded "HFES NEC Best Presentation

Methods:
A laboratory experiment on 10 right-handed participants measured the 3D position of markers on the thumb, hand, and forearm using an active-marker motion capture system (Optotrak - Certus, Northern Digital Inc.). Participants were instructed to accomplish different reciprocal thumb tapping tasks on a mobile phone. Three of the participants also accomplished flexion/extension and/or adduction/abduction-type movements for single joints. Each trial was videotaped using a digital video camera. Two markers were placed on the thumb tip, and clusters of three markers were placed on the thumb's proximal phalange, hand, and forearm.

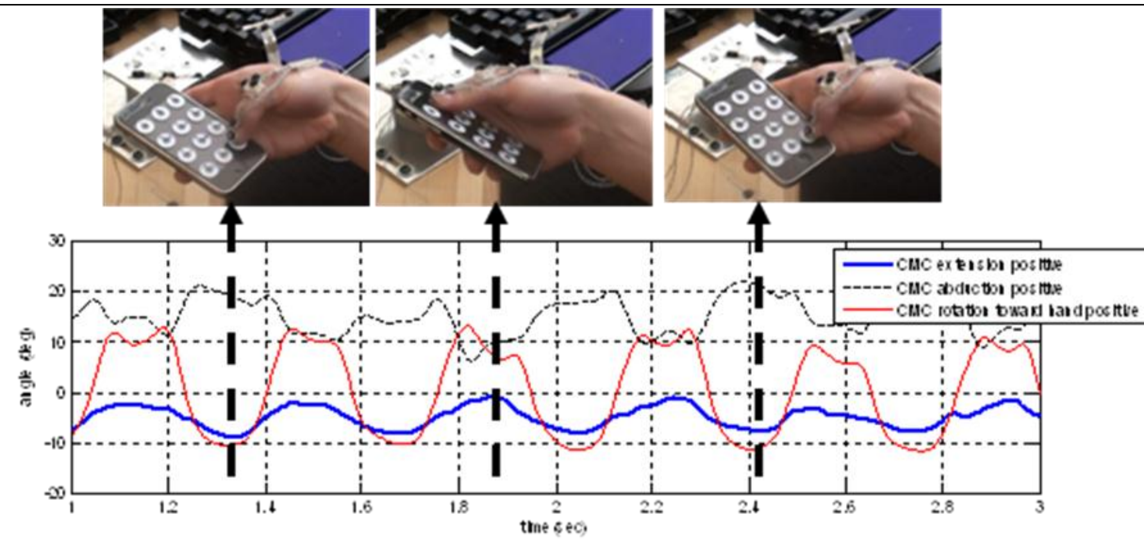

Figure 3: Thumb carpometacarpal (CMC) joint angles during a reciprocal tapping task qualitatively demonstrate that the joint angles measurement method provides a representative measure of thumb kinematics during mobile computing device use.

To calculate thumb kinematics, reference frames were defined for each segment, and Euler angles were calculated from rotation matrices defining a segment's orientation relative to the proximal segment. Calculated joint angles were validated qualitatively by comparing them to the joint angles observed from the video footage for each trial. A more accurate qualitative validation was obtained for the participants who accomplished the flexion/extension and/or adduction/abduction-type movements for single joints since the video camera view was normal to the movement plane.

Results:
Calculated joint angles matched the movements accomplished by the participants as observed from the video footage of each trial.

Discussion/Conclusions:
The kinematic model proposed in this study can and has been used as a way to measure thumb kinematics for mobile device use with minimal obstruction. However, a more robust validation of this method is needed before conclusions about its accuracy can be made. This study provides a method for researchers in the field of mobile devices to measure the effects of device design on thumb biomechanics.

Aim 2 Final Progress: Determining the biomechanical advantages for various computer ergonomic practices

The second aim as stated in the grant is to: *Measure and characterize the biomechanical demands of upper extremity during single finger tapping and multi-finger typing and determine how specific ergonomic and task configurations reduce these biomechanical demands. We will measure the kinematics of the finger, wrist,* *forearm, elbow, upper arm and shoulder, the muscle activity of prime wrist, elbow and shoulder muscles, and the forces applied at the fingertip and at any forearm and/or wrist supports.*

Effects of Forearm support on upper extremity dynamics

Asundi K, Trudeau M, Dennerlein J.T. Changes in shoulder, elbow, and wrist torque and EMG while typing with and without forearm support. *Ergonomics*, In Preparation.

