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Effect of Keyboard Keyswitch Design on Hand Pain

[Original Articles]

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Outline

Graphics

Abstract^

This randomized clinical trial evaluated the effects of keyboard keyswitch design on computer users with hand paresthesias. Twenty computer users were matched and randomly assigned to keyboard A (n = 10) or B (n = 10). The keyboards were of conventional layout and differed in keyswitch design. Various outcome measures were assessed during the 12 weeks of use. Subjects assigned keyboard A experienced a decrease in hand pain between weeks 6 and 12 when compared with keyboard B subjects (P = 0.05) and demonstrated an improvement in the Phalen test time (right hand, P = 0.006; left hand, P = 0.06). Keyboard assignment had no significant effect on change in hand function or median nerve latency. We conclude that use of keyboard A for 12 weeks led to a reduction in hand pain and an improved physical examination finding when compared with keyboard B. There was no corresponding improvement in hand function or median nerve latency.

Reports of persistent hand and arm pain and discomfort are common among computer users and appear to be related to long hours of computer use, sustained awkward body postures, and other factors.[1-5] Compared with other office workers, computer users are at increased risk for musculoskeletal problems in the neck, shoulder, arm, and hand regions, but a recent review noted that the highest relative risks are for hand and wrist problems.[6] Carpal tunnel syndrome is a specific hand-wrist disorder that involves the compression of the median nerve at the wrist and leads to progressive tingling, numbness, pain, and weakness in the hand. Its prevalence may be elevated among computer users.[7-9]

Few studies have systematically evaluated the health effects of modifying office furniture, computer equipment, or work organization among computer users. Reducing hours on the computer and work pace, providing frequent short work breaks, and providing adjustable furniture, if coupled with appropriate training, have been associated with a reduction of upper extremity musculoskeletal symptom severity or frequency.[10-14] In a 7-year follow-up study of computer operators, Bergqvist [15] noted that assignment of a new keyboard was associated with recovery from upper extremity musculoskeletal problems. However, this was not a controlled intervention study, and the authors did not identify the characteristics of the new keyboards. Alternative keyboard designs (eg, split or adjustable keyboards) have been proposed as a low-cost method to reduce the risk of musculoskeletal problems among computer users,[16] yet there have been no clinical trials to evaluate their health value.

Several laboratory studies have investigated the effects of altering the keyboard switch characteristics on fingertip force and muscle activity. It has been hypothesized that although the forces applied by the fingers during typing are small, the loads occur repeatedly and rapidly, and therefore a modification in the applied force may reduce muscle load and risk of tendon or muscle injury.[17] Surprisingly, given the low force required to activate these keys, the peak muscle activity of the finger-moving muscles is higher than might be expected, on the order of 15% to 20% of full muscle strength.[18] Altering some keyswitch force-displacement characteristics (eg, switch make-force, travel distance) will cause typists to change their finger-muscle activity and the forces applied to the keycaps.[19,20]

Several years ago, a physician at a large manufacturing facility noted that secretaries diagnosed with carpal tunnel syndrome seemed to prefer a certain keyboard. The keyboard preferred was of conventional external appearance but used a new switch design that provided different keyswitch force-displacement characteristics or switch "feel" than did the keyboard that the secretaries were used to. The clinician relayed this information to the manufacturer. Subsequently, the manufacturer, Key Tronic Corporation (Spokane, WA), and The Northwest Trade Adjustment Corporation (Seattle, WA), sponsored this pilot study to evaluate the health effects of the new keyboard in computer users with possible carpal tunnel syndrome in comparison to a keyboard containing typical switches.

Methods^

This was a 3-month, randomized, controlled, double-blinded, clinical trial with matching to evaluate the effects of keyboard keyswitch design on patients with hand paresthesias and physical examination findings consistent with carpal tunnel syndrome. The two keyboards used were of conventional layout [21] and differed in the force-displacement characteristics of their switches. The study was approved by the institutional review boards of the University of California at San Francisco and Lawrence Livermore National Laboratories, and informed consent was obtained from subjects in writing.

