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Short term and long term effects of enhanced auditory feedback on typing force, EMG, and comfort while typing

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Abstract

Two studies were conducted to determine the effects of enhanced auditory feedback on typing force, electromyography (EMG) and subjective discomfort. The introduction of enhanced auditory feedback caused a 10–20% reduction in 90th percentile typing force, finger flexor EMG, and finger extensor EMG. Adaptation to the enhanced auditory feedback occurred in <3 min. After 1 week of intermittent enhanced auditory feedback there were no differences in typing force or EMG while subjects were typing with or without the enhanced auditory feedback. The continued use of auditory feedback did not further reduce the levels of typing force or EMG after 1 or 2 weeks of exposure.

Keywords: Feedback; EMG; Computer keyboard design; Cumulative trauma disorders

1. Introduction

The number of computers in use in the United States has increased from 13 million in 1980 (Lyon, 1992) to 129 million in 1998 (Computer Industry Almanac, 1999). This increase in computer usage has been accompanied by an increase in reports of work-related musculoskeletal disorders including tenosynovitis, carpal tunnel syndrome, tendinitis, epicondylitis, and others. The total number of recorded cases of repetitive motion injury cases has increased from 34,700 cases in 1984 to 372,300 cases in 1999 and represents 66% of all workplace illnesses (Bureau of Labor Statistics, 2000) with cumulative trauma disorders being the most costly and severe disorders occurring in office work environments (Lyon, 1992). Primary risk factors for the development of cumulative trauma disorders encountered while typing include: force, static exertion, repetition, contact stress, and awkward posture (Armstrong et al., 1993; Kroemer, 1972).

Several studies have monitored typing force and have found that subjects strike the keys much harder than necessary to activate the keys (Fig. 1). Peak typing forces in these studies range from 2.5 to 9.3 times the required key activation force. The previous studies have suggested that the amount of overstrike is partially determined by the key activation force, with higher key activation forces resulting in higher typing forces. Also, the feedback characteristics of the keyboard are important in determining the level of overstrike during typing (Gerard et al., 1999).

Electromyography (EMG) biofeedback has been used to reduce EMG levels while speaking by 31% in subjects that stutter (Craig and Cleary, 1982), and trapezius EMG levels while sitting 50% (Poppen et al., 1988). Biofeedback has also been used as a teaching tool to reduce tension in violin and viola players (LeVine and Irvine, 1984), during fine motor skill acquisition (French, 1980), and a variety of other areas (Basmajian, 1988).

Force feedback is already intentionally incorporated into many keyboard designs. Based on work by Monty et al. (1983) the ANSI/HFS standard (1988) states that "actuation of a key shall be accompanied by either tactile or auditory feedback, or both". Previous research suggests that subjects can type with less force on buckling spring keyboards than on rubber dome keyboards (see Fig. 1). One of the main differences between

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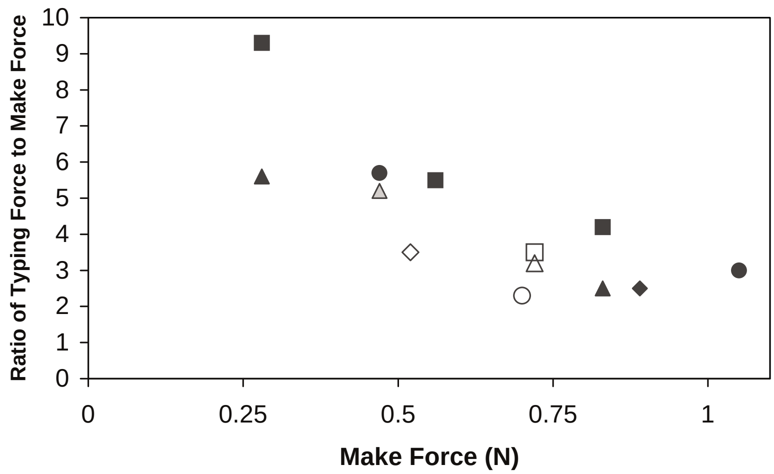

Fig. 1. Ratio of typing force to make force plotted by make force. ◆ Armstrong et al., 1994 (Dome); ■ Gerard et al., 1999 (Dome); ▲ Gerard et al., 1996 (Dome); △ Martin et al., 1996 (Dome); ● Rempel et al., 1997 (Dome); ◇ Armstrong et al., 1994 (Spring); △ Feuerstein et al., 1997 (Spring); □ Gerard et al., 1999 (Spring); ○ Sommerich et al., 1996 (Spring).

these keyboards is the sharp drop in force and the auditory "click" after the buckling spring keyboard has been activated.

Feedback can be thought of as a system that informs subjects if they have reached a desired goal. Enhanced auditory feedback can then be considered part of a direct physiological loop whose goal is to assist the execution of specific motor behavior (Olton and Noonberg, 1980). Biofeedback and force feedback can be used to gain control over a feedforward mechanism. In order to have accurate feedforward, the subject needs adequate feedback. Increasing the amount of feedback available to the subject via biofeedback or force feedback increases the amount of information available for the feedforward mechanism (Croce, 1986).

It is hypothesized that increased auditory feedback during typing can assist subjects in reducing the level of overstrike. The goal of this study was to determine the short term and long term effects of enhanced auditory feedback on reducing typing force and EMG in the finger flexors and extensors while typing. Two experiments were conducted. The first experiment examined the short term effects of force feedback and EMG feedback on typing. The second experiment examined long term effects of force feedback on typing.