Asundi, K., Trudeau M., Dennerlein, J. The role of palm, forearm and elbow supports on upper extremity joint torques during multifinger typing. *Proceedings of 6th World Congress on Biomechanics*. Singapore, 2010

Onyebeke L, Young JG, Trudeau M, Dennerlein JT. Forearm supports during mouse use improve shoulder and elbow torques. *Ergonomics*, In Preparation

Background:
The use of forearm and palm supports may help to reduce biomechanical load on computer users. However, specific biomechanical effects of using these supports on the upper extremity have not yet been elucidated. In addition, the impact of using these supports may be different when using the keyboard than when using the mouse due to the different location of these devices in standard desktop computing situations.

Methods:
The effect of using arm support(s) on the upper extremity was measured in two separate studies: one for keyboarding tasks and the other for mousing tasks. In each, surface electromyography (EMG) and joint trajectories were measured while subjects performed various computer tasks with and without arm supports that included various combinations of palm supports, forearm support, and elbow support. Forces applied to all supports and either the mousepad or keyboard were measured and along with kinematic data were used to calculate joint torques at the shoulder, elbow, and wrist using an inverse dynamics model. Repeated measures analysis of variance was performed to compare posture, EMG, and joint torques for each arm support condition.

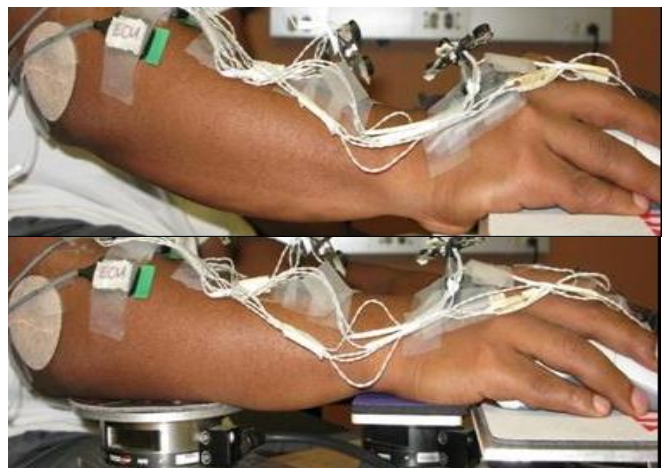

Figure 4. Example of a subject using a mouse with either no support (top) or with forearm and flat-palm supports (bottom). Optical tracking markers and EMG electrodes can be seen attached to the subject as well as load cells underneath supports.

Results:
Net external torques at the shoulder, elbow and wrist were significantly ($p<0.05$) affected by upper extremity supports for both typing and mousing scenarios. In both scenarios, shoulder torques were decreased when using supports compared to the no support configurations. Correspondingly, muscle activity in the anterior deltoid was significantly greater without the use of supports during mousing.

For mousing scenarios, configurations with the forearm support reduced shoulder extension torque significantly. Palm supports alone did not significantly reduce shoulder torque compared to the no support configuration, although the raised palm support significantly reduced wrist extension posture. Wrist extension torque was reduced when using any type of support.

For keyboarding scenarios, configurations with a palm support had the greatest overall effect in reducing external torques. The palm support alone led to reductions of 67% shoulder and elbow extension, 83% elbow abduction, 55% wrist extension and 118% wrist pronation torques.
Additional supports (forearm or elbow) alone with the palm support did not significantly change these values. Forearm and elbow supports had no effect on wrist torques.

Discussion/Conclusions:
These findings demonstrate the benefits of upper extremity supports for reducing required biomechanical load during computer use. It seems that for keyboarding/typing tasks, the greatest benefits were observed while using palm supports, whereas for mouse tasks, the greatest benefit was observed while using forearm supports. These findings show that a complex relationship exists between workstation configuration and biomechanical load. Future studies are needed to evaluate longer computer task exposures and how supports may be implemented and affect biomechanical load in non-laboratory settings.

Upper extremity dynamics of multiple finger typing versus single-finger tapping.

Qin J, Trudeau M, Katz JN, Buckholz B, Dennerlein JT. Biomechanical loading on the upper extremity increases from single key tapping to directional tapping. *Journal of Electromyography and Kinesiology* 2011: 21(4) 587–594. PMID: 21216620

Qin J, Trudeau M, Dennerlein JT. The Upper Extremity Loading during Typing Using One, Two and Three Fingers. *Proceedings of HCI International 2011*, Orlando FL. 2011

Background:
Musculoskeletal disorders associated with computer use span the joints of the upper extremity. Computing typically involves tapping in multiple directions. Thus, we sought to describe the loading on the finger, wrist, elbow and shoulder joints in terms of kinematic and kinetic difference across single key switch tapping to directional tapping on multiple keys.