Eligibility Criteria^

Subjects were selected from among full-time employees of Lawrence Livermore National Laboratory who reported to the site occupational medicine clinic for hand or wrist symptoms within 6 months of the onset of the study. All such patients completed a standardized medical questionnaire and physical examination. Patients were eligible for participation if they (1) used a computer keyboard for >= 2 hours per day or >= 10 hours per week, (2) were employed in their current job for >= 3 months, (3) met the criteria for possible carpal tunnel syndrome, and (4) had no prior surgery of the hands or wrists.

Criteria for possible carpal tunnel syndrome were based on history and physical examination: (1) symptoms of paresthesia, numbness or tingling in at least two fingers innervated by the median nerve, and (2) numbness, tingling, or decreased sensation with use of hands or with hands in an awkward posture, and (3) no neck symptoms, and (4) no acute major trauma to the arm or shoulder, and (5) positive Phalen's test or Tinel's test or thenar atrophy, and (6) no evidence of cervical root involvement, thoracic outlet syndrome, or pronator teres syndrome upon physical examination.[22] Electrodiagnostic studies were performed in all participants but were not used for determining their eligibility.

A recruitment interview confirmed employment history and keyboard exposure. Of the 28 eligible employees, three declined to participate. The remaining 25 eligible participants were administrative assistants or technical writer/editors.

Matching and Randomization^

Subjects were matched according to self-reported average computer usage hours per week and to the hand involved. After matching, one of the partners of a pair was randomly assigned to keyboard A and the other partner was assigned to the control, keyboard B. Standard clinical treatment (eg, work limitation, wrist splints, nonsteroidal anti-inflammatory agents) continued to be provided regardless of the keyboard assignment. The clinician recommending these treatments was blinded to the keyboard assignment.

From the 25 eligible patients, 24 were matched into 12 pairs. During the first 2 weeks of the study, four subjects dropped out. The dropouts were all female: three had right hand symptoms and one had bilateral symptoms; three were administrative assistants and one was a technical writer/editor. Two reported that they could no longer participate in the study because of their heavy workloads. The other two withdrew because of worsening symptoms and discomfort (both assigned keyboard B).

Of the remaining four subjects from the four broken pairs, one could not be rematched and was dropped, and three were rematched using the original matching criteria: two to each other and one to the back-up subject. Therefore, 20 subjects (ten matched pairs) completed the study.

Keyboards^

Keyboard A (Protouch keyboard, Key Tronic Corporation) and keyboard B (MacPro Plus keyboard with 2-ounce rubber domes, Key Tronic Corporation) were similar in external appearance. Both keyboards were of conventional layout with 101 keys [21] and differed in the force-displacement characteristics of the keys.

At the end of the study, three keyboards from each group were randomly selected, and the static force-displacement characteristics of four keyswitches on each keyboard were measured (Table 1).[23] Three prominent landmarks (eg, P1, P2, and P3) on a typical force-displacement curve for both keyboards are identified in Fig. 1. Differences between the force-displacement characteristics are explored further in the Discussion section.

TABLE 1 Mean Values of Landmarks P1, P2, and P3 (see Fig. 1) From the Switch Force-Displacement Curves From Three A Keyboards and Three B Keyboards*

Fig. 1. Typical static keyswitch force-displacement curves for keyboard A (Fig. 1A) and keyboard B (Fig. 1B). Three landmarks on the curves are identified: P1 (make-force point, or minimum force required to activate the key), P2 (lowest force after make-force point) and P3 (total key travel, or travel to 1.5 N force).

