EMG-Based Methods for Testing Non-Keyboard Input Devices

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Abstract

Computer users who experience repetitive wrist movements and awkward hand positions are prone to developing upper extremity disorders. Manufacturers have designed various ergonomic mice in response to complaints of pain and discomfort related to computer mouse use. The objective of this work was to validate the use of surface electromyography (EMG) in assessing the design of non-keyboard input devices (computer mice). While holding the computer mouse EMG of the forearm and hand were recorded during a set of static tasks. The EMG signal provided information regarding the level of muscle activity and the varied combinations of muscular effort needed during computer mouse use. A significant decrease in the level of EMG activity was observed for the pronator muscles when subjects were tested using ergonomic computer mice. The EMG-based method was validated to be sensitive to the impact of subtle differences in shape/design of the computer mice on the amplitude of the surface EMG data. We also proved a significant effect of hand size on the level of muscle activity associated with different computer mice.

Significant and Usefulness of the Research Findings

The results gathered during the duration of this project allowed us to demonstrate that EMG patterns are sensitive to design differences among computer mice. We approach the study by first examining static conditions, i.e. investigating the pattern of amplitude of the data gathered from forearm and hand muscles while subjects held different devices without moving it. We then progressed from static to dynamic tests, first via controlled movements and later by monitoring EMG activity during the execution of an actual computer task (e.g. playing a videogame). Throughout these studies we were able to identify patterns of EMG activity that appear to reflect the quality of the ergonomic design of the computer mice that we tested. The method developed in this project could therefore be used as a tool to design computer mice with minimal impact on the health of users. Furthermore, our results clearly indicate that the hand size is an important factor that needs to be considered when evaluating the design of computer mice. For a big hand size the area of contact of the superior surface of the computer mice is significantly smaller than the surface of the palm. As a result, the hand "surrounds" the mouse and the shape of the computer mouse does not significantly affect muscle activity. Similarly, for a small hand size the hand "sits" on the superior surface of the computer mouse and once again the shape of such surface does not significantly affect the EMG patterns. It is only for a medium hand size that the surface of the computer mouse makes a significant difference. This observation calls for a design that is specific for different hand sizes so as to accommodate for the anthropometric characteristics of individuals.

The approach that we developed revealed systematic distinctions among the muscle activity required for different hand positions and for different computer mice. Among the three positions used in this study, the *rest* position (i.e. when the hand was let to rest on the superior surface of the computer mouse – see definition in the Scientific Report section) appeared to be most effective in identifying differences among the computer mice tested in the study. The EMG data recorded from the pronator quadratus muscle appeared to be particularly sensitive to the difference between traditional designs, which are marked by an almost flat superior surface of the computer mouse, and more modern designs, which are characterized by a slanted superior surface of the device as to allow for a closer to neutral position of the forearm while holding the computer mouse. Recordings from the pronator teres and flexor digitorum superficialis muscles appeared to be also sensitive to differences among computer mice. Finally, the EMG recordings from the extensor carpi ulnaris muscle showed high sensitivity to small deviations of the wrist from neutral and thus allowed us to capture differences in how computer mice are held by users which involve wrist posture. All in all, one can conclude that old designs are associated with greater muscle activity than new designs of computer mice, thus making old designs less desirable than new designs because of the additional force required to utilize a computer mouse associated with old designs.

These results demonstrate that the EMG-based method developed in this project is suitable to assess computer mouse designs. This is an important issue because of the epidemic levels recently reached by musculoskeletal disorders of the hand/wrist region among workers who perform repetitive, sustained, coordinated movements of the upper limbs (e.g., computer programmers, data entry workers, editors, and writers). The *National Occupational Research Agenda* has recognized this topic as one of the main areas where an urgent intervention is needed. The costs to society of work-related hand/wrist disorders account for billions of dollars in the United States only. According to the *National Occupational Research Agenda* "more than $2.1 billion in workers' compensation costs and $90 million in indirect costs are incurred annually for these musculoskeletal disorders".

A report of the *National Institute for Occupational Safety and Health* entitled "Musculoskeletal Disorders and Workplace Factors" demonstrates evidence of an association between exposure to risk factors (e.g., repetition, force, and posture) and carpal tunnel syndrome as well as hand/wrist tendonitis. This observation is also supported by clinical observations, ergonomic and epidemiologic studies, and in vivo experimental measurements that show a relationship between musculoskeletal disorders of the upper-extremities and the biomechanics of the wrist/hand.

The relevance of possible interventions in musculoskeletal disorders related to repeated trauma is clear when one considers the number of cases reported in the workplace (332,000 in the United States only in 1994), by the fact that musculoskeletal disorders of the upper extremities represent the great majority (65 %) of all illness cases reported by the *Bureau of Labor Statistics*, and by the trend in recent years of this type of disorders that shows a continuous increase in the percentage of workers affected by musculoskeletal disorders of the upper extremities. Disorders of the hand/wrist region are those most frequently reported. A large percentage of these disorders is observed in the office settings where computer related pains and injuries have been claimed to be responsible for about 50 % of the reported cases.

The figures associated with computer related musculoskeletal disorders have caused a dramatic interest for ergonomically assessing and designing VDT workstations and human-computer interfaces. Particular emphasis have been put on an ergonomic design of non-keyboard input devices that prevents awkward postures and movements that lead to musculoskeletal disorders. In fact, musculoskeletal disorders of the upper extremities have been associated with postures and movements commonly performed in computer use. The activation of the Pronator Teres muscle for forearm pronation causes a compression of the median nerve and a reduction of the blood supply to the forearm and hand through the ulnar artery. A sustained ulnar deviation posture could result in damaging the ulnar nerve. Due to the angle through which the flexor tendons of the hand are required to work in computer use, stress to these tendons and their associated bursae increase friction damage to tissues in the carpal tunnel. Extension of the wrist causes the extensor retinaculum to compress the tendons of the flexor muscles to the hand and the median nerve as they pass into the carpal tunnel. Pressure of the weight of the forearm and hands resting on wrist rests, or other support surfaces contributes to increased pressure in the carpal tunnel. Sustained wrist extension combined with continuous flexion and extension motions of the fingers over time affects the flexor tendons of the hand. Nerve compression in the carpal tunnel may also occur directly as a result of the extended posture and indirectly as a result of inflammation of the tendons and bursae in the carpal tunnel. In a nutshell, a variety of postures and movements associated with computer use may be related to the occurrence of injuries.

New ergonomic designs of the human-computer interface, including keyboard and non-keyboard devices, have been proposed to address these problems. The assessment of these designs requires developing objective techniques that allow direct or indirect measurement of the above-mentioned postures and movements associated with musculoskeletal disorders of the upper extremities. In this research project, we have collected evidence that the proposed EMG-based technique is an effective tool to assess computer mice designs and thus allow one to design new non-keyboard input devices that are better conceived from an ergonomic standpoint.

Scientific Report

The study was divided into three parts, roughly corresponding to the three years of the research project. The project evolved from the investigation of static conditions, i.e. tests performed while subjects held the computer mouse without performing any movement, to the study of actual computer tasks. In the following, results for three phases of the study are reported separately. The first section mostly refers to Year 1 of the project and largely includes results reported in the report submitted at the end of Year 1. This phase of the project was limited to static tests. The second section of the report summarizes results obtained by testing individuals while performing a computer task, but still under constrained conditions. This section corresponds to Year 2 of the project and is partially taken from the report submitted at the end of Year 2 of the project. These two phases of the project were accomplished while the PI was a faculty member at Boston University. At the transition between Year 2 and Year 3 of the project, the PI moved to Harvard Medical School. In this setting, the focus of the project was concentrated on the assessment of actual computer tasks without physical constraints (i.e. a special support for the arm) and without specific directions about how the subject was supposed to utilize software involved in the tests. The results all point toward the suitability of the proposed EMG technique for assessing computer mouse designs.

Surface EMG Data Can Contrast Computer Mouse Designs During Static Tests

The goal of the method developed in the first phase of the project was to test the way in which the hand conforms to the surface of the computer mouse. Computer mouse designs differ because of the shape of their surface. In order to compare computer mouse designs, it is necessary to specify hand positions that are the same across tests performed with different computer mice. Because EMG signals recorded from muscles of the forearm and hand are sensitive to the position of the upper limb, it is necessary to utilize a device that allows constraining the position of the shoulder and forearm. Once hand positions are specified and shoulder and forearm are properly constrained, surface EMG signals will demonstrate differences solely related to computer mouse surface/design. The procedure that we developed is based on monitoring EMG sites that relate to the above-mentioned postures and movements associated with computer related musculoskeletal disorders. As the amplitude of the surface EMG recordings reflects the force produced by the monitored muscles, the root mean square (RMS) value of the EMG data was utilized as a parameter to compare computer mouse designs. The criterion that was proposed is that lower RMS values are associated with computer mouse designs that are better thought from the ergonomic standpoint.

The study was performed using the following four computer mice: Logitech Mouse, Logitech MouseMan, Microsoft IntelliMouse, and Microsoft IntelliMouse Pro. The first two represent an "old design" style, while the other two are marked by an ergonomic design that in the following we refer to as "new design" style.