Methods:
Six subjects tapped with their right index finger on a stand-alone number key pad placed horizontally in three conditions: (1) on single key switch (number key 5); (2) left and right on number key 4 and 6; (3) up and down on number key 8 and 2. They also typed in phone numbers using their right hand on a stand-alone numeric keypad in three conditions: (1) typing using only the index finger; (2) typing using the index and the middle fingers; (3) typing using the index, middle and ring fingers. A force-torque transducer underneath the key-pad measured the fingertip force. An active-marker infrared motion analysis system measured the kinematics of the fingertip, hand, forearm, upper arm and torso. Joint moments for the metacarpophalangeal, wrist, elbow, and shoulder joints were estimated using inverse dynamics.

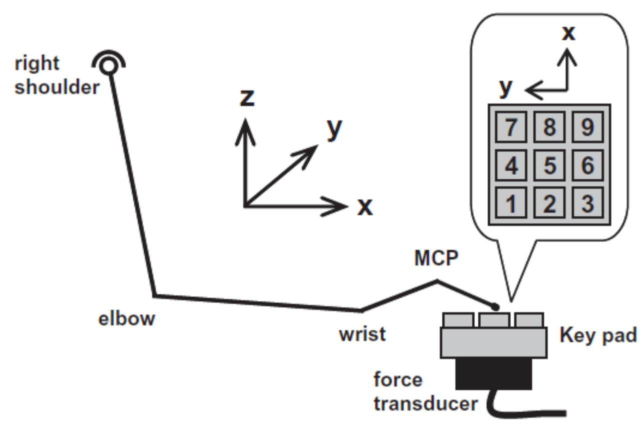

Figure 5: Schematic view of the sagittal plane of the right upper extremity during tapping.

Results:
Tapping in the up-down orientation introduced the largest biomechanical loading on the upper extremity especially for the proximal joint, followed by tapping in the left-right orientation, and the lowest loading was observed during single key switch tapping. Directional tapping on average increased the fingertip force, joint excursion, and peak-to-peak joint torque by 45%, 190% and 55%, respectively. By adding more fingers to assist in completing the task of numeric keypad data entry, peak to peak torques at the wrist and shoulder joints decreased, as well as the kinetic energy of the hand and upper arm.

Conclusions:
Keying styles and conditions affect motor control responses and joint contribution to fingertip movements, resulting in different biomechanical loading at shoulder, elbow, wrist and finger joints. Identifying the

biomechanical loading patterns associated with these fundamental movements of keying improves the understanding of the risks of upper extremity musculoskeletal disorders for computer keyboard users.

Typing Style effects on upper extremity dynamics

Trudeau M, Asundi K, Dennerlein JT. Typing Style Affects Arm Kinetics, Kinematics and Muscle Activation *Proceedings of the American Society of Biomechanics Annual Meeting*, 2011, Long Beach, CA.

Dennerlein JT, Asundi K, Faber G, Trudeau. Typing Style Affects Arm Kinetics, Kinematics and Muscle Activation, *Ergonomics* In Preparation

Background:
Ergonomic interventions lean towards “relaxed” touch typing methods; however, typing styles have not been quantified through biomechanical measures. This study aims to determine the effects of two different typing styles on posture, joint torque, and muscle activity in the upper extremity.

Methods:
Two groups of participants were recruited according to their typing style: 15 two-fingered typists (11 men, 4 women, mean age 44 years old) and 16 touch-typists (7 men, 9 women, mean age 39 years old). Participants completed a typing task consisting of transcribing text into a word processing document. Two minutes of force and kinematic data were collected after some practice time.

Three-dimensional (3-D) kinematics of the right upper extremity were recorded using an active-marker infrared motion analysis system (Optotrak Certus System, Northern Digital, Ontario, CAN). Typing force was measured by a 6-axis force-torque transducer (ATI Industrial Automation, model Gamma, SI-65-5.5, Apex, NC, USA) underneath the right-hand side of a split keyboard, and electromyographic (EMG) activity from eight muscles of the arm was recorded during the task (DE-2.1 Single Differential Electrode; Delsys, Boston, MA, USA).. A 3-D multi-segment inverse dynamic model [3,4] calculated net torques for the right wrist, elbow and shoulder joints. Root mean square (RMS) EMG signals were normalized to maximum voluntary contractions. Sample t-tests were used to determine the effect of typing style on the biomechanical parameters (alpha = 0.05).