2. Part I—short term effects of enhanced auditory feedback

2.1. Methods

The purpose of this study was to examine and compare the effects of force feedback and EMG feedback on typing force and finger flexor and extensor muscle activity.

2.2. Subjects

Twelve subjects participated in the experiment (35 ± 9 years old). All subjects were touch typists employed at the University of Michigan. The subjects had an average of 15 (± 11) years of experience and typed an average of 73 words per minute (WPM) (± 23 WPM).

2.3. Equipment

A keyboard force monitor developed for a previous study (Gerard et al., 1999) was used. The keyboard force monitor containing three load cells was mounted below a Keytronic KB101 computer keyboard. The plastic cover on the keyboard was removed to decrease keyboard resonance on the load cells and to reduce the possibility of subjects being able to rest their hands or fingers on the keyboard. The forces on the load cells were added and amplified. The EMG electrodes were bipolar, with 1.8 cm spacing between electrodes. The electrodes featured a preamplifier located directly above the bipolar electrodes to minimize noise. EMG signals were then amplified and converted to RMS EMG with a time constant of 55 ms. These signals were sampled at 250 Hz and digitized by a National Instruments Lab NB board (National Instruments, 1992).

Text scrolling software was developed using LabView 3.0 (National Instruments, 1994) to conduct the experiment. The software presented five lines of text to the subject with ~13 words presented on each line. The third line of the text was bound above by a solid border and below by a sliding border. The sliding border moved across the screen at the same speed at which the subject was instructed to type. When the sliding border reached the end of a line the text was scrolled up one line and the sliding border returned to the start of the third line.

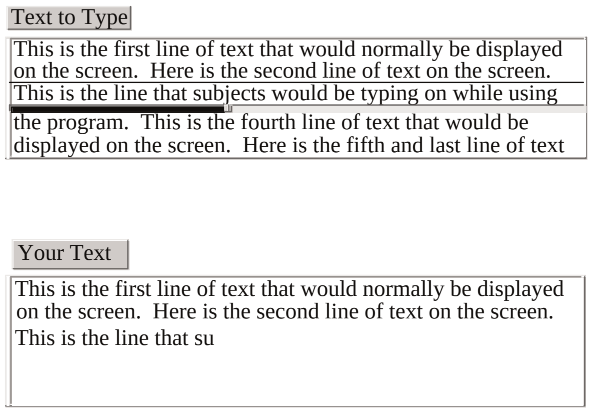

Fig. 2. Sample data screen. At this point in the sample the subject would be typing the letter "b" in the word "subjects".

Typing speed was controlled to prevent pacing effects from affecting the results (Gerard et al., 2001). A sample screen is shown in Fig. 2.

The computer that ran the text scrolling software also collected EMG and force data at 250 Hz. The data collection was displayed in real time to the experimenter on a separate monitor.

A second computer was used to deliver the auditory feedback to the subject. A software program was developed to present enhanced auditory feedback to the subject based on peak typing force or finger flexor EMG. The enhanced auditory feedback program sampled at 200 Hz and determined the peak value for the most recent second of data collected. A threshold was set at either three times keyboard make force (1.7 N) to test the force feedback mode or flexor EMG activity of 9% MVC to test the EMG feedback mode. When peak values were below these levels no auditory feedback was given to the subject. If the typing force or EMG exceeded the threshold then a tone was produced. The tone produced had a frequency of 400 Hz and was 1.2 dB above ambient room noise for each multiple of key activation force or for each 3% MVC. Enhanced auditory feedback was given for peak typing forces ranging from three times make force up to twelve times make force. Peak typing forces above twelve times make force produced the same signal as twelve times make force. Similar intervals were set up for peak finger flexor EMG (Table 1).

2.4. Procedure

The subjects participated in a controlled study of typing force and muscle activity. First, each subject completed three 1 min typing tests to determine their maximum typing speed and to insure, through visual inspection, that they were touch typists. Gross typing

Table 1
Feedback levels

Sound level (dB above ambient)	Peak muscle activity (% MVC)	Peak typing force (times activation force)
1.2	9	3
2.4	12	4
3.6	15	5
4.8	18	6
6	21	7
7.2	24	8
8.4	27	9
9.6	30	10
10.8	33	11
12	36	12

speed from the fastest 1 min test with $<5\%$ errors was recorded as the maximum typing speed.

EMG electrodes were attached to the left forearm to record the muscle activity of the underlying finger flexors (*Flexor digitorum superficialis*) and finger extensors (*Extensor digitorum communis*) (Delagi et al., 1975; Basmajian, 1978). Efforts were made to minimize signal contamination from adjacent wrist flexor and extensor muscles by moving the electrodes over the desired muscle until the activity from the contaminating muscle was minimized. Electrodes were placed using published guidelines (Basmajian, 1978) along with palpation of muscle activity and visual monitoring of electrode activity via oscilloscope. The left hand was chosen for electrode placement because it is responsible for 57% of all keystrokes on a QWERTY keyboard (Dvorak, 1936).