To the extent possible, patients were blinded to keyboard group. The keyboards could not be identified from external appearance; all identifying labels were masked. Patients were told that the study was to "evaluate the effectiveness of different keyboards" but were not provided with information about the differences between the keyboards nor the number of different keyboards evaluated. At the time the keyboards were installed, all participants received the same 1-hour training that included suggestions for avoiding awkward postures, the importance of work breaks, and typically recommended adjustments to the workstation. At unannounced times throughout the study, subject workstations were visited to ensure that the assigned keyboard was used. Prior to the intervention, subjects used the Apple Extended keyboard™ (Cupertino, CA).

Health Outcomes^

Each subject used the assigned keyboard for 12 weeks. Various health measures were collected before the keyboards were used (week 0), 6 weeks into the study, and at the conclusion of the study at week 12 (Table 2). The medical personnel performing these measures were blinded to the patients' keyboard assignments.

TABLE 2 Health Outcome Measures Collected During the Study

The self-administered medical history questionnaire was designed to elicit information on demographics, job tasks, work practices, and prior medical conditions, as well as hand-intensive activities at work and outside of work.

A self-administered symptom survey assessed pain levels in the hands on the day the form was filled out. This scale was based on a Likert summative 10-point scale in which numerical response 0 represents no pain, 5 represents somewhat painful, and 10 represents the worst pain imaginable. The symptom survey was completed only at weeks 6 and 12. The pain questions on the survey were different from those asked on the medical history questionnaire, limiting possible comparisons to week 0.

A self-administered questionnaire assessed hand-function status by rating the level of difficulty for performing activities of daily living, such as turning the doorknob, writing, opening jars, driving, lifting a heavy box, etc.[24,25] Functional difficulty was rated on a Likert summative 5-point scale (1 represents not a problem and 5 represents very significant problem). A summary functional score was generated by summing the values across the 13 questions for each subject, yielding a range of scores from 13 (least problem) to 65 (worst problem).[26] Again, this questionnaire was completed at weeks 6 and 12, limiting possible comparisons to week 0.

A standardized physical examination of the upper extremities consisting of a timed Phalen's test was performed by a trained nurse practitioner who was also blinded to the questionnaire response. For each subject, the three examinations were performed by the same examiner. For the Phalen's test, subjects are asked to actively flex their wrists to maximum,[27] maintain this position for 60 seconds, and report when, if at all, symptoms of numbness and tingling occur in the fingers. The duration of time from when the wrist is bent to the onset of the symptoms is called the Phalen test time and is considered an indication of the severity of carpal tunnel syndrome.[28,29]

A nerve-conduction study of the symptomatic hand(s) was administered at weeks 0 and 12 to detect a change in the median nerve conduction latency at the carpal tunnel. An occupational therapist, trained by a neurologist board-certified in electromyography (Y.S.), recorded the palm-wrist orthodromic median sensory action potential using a Cadwell S-5200 electromyograph (Kennewick, WA). A conduction distance of 8 cm was used. Each subject's skin temperature was monitored and maintained at 32°C or above. All nerve-conduction study results were reviewed by the neurologist. The criteria for abnormality was a latency of the peak median sensory nerve action potential of greater than or equal to 2.1 ms.[30] The occupational therapist and neurologist were blinded to clinical findings, physical examination findings, and keyboard assignment.

At the end of the study, subjects completed a keyboard survey, which rated various characteristics of the assigned keyboard. The characteristics evaluated were comfort characteristics (eg, hand, wrist, shoulder, and forearm comfort; fatigue; ease of use), posture characteristics, keyboard features (eg, feel/touch, key size, keying rhythm), and overall attributes. A summative categorical 5-point scale ranging from unfavorable (scored as 1) to favorable (scored as 5) was assigned to each characteristic.