Results:
Touch typists had significantly higher shoulder internal rotation angle and wrist ulnar deviation (Table 1), which might be explained by the fact that they sat significantly closer to the keyboard compared to two-fingered typists (32.8 (1.3)cm vs. 28.2 (0.9)cm respectively). Two-fingered typists had significantly higher variation for shoulder rotation and flexion angles (Table 2).

Table 2: Across subject mean (s.e.) joint angles and angle variation (s.e.) for two-fingered typists (Finger) and touch-typists (Touch).

	Flexion				Internal rotation				Abduction			
	Finger		Touch		Finger		Touch		Finger		Touch	
Shoulder												
mean angle (°)	-2.8	(1.7)	-2.20	(1.2)	**19.4**	**(1.4)**	**26.1**	**(1.8)**	-7.2	(0.9)	-6.9	(1.2)
angle variation (°)	**2.5**	**(0.3)**	**1.52**	**(0.2)**	**4.2**	**(0.5)**	**1.8**	**(0.2)**	1.1	(0.2)	0.8	(0.1)
Elbow												
mean angle (°)	-7.5	(1.2)	-4.94	(1.5)	8.6	(1.9)	4.1	(2.2)	-	-	-	-
angle variation (°)	2.0	(0.4)	1.44	(0.1)	2.9	(0.3)	2.8	(0.2)	-	-	-	-
Wrist												
mean angle (°)	-25.2	(2.1)	-20.0	(2.3)	-	-	-	-	**13.8**	**(1.3)**	**19.1**	**(1.5)**
angle variation (°)	6.25	(0.4)	5.5	(0.3)	-	-	-	-	3.3	(0.3)	3.2	(0.3)

Two-fingered typists had generally higher total joint torques and total torque variation compared to touch-typists, with wrist total torque and torque variation being significantly different between the two groups (Table

2). More specifically, the two-fingered typists had significantly higher wrist RMS torque in flexion/extension (0.28 (0.02)Nm vs. 0.19 (0.02)Nm respectively) and in rotation (0.29 (0.04)Nm vs. 0.20 (0.02)Nm respectively), and significantly higher shoulder torque variation in flexion/extension (0.46 (0.05)Nm vs. 0.32 (0.04)Nm respectively), rotation (0.29 (0.04)Nm vs. 0.20 (0.02)Nm respectively), as well as in add/abduction (0.21 (0.02)Nm vs. 0.14 (0.01)Nm respectively). All other RMS torques and torque variations were not significantly different between the two groups.

The 10th percentile value of EMG amplitude for the anterior deltoid muscle was significantly greater for two-finger typists (p = 0.047) suggesting more of a static load.

Conclusions:
In conclusion, two-finger typists had larger dynamic loading and increased variability in joint torques and postures compared to touch typists. These differences suggest that injury mechanisms for the upper extremity associated with computer work may be different for the two typing styles.

Table 3: Across subject mean (s.e.) total joint torques and total torque variation (s.e.) for two-fingered typists (finger) and touch-typists (touch). Statistically significant differences between the two groups are in bold.

	Finger		Touch	
Shoulder				
mean total torque (Nm)	2.1	(0.7)	1.20	(0.40)
total torque variation (Nm)	1.4	(0.5)	0.60	(0.17)
Elbow				
mean total torque (Nm)	0.35	(0.1)	0.19	(0.07)
total torque variation (Nm)	0.22	(0.1)	0.11	(0.03)
Wrist				
mean total torque (Nm)	**0.01**	**(0.00)**	**0.00**	**(0.00)**
total torque variation (Nm)	0.00	(0.00)	0.00	(0.00)

New activities: Exploring wrist and arm dynamics during mobile computing

Asundi K; Odell D; Luce A; Dennerlein JT. Notebook computer use on a desk, lap, and lap support: Effects on posture, performance, and comfort. Ergonomics. 2010; 53(1):74-82. PMID: 20069483

Asundi K; Odell D; Luce A; Dennerlein JT Changes in posture through the use of simple inclines with notebook computers placed on a standard desk. Applied Ergonomics, 2012: 43(2):400-407. PMID: 21774912

Young JG, Trudeau M, Odell D, Marinelli K, Dennerlein JT. Touch-screen tablet user configurations and case-supported tilt affect head and neck flexion angles. Work: A Journal of Prevention, Assessment and Rehabilitation. 2012: 41(1):81-91. PMID: 22246308

Young JG, Trudeau M, Odell D, Marinelli K, Dennerlein JT. Touch-screen tablet user configurations affect wrist and arm posture and muscle activity. *Work: A Journal of Prevention, Assessment and Rehabilitation*. In preparation.