Three static positions of the hand, that correspond to three different ways of holding the computer mouse, were tested: 1) *rest position*; 2) *side grip position*; and 3) *grab position.* Two dynamic tests were also performed: *1) clicking the computer mouse buttons*, and *2) lifting the computer mouse* while holding it in the *grab position.* These positions were tested to assess the degree of activity of the monitored muscles when the hand conforms to the shape of the different computer mice. The *clicking* task tested the suitability of the buttons' position by indicating the degree of muscle effort required to reach and press the button. The *lifting* task tested the suitability of the design for lifting the mouse. A detailed description of this positions is reported in the grant application.

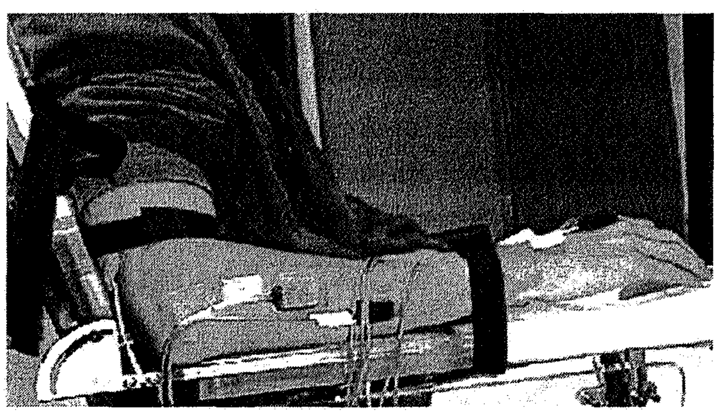

Figure 1 Custom made apparatus to constrain the upper limb posture during the experiments.

In order to test the manner in which the hand conforms to the surface of the computer mouse without introducing confounding factors due to the posture of the upper limb, a custom made restraining device was used. The use of this device is an important point of the experimental design since the amplitude of the EMG signals recorded from the muscles of the forearm and hand is sensitive to the shoulder, forearm, and hand position. Changes in the subject's posture may result in modifications of the EMG signals that could potentially mask differences associated with using different computer mice. By constraining the subject's posture we ruled out an important confounding factor and could therefore link the EMG patterns to the computer mouse design. This device consisted of two Plexiglas surfaces attached to a straight-back chair. One surface was horizontal and contained straps to restrain the subject's forearm in a desired position. The other was vertical and constrained the shoulder abduction in the range of 15-20 deg and the elbow flexion in the range of 110-120 deg. Figure 1 shows the device during a data collection.

Data collected prior to initiating this project (see preliminary study as described in the grant application) and data collected from the 17subjects recruited during Year 1 of the study were pulled for a total of 21 subjects (12 female subjects and 9 male subjects). Their age ranged from 20 to 38 years. None had any known neuromuscular disorders. All subjects read and signed an informed consent form approved by the Institutional Review Board prior to participating in the experiments. The inclusion criteria for participation were: 1) male or female 20 to 40 years old; 2) right-handed; 3) extensive use of computer mouse manifested by at least 2 hours per day of a personal computer use. The exclusion criteria were: 1) hand or wrist cumulative trauma disorders; 2) aching, soreness, or numbness in the fingers, wrists, hands, and arms; 3) open sores or wounds in the fingers, wrists, hands, and arms. The hand size of the subjects was measured by the distance between the wrist pivot point and the tip of the middle finger with the hand in the neutral position. Subjects were recruited in order to cover the range from the 5th percentile of the female population to the 95th percentile of the male population in the United States. They were recruited in order to obtain a uniform distribution between minimum and maximum of the selected range. Subjects were then divided into three groups of equal size based on their hand size (small, medium, and big). It is worth emphasizing that we recruited people with hand size in a range larger than what originally planned in our grant application. This is a modification that we decided to make based on the reviewers' comments.

EMG signals were recorded from the following eight muscles of the forearm and the hand: extensor carpi ulnaris, extensor digitorum, pronator quadratus, pronator teres, flexor digitorum superficialis, first dorsal interosseus, second dorsal interosseus, opponens pollicis muscles. The surface EMG signal from the opponens pollicis muscle was recorded only when performing the tests associated with the *grab position*. The EMG electrodes on this muscle were positioned only after the other tests (*rest position* and *side grip position*) were accomplished. These muscles were chosen because they are the dominant muscles that control the hand to assume the three tested positions and the movement required for the dynamic tasks.
The extensor carpi ulnaris muscle is important because it shows the degree of ulnar deviation necessary to hold the computer mouse. The EMG signal recorded from the extensor digitorum muscle provides a measure of the extension of the wrist and the fingers necessary to meet the computer mouse superior surface. The pronator quadratus and pronator teres muscles indicate the way the forearm needs to be positioned to hold the mouse. The degree of forearm and hand pronation is important since it has been related to the carpal tunnel syndrome. The flexor digitorum superficialis muscle shows the way the fingers rest on the surface of the computer mouse. Particularly, the EMG signal recorded from this muscle reflects the concavity of the superior surface of the computer mouse. The EMG signal recorded from these muscles indicates

the way the fingers reach the computer mouse buttons. Monitoring the opponens pollicis muscle provides a way to assess the grip force necessary to grab and lift the computer mouse.

The EMG signals were detected with an eight-channel EMG system equipped with active electrodes. The gains were set at either 1,000 or 10,000 to provide an output in the order of 0.1-1 V (peak-to-peak). The signals were filtered with a bandwidth of 20 to 450 Hz. Data were sampled at 1024 Hz using a 12 bit A/D converter and stored in computer memory.
All the tests were performed sequentially on each computer mouse. The computer mice were tested in a random order.
We calculated the root mean square (RMS) value of the surface EMG signals recorded from all eight muscles. Time intervals of 5 s were selected from the static and lifting contractions by choosing sections where the EMG data showed stable constant amplitude. This criterion was chosen to avoid including time intervals when movements or, although unlikely, artifacts might have occurred. For the clicking tasks the time interval from both the left and right computer mouse clicking were chosen.
The RMS values of the EMG signal were plotted for each subject, for each muscle and for each mouse. The Friedman ANOVA statistical test was used to measure the difference in the RMS values associated with different computer mice. The results of the Friedman ANOVA test indicate whether there is a significant difference among the data related to different computer mice for each specific test and muscle site. However, it does not demonstrate whether there is a significant difference between specific pairs of computer mice. Therefore, when a significant difference (p-value<0.05) was found among the RMS values associated with different computer mice, a further procedure was applied to test for pairwise differences among computer mice. We used a method referred to as Minimum Significant Difference. This test allows one to verify whether the differences between the average ranks associated with two computer mice are significantly different.

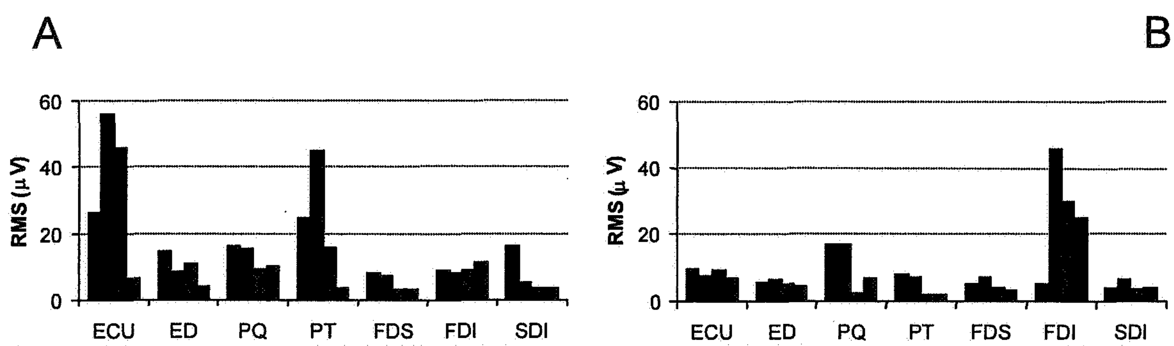

Figure 2 Barplot representation of the RMS values recorded for 2 subjects recruited in this study. See text for details.

The RMS values obtained in the rest position from two subjects are presented in Figure 2. The bars are grouped so as to facilitate the comparison of the muscular activity associated with different muscles: extensor carpi ulnaris (ECU), extensor digitorum (ED), pronator quadratus (PQ), pronator teres (PT), flexor digitorum superficialis (FDS), first dorsal interosseous (FDI), second dorsal interosseous (SDI), and opponens pollicis (OP). The order of the presentation of the muscles was chosen so as to locate muscles with similar function adjacent to each other. For each muscle, four bars represent the RMS values associated with Microsoft IntelliMouse, Logitech Mouse, Microsoft IntelliMouse Pro, and Logitech MouseMan.

