

COMPARATIVE ERGONOMIC EVALUATION OF DIFFERENTLY DESIGNED
COMPUTER MICE USING EMG-ANALYSES

by
EVA FLUG

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Department of Psychology
Organizational and Industrial Psychology Unit
Carl von Ossietzky University

UNIVERSITY OF OLDENBURG
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Approved by:

Supervisor
Prof. Dr. Friedhelm NACHREINER

Second examiner
Dr. Peter NICKEL

Abstract

Objectives: This study compared the muscle load induced by the use of three computer mice: a traditional mouse, a vertical (joystick-like) ergonomic mouse (Anir mouse), designed to give the operator a more neutral forearm position, and a slightly modified version of the Anir mouse, named Sico mouse, flexible at the basis of the handle, to allow for lateral buckling. **Methods:** Surface electromyography was used to record the muscle activity from forearm (extensor carpi ulnaris and extensor digitorum communis) and shoulder muscles (deltoideus pars clavicularis and trapezius pars descendens) while 9 male participants completed three different tasks, designed for the study: A pointing task, a dragging task, and a tracing task. **Results:** A highly significant task by muscle by mouse interaction ($p = .001$) was found. The muscle load on the forearm was less when using the ergo mice as compared to the traditional mouse. The muscle load on the deltoid was higher when using the ergo mice. For the trapezius no significant difference in terms of workload was found between the usage of the three mice. The Sico mouse yielded least activity, as compared to the other mice, in the extensor carpi ulnaris and the extensor digitorum when participants performed the tracing task. Overall activity in the trapezius was very low with each of the mice. **Conclusions:** When using the ergo mice the workload might be transferred from the minor muscles of the forearm to the bigger muscles of the upper arm and shoulder. Further investigation could use a wide range of measurement tools and combine EMG analyses with other diagnostic instruments like pressure tests and questionnaires to gather diversified data preferably under real working conditions over an extended period of time.

Zusammenfassung

Zielsetzung: In dieser Studie fand eine vergleichende Evaluation dreier Computermäuse mittels Oberflächen-Elektromyographie statt, nämlich einer traditionellen Computermouse und zweier (joystickähnlicher) Ergomäuse die eine neutralere Unterarmhaltung ermöglichen. **Methode:** Zur Messung der Muskelbelastung wurden elektromyographische Daten bei 9 männlichen Versuchsteilnehmern abgeleitet, und zwar von folgenden Muskeln: Für den Unterarm vom extensor carpi ulnaris und vom extensor digitorum communis, für die Schulter vom deltoideus pars clavicularis und vom trapezius pars descendens. Die Aufgaben bestanden aus einer Zielaufgabe, einer Textverarbeitungsaufgabe und aus einer Zeichenaufgabe. **Ergebnisse:** Die Maus-Muskel-Aufgaben-Interaktion war hochsignifikant ($p = .001$). Bei Benutzung der traditionellen Maus war die Belastung der Unterarmmuskeln größer als wenn die Ergomäuse benutzt wurden, während die Belastung des Deltoids bei Gebrauch der Ergomäuse höher ausfiel. Im Trapezius war die Muskelaktivität bei der Benutzung aller Mäuse sehr gering. **Schlussfolgerungen:** Bei Benutzung der Ergomäuse scheint sich die Muskelbelastung von den kleineren Unterarmmuskeln auf die größeren Oberarm-/Schultermuskeln zu verlagern. Weitere Untersuchungen (nach Möglichkeit in natürlicher Arbeitsumgebung und über einen längeren Zeitraum) könnten EMG-Analysen mit anderen diagnostischen Instrumenten wie beispielsweise Druckbelastungstests und Fragebögen kombinieren, um so umfang- und facettenreichere Daten zu erheben.

Acknowledgements

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Abbreviations

CTD:	cumulative trauma disorder
CTP:	carpal tunnel pressure
CTS:	carpal tunnel syndrome
CYC:	task 1: clicking off cycles
ECU:	extensor carpi ulnaris
ED:	extensor digitorum
EMG:	electromyography
ERGO:	ergo mouse by 3M
FIG:	task 3: tracing outlines of geometrical figures
HCI:	human-computer interaction
IEMG:	integrated EMG
MSD:	musculoskeletal disorder
MUAP:	motor unit action potential
MVC:	maximum voluntary contraction
NORM:	traditional mouse used in the experiment
RSI:	repetitive strain injury
SICO:	3M mouse with foamed rubber at the basis
sEMG:	surface electromyography
TXT:	task 2: word processing
UE:	upper extremity
UEP:	upper extremity problems
USB:	universal serial bus
VAS:	visual analogue scale
VDT:	visual display terminal
VDU:	visual display unit

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1 - Introduction

As early as 1963-64 Douglas Engelbart, a member of the Stanford Research Institute, and his colleagues developed the first prototype computer mouse as a point-and-click device for display screens. This early mouse consisted of a wooden casing with only one button as the micro-switches produced in those days were big and took a certain amount of space, easily too much to be covered under one hand. The first mice sensed motion through large protruding wheels (*Figure 1.1*) which were attached to potentiometers (ZHAI and MACKENZIE, 1998; BOOTSTRAP ALLIANCE, 2003).