Statistical Analyses^

The distribution of matching variables (hours typing per week, involved hand) and potential covariates (age, sex, typing speed, and years of computer use, etc) between subjects in the two keyboard groups was compared using the paired *t* test, McNemar's test (modified [chi]^2 statistics), or the Wilcoxon signed-rank test. Comparison of outcome measures between keyboard groups was done using the repeated measures analyses of variance (RANOVA) or the Wilcoxon signed-rank test. Analyses were considered statistically significant if $P < 0.05$. Statistical analyses were performed using Statview version 4.1 and SuperAnova Linear Modeling Program version 4.0 (Abacus Concepts, Berkeley, CA).

Results^

The final distribution of matching criteria between keyboard groups was almost identical. Mean estimated hours of keyboard use per day were 5.3 (standard deviation [SD], 0.9) hours for the keyboard A group and 5.2 (SD, 2.0) for the keyboard B group. One matched pair had left-sided symptoms (n = 2), three matched pairs had right-sided symptoms (n = 6), and six matched pairs had bilateral symptoms (n = 12).

Demographic and clinical characteristics and the distribution of potential covariates between the two keyboard groups were similar (Table 3). The keyboard groups did not differ significantly by gender, handedness, typing speed, smoking status, pregnancy status, childcare, various measures of hand-symptom severity, and treatments. The presence of median mononeuropathy (abnormal electrodiagnostic study) was not significantly different between keyboard groups. Those assigned to keyboard A were older and had fewer years of exposure to computers, but these differences were not statistically significant.

TABLE 3 Characteristics of the Study Group, by Keyboard, at Baseline*

After 6 weeks of exposure to the keyboards, there were no significant differences in pain levels between the keyboard groups; however, by 12 weeks, there were (Table 4). Between 6 and 12 weeks, subjects using keyboard A experienced a significantly greater reduction in pain, compared with subjects using keyboard B (RANOVA, $P = 0.05$). The mean reported pain in the keyboard A group decreased by 0.8 points, while it increased by 1.4 points in keyboard group B. The questions asked at week 0 regarding pain were not identical to those asked at weeks 6 and 12. Therefore, only the changes between the 6- and 12-week pain scores can be compared. The effect size associated with keyboard A, calculated as the mean symptom score change divided by the standard deviation of the 6-week symptom score,[31,26] was 0.5.

TABLE 4 Mean (SD) Overall Hand-Pain Levels (0, no pain; 10, worst pain) at the Middle and End of the Study, by Keyboard Group

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For the same 6- and 12-week time points, the changes in hand-function ratings were not significantly different between keyboard groups (Table 5). Specifically, there was no perceived improvement in keyboard use when the keyboard groups were compared between 6 and 12 weeks ($P = 0.55$). There was also no difference between keyboard groups in change in summary functional scores ($P = 0.7$).

TABLE 5 Mean Ratings of Self-Assessed Hand Function and Change in Hand Function Between the Middle and End of the Study (1, Not a Problem; 5, Very Significant Problem)*

Across the 12 weeks of the study, a greater improvement in the Phalen test time was noted in keyboard group A in comparison to group B. Mean values for the 18 subjects with right-sided symptoms (nine matched pairs) are presented in Figure 2. The change in the Phalen test time between weeks 0, 6, and 12 between the keyboard groups was statistically significant (RANOVA, *P* = 0.006). Follow-up contrast tests demonstrated that among subjects assigned to keyboard A, the Phalen test time improved significantly from week 0 to week 12 (*P* = 0.0004). On the other hand, among those assigned to keyboard B, the change in the Phalen test time was not significant (*P* = 0.5).

Fig. 2. Mean time to positive Phalen's test for right hand at study times 0, 6, and 12 weeks. A significant difference in change in the Phalen test time between visits is observed between keyboards groups (RANOVA *P* = 0.006).

Mean values for the left-sided Phalen test time for the 14 subjects with left-sided symptoms (seven matched pairs) are plotted in Figure 3. The change in the Phalen test time between weeks 0, 6, and 12 between the keyboard groups was of borderline statistical significance (RANOVA, *P* = 0.06). Among subjects assigned to keyboard A, the improvement in the Phalen test time from week 0 to 12 was of borderline statistical significance (*P* = 0.08). There was no significant change in the Phalen test time among subjects assigned keyboard B (*P* = 0.29).