The plots for different subjects and tasks demonstrated that the proposed EMG-based technique is capable of detecting differences among the level of muscular activity associated with different computer mice. A qualitative analysis of these plots showed that lower levels of EMG activity were generally associated with the Microsoft IntelliMouse Pro and Logitech MouseMan compared to the Microsoft IntelliMouse and Logitech Mouse. Differences were also observed for different hand size. Statistical tests were then performed in order to examine differences among the computer mice for each hand size group (small, medium, and big) and to investigate pairwise differences between mice.

The results of the Friedman ANOVA test are presented in Tables 1, 2, and 3. The cases for $p<0.05$ are shaded lightly and in the corresponding cell of the table the p-value obtained from the test is reported. Therefore the shaded cells indicate when we found statistically significant differences among the EMG activity of the individual muscles associated with different computer mice. When the Minimum Significance Difference test showed that there was a significant difference between "old" designs and "new" designs, an arrow was added to the corresponding cell of the table. The arrow points down if the test demonstrated that "new" design computer mice were associated with lower level of muscular activity then the "old" design computer mice. It points up if the opposite was demonstrated.

REST

	SMALL	MEDIUM	BIG
ECU	*NS*	*NS*	*NS*
ED	*NS*	*NS*	*NS*
PQ	*0.03* ↓	*<0.01* ↓	*<0.01* ↓
PT	*NS*	*<0.01* ↓	*NS*
FDS	*NS*	*0.01* ↓	*0.01* ↓
FDI	*<0.01* ↑	*0.02*	*0.03* ↑
SDI	NS	*0.04* ↓	*NS*

REST & CLICK

	SMALL	MEDIUM	BIG
ECU	*NS*	*NS*	*NS*
ED	*NS*	*NS*	*NS*
PQ	*NS*	*<0.01* ↓	*NS*
PT	*0.03* ↓	*<0.01* ↓	*NS*
FDS	*NS*	*<0.01* ↓	*0.01* ↓
FDI	*<0.01* ↑	*0.01* ↑	*NS*
SDI	*NS*	*NS*	*0.03* ↓

Table 1 Results of the statistical analysis of the data collected during Rest and Rest & Click position.

SIDE GRIP

	SMALL	MEDIUM	BIG
ECU	*NS*	*NS*	*NS*
ED	*NS*	*<0.01* ↓	*NS*
PQ	*NS*	*0.03* ↓	*NS*
PT	*NS*	*0.02* ↓	*NS*
FDS	*NS*	*0.02* ↓	*NS*
FDI	*NS*	*NS*	*NS*
SDI	*NS*	*NS*	*NS*

SIDE GRIP & CLICK

	SMALL	MEDIUM	BIG
ECU	*0.01* ↑	*NS*	*NS*
ED	*NS*	*NS*	*NS*
PQ	*NS*	*NS*	*NS*
PT	*NS*	*0.03* ↓	*NS*
FDS	*0.01* ↑	*<0.01*	*NS*
FDI	*0.03* ↑	*NS*	*NS*
SDI	*NS*	*NS*	*<0.01* ↓

Table 2 Results of the statistical analysis of the data collected during Side Grip and Side Grip & Click position.

Results varied according to the hand position, thus suggesting different sensitivities to the shape of the computer mouse. Most of the significant differences among computer mice were found for the *rest* and *rest & click* tasks (Table 1). The *side grip* and *side grip & click* tasks appeared to be mildly sensitive to the different shape of the computer mice (Table 2). The tasks associated with the *grab* position (Table 3) were found to be almost insensitive to differences among the computer mice.

Different behaviors were shown for the groups selected according to the subject's hand size. Subjects belonging to the medium hand size group were those for which the highest number of muscle sites showed significant differences among the computer mice. This was particularly evident for the *rest* position as well as for the *side grip* position, while low sensitivity was shown for all the groups for the tasks associated with the *grab* position.

In summary, the results indicate that the proposed EMG-based technique is able to demonstrate that different patterns of muscular activity are associated with computer mice marked by different shapes. Tasks associated with the *rest* position of the hand were found to be highly sensitive, while those associated with the *grab* position were found almost insensitive to differences among computer mice. Finally, the group identified as "medium hand size" showed the highest number of differences among the muscular activity associated with different computer mice.

GRAB

	SMALL	MEDIUM	BIG
ECU	*NS*	*NS*	*NS*
ED	*NS*	*NS*	*NS*
PQ	*NS*	*NS*	*NS*
PT	*NS*	*NS*	*NS*
FDS	*NS*	*NS*	*0.03*
FDI	*0.02* ↑	*NS*	*NS*
SDI	*0.02*	*NS*	*NS*
OP	*NS*	*NS*	*NS*

GRAB & CLICK

	SMALL	MEDIUM	BIG
ECU	*NS*	*0.04*	*<0.01* ↑
ED	*NS*	*NS*	*NS*
PQ	*NS*	*0.03*	*NS*
PT	*NS*	*NS*	*NS*
FDS	*NS*	*NS*	*NS*
FDI	*NS*	*NS*	*NS*
SDI	*NS*	*NS*	*0.04* ↑
OP	*NS*	*NS*	*NS*

GRAB & LIFT

	SMALL	MEDIUM	BIG
ECU	*NS*	*NS*	*NS*
ED	*NS*	*NS*	*NS*
PQ	*NS*	*NS*	*NS*
PT	*NS*	*NS*	*NS*
FDS	*NS*	*NS*	*NS*
FDI	*NS*	*NS*	*NS*
SDI	*NS*	*NS*	*NS*
OP	*NS*	*NS*	*NS*

Table 3 Results of the statistical analysis of the data collected during Grab, Grab & Click, and Grab & Lift position.

Based on these results we decided to investigate whether the differences identified via the proposed EMG technique were associated with differences in the position of the forearm and hand that could be identified via a stereophotogrammetric system, i.e., a two-camera motion analysis system.
We set up our equipment in the Motion Analysis Laboratory and performed a series of preliminary experiments to test the hypothesis that the activity of the pronator muscles (that we found to be lower in the new design computer mice compared to the old design style) could be related to the degree of pronation of the forearm while holding the computer mice. Our results demonstrated a significant difference between old and new design computer mice. These results validated the EMG-based method that we developed during the first phase of this project for static tests.

Surface EMG Data Can Contrast Computer Mouse Designs During Dynamic Tests

In the second phase of the project, we decided to start looking into actual computer tasks, but still we kept using the arm constraint as shown in Figure 1 for the studies accomplished during the first phase of the project. The set up was very similar, but subjects wer now asked to sit in front a computer and perform tasks using commonly utilized software..

Five different tests were developed to investigate EMG patterns of activation during tasks commonly encountered in computer mouse use. We refer to these tests as follows: *Click-and-*

Drag, *Resize*, *Double-Click*, *Web-Browsing*, and *Desktop* tests. In the following we provide a short description of each one.

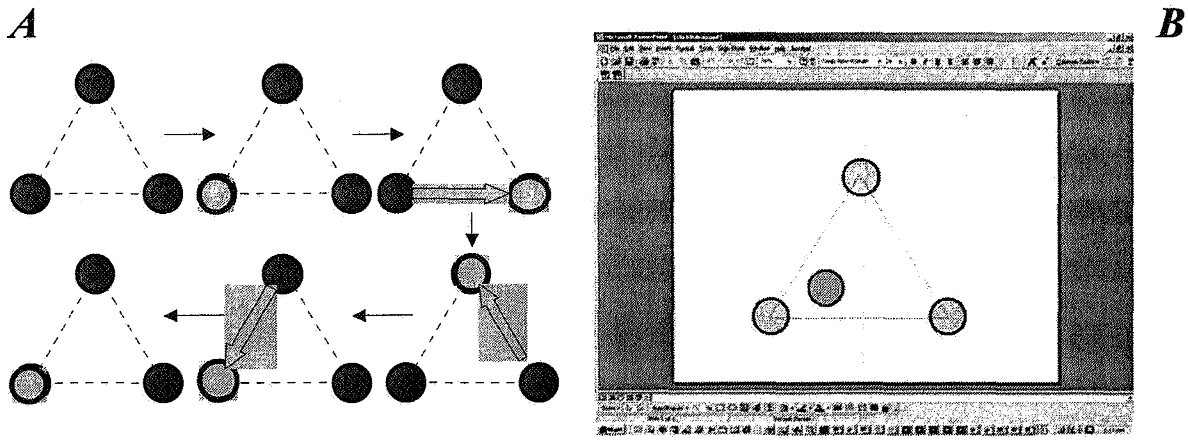

Figure 3 Schematic representation of the Click-and-Drag test. Panel A shows the sequence constituting the task. Panel B demonstrates the computer screen as seen by the subject during the test.

The *Click-and-Drag* test was designed along the lines of the ISO standards. *Figure 3A* schematically illustrates the task. Three circles were placed in a triangle configuration and made unmovable (i.e. they were part of the master slide of a Microsoft PowerPoint presentation). On the workable layer of the user interface we placed another circle, which the subject was free to move using the mouse. Subjects were instructed to begin with the movable circle aligned with the bottom left static circle. When the test began, subjects did repetitively click and drag the movable circle from one static circle to the next, going around the triangle in a counterclockwise manner. The test was implemented using Microsoft PowerPoint. The three circles placed in a triangle configuration were drawn on the master slider, while the fourth circle was placed on the workable slide. *Figure 3B* demonstrates the computer screen as seen by the subject during the test.