Figure 1.1 The first computer mouse

Today, working with a computer is an integral part of the modern business community. According to PETERSEN (2006) there are an estimated 14 to 16 million VDU (visual display unit) working places in Germany alone and one out of two EU workers uses a computer for work (COMMISSION OF THE EUROPEAN COMMUNITIES, 2003). During the past two decades the use of non-keyboard input devices has constantly been increasing. Among them the one most widely used is the computer mouse (ZHAI and MACKENZIE, 1998; WOODS, HASTINGS and BUCKLE, 2003). The FOURTH EUROPEAN WORKING CONDITIONS SURVEY's (2007) results reveal that increasing use of information technology counts among the most important changes in the workplace:

Computer use has risen considerably across Europe and younger workers use computers twice as much as older workers. Around 26% of workers now work with computers all, or almost all, of the time; in 1990, the equivalent figure was around 13%. (p. 92)

How blissful the employment of modern technology might be, increased computer and mouse use requires muscle work and may entail pain in muscles, tendons and joints. Operating a traditional computer mouse requires the abduction (movement away from the median axis of the body) of the upper arm and the pronation (inward

rotation) of the forearm as well as an ulnar deviation (bend of the hand at the wrist in the direction of the little finger) with a dorsal extension (upward movement at the wrist) of the hand (ISO 9241-9, 2000). This posture strains the whole hand-arm-shoulder system to a minor or major extent and may eventually result in work-related musculoskeletal disorders (MSDs; STRASSER, FLEISCHER and KELLER, 2004).

While researchers in work physiology have been dealing with the issues of physical strain derived from both heavy dynamic muscular work and static work from early on, for many years only little attention has been paid to one-sided dynamic muscular work. The majority of modern work environments do require physical challenging work to a far less extent as compared to working conditions decades ago. Instead workload has commonly been transferred to minor anatomical structures (MÜLLER, ERNST and STRASSER, 1988). "A trend in industrial tasks is that tasks are becoming increasingly repetitive, yet involve lighter loads" (MARRAS, 2006, p. 341). Strain resulting from such kind of workload is often underestimated due to a lack of physical fatigue symptoms, or because valid indicators are unavailable. One-sided dynamic muscular work mostly is a result of consecutive repetitive movements with - in many cases - superimposed static work (MÜLLER *et al.*, 1988). HÄGG (2000) mentions both long-lasting static and highly repetitive load *and* demands for manual precision as a common denominator for occupational load and MATHIASSEN *et al.* (1993) refer to light-assembly work as an example of low intensity work held responsible for the development of shoulder-neck disorders. Findings suggest an increase in musculoskeletal discomfort as a consequence of extensive computer mouse use (FOGLEMAN and BROGMUS, 1995) and computer workers are at a high risk of developing neck-shoulder complaints, which may become chronic and subsequently result in absenteeism causing considerable economical damage in the long run (KALLENBERG, HERMENS and VOLLENBROEK-HUTTEN, 2006; COOK, BURGESS-LIMERICK and CHANG, 2000). While researchers did not prove chronic illness due to VDU work to date, employee complaints concerning the musculoskeletal system are not uncommon (PETERSEN, 2006). In fact, MSDs constitute the biggest group of disability causing diseases in the work force in Germany. MSDs accounted for 23.7% of the absence from work and a loss of 15.4 billion Euro gross value added in 2006 alone (BUNDESMINISTERIUM FÜR ARBEIT UND SOZIALES, 2007).

Likewise, non-specific forearm pain is a frequent complaint among computer workers, but the findings in epidemiological studies concerned with the relation between computer use and forearm pain were inconsistent and hence have led to dispute as to whether computer use increases the risk of forearm symptoms and related diseases (KRYGER *et al.*, 2003). In addition, forearm pain is often included in broader terms such as repetitive strain injury (RSI) or cumulative trauma disorders (CTDs; MACFARLANE, HUNT and SILMAN, 2000) and has rarely been examined as an isolated anatomical region (KRYGER *et al.*, 2003).

In their prospective population based study MACFARLANE *et al.* (2000) discovered that forearm pain - in addition to mechanical factors, like repetitive movements of the arm or wrist, and the work related psychological risk of being dissatisfied with support from supervisors or colleagues - was associated with high levels of psychological stress, other somatic symptoms, and health related anxiety.