Muscle activity for the finger flexors was first calibrated to percent of maximum voluntary contraction by having subjects press down as hard as possible on the test keypad with all fingers simultaneously. The arm was placed in the same posture used while typing and the wrist was restrained so that only the finger flexors could be used for the maximum contraction. The test keypad was used to find the maximum voluntary contraction for the finger extensors by having the subjects pull up against a strap with all fingers as hard as possible and with the hand placed in such a way that only the finger extensors could be used. To determine baseline levels for the fatigue trials subjects performed 10 N static reference contractions in flexion and extension during which force and raw EMG were monitored at 500 Hz for 20 s.

Subjects participated on two separate days with two trials per day. The subjects were randomly assigned to one of two 30 min test sequences: (1) auditory feedback, or (2) no auditory feedback. After a rest break subjects then typed the remaining test condition. Typing speed was controlled to prevent pacing effects from affecting the results and was set to 82% of the maximum typing speed which was found to be the average self-selected speed in a previous study (Gerard et al., 2001). Typing

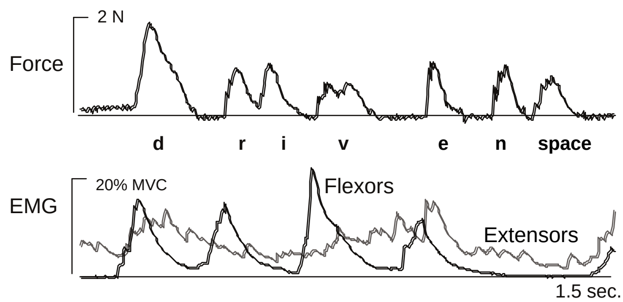

Fig. 3. Force and EMG sample graph while typing the word ‘‘driven’’. The gray letters (‘i’, ‘n’, and ‘space’) are typed by the right hand and do not show up on the EMG trace.

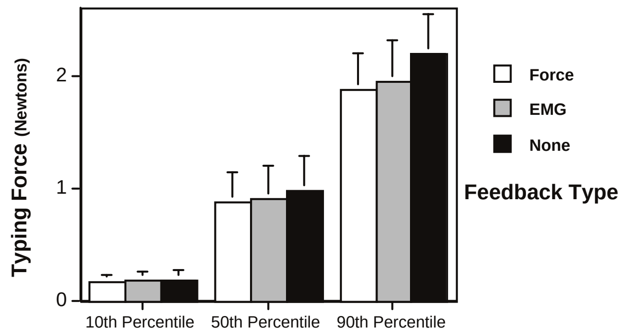

Fig. 4. Effects of enhanced auditory feedback on typing force.

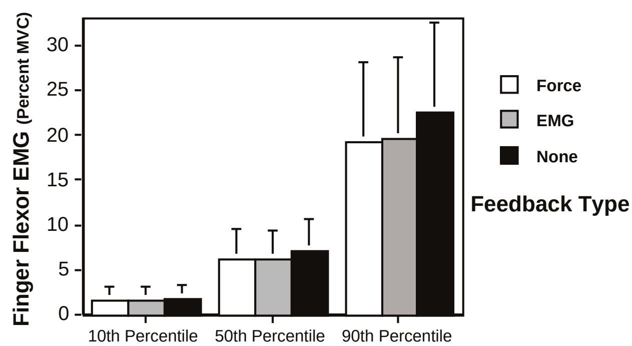

Fig. 5. Effects of enhanced auditory feedback on finger flexor EMG.

force and RMS EMG were collected at 250 Hz for 30 continuous seconds every 3 min during the typing period. Sample EMG and force data are presented in Fig. 3.

Before and immediately following each typing session, subjects performed a 10 N static reference contraction in flexion and then extension during which force and raw EMG were monitored at 500 Hz for 20 s. These reference contractions were performed to determine changes in mean power frequency resulting from muscle fatigue during the test (Oberg et al., 1994).

After performing the reference contractions, subjects filled out a subjective rating form identifying areas of discomfort and the overall difficulty of typing at the required typing speed. The ratings form consisted of a series of 10 cm visual-analog scales (Arstila et al., 1974). Subjects were then given 30 min of rest. After the rest period, subjects began trial 2 following the above procedure. Subjects returned to the lab between 2 and 14 days later to perform the second two-test trials.

2.5. Data analysis

Independent variables in the experiment were: subjects (random effect), type of enhanced auditory feedback, day, and trial. Dependent variables in the experiment were: typing force, finger flexor EMG, finger extensor EMG, and subjective discomfort. Amplitude probability distributions (APDs) were developed to determine the 10th, 50th, and 90th percentile levels of activity for the typing force and finger flexor and extensor EMG (Jonsson, 1988). All ANOVAs were performed with all independent variables and a single dependent variable. All significant values are reported at $p<0.05$.

2.6. Results

No significant differences were found between days or trials. For this reason, the two ‘‘no-feedback’’ trials have been combined in the data presented below.

2.6.1. Typing force

The effects of enhanced auditory feedback on typing force are presented in Fig. 4. Ninetieth percentile typing force significantly decreased 15% (from 2.20 to 1.88 N) when force feedback was given and 11% (from 2.20 to 1.95 N) when EMG feedback was given. There were no significant changes in 50th percentile or 10th percentile typing force.