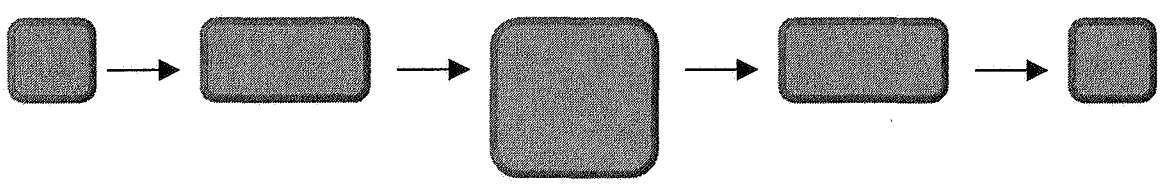

Figure 4 Schematic representation of the Resize test.

The second test that we implemented was referred to as *Resize* test. This test is schematically demonstrated in *Figure 4*. The test was designed using Microsoft PowerPoint as per the Click-and-Drag test. The PowerPoint slide had a simple rectangle on it, but the subject was required to go through many steps to resize it. The subject would begin by moving the cursor onto the rectangle and clicking the left mouse button (left-click) on the rectangle to select it. He/she would then right-click to bring up a menu and then left-click to select the resize option from the menu. In the resize window, the subject would left-click and hold on the resize width button. He/she would hold this until the resize option exceeded 200%, at which point the subject would release the left button, slide the cursor to the okay button, and left-click. The subject would proceed to right-click again on the rectangle, left-click to select the resize option from the menu and, this time, left-click on the resize height button within the resize window. He/she would hold the button down until this resize option exceeded 200%, at which point the subject would again release the left button, slide the cursor to the okay button, and left-click to close the resize window. The subject would then slide the cursor to the undo button on the task bar, and left-click twice, once to undo the height resize, and once to undo the width resize.

A further test was referred to as *Double-Click* test. For this protocol, a simple object, such as a rectangle, was on the slide. The subject would double-click on the object using the left mouse button, causing a formatting box to pop up. Prior to the beginning of the testing, this formatting box would be set to be located to the right of the object, forcing the subject to move the mouse to the right in order to place it in the formatting box. The subject would then click on the okay button within the formatting box, causing the box to close. This task was then be repeated a set number of times.

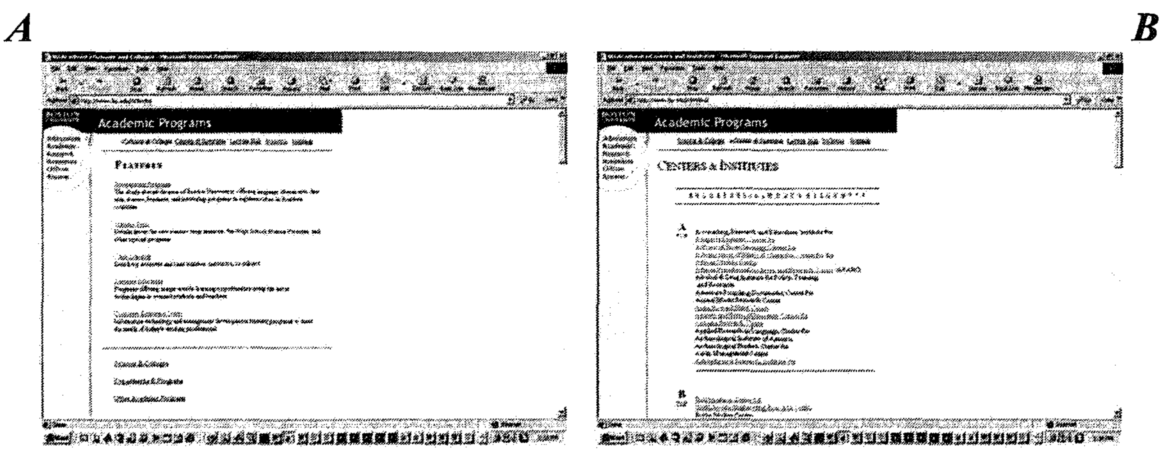

Figure 5 Schematic demonstration of the Web-Browsing test. Panels A and B show two different web pages that subject was asked to scroll through while switching between the two using the back and forward buttons.

The fourth test that we designed was the Web-Browsing test. This test uses Internet Explorer. Two websites are opened in the browser, allowing the subject to go between them using the back and forward buttons on the top taskbar. The subject would begin by clicking back and then using the scrollbar at the right to scroll to the bottom of the page. He/she would then click forward, and scroll to the bottom of that page. Next the subject would click back again, and this time scroll to the top of the page, and then click forward and scroll to the top of that page. This task can then be repeated a set number of times. Figure 5 shows the two web-pages utilized for testing.

The last designed test was referred to as Desktop test. The subject would right-click on the Desktop, bringing up a menu, in which he/she would left-click on the Active Desktop and then on the Customize My Desktop option. This caused a formatting box to open up. The subject would left-click on the ScreenSaver tab in the formatting box, left-click on the pull-down menu, and select the bottom screensaver option by clicking on it with the left mouse button. He/she would then click on the Cancel button to close the formatting box.

Nineteen right-handed subjects were tested in this study. The age of the subjects ranged from 18 to 40 years old. They did not have any hand or wrist musculoskeletal disorders, and were frequent computer users. Hand size was used as a qualification for the subjects' inclusion in the study. Hand size is determined by measuring from the pivotal point of the writs to the tip of the middle finger. The range from the fifth percentile of female hand sizes to the ninety-fifth percentile of male hand sizes was divided into three intervals. During the first phase of the project we found that the middle range, which includes hands between 18.4 and 19.4 centimeters, shows the most significant differences in muscle activity between computer mouse designs. Therefore, subjects with hand sizes between 18.4 and 19.4 cm, in the category of medium hand size, were chosen for the investigation performed during the second phase (Year 2) of the project.

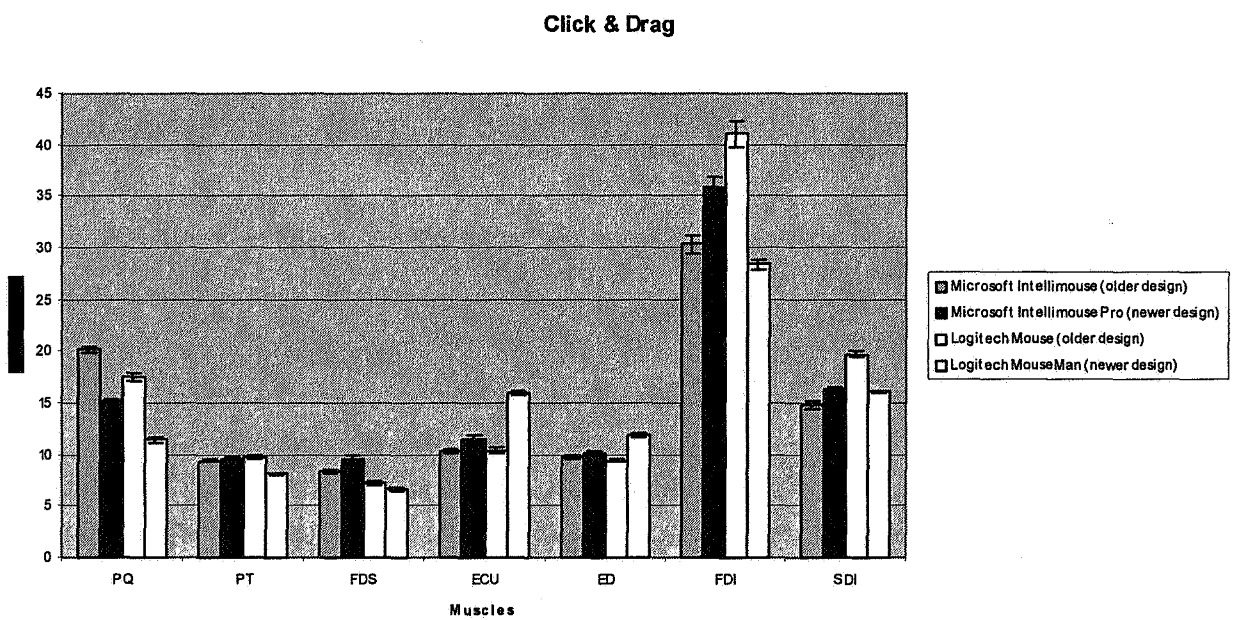

Figure 6 Average RMS values for seven muscles of one subject while using four different computer mouse designs during the Click-and-Drag testing protocol. PQ: pronator quadratus. PT: pronator teres FDS: flexor digitorum superficialis. ECU: extensor carpi ulnaris. ED: extensor digitorum. FDI: first dorsal interosseous. SDI: second dorsal interosseous.