A sharp rise in CTDs of the upper extremities since the early 1980s encompassed an increase in labor costs and costs on medical treatment. One of the commonly observed CTDs is the Carpal tunnel syndrome (CTS), a medical condition affecting hand and wrist. The reasons for the development of CTS are manifold. They include rapid and repetitive finger movements, repeated activity with a bent wrist, static exertion for a long time, and pressure at the base of the palm (WICKENS, GORDON and LIU, 1997), all of which may be seen as characteristic events during computer mouse work. Wrist activities can also affect the elbow, as many of the forearm muscles have their origin here (WICKENS *et al.*, 1997). Working with a computer mouse creates a static load in the forearm extensors which can be seen in the almost absence of gaps in the EMG levels of the assessed muscles. A low number of gaps are also reported being a risk factor for developing musculoskeletal symptoms in the trapezius muscle (AARÅS, DAINOFF, RO and THORESEN, 2002).

Since the invention of the first computer mouse designers and ergonomists have made many attempts to improve the usability of this commonly used input device in order to reduce high levels of strain on muscles and thus prevent tension, musculoskeletal discomfort, and illness. A promising model was the Anir vertical mouse, a joystick-like input device designed to be held with a neutral (handshake) hand position with the thumb pointing upwards and the back of the hand resting on the base of the mouse. The Anir mouse was evaluated in 1997 by AARÅS and RO in an electromyographic (EMG) study. Electromyography is the technique most commonly used to assess muscle load, i. e. the level of activity over a period of time when the muscle is in use (ISO 9241-9, 2000). Since the above mentioned study no attempt has been made to improve the model or extend the electromyographic analysis to other muscles or tasks than those assessed by AARÅS and RO.

The objective of the present study was to compare - by use of surface EMG - the load on forearm and shoulder muscles when using three differently designed optical mice: A traditional mouse (such as nowadays commonly sold with computers), an ergonomic (vertical) mouse by 3M (Anir mouse), and a slightly modified model of the 3M mouse allowing for minimal lateral movement of the mouse handle by the insertion of a piece of foamed rubber at the basis of the handle.

2 - Theoretical background

2.1 Literature review

"Prolonged self-reported computer usage is the most consistently reported risk factor for computing-related MSDs across study populations" (GERR, MARCUS and MONTEILH, 2004, as cited by CHANG *et al.*, 2007, p. 481).

A study by KATZ *et al.* (2000) among 1,601 senior undergraduates revealed that more than one half of the polled university students reported upper extremity symptoms during computer usage, and one in eight students already reported symptoms after using a computer for one hour or less. Additionally, a more recent study by HAMILTON, JACOBS and ORSMOND (2005) confirmed that computer related musculoskeletal complaints are common in female college students. As students constitute the next generation of professional workers, it is important to assess if such symptoms are frequently occurring in this population and to examine whether psychological factors - such as job strain - might contribute to their complaints.

According to BUCKLE (1997) the carpal tunnel syndrome (CTS) is associated with several factors in the work system like the stretching or compression of the median nerve at the wrist and ischemia together with increased pressure in the carpal tunnel when the wrist is in extreme postures. Moreover, WERNER *et al.* (1997) report elevated carpal tunnel pressure (CTP) when the wrist is deviated from neutral, and KEIR, BACH and REMPEL (1999) suggest two factors that may be held responsible for elevated carpal tunnel pressure during computer mouse use, namely wrist extension and fingertip force applied to depress the mouse button and to hold the sides of the mouse. These findings are supported by MARKLIN *et al.* (1999) who report that wrist extension has a greater effect on CTP than ulnar deviation. AMELL and KUMAR (1999, as cited by FAGARASANU and KUMAR, 2003) found that the nature of the task performed with the computer mouse might additionally increase wrist extension:

The total time when [*sic*] wrist is extended is increased by the use of the mouse that also strains the hand by forcing repetitive use of one finger and is awkward to hold. This effect is much more visible when VDT users are required to perform double-clicking and dragging tasks most of the time. (p. 122)

Among the many factors that play an important role in the CTS onset FAGARASANU and KUMAR (2003) mention "personal characteristics, awkward postures, repetitiveness and combination of these" (p. 122).

Other findings indicate that time may also constitute an important factor in the development of musculoskeletal disorders. This corresponds with ergonomic concepts like the stress-strain concept (SCHMIDTKE and BUBB, 1993), where

work stress is conceived as a function of *intensity and duration* of work. Thus, ANDERSEN *et al.* (2003) related mouse use for more than 20 hours per week and the risk of possible carpal tunnel syndrome and KRYGER *et al.* (2003) report an increased risk of developing forearm pain when using a computer mouse for more than 30 hours per week. Likewise, CHANG *et al.* (2007) found that more than 3 hours of computer usage per day was related to 50% higher odds of reporting musculoskeletal symptoms.

