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Effects of computer keyboarding on ultrasonographic measures of the median nerve

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Abstract

Background—Keyboarding is a highly repetitive daily task and has been linked to musculoskeletal disorders of the upper extremity. However, the effect of keyboarding on median nerve injuries is not well understood. The purpose of this study was to use ultrasonographic measurements to determine whether continuous keyboarding can cause acute changes in the median nerve.

Methods—Ultrasound images of the median nerve from twenty-one volunteers were captured at the levels of the pisiform and distal radius prior to and following a prolonged keyboarding task (i.e., one hour of continuous keyboarding). Images were analyzed by a blinded investigator to quantify the median nerve characteristics. Changes in the median nerve ultrasonographic measures as a result of continuous keyboarding task were evaluated.

Results—Cross-sectional areas at the pisiform level were significantly larger in both dominant ($p=0.004$) and non-dominant ($p=0.001$) hands following the keyboarding task. Swelling ratio was significantly greater in the dominant hand ($p=0.020$) after 60 minutes of keyboarding when compared to the baseline measures. Flattening ratios were not significantly different in either hand as a result of keyboarding.

Conclusion—We were able to detect an acute increase in the area of the median nerve following one hour of keyboarding with a computer keyboard. This suggests that keyboarding has an impact on the median nerve. Further studies are required to understand this relationship, which would provide insight into the pathophysiology of median neuropathies such as carpal tunnel syndrome.

Key terms

carpal tunnel syndrome; computer keyboarding; median nerve; ultrasonography; ultrasound

INTRODUCTION

Carpal tunnel syndrome (CTS) is a common, costly problem in the general population and in manual workers.(1–3) In the United States of America alone, an estimated 1.6% of adults population self-reported carpal tunnel syndrome, with more than 3 million individuals experiencing its symptoms and signs,(4) including pain, tingling, numbness, fatigue and weakness in the hands and fingers. In another study, the prevalence of clinically and electrodiagnostically confirmed CTS in a general population was reported as 2.7%.(5) Treatment of CTS is estimated to cost over one billion dollars a year.(6) The most prevalent

theory for the pathogenesis of CTS is compression of median nerve in the carpal tunnel.(7, 8) Although this theory is widely accepted, the cause of the compression in the carpal tunnel is not fully understood. Epidemiological research has identified several occupational risk factors associated with the development of CTS in general industry including: force, repetition, awkward/static postures, localized mechanical compression, and vibration.(9–12) Several studies have found a greater prevalence of carpal tunnel syndrome in workers with highly repetitive manual jobs.(3, 13, 14)

Keyboarding is a highly repetitive daily task, and its association with musculoskeletal disorders of the upper extremity has been a public health concern since the mid 1980s.(1) An extensive review of the literature demonstrated that the prevalence of musculoskeletal disorders among keyboard users varied from 9% to 50%, when compared to control groups (low levels of or no keyboard use) where prevalence ranged from 4.5% to 17%.(14, 15) The incidence of computer related musculoskeletal disorders remains a serious concern as the number of people using a computer at work continues to steadily rise. While the literature strongly suggests a causal relationship between computer keyboarding and musculoskeletal disorders of the upper extremity, the association between keyboarding and CTS is not well-established. A systematic review of eight studies of computer work and carpal tunnel syndrome, performed by Thomsen et al., showed that there was insufficient epidemiological evidence that computer work causes CTS.(16) In fact, a few studies have concluded that prevalence of CTS in computer users is similar to that in the general population. In a study conducted by Stevens et al.,(17) the frequency of carpal tunnel syndrome in computer users at a medical facility was reported to be comparable to that in the general US population. Hou et al. also found a similar prevalence of CTS in a group of video display terminal workers to that of the general population.(18) However, the case definition and dose measurement were not clear in these two studies. In addition, there was little difference in hours of keyboarding between the computer users in the former study. In a study of professional technicians, Andersen et al. reported no relationship between keyboard use and incidence of CTS. However, most of the participants in the study used a keyboard less than 20 hours per week.(19)