All the tests were performed sequentially on each computer mouse. The computer mice were tested in a random order. The average RMS value for each of the seven observed muscles was computed for each of the four computer mice and each of the five testing protocols. These values were then compared using a bar chart format, as seen in Figure 6, which shows results from the Click and Drag protocol for subject 1. The results seen here are representative of the results found across the nineteen subjects. The amplitude of the RMS value corresponds to the amount of muscle activity required to perform a specific task. Therefore, by comparing the RMS values for a specific muscle for a controlled task performed with four different computer mice, it is possible to assess whether using these different computer mice requires different patterns of force across the monitored muscles. It can be seen in Figure 6, for example, that the activity for the pronator quadratus muscle decreased for this subject from the old Microsoft mouse to the new Microsoft mouse as well as from the old Logitech mouse to the new Logitech mouse. At the same time, it can be seen that for the extensor carpi ulnaris, muscle activity increased for the newer designs.

Once the variations in muscle activity between the computer mice was observed visually, statistical analysis was performed to determine to what extent the observed differences were statistically significant. This was done using the Friedman ANOVA and Minimum Significant Difference tests described above. The Friedman ANOVA analysis provided p-values for each muscle during each task. This compares the muscle activity across all four computer mice and determines whether the differences were due to coincidence. If the p-value is less than 0.05, there is only a 5% chance that the difference was due to coincidence, and a 95% certainty that there is a true physiological reason for the occurrence. If the p-value is less than 0.10, there is a 10% chance of coincidence being the reason for the difference in muscle activity. Table 4 shows the p-values for the seven muscles for each of the five tasks. The bold values (highlighted in yellow) are over 95% significant, while the italic values (highlighted in blue) are only significant to 90%. The remaining values did not show differences to a recognizable level of significance.

Friedman ANOVA	PQ	SDI	ECU	FDS	PT	FDI	ED
Static Protocol	**0.03016**	*0.06674*	**0.00469**	NS	NS	**0.001**	**0.01745**
Click & Drag Protocol	**0.00728**	NS	**0.00211**	NS	**0.00166**	**0.00016**	NS
Double Click Protocol	**0.00003**	**0.00205**	*0.07259*	**0.00157**	**0.00543**	NS	NS
Web Browsing Protocol	**0.00405**	**0.03016**	NS	**0.03103**	NS	NS	NS
Active Desktop Protocol	**0.00006**	**0.00006**	*0.08347*	*0.07259*	NS	NS	NS

bold = significant to p<0.05 (5%)
italic = significant to p<0.10 (10%)
NS = no significant differences

Table 4 Friedman ANOVA analysis of differences in muscle activity between four computer mouse designs

As seen in Table 4, significant differences in muscle activity were found for all seven muscles, but these results were spread out among the five different testing protocols. The most prominent significance is that of the differences in pronator quadratus muscle activity. Following completion of the Friedman ANOVA analysis, the Minimum Significant Difference test was performed to determine if the significance shown in the table was specifically due to the differences between the old and new designs of computer mice. For the majority of muscles and tasks, it was determined that the significance correlated to a difference in muscle activity either between the old and new Microsoft designs, or between the old and new Logitech designs. The ranks from the ANOVA analysis were used to determine if the muscle activity was increased or decreased between the old and new designs in situations where significant differences were found. These comparisons can be seen in Table 5. For each muscle and task, this table shows the comparison between mice 1 and 2, Microsoft Intellimouse (older design) and Microsoft Intellimouse Pro (newer design), and between mice 3 and 4, Logitech Mouse (older design) and Logitech MouseMan (newer design). The arrows indicate whether muscle activity was increased (upward arrow) or decreased (downward arrow) for the newer mouse when compared with the older mouse. The level of significance is indicated by the highlighted boxes. Yellow indicates 95% significance and blue indicates 90% significance. The boxes with no highlighting or arrows did not show any significant relationship between the two mice being compared.

In a nutshell, the studies conducted during the second phase of the project allowed us to demonstrate that the proposed EMG-based technique could be extended to assessing computer mouse design during simple computer tasks as long as the forearm and hand were constrained in a given position and the tasks were highly controlled.

Minimum Significant Difference Test	PQ		SDI		ECU		FDS		PT		FDI		ED	
	1-->2	3-->4	1-->2	3-->4	1-->2	3-->4	1-->2	3-->4	1-->2	3-->4	1-->2	3-->4	1-->2	3-->4
Static Protocol	↓	NS	↑	NS	NS	NS	NS	NS	NS	NS	↑	NS	NS	NS
Click & Drag Protocol	NS	↓	NS	NS	↑	↑	NS	NS	NS	↓	↑	↓	NS	NS
Double Click Protocol	↓	↓	↓	NS	NS	NS	↓	NS	NS	NS	NS	NS	NS	NS
Web Browsing Protocol	↓	NS	NS	NS	NS	NS	↓	↑	NS	NS	NS	NS	NS	NS
Active Desktop Protocol	↓	NS	↓	↑	↑	NS	↓	NS	NS	NS	NS	NS	NS	NS

significant to p<0.05 (5%)
significant to p<0.10 (10%)
NS = no significant differences

Table 5 Minimum Significant Difference Test comparing differences in muscle activity between old and new Microsoft mouse designs (1 and 2), and between old and new Logitech mouse designs (3 and 4). The arrows indicate whether muscle activity was increased (upward arrow) or decreased (downward arrow) for the newer mouse when compared with the older mouse.

Although the results obtained during the second phase of the project were very attractive, we were interested in further extending the application of the proposed EMG-based technique to real computer mouse use. This was the final step of the project, which demonstrated the suitability of our technique for a field assessment of computer mouse use and thus to contrast different computer mouse designs. In the following, we summarize the outcome of this final part of the project. Tests were performed to assess differences among computer mice during actual use of software commonly utilized by computer users. Also, we aimed at identifying specific events that we hypothesized to be suitable events for the analysis, such as clicking, dragging, etc. Their identification was pursued via collecting training and testing data sets and processing EMG data via an artificial neural network (ANN).

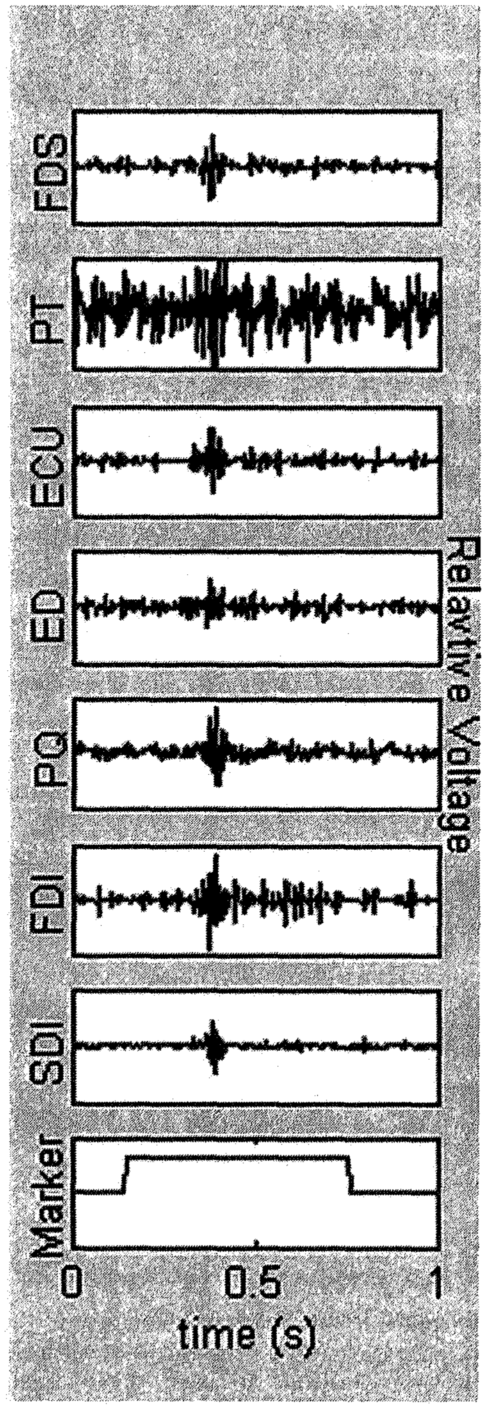

Figure 7 Subject 18 Left Click Event. The RMS voltage of seven muscles under investigation are along the y-axis. The voltage scale varies per muscle. The left clicking event took each subject an average of one second.

Twenty right-handed, frequent computer users with no neuromuscular disease of the upper limbs were recruited for this study. Their ages ranged from 20-32 with a median age of 22. Eight females and twelve males were used. Based on our results from Years 1 and 2 of the project that showed a hand size of 18.4-19.4cm to be the medium size category mostly affected by the shape of the computer mouse, we decided to recruit all subjects for this study last portion of the project with hands that measured within the above-referenced range. Orientation of the subject relative to the computer workstation included adjusting the height of the seat and armrest such that the armrest lies at the same level as the desk surface and supports the forearm at a comfortable level. The individual subjects determined comfort level.