Short-term relationships between computer usage and musculoskeletal symptoms might also be possible according to CHANG *et al.* (2007), but to test such relationships, "accurate longitudinal exposure data of computer usage is needed" (p. 482) as "musculoskeletal symptoms can vary within the framework of a single day" (Amick *et al.*, 2003, as cited by CHANG *et al.*, 2007, p. 482). CHANG *et al.* (2007) suggest a longitudinal and continuous data collection with the aid of computer usage monitor software "to examine the short-term dose-response relationship between computer usage and MSD" (p. 482). They conducted a study to assess the relationships between daily computer usage time and reported musculoskeletal symptoms and found a relationship between high daily exposure and the odds of reporting daily symptoms with short latency.

ARMSTRONG *et al.* (1993, as cited by SOMMERICH, MARRAS and KARWOWSKI, 2006) developed a conceptual model of work-related MSDs that depicts relationships between exposure, dose, response, and worker capacity.

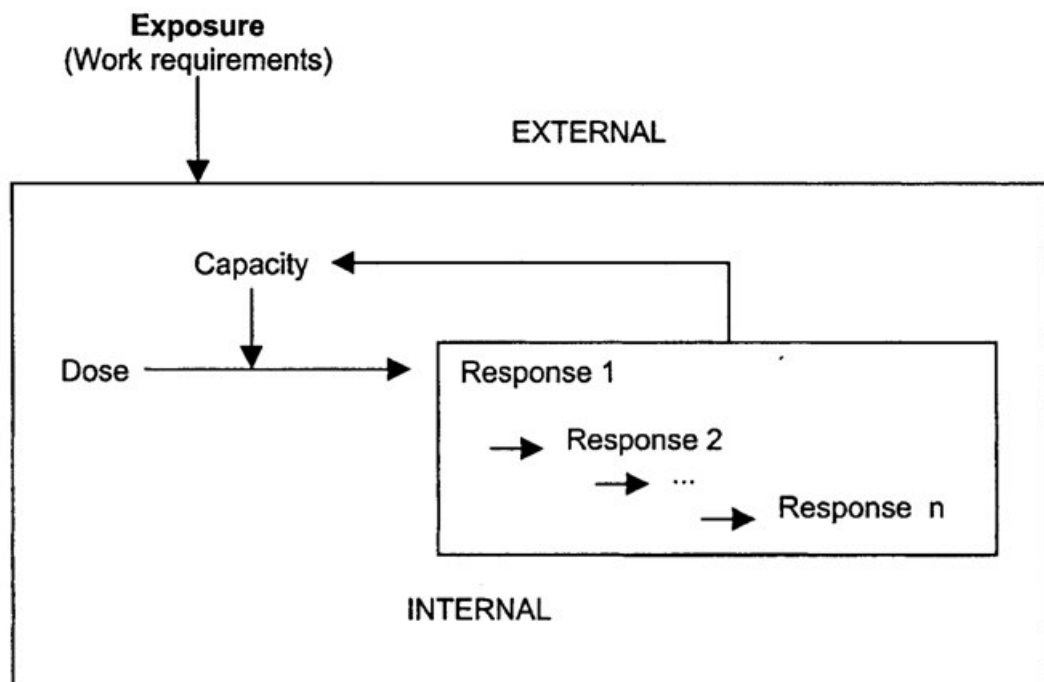


Figure 2.1 Dose-response model for work-related MSDs (ARMSTRONG *et al.*, 1993, as cited by SOMMERICH *et al.*, 2006, p. 868)

The model reflects the multifactorial nature of MSD and the complex interactions among the variables involved. It suggests that *external exposure* to work requirements - computer mouse design characteristics might serve as example for an external factor which determines work postures and consequently influences muscle load - might result in an *internal dose* (e. g. tissue loads, metabolic demands). This internal dose for its part provokes internal disturbances (mechanical, physiological, psychological changes). Repeated or sustained doses either improve or compromise the worker's adaptive abilities. Are the adaptive abilities compromised, disorders (e. g. MSD) are likely to develop.

The workstyle model (Figure 2.2) proposed by FEUERSTEIN (1996, as cited by HUANG, FEUERSTEIN and SAUTER, 2002) helps understand why identical work tasks might provoke different results in different workers when the development and aggravation of upper extremity problems (UEP) is concerned:

The model provides a framework to help explain how occupational stress and ergonomic exposures might interact to contribute to UE symptoms, disorders and disability. For example, a worker with a high-risk workstyle who is concerned about completing a deadline may be more likely to take fewer breaks, exert greater force on his/her keyboard, and sustain prolonged awkward postures, thereby increasing exposure to suspected ergonomic risk factors. Also, time pressure in this case can be a work demand and/or psychosocial stressor and can by itself trigger higher levels of muscle activity. (p. 311)