2.6.2. Finger flexor EMG

Results for finger flexor EMG are presented in Fig. 5. There was a significant decrease of 15% in 90th percentile EMG (from 22.6% to 19.3% MVC) when force feedback was given and 13% (from 22.6% to 19.6% MVC) when EMG feedback was given. Fiftieth percentile EMG decreased 11% (from 7.1% to 6.3% MVC) when force feedback was given and decreased 13% (from 7.1% to 6.2% MVC) when EMG feedback was given. There were no significant changes in 10th percentile finger flexor EMG.

2.6.3. Finger extensor EMG

Results for finger extensor EMG are presented in Fig. 6. There was a significant decrease of 10% in 90th percentile EMG (from 22.0% to 19.7% MVC) when force feedback was given and 10% (from 22.0% to 19.8% MVC) when EMG feedback was given. Fiftieth percentile EMG decreased 9% (from 11.0% to 10.0% MVC) when force feedback was given and decreased 9%

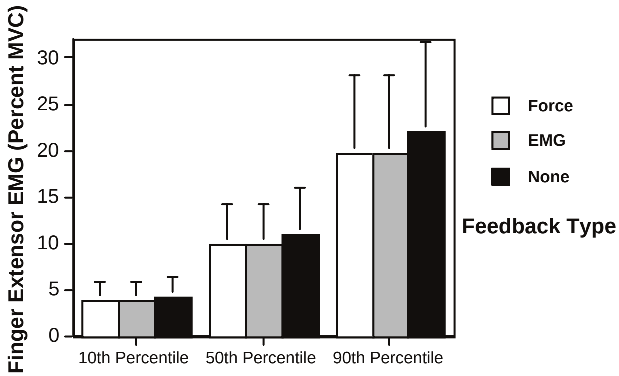

Fig. 6. Effects of enhanced auditory feedback on finger extensor EMG.

(from 11.0% to 10.0% MVC) when EMG feedback was given. There were no significant changes in 10th percentile finger extensor EMG.

2.6.4. Subjective discomfort

Results for subjective discomfort are presented in Fig. 7. There were no significant differences found in discomfort between the different test conditions.

2.7. Fatigue

Subjects were monitored before typing and immediately after each typing test condition in an attempt to measure muscle fatigue. There were no significant changes in mean frequency of the power spectrum, baseline EMG levels, or ratio of EMG to force between the fatigue trial at the start of the study and the fatigue trial after each 30 min test sequence.

3. Part II—long term effects of enhanced auditory feedback

3.1. Methods

The purpose of this study was to examine how long term auditory feedback would effect typing behavior, both during and after the presentation of feedback. The short term study found a slight advantage for force feedback over EMG feedback. For this reason the long term study evaluated only the effects of force feedback.

3.2. Subjects

Ten females participated in the experiment (41 ± 9 years old). All subjects were touch typists employed at a text processing facility in Massachusetts. The subjects had an average of 20 ± 9 years of typing experience and typed an average of 76 ± 7 WPM.

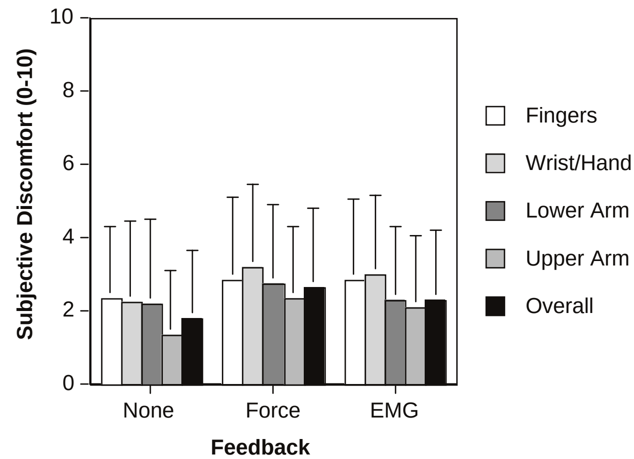

Fig. 7. Effects of enhanced auditory feedback on subjective discomfort.

3.3. Equipment

The data acquisition equipment used in short term study was also used in the long term study. Auditory feedback devices were constructed to provide feedback at each subject's workstation. The devices received force data from four force sensitive resistors (FSRs) mounted underneath the subject's keyboard, which was a buckling spring keyboard with a make force of 0.72 N. The peak keyforce while typing was determined by measuring any static forces placed on the keyboard (including subjects resting their hands or fingers on the keyboard) and subtracting the static value from the peak value. Auditory feedback was provided through headphones that the subject wore. No enhanced auditory feedback was provided when the peak force was below three times the key activation force ($\sim$2.2 N). Enhanced auditory feedback was given when the peak force was above three times the key activation force in the form of a beep lasting 1 s. The frequency of the beep increased from 200 to 700 Hz as the peak force increased from three to eight times key activation force.

3.4. Procedure

Subjects used the feedback device at their workstation every day for a 2-week period. Feedback was provided via headphones for the first hour each morning. The subjects were instructed to use the auditory feedback to attempt to reduce their typing force. After the first hour each morning subjects removed their headphones and continued working. The feedback device recorded the peak typing force as a function of key activation force four times a second throughout the day. At the end of each day the data were uploaded to a computer for storage and analysis.

An experimental cubicle was designed to replicate the workstations that employees used and was constructed

Fig. 8. Photograph of experimental setup.

at the subjects' work site (Fig. 8). Subjects were able to control chair height and keyboard height. Subjects reported to the experimental cubicle where the experiment was explained and their written consent was obtained. Each subject then adjusted the workstation to a comfortable position. Subjects then participated in three 1 min typing tests to determine their maximum typing speed. The fastest 1 min test was recorded as the maximum typing speed.