Three data sets were collected. The first and second data sets were identical. Two identical data sets were acquired for the eventual implementation of the ANN. One set was used to train the ANN and the other to test it. Each of the two identical data sets included forty repetitions of six common computer mouse use actions. These motions include resting, left-clicking, right-clicking, clicking and dragging with the left button from bottom to top, clicking and dragging with the left button from left to right, and double-clicking of the left button. Combinations of these six actions can describe most computer mouse use situations. The clicking and dragging procedures were done through the use of a Microsoft PowerPoint file. Clicking and dragging involved clicking and dragging forty disks from one goal to another. The separating distance between the left and right goals was 6.5" and the separating distance for the bottom and top goals was 4.5". The clicking procedures did not require the creation of a Microsoft PowerPoint file. Clicking was done at arbitrary points on the screen while the user was in a comfortable position. The resting data was collected while the subject was resting on the mouse, in preparation to perform active mouse use. Between each collection of data for the resting set, the user reset his/her hand on the mouse by moving the mouse side-to-side a few times. This ensured that the users hand did not settled in an unnatural resting position over time. Each of the forty repetitions of the common computer mouse use actions was windowed by the user. A button was depressed during the entire duration of the event. Figure 7 shows one epoch from one event, which was marked by the user.

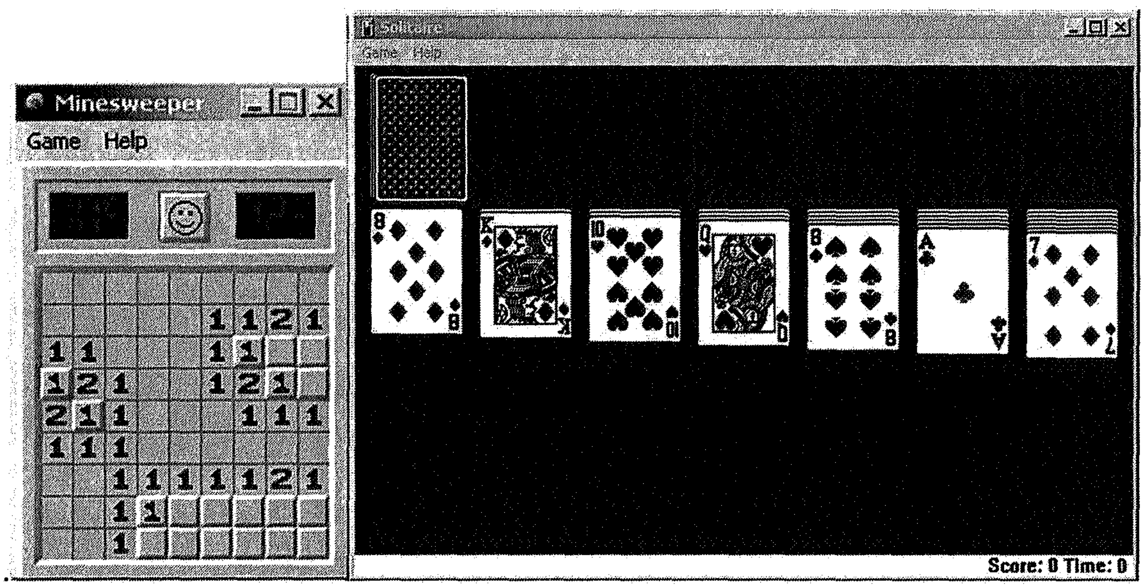

Figure 8 Third Data Set User Interfaces. For the third data set, the user played Minesweeper and Solitaire. These games involve repetition of the six computer mouse use actions under investigation.

The third data set included a scenario where the user was interacting with the computer in a realistic condition. The two conditions under investigation include playing solitaire and minesweeper (Microsoft Corp., 1981-1999). These two games are shown in Figure 8. These two conditions were chosen because they represent realistic computer mouse situations with much repetition of the six tasks under investigation. These two games are familiar to most frequent computer users. Since these two situations need to be as realistic as possible, the user did not mark the events in these procedures. Instead, the experimenter marked the events immediately after their occurrence with a 4.5V pulse. The events marked in minesweeper include resting on the mouse, left-clicking, right-clicking, and double-clicking. The events marked in solitaire include clicking and dragging from bottom to top and from left to right. It took about 2.5 hours per subject to execute the testing protocols.

Data processing included the extraction of features from the marked events in the data, and calculation of the standard error of the RMS voltage. The features extracted from the data sets include the RMS voltage from each EMG channel, autocovariance from each EMG channel, and covariance between pairs of EMG channels. Autocovariance and covariance were extracted for the eventual implementation of the ANN. Autocovariance and covariance are similar to convolution, where an epoch of data is shifted and slid through the same or another epoch and multiplied. The difference between convolution and the calculation of autocovariance or covariance is that the calculation of autocovariance or covariance does not include the flipping of the first data set before shifting and sliding through the second. Since there were seven EMG channels, there were 7 autocovariance calculations and 28 combinations of covariance per event. The 7 RMS voltages, 7 autocovariance, and 28 covariance features give a total of 42 extracted features per epoch of each event and muscle.

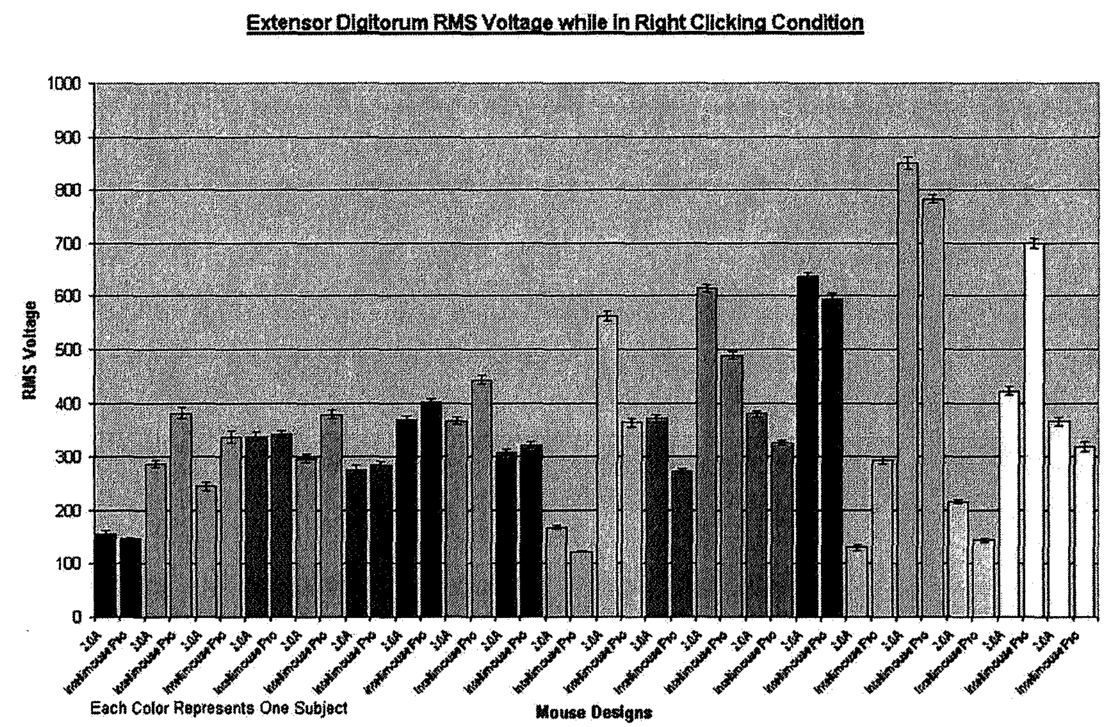

Figure 9 Extensor Digitorum RMS Voltage while in Right Clicking Condition. The bars alternate between Microsoft 2.0 and Intellimouse Pro mouse designs. Each color represents an individual subject. Subject hand size increases from left to right. Because the data from subject testing procedures 1 and 2 were acquired with the same methods, this data represents the results from the two data sets combined.

The RMS voltage was calculated and output within a created MATLAB function. The appropriate standard errors were then extracted with another script. This script also formatted the RMS and standard error data for export into Microsoft Excel. Excel was used to display the RMS voltage and standard error for each combination of task and muscle across subjects.

Two approaches were taken in the statistical analysis of the RMS voltage data. The first involved determining significant and consistent RMS voltage change across mouse design by combining the average RMS voltages for each task and each subject. The two data sets compared included data from all subjects for the two mouse designs. In order to determine significance, a paired t-test was used.

Muscle Testing Condition	FDS		PT		ECU		ED		PQ		FDI		SDI	
	P value	% Δ	P value	% Δ	P value	% Δ	P value	% Δ	P value	% Δ	P value	% Δ	P value	% Δ
Resting	.16	-	.11	11↓	.18	-	.24	-	.02	12↓	.22	-	.13	-
Left Click	.26	-	.08	15↓	.08	12↑	.38	-	.10	22↓	.29	-	.26	-
Right Click	.20	-	.02	17↓	.15	-	.43	-	.11	42↓	.30	-	.17	-
Click & Drag Bottom to Top	.45	-	.27	-	.48	-	.01	10↓	.16	-	.01	19↑	.28	-
Click & Drag Left to Right	43	-	.21	-	.20	-	.21	-	.17	-	.02	12↑	.24	-
Double Click	.35	-	.31	-	.08	12↑	.46	-	.17	-	.02	22↑	.13	-

Table 6 Paired T-Test Results & Average Percent Change in RMS Voltage. These results include data grouped by muscle and task across subjects. The down-facing arrow indicates a decrease in RMS voltage when using the Intellimouse Pro. The up-facing arrow indicates an increase in RMS voltage when using the Intellimouse Pro. A decrease in RMS voltage translates to a lesser magnitude of muscle exertion. Yellow indicates p<.0.10. Orange indicates p<0.05.