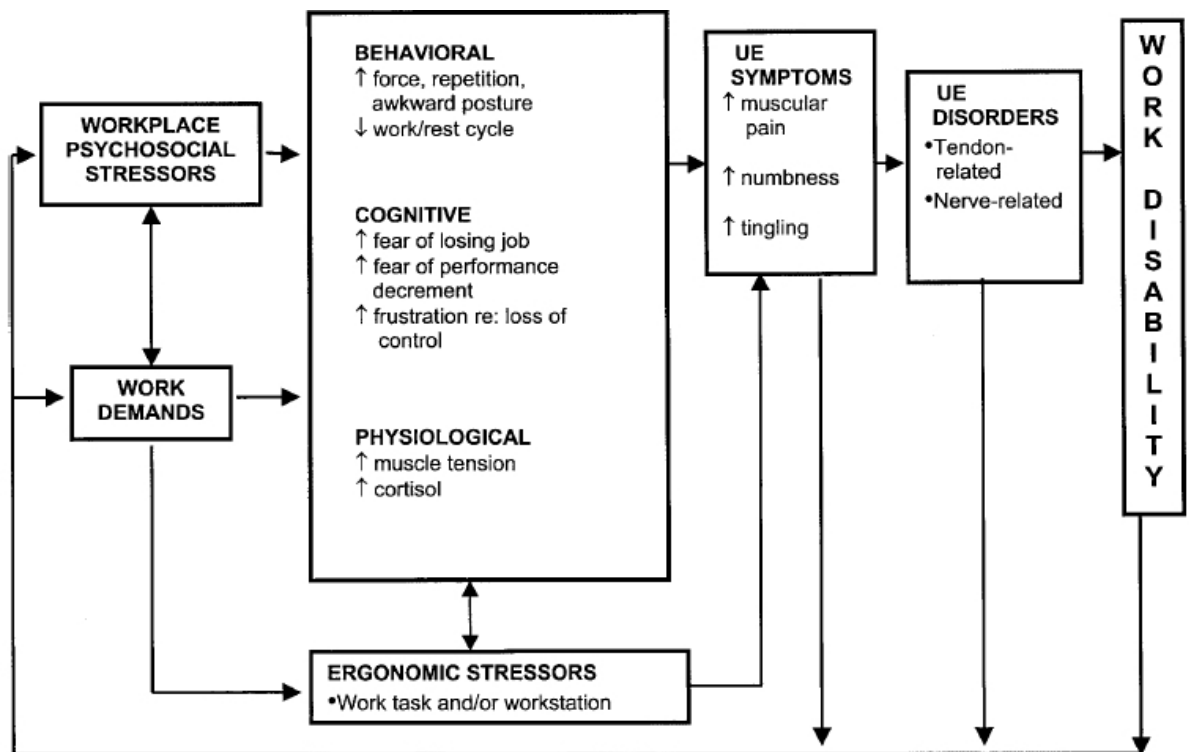


Figure 2.2 Workstyle model (FEUERSTEIN, 1996, as cited by HUANG et al., 2002, p. 310)

Task coping strategies are influenced by the worker's cognition and behavior and vary to a great extent. As only 9 participants took part in our study and more trials and participants are needed to investigate the subject, this issue is not further tackled in this paper.

CHEN and LEUNG (2007) tested the effect of five differently slanted computer mice (from 0° to 30°) on shoulder and forearm muscle activity and noticed - with an increasing slant - a decreasing activity in the extensor carpi ulnaris, pronator teres and upper trapezius muscle, but a higher activity for the extensor digitorum.

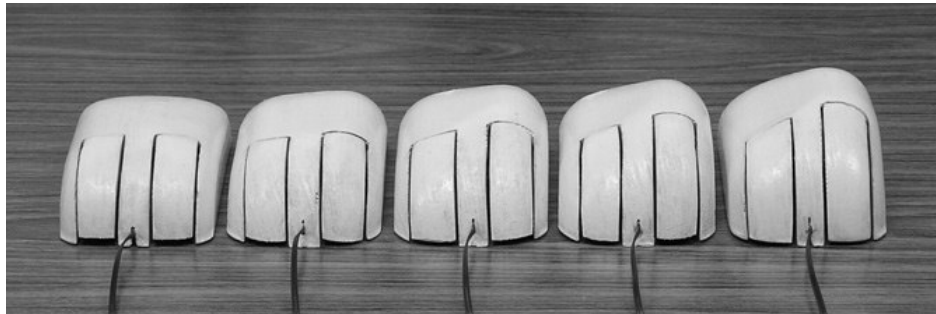


Figure 2.3 Differently slanted computer mice (CHEN and LEUNG, 2007, p. 520)

They assumed that the higher activity in the extensor digitorum was due to the fact that a larger slanted angle increased the height of the mouse (*Figure 2.3*) which might cause larger wrist extension and thus encompass a higher risk of CTS.