Fig. 3. Mean time to positive Phalen's test for left hand at study times 0, 6, and 12 weeks. The difference in change in the Phalen test time between visits observed between keyboard groups was of borderline significance (RANOVA *P* = 0.06).

Nerve-conduction studies were conducted on all subjects at week 0, but two subjects refused the nerve conduction study at week 12 because of discomfort associated with the initial nerve-conduction study. Therefore, the sample sizes are smaller for this outcome measure. These two subjects completed all other aspects of the study.

The mean palm-wrist median sensory latencies are presented for the right-sided and left-sided symptomatic subjects in Table 6 (14 subjects and 12 subjects, respectively). There was no significant difference in the 0- to 12-week change in latency between the two keyboard groups for either those with right-sided carpal tunnel syndrome (RANOVA, *P* = 0.81) or those with left-sided carpal tunnel syndrome (RANOVA, *P* = 0.13).

TABLE 6 Mean (SD) Right and Left Palm-Wrist Median Sensory Latencies at the Beginning and End of the Study, by Keyboard Group

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At the end of the study, subjects rated various characteristics of the keyboard assigned to them (Table 7). Although keyboard A received better ratings for almost all characteristics, the difference was only significant for the feature of "keying rhythm/smoothness" (*P* = 0.02).

TABLE 7 Mean (SD) Ranking Scores of Keyboard Characteristics as Assessed by Subjects at the End of the Study (1, unfavorable; 5, favorable)

Discussion^

This pilot study demonstrates a positive effect of keyboard A on hand pain and on the Phalen test time, in comparison to keyboard B, among computer users with symptoms and physical examination findings consistent with carpal tunnel syndrome. The improvement in hand pain was delayed, occurring after 12 weeks of use of the new keyboard. The reporting of hand-symptom intensity over a short period has high test-retest reliability in working populations,32 and in this study participants were asked to rate their hand-symptom intensity on the day of testing. The response of hand pain to keyboard can be expressed as an effect size of 0.5, which is a low or moderate response to an intervention 31 and can be compared to the much larger effect size of 1.4 following carpal tunnel surgery.25

The improvement in hand pain is accompanied by an improvement in the Phalen test time. Although the typical Phalen's test (eg, wrist flexion with the reporting of presence or absence of paresthesias at 60 seconds) has been shown to have relatively poor sensitivity and specificity,22 the Phalen test time has not been extensively evaluated. Kaplan et al 28 demonstrated a relationship between the Phalen test time and the severity of carpal tunnel syndrome: the more severe the condition, as assessed by symptoms and signs, the sooner that wrist flexion produced symptoms. Therefore, the findings of an improvement of both hand pain and the Phalen test time support a positive effect of the keyboard. However, there was no significant effect of the keyboard on hand function or median nerve latency.

The disparity of the effect of the keyboard on outcome measures may be due to differences in the responsiveness of the outcome measures or to a lack of effect of keyboard on the functional measures and median nerve latency. In patients evaluated after carpal tunnel release surgery, the most responsive outcome measure was the symptom severity score, followed by the functional scores, followed by the physical examination findings.25 The responsiveness of functional scores after carpal tunnel release surgery are approximately half that of symptom-severity scores.26 Furthermore, the measures of hand function used in this study, which were originally designed for the follow-up of the status of patients with hand arthritis, are not particularly sensitive for the follow-up of working populations with carpal tunnel syndrome.[24] In addition, it is possible that the effect of the keyboard was not large enough or that the duration of exposure was too brief to alter the electrophysiologic characteristics of the median nerve. Nerve-conduction latency improves after carpal tunnel surgery, but this improvement appears to lag that of symptoms.[33]