Muscle Testing Condition	FDS		PT		ECU		ED		PQ		FDI		SDI	
	% p<.05	% Δ	% p<.05	% Δ	% p<.05	% Δ	% p<.05	% Δ	% p<.05	% Δ	% p<.05	% Δ	% p<.05	% Δ
Resting	85	1↑	85	6↓	70	14↑	75	5↑	85	8↓	70	37↑	60	5↑
Left Click	80	3↓	85	5↓	80	19↑	65	0	60	8↓	85	34↑	80	4↑
Right Click	75	1↓	95	11↓	75	28↑	80	7↑	80	17↓	65	13↑	80	1↓
Click & Drag Bottom to Top	75	1↓	75	1↓	65	3↑	80	11↓	80	8↓	95	23↑	65	1↑
Click & Drag Left to Right	70	11↑	80	2↓	70	7↑	75	4↑	80	3↓	95	16↑	70	3↑
Double Click	90	11↑	80	3↑	80	22↑	85	3↑	90	5↑	95	34↑	60	8↑

Table 7 Percentage of Subjects Showing Significance at p<0.05 & Average Percentage Change In RMS Voltage Between New and Old Mouse Designs. This table represents analyses done between individual subjects. Twenty subjects were tested. Yellow indicates p<0.05 for atleast 75% of subjects. Orange indicates an average percent change in RMS voltage of at least than 8% in subjects that have p<0.05.

The second approach in the analysis of the RMS voltage data included comparing the RMS voltages between each mouse design for each task for each individual subject. A two-sample t-test was used with this approach.

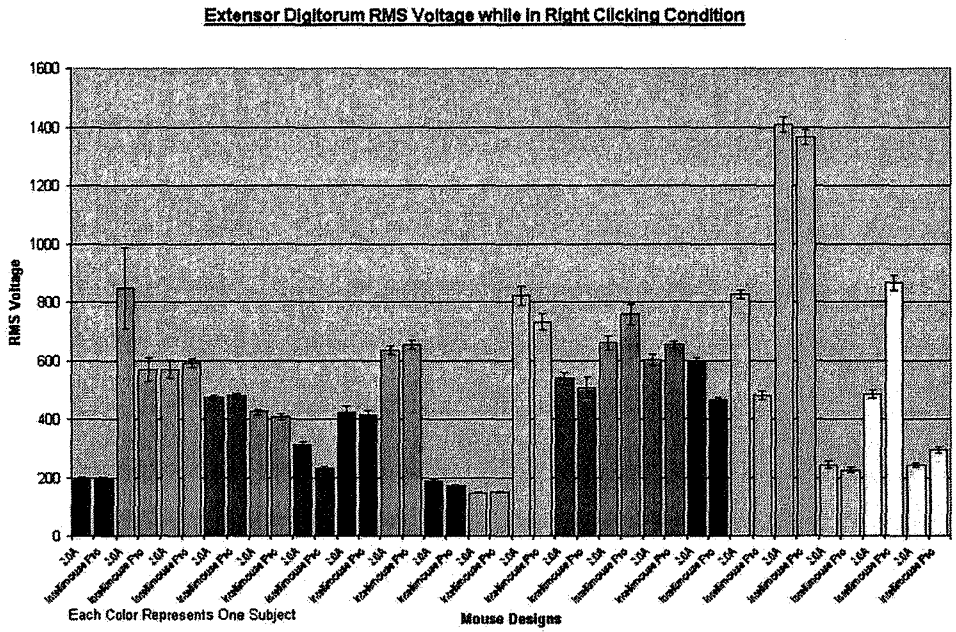

Figure 10 Extensor Digitorum RMS Voltage while in Right Clicking Condition. The bars alternate between Microsoft 2.0 and Intellimouse Pro mouse designs. Each color represents an individual subject. Subject hand size increases from left to right. This data was taken from subject testing procedure 3.

This first set of results includes data from the identical first and second data sets. The difference between these data and data acquired in previous studies (Years 1 and 2) included the removal of physical restraints, while maintaining strict procedural guidelines. Initial processing of the results involved combining the subject data for each muscle and task. This allowed for statistical significance determination across mouse design for each muscle. With statistically significant increase or decrease in RMS voltage across mouse designs in combination with significant RMS voltage magnitude change, the ergonomic value of choosing one design over the other could be determined. Figure 9 shows a typical RMS plot of data for all subjects during a specific task on a specific muscle.

The first statistical analysis done included combining the average RMS voltages of each subject for a specific task and specific muscle and performing a paired t-test to show whether or not the change in RMS voltage across mouse design was statistically significant. The results of this analysis are shown in Table 6. Although there are cases where statistical significance was found, the results were not overwhelming. Therefore, further statistical analysis was done on a subject-by-subject basis.

The RMS voltages for each subject for a specific task and specific muscle were compared across mouse designs by performing a two-sample t-test. Table 7 shows the percentage of subjects who show statistically significant changes in muscle exertion across mouse designs ($p<.05$) and the accompanying percentage change in magnitude of muscle exertion.

Muscle Testing Condition	FDS		PT		ECU		ED		PQ		FDI		SDI	
	P value	% Δ	P value	% Δ	P value	% Δ	P value	% Δ	P value	% Δ	P value	% Δ	P value	% Δ
Resting	.22	-	.35	-	.45	-	.23	-	.37	-	.38	-	.08	15↓
Left Click	.44	-	.20	-	.16	-	.14	08↓	.33	-	.23	-	.11	10↓
Right Click	.12	15↓	.08	18↓	.33	-	.26	-	.25	-	.07	23↑	.02	29↓
Click & Drag Bottom to Top	.03	19↓	.27	-	.16	-	.13	05↓	.18	-	.01	11↑	.17	-
Click & Drag Left to Right	.07	13↓	.32	-	.21	-	.22	-	.19	-	.01	16↑	.43	-
Double Click	.32	-	.15	-	.19	-	.30	-	.16	-	.49	-	.33	-

Table 8 Paired T-Test Results & Average Percent Change in RMS Voltage. These results include data grouped by muscle and task across subjects. The down-facing arrow indicates a decrease in RMS voltage when using the Intellimouse Pro. The up-facing arrow indicates an increase in RMS voltage when using the Intellimouse Pro. A decrease in RMS voltage translates to a lesser magnitude of muscle exertion. Yellow indicates p<0.10. Orange indicates p<0.05.

Muscle Testing Condition	FDS		PT		ECU		ED		PQ		FDI		SDI	
	% p<.05	% Δ	% p<.05	% Δ	% p<.05	% Δ	% p<.05	% Δ	% p<.05	% Δ	% p<.05	% Δ	% p<.05	% Δ
Resting	35	04↑	30	00-	35	02↑	25	01↓	20	04↓	30	08↑	50	04↓
Left Click	50	05↓	50	06↓	35	07↓	40	09↓	55	05↓	60	14↑	45	05↓
Right Click	60	12↓	45	12↓	35	08↑	30	01↓	35	01↓	55	23↑	75	18↓
Click & Drag Bottom to Top	35	12↓	50	02↓	20	09↑	30	02↓	40	17↑	40	12↑	35	07↓
Click & Drag Left to Right	45	06↓	50	02↓	35	11↑	45	00-	40	23↑	50	11↑	30	00-
Double Click	15	01↑	35	02↓	20	01↓	20	01↓	20	02↑	40	07↑	35	04↑

Table 9 Percentage of Subjects Showing Significance at p<0.05 & Average Percentage Change In RMS Voltage Between New and Old Mouse Designs. This table represents analyses done between individual subjects. Twenty subjects were tested. Yellow indicates p<0.05 for atleast 75% of subjects. Orange indicates an average percent change in RMS voltage of at least than 8% in subjects that have p<0.05.

This set of results includes data from the third data set. This set of data represents the situation where the computer user is in a completely unconstrained, realistic condition while playing Solitaire and Minesweeper. Initial processing of the results involved combining the subject data for each muscle and task. This allows for statistical significance determination across mouse design for each muscle. Figure 9 shows a typical RMS plot of data for all subjects during a specific task on a specific muscle. As shown in Figures 9 and 10, the RMS error for the extensor digitorum while in a right-clicking condition is very low. This small value in RMS error is consistent throughout each muscle under investigation for each task. Furthermore, the variation in RMS voltage is consistent for each subject across mouse designs.