To assess the potential health hazards arising from traditional mouse use, KARLQVIST, HAGBERG and SELIN (1994) analyzed work postures as well as neck and arm movements for mouse using and non-mouse using (only keyboard) operators after recording the operators' movements with two video cameras for 30 minutes while those were accomplishing a word processing task. After 30 minutes the operators rated their discomfort on a visual analog scale (VAS). Mouse workers spent 34% of the analyzed working time in the interval 15° to 30° ulnar deviation of the wrist whereas the corresponding percentage for non-mouse operators was only 2%. Additionally, mouse operators rotated their upper arms in the shoulder joint more outward than non-mouse operators. The authors found that mouse users spent long periods with a flexed and outward rotated shoulder. Moreover the elbow was less flexed and the ulnar deviation of the wrist was higher as compared with non-mouse users. These more extreme postures hold the risk for discomfort in the shoulder, elbow, and wrist. Already thirteen years earlier, similar conclusions were reached by HÜNTING, LÄUBLI and GRANDJEAN (1981) who report a high correlation between the degree of ulnar deviation of the hand and the frequency of medical impairments in the forearm muscles. Their study showed a sensible increase in medical findings when the ulnar abduction of the hand exceeded 20° , which leads to the conclusion that the ulnar deviation of the hand in the wrist should be less than 20° and that the hand should preferably be held in a neutral position.

According to the Cinderella-Hypothesis (named so by HÄGG, 1991, cited by HÄGG, LUTTMANN and JÄGER, 2000) constant low level muscle activity due to monotonous workload induces pain, so that, in order to prevent musculoskeletal illness, methods should be found to minimize co-activity. Consequently, in order to prevent musculoskeletal illness, AARÅS (1994a) recommends keeping the static trapezius load at a minimum and the median arm abduction less than 10° . Even if computer workers do not actually *perceive* muscle fatigue they should be conscious to include recurrent breaks in their schedule when doing repetitive work with low muscle contraction. The fact that different people are using different motor task coping strategies should always be taken into consideration when an ergonomic optimization of input devices is intended (SCHNOZ, LÄUBLI and KRUEGER, 2000). Findings by WAERSTED and WESTGAARD (1996, as cited by SCHNOZ *et al.*, 2000) suggest that the trapezius "can ... be highly active with high attention demands but minimised physical activity" (p.213). It therefore is sensible to measure both physical *and* psychosocial influences from work environments to reveal potentially harmful levels of exposure. HUGHES (2007) suggests a whole set of measures to assess a wide range of work-related risks for the development of MSDs: the NASA-TLX ratings of perceived workload, EMG, heart rate recording for mean and variability, Borg-CR 10 ratings of discomfort, and a psychosocial questionnaire based on the Job Content Questionnaire.

BONGERS, KREMER and TER LAAK (2002) conducted an extensive review on the role of psychosocial factors in the development of UEP and found that high-perceived occupational stress was consistently associated with UEP and that there was some evidence, although not consistent, relating high job demands and UEP.

As has been discussed earlier, traditionally designed computer mice are held with a pronated forearm and are essentially controlled by wrist movements. Usually the hand is also extended in the wrist and deviated to the ulnar side.

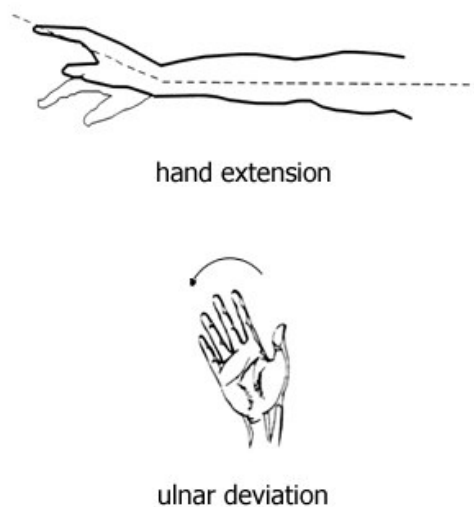


Figure 2.4 Hand extension and ulnar deviation (ISO 9241-9, 2000)

This leads to repeated impairments. A solution to the problem would be the development and use of a computer mouse, which avoids pronation and excessive wrist movements by giving the operator a more neutral forearm and wrist joint position compared to a traditional mouse design, thus reducing the muscle load in the forearm (AARÅS and RO, 1997).

During the past few years many alternatives have been created - among them a joystick like vertical mouse (*Figure 2.5*) moved by the whole arm.



Figure 2.5 *Anir ergonomic mouse (today distributed by 3M)*

Compared with the traditional computer mouse, the hand is in a more neutral position (0° pronation, 0° supination) when using this pointing device and the thumb is the main button controller.