Subjects were tested once per week to determine the effects of auditory feedback. Testing took place on three separate days over the 2-week period: before the introduction of feedback, after 1 week of feedback and after 2 weeks of feedback.

EMG electrodes were attached to the left forearm to record the muscle activity of the underlying finger flexors (*Flexor digitorum superficialis*) and finger extensors (*Extensor digitorum communis*) as described in Part I. Muscle activity was then calibrated for the finger flexors and finger extensors. The position of the electrodes was noted to facilitate placement in subsequent test trials.

Subjects typed for 10 min with and 10 min without auditory feedback. Typing speeds were controlled by setting the scrolling speed of the text display software. Typing force and RMS EMG were collected at 250 Hz for 30 continuous seconds every minute during the typing period.

Before and immediately following each typing session, subjects performed a 10 N static reference contraction in flexion and then extension during which force and raw EMG were monitored at 500 Hz for 20 s. These reference contractions were performed to determine changes in mean power frequency resulting from muscle fatigue during the test (Oberg et al., 1994).

After performing the reference contractions, subjects filled out a subjective rating form identifying areas of discomfort and the overall difficulty of typing at the required typing speed. The ratings form consisted of a series of 10 cm visual-analog scales (Arstila et al., 1974). Subjects were then given 5 min of rest. After the rest period, subjects began a second trial following the above procedure. If the subject had enhanced auditory feedback in the first trial then there was no enhanced auditory feedback in the second trial.

3.5. Data analysis

The data analysis for Part II of the experiment was identical to the data analysis technique used in Part I.

3.6. Results: introduction of enhanced auditory feedback

The results presented below are a comparison of typing force and EMG during the three controlled testing sessions that occurred at the experimental cubicle. These results closely parallel Part I of this study.

3.6.1. Typing force

The initial effects of enhanced auditory feedback on typing force are presented in Fig. 9. Ninetieth percentile typing force significantly decreased 20% (from 2.50 to 2.01 N) when enhanced auditory feedback was initially given. Fiftieth percentile typing force decreased 23% (from 1.17 to 0.90 N) when enhanced auditory feedback was given. The 10th percentile typing force decreased from 0.35 to 0.26 N; however, this change was not significant.

There were no significant differences in typing force for subjects while receiving enhanced auditory feedback during the 2-week duration of the experiment. For the trials when subjects were not receiving enhanced auditory feedback, there were significant decreases in 90th percentile (2.50–2.07 N), 50th percentile (1.17–0.90 N), and 10th percentile (0.35–0.21 N) typing force between the start of the experiment and the end of week 1 (Fig. 10). There were no significant differences between the end of week 1 and the end of week 2 during the trials when subjects were not receiving enhanced auditory feedback.

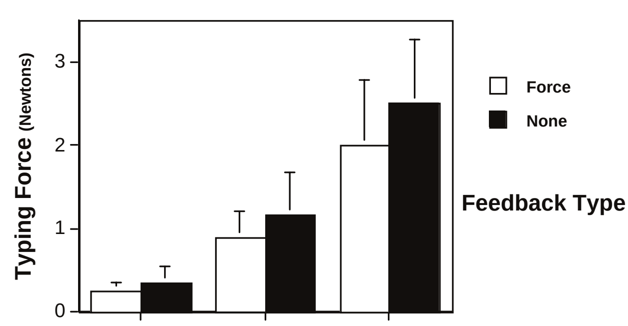

Fig. 9. Initial effects of enhanced auditory feedback on typing force.

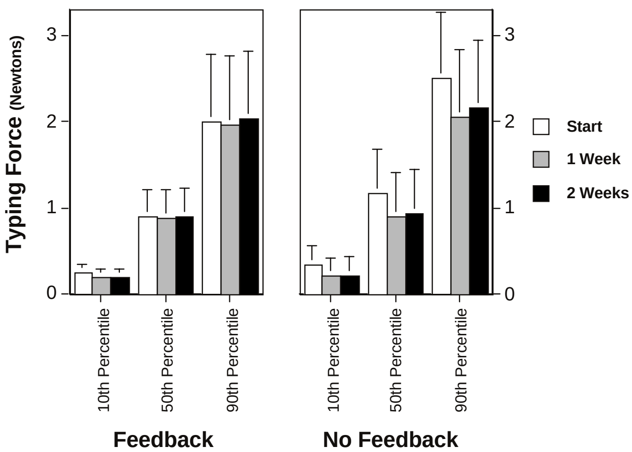

Fig. 10. Typing force with and without feedback at three timepoints.

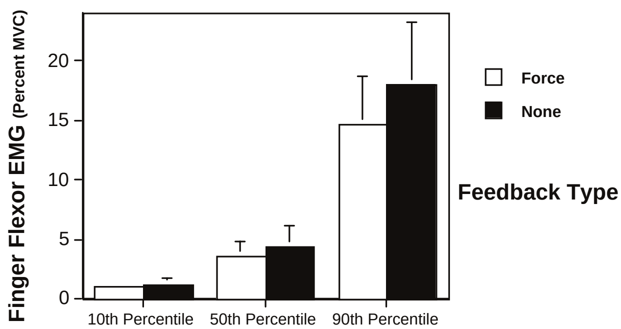

Fig. 11. Effects of enhanced auditory feedback on flexor EMG.