Keyboards A and B differed only in the force-displacement characteristic of the keys. At first glance, these differences appear to be trivial (Figure 1). Three landmarks on the force-displacement curves-make force (P1), breakaway force (P2), and total travel distance (P3)-are not strikingly different between the keyboards. Two of these landmarks, make force and total travel distance, have been shown in laboratory studies to influence applied force and muscle activity.[17,19,20] The primary differences between the switches of keyboards A and B are travel distance to P1 and curve shape at the end of key travel. The increased travel distance to P1 gives the keys of keyboard A a greater feeling of looseness when one rests his or her fingers on the keycaps. This feature may be associated with less chance of accidental activation of the keys when touching the keys and therefore may promote greater resting of fingertips on the keycaps between keystrokes or allow for more small, random finger movement between keystrokes. The second difference is in the stiffness of the key (slope of the curve) near the end of key travel. The switches of keyboard A may be associated with less fingertip impact force at the end of key travel [23] because of the gradual increase in stiffness at the end of key travel. Keyboard B switches have a much sharper increase in stiffness at the end of key travel. In essence, keyboard A has greater dampening when the key hits bottom.

The limitations of this study include the rematching carried out at the beginning of the study, the potential problem of blinding subjects to the nature of the study, the short duration of exposure, and the small sample size. During the first 2 weeks of the study, four subjects dropped out and their remaining partners were rematched. Given that the two who dropped out because of increasing hand pain were using keyboard B, the rematching would likely have biased the outcome toward the null. Therefore, it is likely that the rematching reduced the possibility of observing positive findings for keyboard A.

Subjects were blinded to the specific nature of the intervention and could not distinguish between the assigned keyboards on the basis of their outward appearance. It is possible that they noted a difference in the feel of the keys during use. In fact, at the end of the study, subjects in the two keyboard groups rated "keying rhythm/smoothness" and, to a lesser degree, "key touch" differently. However, since the subjects did not know the other keyboard used in the study nor did they know to which keyboard group they were assigned, it is unlikely that they were able to compare the two keyboards.

The significant differences between keyboard groups are intriguing in light of the small sample size. With this sample size, it is more likely that the analysis suffered from a Type II error (eg, missing a real effect) than a Type I error (eg, observing an effect when there is no real effect), especially since there were minimal differences between the keyboards groups at the start of the study.

This is the first study to use a randomized clinical trial design to evaluate the effect of a workplace intervention on hand pain. The study demonstrated that a significant reduction in symptoms is possible with a simple intervention measure: namely, changes in the force-displacement characteristics of the keyboard keyswitches. Given the low cost and the lack of negative consequences, it would be reasonable for health care providers caring for computer users with hand paresthesias to recommend a 3-month trial of a keyboard with keys with a long travel distance to P1 and a gradual increase in stiffness at the end of key travel. Patients should be advised that the effect of the keyboard, if any, will be minimal. This recommendation should be in addition to recommendations to reduce time on the keyboard or other aggravating tasks and to complete appropriate training regarding working postures at the computer and work-break patterns. In addition, treatments that have been shown to be effective in managing carpal tunnel syndrome, such as splinting, corticosteroid injections,[34,35] and carpal tunnel surgery,[36] should not be ignored. Generalizing the findings of this study to asymptomatic computer users or computer users with other upper extremity problems should be limited. A longer keyboard trial could determine whether the improvements in hand pain persist and whether improvements in functional measures and nerve latency would follow. The findings of this study and the potential mechanisms linking keyswitch design to hand and arm disorders deserve further exploration. Keyboard manufacturers should consider studying the preventive health effects of alternative keyswitch designs.