On the other hand, several research studies have demonstrated a correlation between computer keyboarding and CTS. A population survey of clinically and electrodiagnostically confirmed CTS suggested an association with computer use.(20) Liu et al. reported that the prevalence of CTS among computer users at their medical facility was 16.7%,(21) almost 3 times higher than the general population. Moreover, a number of epidemiologic studies have demonstrated the risk of CTS is increased with keyboard use above 20 hours per week.(22, 23) Using MRI to visualize acute changes in the median nerve as a result of continuous keyboarding, Shafer-Crane reported that the median nerve long axis/short axis ratio decreased in subject without CTS symptoms after three hours of keyboarding, while symptomatic subjects demonstrated no significant changes in their median nerves.(24)

The controversial results regarding the association between keyboarding and CTS indicate that we have an insufficient understanding of an association between keyboarding and upper limb neuropathy. Assessing acute median nerve changes may be useful in predicting the likelihood of developing CTS and evaluating the risks involved with certain tasks. The

purpose of this study was to use ultrasonographic measurements to determine whether continuous keyboarding can cause acute changes in the median nerve. Ultrasonography is relatively inexpensive, noninvasive, requires short examination times, and can be used even in non-clinical settings.(25) Ultrasound has been established as a reliable diagnostic tool for detecting peripheral nerve injuries, including carpal tunnel syndrome.(26–30) It has been used to make accurate measurements of the shape, size, and even movement of the median nerve at various levels of the wrist.(25–29) Several studies have compared ultrasonographic characteristics of the median nerve with electrodiagnostic and clinical examinations in individuals with CTS. The most common findings included an increased median nerve cross-sectional area (CSA) at the level of the pisiform bone, increased flattening ratio at the level of the hook of the hamate, and an increased swelling ratio, defined as the ratio of the median nerve CSA at the pisiform level to that at the distal radius level.(25–29) We hypothesized that the median nerve would exhibit a larger cross-sectional area at the pisiform level, an increased swelling ratio, and an increased flattening ratio at the pisiform level following a continuous keyboarding task when compared to baseline images collected prior to keyboarding.

METHODS

Subjects

A convenience sample of twenty-one healthy volunteers participated in this study. Prior to testing, the participants were screened for any hand symptoms, prior history of median neuropathy, or history of trauma, surgery or underlying conditions related to CTS by filling in a questionnaire. All participants self-reported that they were expert typists (i.e., typing at least 40 words per minute), used a keyboard at least four hours a day, three days a week, and typed using all digits. In order to minimize the effects of prior actions, all subjects were asked to refrain from intense physical activity for 48 hours prior to testing. They all provided written informed consent approved by the Institutional Review Board (IRB) prior to enrolling in the study.

Data Collection

Quantitative Ultrasound Examination—The details of the quantitative ultrasound examination were described elsewhere.(32, 33) Briefly, ultrasound images of the carpal tunnel, with primary emphasis on the median nerve, were collected at the distal radius and the pisiform levels. These two regions are easily viewed using ultrasound and nerve measures. Changes at these locations have previously been linked to CTS both electrodiagnostically and symptomatically.(25–30) Our laboratory has demonstrated good reliability of intra-rater measures of median nerve ultrasound characteristics, including the cross-sectional area, swelling ratio, and flattening ratio at the pisiform and distal radius levels.(31, 32)

Images were obtained using a Philips HD11 XE ultrasound machine with a 5-12 MHz 50 mm linear array transducer (Philips Medical Systems, Bothell, WA, USA). The machine settings were optimized as in our previous studies and held constant across all participants. (31, 32) The ultrasonographic images were collected while participants remained seated

with upper arm relaxed and fully adducted with no internal/external rotation, the elbow flexed to 90 degrees, forearm supinated and supported, and the wrist maintained at neutral posture with the fingers relaxed. The baseline images were collected prior to participation in the keyboarding task and served as a reference for comparing the post-keyboarding measurements in order to quantify acute changes of the median nerve. Figure 1 shows sample ultrasound images collected, depicting the median nerve and bony landmarks at the carpal tunnel.