The first statistical analysis done included combining the average RMS voltages of each subject for a specific task and specific muscle and performing a paired t-test to show whether or not the change in RMS voltage across mouse design was statistically significant. The results of this analysis are shown in Table 8. As with procedures 1 and 2, there are cases where statistical significance was found, but the results were not overwhelming. Therefore, further statistical analysis was done again on a subject-by-subject basis.

The RMS voltages for each subject for a specific task and specific muscle were compared across mouse designs by performing a two-sample t-test. Table 9 shows the percentage of subjects who show statistically significant change in muscle exertion across mouse designs ($p<.05$) and the accompanying percentage change in magnitude of muscle exertion.

By inspection of the statistical results in Tables 6-9, it is apparent that there is statistically significant variation in RMS voltage for certain muscles during specific tasks for many subjects. By inspection of the results for the pronator teres and pronator quadratus, we can conclude that there is significant decrease in RMS voltage and thus pronation of the wrist and forearm when using the Intellimouse Pro and this is evident in the three testing conditions. Recall that sustained pronation of the forearm and wrist is a direct cause of carpal tunnel syndrome. By

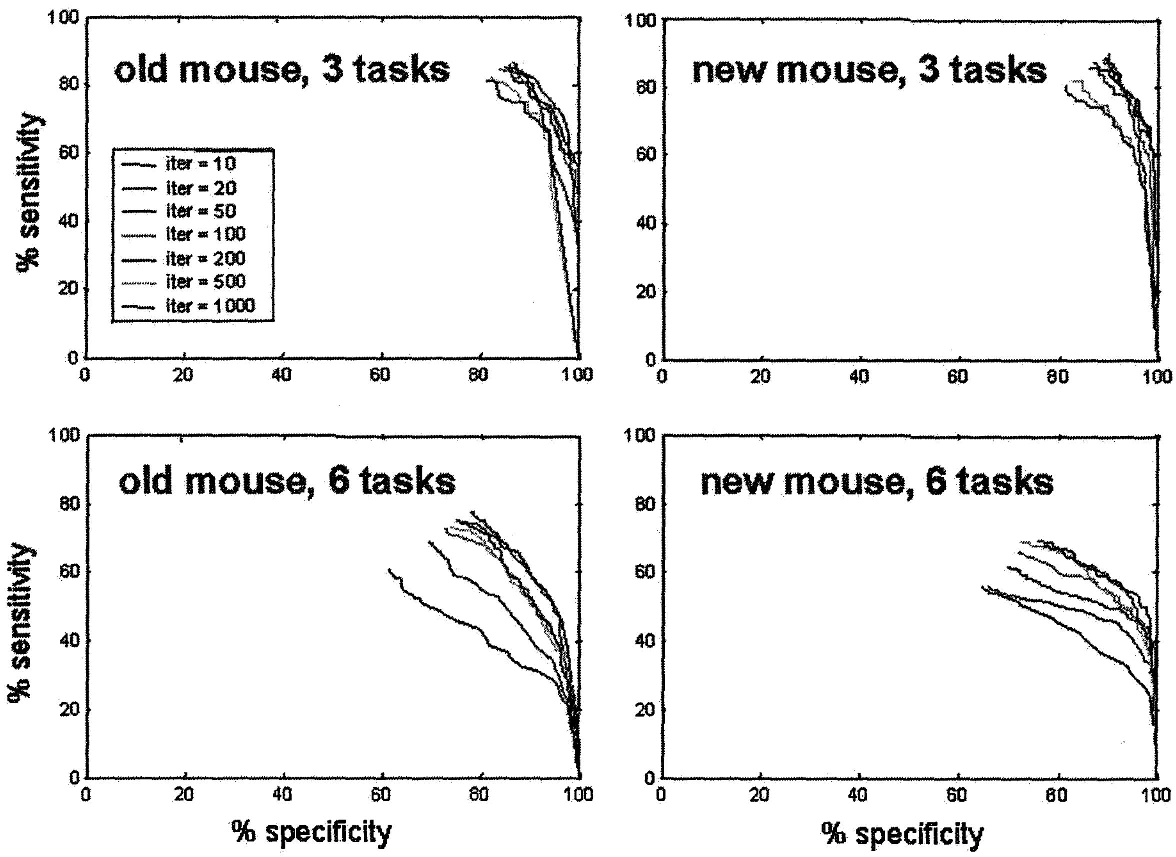

Figure 11 Sensitivity vs. Specificity of ANN Preliminary Results. Six tasks were examined total. In the top two plots, left click, right click, and double click were grouped, and click and drag from bottom to top and left to right were grouped. This leaves three total separate groups of tasks. The groups include clicking events, click and drag events, and resting. This data is from one subject only.

inspection of the results for the first dorsal interosseus, there is significant increase in RMS voltage when using the Intellimouse Pro and this is evident in the three testing conditions. It is speculated that a combination of the following factors causes this increase. The depression of the button on the Intellimouse Pro could require more force. Also, the supinated position of the hand and wrist caused by the design of the Intellimouse Pro could put the FDI in a disadvantage. Even with this statistical significance however, this does not validate the ergonomic value of one computer mouse design over another. In order for the design of the mouse to play a role in decreasing the RMS voltage and thus decrease the chance of developing neuromuscular disease of the upper limbs, the percent decrease or increase between the RMS voltages of the Intellimouse Pro and Microsoft 2.0 must be significant. Remembering that the magnitude of muscle exertion is directly related to the RMS voltage detected by the surface electrodes validates this determination. In order to discover what percentage decrease in muscle exertion is necessary to avoid the development of neuromuscular disease of the upper limbs, a method for acquiring subject data while in realistic conditions must be developed and implemented over a long period of time. The time period must be long enough for a healthy individual to develop problems. In order to accomplish this, ANN data processing and analysis protocols in combination with EMG data acquisition must be explored. This is in fact what we need in the final part of the project.

The method in which the six computer mouse tasks were extracted was not the same when deriving data from the three sets utilized for the study. In data sets 1 and 2, the user windowed the entire event, containing all EMG data associated with the specific task. In data set 3, the experimenter marked the events immediately after their occurrence. In a realistic situation, click and drags, clicking, and resting epochs do not consistently take the same amount of time. For example, some click and drag tasks require a longer drag. Therefore, more than one window limit is needed when extracting data from data set 3 in order to consistently extract the same EMG activation signal components. There were a few options for monitoring the computer mouse user and extracting data. These include monitoring the subject and manually marking the data for extraction, video taping the activity of the user and extracting data based on the video, keeping a data log in the computer of the activity of the mouse, and using an automated pattern recognition data extraction tool. In this study, the first and last approaches were explored. Manually marking data while maintaining the user in realistic situations has its flaws as described above. Preliminary results of an ANN pattern recognition algorithm are described next.

The artificial neural network toolbox in the software package MATLAB was used to train and test the artificial neural network. Two approaches were taken when training and testing the ANN and corresponding results are shown in Figure 11. The first included recognizing the six specific tasks and included 6 corresponding output nodes. The second approach included grouping similar tasks and recognizing a task within the group. The three groups included clicking tasks, click and drag tasks, and resting and included three corresponding output nodes. The latter approach is a more general in training and testing and results in better sensitivity and specificity. The eventual objective of grouping the tasks is to create a tiered group of ANNs. The first would specify which group of tasks is performed (eg. clicking, click and dragging, or resting) and the second tier would specify the type of action within these groups, totaling six specific tasks. Both approaches employed an ANN structure including one hidden layer with 10 nodes, and an input layer with 42 nodes corresponding to the 42 extracted data features.

The amount of training of the ANN was controlled by limiting the number of training iterations. On each training iteration, the entire set of training examples was presented as a batch. Training was halted after 10, 20, 50, 100, 200, 500, and 1000 training iterations, and the sensitivity and specificity were calculated at each stage of training. The amount of training iterations that produced the highest sensitivity and specificity was used.

Further modification of the ANN parameters needs to be done in order to decide if the approach is feasible. With the ANN an effective pattern recognition tool, case studies can be done on many subjects while they interact with computer mice in realistic conditions at work or at home over long periods of time. Their choice of computer mice can then be correlated with the onset or not of neuromuscular disease of the upper limbs, namely CTS. Depending on the location of placement of surface electrodes, the acquired EMG signal varies, dependent on impedance characteristics between the electrode and muscle. Therefore, the consistent placement of electrodes is necessary. Electrode placement was not a problem in this study because data was compared on a subject-by-subject basis across mouse designs without removal and re-application of electrodes on each subject. A method for consistently placing the surface electrodes in the same position on the skin needs to be developed if this future work is executed. Other areas of subject monitoring which could be explored include creating a data log within the computer of mouse activity or monitoring the subject with video and again manually extracting

Acknowledgments

During this project I supervised the work of three undergraduate students who developed a senior project on the basis of the aims of this research and substantially contributed to the results herein reported. These individuals are Mina Agarabi, Toby Levy, and Andy Lynn. I would like to acknowledge their dedication to the project and tremendous contribution. During Year 3 of the project, one of my research associates, Delsey Sherrill, helped me supervising the undergraduate student working on this project. I would like to acknowledge her tremendous contribution particularly in the development of the ANN technique for the identification of computer mouse tasks.

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