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References^

1. Burt S, Hornung R, Fine L, Silverstein B, Armstrong T. *Health Hazard Evaluation Report: Newsday Inc.* [HETA 89-250-2046.] Cincinnati, OH: US Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health; 1990. [Context Link]

2. Sauter SL, Schleifer LM. Work posture, workstation design, and musculoskeletal discomfort in a VDT data entry task. *Hum Factors.* 1991;33:151-167. Bibliographic Links [Context Link]

3. Bernard B, Sauter S, Fine L, Petersen M, Hales T. Job task and psychosocial risk factors for work-related musculoskeletal disorders among newspaper employees. *Scand J Work Environ Health.* 1994;20:417-426. Bibliographic Links [Context Link]

4. Faucett J, Rempel D. VDT-related musculoskeletal symptoms: interactions between work posture and psychosocial work factors. *Am J Ind Med.* 1994;26:597-612. Bibliographic Links [Context Link]

5. Bergqvist U, Wolgast E, Nilsson B, Voss M. Musculoskeletal disorders among visual display terminal workers: individual, ergonomic, and work organizational factors. *Ergonomics.* 1995;38:763-776. [Context Link]

6. Punnett L, Bergqvist U. *Visual Display Unit Work and Upper Extremity Musculoskeletal Disorders: A Review of Epidemiologic Findings.* [National Institute for Working Life-Ergonomic Expert Committee Document No. 1.] Solna, Sweden: National Institute for Working Life; 1997. [Context Link]

7. Bernard B, Sauter S, Peterson M, Fine L, Hales T. *Los Angeles Times Health Hazard Report.* [HETA 90-013-2277.] Cincinnati, OH: NIOSH, Centers for Disease Control; 1993. [Context Link]

8. Hales TR, Sauter SL, Peterson MR, et al. Musculoskeletal disorders among visual display terminal users in a telecommunications company. *Ergonomics.* 1994;10:1603-1621. [Context Link]

9. Murata K, Araki S, Okajima F, Saito Y. Subclinical impairment in the median nerve across the carpal tunnel among female VDT operators. *Int Arch Occup Environ Health.* 1996;68:75-79. Bibliographic Links [Context Link]

10. Oxenburgh M, Rowe S, Douglas D. Repetitive strain injury in keyboard operators. *J Occup Health Safety Aust N Z.* 1985;1:106-112. [Context Link]

11. Safety and Health Assessment and Research for Prevention (SHARP). *Cumulative Trauma Disorders in Claims Initiation Follow-Up: 1992.* [Technical Report no. 16-5-1992.] Olympia, WA: Washington State Department of Labor; 1992. [Context Link]

12. Conway F, Sauter S, Swanson N, Galinsky T. Frequent rest breaks and musculoskeletal discomfort in keyboard intensive work. *Proceedings of the Human Factors and Ergonomics Society 41st Annual Meeting,* Santa Monica, California, 1997;2:1375. [Context Link]

13. Aaras A. Relationship between trapezius load and the incidence of musculoskeletal illness in the neck and shoulder. *Int J Ind Ergonomics.* 1994;14:341-348. [Context Link]

14. Shute SJ, Starr SJ. Effects of adjustable furniture on VDT users. *Hum Factors.* 1984;26:157-170. Bibliographic Links [Context Link]

15. Bergqvist U. Visual display terminal work: a perspective on long-term changes and discomforts. *Int J Ind Ergonomics*. 1995;17:162-168. [Context Link]

16. Kroemer K. Human engineering the keyboard. *Hum Factors.* 1972;14:51-63. Bibliographic Links [Context Link]

17. Armstrong T, Foulke J, Martin B, Gerson J, Rempel D. Investigation of applied forces in alphanumeric keyboard work. *Am Ind Hyg Assoc J.* 1994;55:30-35. Bibliographic Links [Context Link]

18. Martin BJ, Armstrong TJ, Foulke JA, et al. Relation of keyboard reaction force and finger flexor muscle electromyograms during keyboard work. *Hum Factors.* 1996;38:654-664. Bibliographic Links [Context Link]

19. Rempel D, Serina E, Klinenberg E, et al. The effect of keyswitch make force on applied force and finger flexor muscle activity. *Ergonomics.* 1997;40:800-808. Bibliographic Links [Context Link]