Continuous Keyboarding Task—All keyboarding was completed on a L100 Dell keyboard (Dell, Inc., Round Rock, TX, USA) set in a “standard” (i.e., flat and non-angled) position. For this experiment the height of the chair and workstation were fully adjustable and the subjects were able to set the chair and desk height according to their own preference. The chair did not have armrests. The subjects directly faced a flat screen monitor and were instructed to type at their normal rate on the keyboard, using their usual style. The keyboarding task was performed using an electronic keyboarding program, Typing Master Pro™ (Typing Master Finland, Inc., Helsinki, Finland), which presents a keyboarding test for the keyboard user on the computer screen. The program provides cues as to where they are in the text and advances the text automatically as the keyboard user works through the paragraph. Alternate input devices (i.e., mouse) were not used. Productivity data, such as keyboarding speed and accuracy, were gathered automatically. After the baseline ultrasound examination, participants typed for 30 minutes and then paused for another ultrasound examination on both wrists. The interruption in keyboarding for this examination lasted less than 10 minutes. Subjects then proceeded to type for another 30 minutes before the final ultrasound examination.

Data Analysis

An interactive semi-automated MATLAB (The MathWorks, Inc., Natick, MA, USA) image analysis program was previously developed to make manual measurements of structures of interest within the ultrasound images.(31, 32) Briefly, median nerve diameter and cross-sectional area were determined by performing a boundary trace along the border between the hypoechoic inner median nerve and the hyperechoic outer epineurium. Figure 2 shows an example of the boundary trace and major and minor axis selections. A single investigator, blinded to occasion and image number, analyzed each image to obtain CSA and measures of the major and minor axes of the nerve. We collected these measurements at each image level and calculated the flattening ratio (major axis / minor axis) at pisiform level, and the swelling ratio, defined as CSA at pisiform level divided by CSA at distal radius. Furthermore, in order to minimize the effects of nerve’s original CSA, we defined a new variable, ΔCSA , which was calculated as the difference between baseline CSA and CSA after 60-minute keyboarding divided by the baseline value. The ΔCSA was used to compare median nerve changes between dominant and non-dominant hands, and also between male and female participants.

Statistical Analysis

Two-way Repeated Measures Analysis of Variance (RM ANOVA) were performed using a commercial statistics software package (SigmaStat; SPSS Inc., Chicago, IL, USA) for each

nerve variable comparing the amount of change observed in subjects at each time point (i.e., at baseline and after 30 minutes and 60 minutes keyboarding) and for both dominant and non-dominant wrists. If the RM ANOVA was significant, it was followed by the pair-wise multiple comparison procedures (Holm-Sidak method). A p-value of <0.05 was considered statistically significant. Correlation between subject characteristics and median nerve measures at all time points was tested using a regression model, where the dependant variables were the change in the median nerve cross-sectional area, swelling ratio, and flattening ratio. The independent variables of interest included the subject age, gender, and keyboarding speed.

RESULTS

Subject Characteristics

Of the 21 subjects enrolled in the study, one male participant was excluded (due to median nerve bifurcation). Table I summarizes the subject characteristics.

Acute Changes in the Median Nerve Measures

Baseline Characteristics—The only significant differences between dominant vs. non-dominant side at the baseline was the flattening ratio, which was higher in the dominant wrist (Table II).

The Cross-Sectional Area—The CSA at the pisiform level showed an increasing trend from the baseline to 30-minute (3.5%) and 60-minute time points (7%) in both dominant and non-dominant wrist. The cross-sectional area of the median nerve at the pisiform level was statistically different following 60 minutes of keyboarding ($p = 0.004$ in dominant side and $p = 0.001$ in non-dominant side), when compared with the baseline values (Table II).

The Swelling Ratio—The swelling ratio also increased gradually following the 30-minute and 60-minute keyboarding task in both the dominant and non-dominant wrist. The increase in the swelling ratio was only significant at the 60-minute time point in the dominant side ($p=0.020$), when compared to the swelling ratio at the baseline (Table II).

The Flattening Ratio—The flattening ratio was the only variable which was significantly higher (13.6%, $p=0.047$) in the dominant median nerve than the non-dominant nerve at the baseline. The RM ANOVA was not significant for either wrist after 30-minutes and 60-minutes of keyboarding in either wrist, when compared to each other or to the flattening ratio values at the baseline (Table II).