Figure 6. Laptop computing scenarios (Asundi et al., 2010, 2012)

The results from studies performed supporting Aim 2 spawned interest in how mobile computing technologies (laptop and tablet computing form factors) may affect user biomechanics differently than traditional desktop situations. To that end, we have performed studies that measured posture and muscle activity for various mobile computing scenarios.
Results from these studies suggest that the location that users choose to place the mobile device (such as on the lap, table, riser or case) can have a significant effect on the resulting posture of the user. In addition to location, the specific tilt of the screen will alter viewing and head and neck flexion angles, which may be much greater than for traditional desktop computing. Holding a tablet computer with the hand leads to large radial deviation of the wrist, increased forearm muscle activity, and reports of fatigue; which is a hazard unique to this form factor.

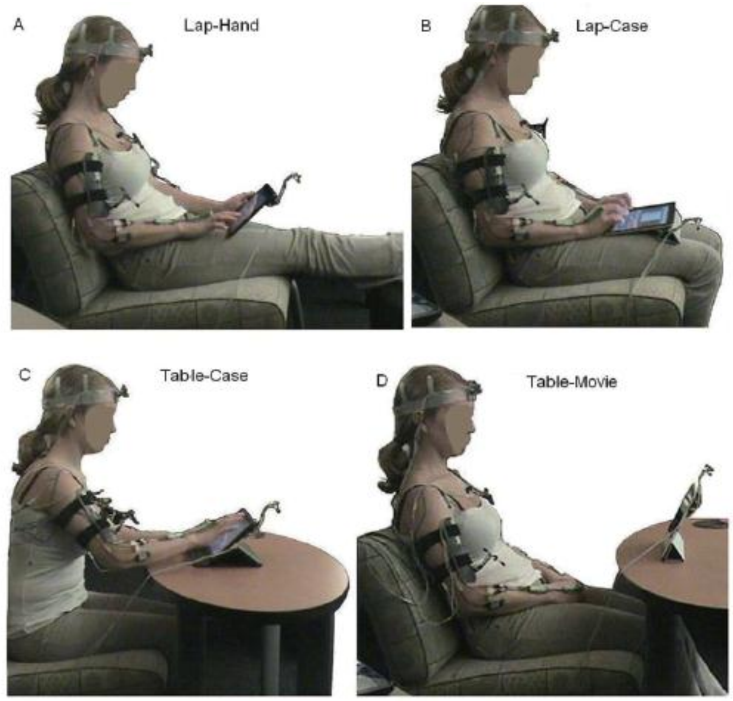

Figure 7. Tablet computing scenarios (Young et al, 2012).

These results suggest that using mobile technologies presents a unique biomechanical load on the upper extremity. However, simple interventions such as cases or risers may be effective ergonomic tools that can reduce exposures if designed properly. More research on mobile and touch-screen interaction will help to elucidate ergonomic hazards and potential interventions for users of these increasingly popular technologies.

Publications

Peer reviewed publications describing specific work completed in this study

1. Dennerlein JT, Kingma I, Visser B, van Dieën J. The contribution of the wrist, elbow and shoulder joints during single finger tapping. *J. Biomechanics*, 2007; 40, 3013-22, 2007. PMID: 17467717
2. Qin J, Lee D, Li Z, Chen H, Dennerlein JT. Estimating in vivo passive forces of the index finger muscles: Exploring model parameters. *J. Biomechanics*. 2010: 7;43(7):1358-63. PMID: 20181338
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[4] Won Best Student Poster – AIHA Ergonomics Working Group

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15. [5]Trudeau MJ, Dennerlein JT. Thumb Motor Performance Varies According to Thumb and Wrist Posture during Single-Handed Mobile Phone Use, *Human Factors and Ergonomics Society - New England Chapter Student Conference*, Cambridge, MA 2011.

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[5] Won Best Conference Presentation