20. Radwin R, Jen O. Activation force and travel effects on overexertion in repetitive key tapping. *Hum Factors.* 1997;39:11:30-140. [Context Link]

21. ANSI/HFS. *American National Standard for Human Factors Engineering of Visual Display Terminal Workstations.* [Standard No. 100-1988.] Santa Monica, CA: Human Factors Society; 1988. [Context Link]

22. Rempel D, Evanoff B, Amadio P, et al. Consensus criteria for the classification of carpal tunnel syndrome in epidemiologic studies. *Am J Public Health.* 1998;88:1447-1451. Bibliographic Links [Context Link]

23. Rempel D, Dennerlein J, Mote CD, Armstrong T. A method of measuring fingertip loading during keyboard use. *J Biomechanics.* 1994;27:1101-1104. Bibliographic Links [Context Link]

24. Pransky G, Feuerstein M, Himmelstein J, Katz JN, Vickers-Lahi M. Measuring functional outcomes in work-related upper extremity disorders: development and validation of the upper extremity functional score. *J Occup Environ Med.* In press. [Context Link]

25. Levine DW, Simmons BP, Koris MJ, et al. A self-administered questionnaire for the assessment of severity of symptoms and functional status in carpal tunnel syndrome. *J Bone Joint Surg [Am].* 1993;75:1585-1592. Buy Now Bibliographic Links [Context Link]

26. Katz JN, Gelberma RH, Wright EA, Lew RA, Liang MH. Responsiveness of self-reported and objective measures of disease severity in carpal tunnel syndrome. *Med Care.* 1994;32:1127-1133. Bibliographic Links [Context Link]

27. Busquets M. Historical commentary: the wrist flexion test (Phalen Sign). *J Hand Surg [Am].* 1995;20:521. [Context Link]

28. Kaplan SJ, Glickel SZ, Eaton RG. Predictive factors in the non-surgical treatment of carpal tunnel syndrome. *J Hand Surg [Br].* 1990;15:106-108. Bibliographic Links [Context Link]

29. Seror P. Phalen's test in the diagnosis of carpal tunnel syndrome. *J Hand Surg [Br].* 1988;13:383-385. Bibliographic Links [Context Link]

30. So YT, Olney RK, Aminoff MJ. Evaluation of thermography in the diagnosis of selected entrapment neuropathies. *Neurology.* 1989;39:1-5. Ovid Full Text Bibliographic Links [Context Link]

31. Cohen J. *Statistical Power Analysis for the Behavioral Sciences,* revised ed. New York: Academic Press; 1977. [Context Link]

32. Franzblau A, Salerno DF, Armstrong TJ, Werner RA. Test-retest reliability of an upper extremity discomfort questionnaire in an industrial population. *Scand J Work Environ Health.* 1997;23:299-307. Bibliographic Links [Context Link]

33. Haupt WF, Wintzer G, Schop A, Lottgen J, Pawlik G. Long-term results of the carpal tunnel decompression: assessment of 60 cases. *J Hand Surg [Br].* 1993;18:471-474. Bibliographic Links [Context Link]

34. Gelberman RH, Aronson D, Weisman MH. Carpal-tunnel syndrome: results of a prospective trial of steroid injection and splinting. *J Bone Joint Surg [Am].* 1980;62:1181-1184. Bibliographic Links [Context Link]

35. Weiss AP, Sachar K, Gendreau M. Conservative management of carpal tunnel syndrome: a reexamination of steroid injection and splinting. *J Hand Surg [Am].* 1994;19:410-415. [Context Link]

36. Brown RA, Gelberman RH, Seiler JG, et al. Carpal tunnel release: a randomized, prospective assessment of open and endoscopic methods. *J Bone Joint Surg [Am].* 1993;75:1265-1275. [Context Link]

Accession Number: 00043764-199902000-00006