Relation between the Median Nerve Measures and Subjects Characteristics

There was a significant positive correlation ($p<0.001$) between subject age and the CSA in both hands, at baseline ($r=0.702$) and also after 60-minutes of keyboarding ($r=0.739$). In addition, changes in the nerve cross-sectional area (i.e., CSA) in the dominant hand were significantly different ($p=0.033$) in male subjects (11.3 ± 3.3) from those of female participants (2.9 ± 2.0). Keyboarding speed demonstrated no significant correlation with any

of the median nerve variables or changes detected in the nerve measures at different time points.

DISCUSSION

This study found that specific median nerve ultrasound measures, which had been previously linked to CTS, changed significantly after 60 minutes of keyboarding. In particular, CSA and swelling ratio demonstrated significant increases from the baseline to the 60-minute time point. Although the cross-sectional area at the pisiform level and swelling ratio showed 5% and 3.5% increases, respectively, compared to the baseline values after 30 minutes of keyboarding, both CSA and swelling ratio became significantly different from the baseline only after 60 minutes of keyboarding in the dominant wrist. These findings are consistent with those of previous studies (24, 33) and support the idea that changes in the median nerve are dose related.

In contrast to the cross-sectional area and swelling ratio, the baseline values of the flattening ratio were significantly different between dominant and non-dominant wrists at baseline, but not after 60 minutes. In fact, flattening ratio was significantly higher in the dominant median nerve than the non-dominant nerve at the baseline. It appears that the median nerve in the dominant hand might demonstrate changes due to other activities of daily living prior to testing, which would cause a significantly higher flattening ratio in the dominant side than in the non-dominant one at the baseline. However, following the 60-minute keyboarding task, the non-dominant hand showed greater changes in the flattening ratio, which resulted in its “catching up” with the dominant side. This might indicate that keyboarding is not necessarily a symmetrical task as suggested by other studies.(34) Further studies are required to address why the flattening ratio is the only median nerve measure to demonstrate such behavior.

In general, epidemiological studies have shown CTS to be more prevalent in females and in elders.(5, 35) The results of this study with regard to age support these studies, as there was a significant positive correlation between the median nerve CSA and subject age. Our results did not show any significant differences in the median nerve characteristics between male and female participants. However, the CSA was significantly higher in male subjects. Further study is needed to evaluate the effect of gender on the median nerve characteristics following a keyboarding task.

Ultrasound has been previously used as a research tool for quantifying the acute response of the median nerve to repetitive activity.(31, 36, 37) The magnitude of change in median nerve measures in the previous studies, including one in our laboratory, ranged from 4 to 20%, while a majority were rather small changes of less than 10%. In this study, using ultrasound, we were able to detect changes in the median nerve CSA, swelling ratio, and flattening ratio which varied from 3.5% to 12.7%. These results were consistent with the previous research work. While acute changes in the median nerve measures following a prolonged keyboarding task were significant and relatively dose-dependent, longitudinal studies are needed to determine long-term changes.

Limitations

Research has shown that there is great variety in preferred postures/styles among different keyboard users that appear to be related to the physical characteristics of the workstation. (38–41) In this study, we did not attempt to recreate each subject's work set up as we believe attempting to recreate the workstation would add variability to the experiment. Future studies, however, need to investigate the potential effects of physical set up of the workstation on the median nerve measures. Although we took many steps to limit participants' physical activity prior to testing, we were unable to fully control the relative rest of the subjects participating in this study. Minimizing participants' activities prior to testing should be a major consideration for the future studies. Furthermore, small sample size ($n=20$) and unequal number of participants from each gender (8 males vs. 12 females) made it difficult to draw a conclusion regarding the effect of gender on the median nerve characteristics following a keyboarding task.

Larger sample size and recruiting equal numbers of male and female subjects will help future studies elucidate the role of gender on the acute changes of median nerve. Means and standard deviations from these data could be used to estimate the statistical power in future studies. For example, the primary effects of interest are the differences between the pre- and post-keyboarding measurements of the median nerve. Using these data, the required sample size for a range of statistical power (80%, 85%, 90%) with two sided $\alpha=0.05$ on the paired t-test would be 27, 31, and 35, respectively.