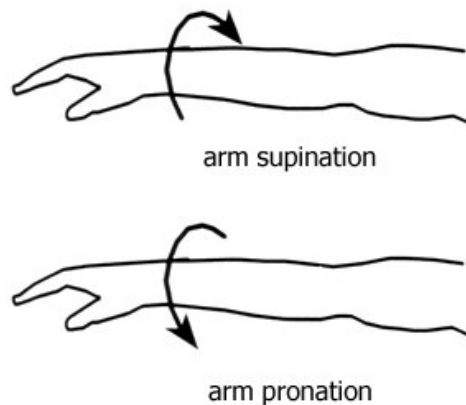


Figure 2.6 *Pronation and Supination (ISO 9241-9, 2000)*

To compare the workload when using a traditional mouse with the workload induced by the then newly developed vertical mouse (*Figure 2.5*), AARÅS and RO (1997) designed an EMG study with 13 male participants. In this short-term intervention they assessed the electromyographic activity from the forearm extensors (extensor digitorum and extensor carpi ulnaris) and the trapezius and found that the muscle load on the forearm was significantly less when working with the vertical mouse compared to the traditional one.

A few years later AARÅS *et al.* (2002) scrutinized these findings in a long-term epidemiological field study with 67 participants reporting musculoskeletal pain. Results showed that a "more neutral position of the forearm and wrist/hand ... reduced significantly the pain in the neck, shoulder, forearm and wrist/hand for VDU workers having pain in these areas" (p. 322). During the first 6 months of the study, participants were randomly divided into two groups, one intervention group using the Anir mouse allowing for a more neutral wrist position, and one control group using a traditional mouse requiring an almost full pronation of the forearm. The authors rated average intensity of pain on a 100 mm visual analog scale (VAS). Six months later, those participants using the Anir mouse reported significant reductions in pain levels, whereas no significant changes were reported in the control group. After 6 months the authors likewise provided the control group with the Anir mouse so that from this time on until the end of the study the population was in one group. The basic question of the study was whether the significant pain reductions would still be present after a 3 years period, when using the Anir mouse. During the study period more than 50% of the participants dropped out, so that only 32 subjects participated until the end of the study. These remaining participants still reported a significantly lower pain level than before the intervention. It would have been interesting to combine the above described study with EMG analyses to assess the muscle activation level before and after the intervention had taken place.

The prototype of the slightly modified ergo mouse - referred to as *Sico* mouse - used in our study, allows for a lateral inclination of the hand. When evaluating keyboards, KROEMER (1972) found that such a posture "about halfway between extreme pronation and supination about the long axis of the forearm, relieves the pronatory and supinatory muscles of isometric tension" (p. 52). He states that most participants in his study "preferred an angular position of the hand in the middle region between extreme pronation and supination" (p. 53) when their upper arm was hanging. Due to the possibility of lateral buckling, the *Sico* mouse should allow for a more natural and less strainful movement of the forearm and wrist when the upper arm is abducted (*Figure 2.7*) while at the same time reducing the abduction angle, thus putting less strain on the deltoid.

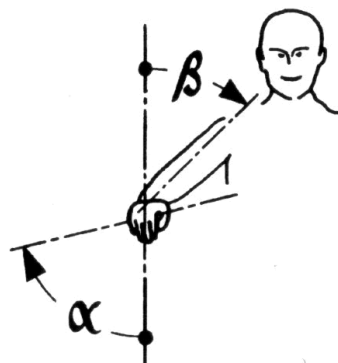


Figure 2.7 Angle of upper arm (β) and degrees of pronation (α) (KROEMER, 1972, p. 54)

The palm angle against vertical experienced as comfortable and relaxing depends on the abduction of the arm (*Figure 2.8*). This fact should be taken into consideration when designing ergonomic computer mice.