3.6.2. *Finger flexor EMG*

Results for finger flexor EMG are presented in Fig. 11. There was a significant decrease of 18% in 90th percentile EMG (from 18.0% to 14.7% MVC) when enhanced auditory feedback was given. Fiftieth percentile EMG significantly decreased from 4.5% to 3.6% MVC and 10th percentile EMG significantly decreased from 1.2% to 1.0% MVC.

There were no significant differences in finger flexor EMG while typing with or without enhanced auditory feedback during the three trials.

3.6.3. *Finger extensor EMG*

The effects of enhanced auditory feedback on finger extensor EMG are presented in Fig. 12. There was a significant decrease of 14% in 90th percentile EMG (from 19.1% to 16.5% MVC) when enhanced auditory feedback was given. Fiftieth percentile EMG significantly decreased from 9.1% to 7.9% MVC and 10th percentile EMG significantly decreased from 3.5% to 3.2% MVC.

There were no significant differences in finger extensor EMG while typing with or without enhanced auditory feedback during the three trials.

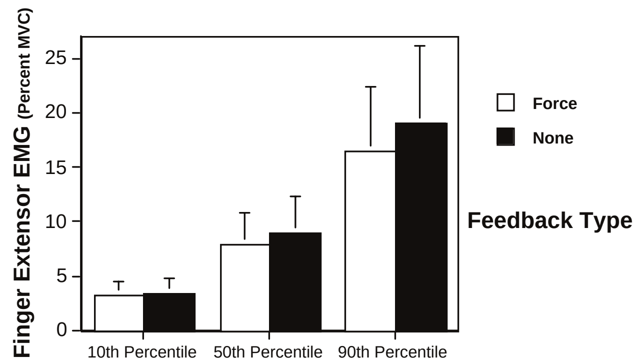

Fig. 12. Effects of enhanced auditory feedback on extensor EMG.

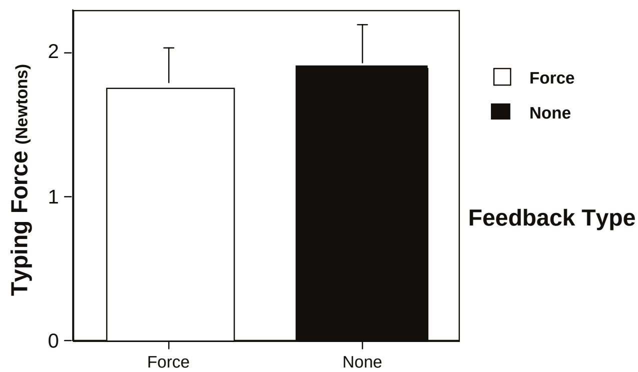

Fig. 13. Average peak typing forces while typing at workstations.

3.6.4. *Subjective discomfort*

There were no significant changes in subjective discomfort immediately after the three trials. There were also no significant changes in subjective discomfort reported at the end of each day of the test.

3.7. *Results: FSR device force measurements*

The results presented below are a comparison of typing force data collected while subjects were working at their desks during the 2-week trial.

The data from the FSR device was first divided into intervals where there was enhanced auditory feedback and intervals where no enhanced auditory feedback was given. The intervals were further divided into time where there was typing activity and time where there was no typing activity during most of the interval (e.g. during rest breaks and lunch). These efforts were made so that comparisons would be made only when the subject was actively typing for the majority of the data collection period. The data is summarized in Fig. 13. Peak typing forces while typing with force feedback (the first hour each day) were significantly lower than peak typing forces while typing with no feedback (the rest of the day). Peak typing forces for either time period did not significantly change from day to day over the 2 weeks of the study. Peak typing forces were found to be roughly equal to 90th percentile typing forces in a previous study (Gerard et al., 1996) and were similar to the 90th percentile typing forces measured during the typing tests in this study.

4. Discussion

4.1. Short term feedback

All subjects quickly responded to the auditory feedback and were able to reduce their 50th and 90th percentile typing force and flexor and extensor EMG when auditory feedback was given. The decreases were slightly greater when force feedback was given; however, the difference between force feedback and EMG feedback was not significant. Subjects that participated in the long term trial had a larger response to the feedback than the subjects in the lab study (Table 2). These changes were also seen for both flexors and extensors which suggests that the extra feedback provided caused changes in the motor activities and thus all the muscles involved in the task rather than just the muscle that is the source of the biofeedback. Poppen et al. (1988) noted similar changes in the muscles in the shoulder when applying biofeedback to the subject based on trapezius activity. However, it is possible that crosstalk between the EMG electrodes could account for some of the changes in the extensor activity.

There were no significant changes over the 30 min trial with auditory feedback for typing force or flexor or extensor EMG. These findings suggest that full adaptation with the auditory feedback occurred within 3 min of exposure to the auditory feedback. Another study by Gerard et al. (1999) looked at the effects of subjects typing on keyboards with different levels of key stiffness. Subjects were able to adapt to the new keyboard within the first 2 min of use and typed with the same level of typing force and EMG for the next 2 weeks. These findings are similar to Poppen et al. (1988), where subjects were able to decrease EMG activity in the trapezius within 1.25 min of use. The above findings suggest that giving a subject enhanced auditory feedback while typing will reduce his/her typing force and muscle activity within minutes.