Finally, this study did not investigate any further changes in the median nerve characteristics that could have occurred after a period of rest following the keyboarding task. One can speculate that the acute changes in the median nerve that were caused by prolonged keyboarding would diminish upon resting the upper extremities. Therefore, a reasonable resting period followed by an additional round of ultrasound examination should be considered in future studies.

CONCLUSION

The median nerve exhibited acute changes in respond to a keyboarding task. This is further evidence of a potential causal relationship between computer keyboarding and median nerve injuries such as carpal tunnel syndrome. Further studies, however, are required to elaborate on any possible pathophysiologic mechanism. Specifically, longitudinal studies could be designed to follow up median nerve changes in participants who continue keyboarding in a frequent manner. In addition, investigating biomechanical measures related to keyboarding, such as forearm and/or wrist posture and angles, finger positioning and movements, and forces and motions experienced by the wrist, would provide insight into the pathophysiology of median nerve injury. This may provide an opportunity to develop interventions specific to these biomechanical risk factors. Inclusion of subjects with known median nerve pathology (e.g., diagnosed CTS patients) in such a study may help investigators differentiate the median nerve response to a repetitive task, like keyboarding, in a physiologic as opposed to a pathologic condition, since it has been shown that changes in the median nerve resulting from keyboarding may be less likely to occur in subjects with symptoms of CTS.(24)

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Figure 1. Sample Ultrasound Images at Two Image Levels

Cross-sectional images of the median nerve (MN) at the a) distal radius (R), and b) pisiform (P) in the right carpal tunnel.

Figure 2. Example of the Image Analysis Selections

The images show a close up of the median nerve (MN) (a) and the same image with the boundary trace (dotted line) and the major and minor axes (dashed lines) selected during the image analysis (b).

The subject characteristics, including gender, age, handedness, keyboarding gross speed, and keyboarding accuracy.

Table 1

	#	Mean Age ± SD (Range)	Right- handed (%)	Mean Gross Speed (wpm) ± SD (Range)	Mean Accuracy ± SD (Range)
Male	9 *	29.3 ± 4.5 (23–37)	5 (62.5%)	53.1 ± 10.8 (34–70)	95.3 ± 2.9 (90–98)
Female	12	30.1 ± 7.7 (22–45)	11 (91.7%)	57.7 ± 11.5 (38–75)	93.0 ± 2.4 (90–97)
Total	20 *	29.8 ± 6.5 (22–45)	16 (80%)	55.9 ± 11.1 (34–75)	93.9 ± 2.8 (90–98)

* One male subject was excluded due to the median nerve bifurcation.
wpm: words per minute. SD: standard deviation.

Table II

The median nerve ultrasound characteristics in dominant (D) and non-dominant (N) hands at baseline and following 30-minute and 60-minute of keyboarding.

		Baseline Mean $\pm$ SD (Range)	30-minute Mean $\pm$ SD (Range)	60-minute Mean $\pm$ SD (Range)
Cross-sectional area (mm²)	D	10.01 $\pm$ 3.41 (5.26–19.12)	10.36 $\pm$ 3.82 (5.71–19.59)	10.70 $\pm$ 3.86* (4.81–20.03)
	N	9.92 $\pm$ 3.78 (5.62–21.27)	10.26 $\pm$ 3.85 (5.85–21.13)	10.53 $\pm$ 3.71* (5.59–21.36)
Swelling ratio	D	1.11 $\pm$.23 (.91–1.72)	1.17 $\pm$.22 (.68–1.61)	1.25 $\pm$.29* (.98–1.69)
	N	1.14 $\pm$.22 (.83–1.61)	1.18 $\pm$.25 (.84–1.68)	1.19 $\pm$.18 (.93–1.63)
Flattening ratio	D	3.28 $\pm$ 1.10 (1.68–6.30)	3.13 $\pm$.94 (2.39–5.68)	3.36 $\pm$.91 (2.50–5.67)
	N	2.89 $\pm$.81** (1.64–4.98)	3.13 $\pm$ 1.31 (1.93–6.98)	3.06 $\pm$ 1.01 (1.32–5.55)

* indicates significant differences when compared to the baseline values.

** indicates significant differences when compared to the dominant side.

SD: standard deviation.