4.2. Long term feedback

It appears that subjects were not able to further decrease their typing force or EMG while typing with enhanced auditory feedback over the 2-week period. This finding agrees with the Gerard et al. (1999) where subjects were able to adapt to a new keyboard within 3 min of exposure but did not further improve their performance over a 2-week period. However, a subset of those subjects participated in a 4-month experiment and were able to continue reducing their typing force and EMG over the experiment. Further studies are needed to examine how feedback over an extended time period affects typing force and EMG.

Table 2
Summary of feedback effects

Study	Δ 90th %tile force	Δ 90th %tile flexors	Δ 90th %tile extensors
Short term force	15	15	10
Short term EMG	11	11	10
Long term	20	18	14

After 1 week of intermittent auditory feedback subjects were able to type with approximately the same force and EMG regardless of the presence or absence of auditory feedback. This finding suggests that subjects were able to use the enhanced auditory feedback to alter their typing behavior and were able to carry that learning over to when they typed without enhanced auditory feedback. Morasky et al. (1983) found that reduced EMG levels during EMG biofeedback continued after an additional period of no-feedback practice.

Several individuals and corporations have submitted patents for devices similar to the ones used in this study (Krugman, 1996; Barker et al., 1998; Belsole, 1999; Korth, 1999; Gould and Rudnick, 2000). However, none of these devices are currently commercially available. The findings of this study suggest that the use of feedback devices would reduce the amount of typing force and EMG of proficient typists.

4.3. Limitations

There were several potential limitations to this study. These limitations are presented below.

1. *Sample size*: Due to the difficulties in collecting data using EMG both studies were limited in subject size (12 subjects in Part I and 10 subjects in Part II). Samples were also limited to proficient touch typists. It is possible that a larger subject pool would provide data that would be easier to generalize to the entire population.
2. *EMG*: Electrodes are subject to crosstalk from nearby muscle activity. Efforts were made during the experiment to minimize crosstalk during electrode placement. Electrode placement on forearm muscles can be very difficult because the size of the muscle is small relative to the size of the electrode. Great care was taken to accurately place the electrodes on the correct muscle while minimizing crosstalk. After each electrode was placed its location was videotaped to facilitate placement on the same subject next week. The electrode placement procedure added 30–60 min to the duration of each trial of the experiment.

3. *Force cell measurements*: The force cells placed underneath the keyboard measured all the forces that were placed on the keyboard. If a subject rested their hands on the keyboard that force would be measured along with the force of striking each key. Efforts were made in both studies to minimize the possibility of extra force being measured. In the first study the plastic cover on the keyboard was removed to reduce the possibility of subjects being able to rest their hands or fingers on the keyboard. In both studies subjects were instructed not to rest their hands or fingers on the keyboard. Additionally, the experimenter was able to monitor the typing force measured in real time and watch for static loads (i.e. hands, or fingers) on the keyboard.
4. *Force sensitive resistors*: FSRs have a natural drift in baseline voltage over time. Additionally, subjects were expected to occasionally rest their hands on the keyboard since this data was collected over their entire workday for a 2-week period. Peak keyforce while typing was determined by measuring any static forces placed on the keyboard (subjects resting their hands or fingers on the keyboard) and any changes in baseline voltage and subtracting these values from the peak value. Also, the FSR devices were not capable of determining 90th percentile typing forces due to limited memory and processing capabilities. Peak typing forces were found to be roughly equal to 90th percentile typing forces in a previous study (Gerard et al., 1996) and were similar to the 90th percentile typing forces measured during the typing tests in this study.

5. Conclusions

This research shows that a simple auditory feedback device can reduce typing force and EMG. The introduction of enhanced auditory feedback caused a 10–20% reduction in 90th percentile typing force, finger flexor EMG, and finger extensor EMG. Adaptation to the enhanced auditory feedback occurred in <3 min. After 1 week of intermittent enhanced auditory feedback there was no difference in typing force or EMG while subjects were typing with or without the enhanced auditory feedback. The continued use of auditory feedback did not further reduce the levels of typing force or EMG after 1 or 2 weeks of exposure. Possible applications for this research would be in the design of tools/devices that require low levels of force to operate but can cause overexertion due to their lack of feedback. It is possible that building a force feedback mechanism into devices such as keyboards, computer mice, or industrial hand tools may effectively reduce the force exerted while using those devices.

References

Armstrong, T.J., Buckle, P., Fine, L.J., Hagberg, M., Jonsson, B., Kilbom, A., Kuorinka, I.A., Silverstein, B.A., Sjogaard, G., Viikari-Juntura, E.R., 1993. A conceptual model for work-related neck and upper-limb musculoskeletal disorders. Scand. J. Work Environ. Health 19, 73–84.

Armstrong, T.J., Foulke, B.J., Martin, B.J., Gerson, J., Rempel, D.M., 1994. Investigation of applied forces in alphanumeric keyboard work. Am. Ind. Hyg. Assoc. J. 55 (1), 30–35.

Arstila, M., Wendelin, H., Vuori, I., 1974. Comparison of two rating scales in the estimation of perceived exertion in a pulse-conducted exercise test. Ergonomics 17 (5), 577–584.

Barker, J.H., Battiloro, G., McClurg, G.R., Verrier, G.F., Webb, G.E., 1998. Method of detecting excessive keyboard force. United States Patent No. 5,745,376.

Basmajian, J.V., 1978. Muscles Alive: Their Functions Revealed by Electromyography. Williams and Wilkins Company, Baltimore.

Basmajian, J.V., 1988. Research foundations of EMG biofeedback in rehabilitation. Biofeedback Self-regulation 13 (4), 275–298.

Belsole, R.J., 1999. Apparatus and method for reducing repetitive strain injuries. United States Patent No. 5,868,647.

Bureau of Labor Statistics, 2000. Workplace Injuries and Illnesses in 1999. US Government Printing Office, Washington, DC.

Computer Industry Almanac, 1999. Computer industry almanac says over 364 million PCs-in-use worldwide year-end 1998. Computer Industry Almanac Inc.

Craig, A.R., Cleary, P.J., 1982. Reduction of stuttering by young male stutters using EMG feedback. Biofeedback Self-regulation 7 (3), 241–255.

Croce, R., 1986. The effects of EMG biofeedback on strength acquisition. Biofeedback Self-regulation 11 (4), 299–310.

Delagi, E.F., Perotto, A., Iazzetti, J., Morrison, D., 1975. Anatomic guide for electromyographer: the limbs. Charles C. Thomas, Springfiled, IL.

Dvorak, A., 1936. Typewriting Behavior. American Book Company, New York.

Feuerstein, M., Armstrong, T., Hickey, P., Lincoln, A., 1997. Computer keyboard force and upper extremity symptoms. J. Occup. Environ. Med. 39 (12), 1144–1153.

French, S.N., 1980. Electromyographic biofeedback for tension control during fine motor skill acquisition. Biofeedback Self-regulation 5 (2), 221–228.

Gerard, M.J., Armstrong, T.J., Foulke, J.A., Martin, B.J., 1996. Effects of key stiffness on force and the development of fatigue while typing. Am. Ind. Hyg. Assoc. J. 57, 849–854.

Gerard, M.J., Armstrong, T.J., Franzblau, A., Martin, B.J., Rempel, D.M., 1999. The effects of keyboard stiffness on typing force, finger electromyography, and subjective discomfort. Am. Ind. Hyg. Assoc. J. 60, 762–769.

Gerard, M.J., Armstrong, T.J., Martin, B.J., Rempel, D.M., 2001. The effects of work pace on intra-subject and inter-subject keying force, electromyography, and fatigue. Hum. Factors, in press.

Gould, B., Rudnick, S., 2000. Computer activity monitoring system. United States Patent No. 6,065,138.

Human Factors Society, 1988. American national standard for human factors engineering of visual display terminal workstations. ANSI/HFS Standard No. 100.

Jonsson, B., 1988. The static load component in muscle work. Euro. J. Appl. Physiol. 57, 305–310.

Korth, H.E., 1999. Device for the prevention of RSI symptoms. United States Patent No. 5,902,257.

Kroemer, K.H.E., 1972. Human engineering the keyboard. Hum. Factors 14, 51–63.

Krugman, M., 1996. Instrumented computer keyboard for prevention of injury. United States Patent No. 5,579,238.

LeVine, W.R., Irvine, J.K., 1984. In vivo EMG biofeedback in violin and viola pedagogy. Biofeedback Self-regulation 9 (2), 161–168.

Lyon, B.K., 1992. Video display terminal ergonomics. Prof. Saf., 32–39.

Martin, B.J., Armstrong, T.J., Foulke, J.A., Natarajan, S., Klinenberg, E., Serina, E., Rempel, D.M., 1996. Keyboard reaction force and finger flexor electromyograms during computer keyboard work. Hum. Factors 38 (4), 654–664.

Monty, R.W., Snyder, H.L., Birdwell, G.G., 1983. Keyboard design: an investigation of user preference and performance. Proceedings of the Human Factors Society 27th Annual Meeting, pp. 201–205.

Morasky, R.L., Reynolds, C., Sowell, L.E., 1983. Generalizations of lowered EMG levels during musical performance following biofeedback training. Biofeedback and Self-Regulation 8 (2), 207–216.

National Instruments, 1992. Lab NB Manual, Austin, TX.

National Instruments, 1994. LabView 3.0.1 Manual, Austin, TX.

Oberg, T., Sandsjo, L., Kadefors, R., 1994. Subjective and objective evaluation of shoulder muscle fatigue. Ergonomics 37 (8), 1323–1333.

Olton, D.S., Noonberg, A.R., 1980. Biofeedback: Clinical Applications in Behavioral Medicine. Prentice Hall, Englewood Cliffs, NJ.

Poppen, R., Hanson, H.B., Ip, S.V., 1988. Generalization of EMG biofeedback training. Biofeedback Self-regulation 13 (3), 235–243.

Rempel, D., Serina, E., Klinenberg, E., Martin, B., Armstrong, T., Foulke, J., Natarajan, S., 1997. The effects of keyboard keyswitch make force on applied force and finger flexor muscle activity. Ergonomics 40 (8), 800–808.

Sommerich, C.M., Marras, W.S., Parnianpour, M., 1996. A quantitative description of typing biomechanics. J. Occup. Rehabilit. 6 (1), 33–55.