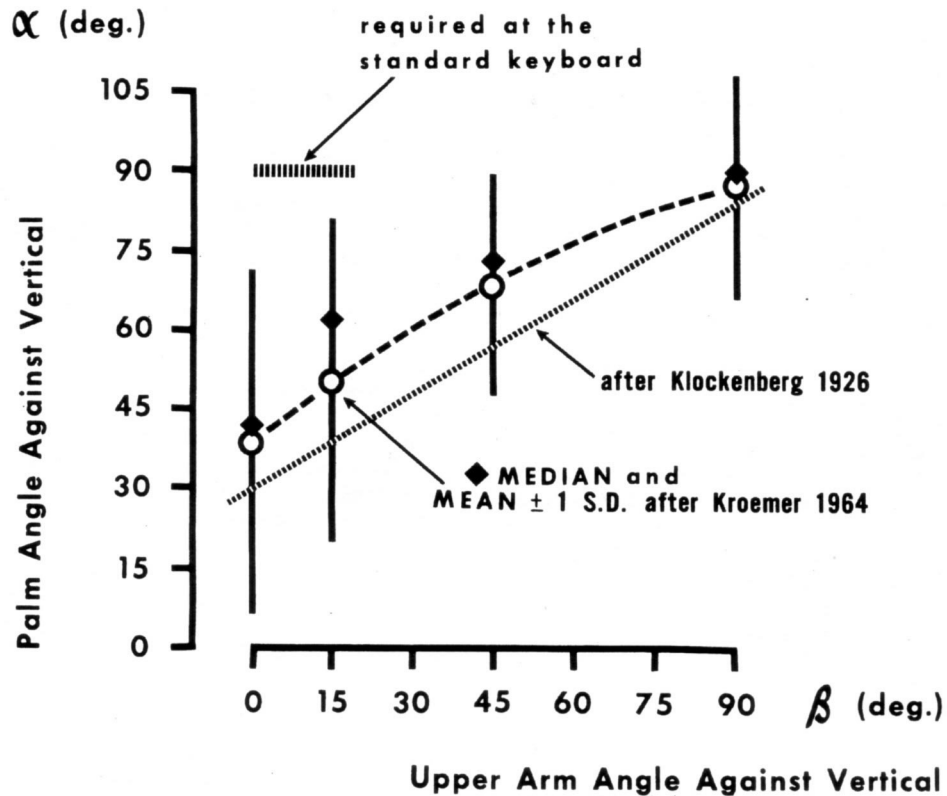


Figure 2.8 Palm position in relation to upper arm posture (KROEMER, 1972, p. 54)

2.2 Evaluation in human-computer interaction

The focus of human-computer interaction (HCI) is on the relationship between people, technology, and work environment. Core questions of this discipline would be: "What makes technology hard to use, and how can we design *better* technology" (BABER, 2005, p. 357). To ensure the human-centered design of any computer-based product, it is important to assist its development throughout the product's lifecycle, hereby influencing its design in the course of its development. Hence, evaluation "is a recursive activity" that "should be incorporated into as many stages of design as possible" (p. 381).

A central theme when discussing evaluation in HCI is *usability*. According to ISO 9241-11 (1998) usability is defined as "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" (p. 2). Efficiency is defined as the "resources expended in relation to the accuracy and completeness with which users achieve goals" (p. 2). The muscular strength mouse users have to expend to cope with different tasks

varies with the user, the muscle, the mouse, and the task respectively. In the present experiment usability was not tested as a much bigger number of participants would have been required to do so.

BABER (2005) emphasizes the 'context of use' "as a key component of usability" (p. 359) and proposes to understand usability "as a shorthand description of the complex inter-relationship between people and technology, and ... *not* as an attribute of a product" (p. 359). He also states that the usability concept, having multiple attributes, "can be measured in terms of at least 34 factors, and that using a single term ('usability') may only serve to mask to [*sic*] complexity of the inter-relationships at work" (p. 359). There is no single measure for the dependant variable 'usability' as it is multidimensional and the independent variable 'context of use' includes a great variety of contributing and confounding variables. A standard measure of 'usability' can hardly be found, as the application and interpretation of such a measure would vary according to the context of use. An engineering approach would attempt to operationalize the components of usability, and set benchmarks against which to test the product. Usability and evaluation are closely related.

Evaluation always calls for a referent model, so that various proceedings can be purposeful: Evaluation of a product against other products, against specified design targets, against (user or organizational) requirements, or evaluation against standards. A point in case would be the comparison of a newly designed product with a well-established and already commonly accepted product as it is the case in the present study.

When evaluating products against similar products, covering a possibly wide range of functions is necessary as the items compared are never *identical*. On occasions, product X might be superior to product Y whereas on other occasions the opposite might be true. Product X might be perfectly suitable to fulfill one specific task whereas product Y could be the appropriate choice for accomplishing a different task. In HCI the focus is directed on the *interaction* rather than on humans or on computers separately. As a consequence, evaluation in HCI is concerned with *user activity* rather than product functioning. One approach to HCI is the "applied science" approach aiming at the development of fundamental principles in human behavior with technology. Here, the focus is directed towards core activities by controlling or eliminating as many intertwining activities and confounding conditions as possible. Typically, the researcher will run an experiment in which participants would have to perform specific tasks under various conditions, whose results, in turn, would be compared with one another. In this case, the activity itself constitutes the referent model.

Just as in the present study, the baseline for performance under disparate conditions can differ to a minor or major extent in the conditions compared. Users might be accustomed to and experienced in the use of a traditional device (like QWERTY key-

boards or traditional computer mice), but alien to a newly developed or less common apparatus (BABER, 2005). Also, the specific tasks mouse users have to perform might influence their proneness to particular forms of MSDs (DENNERLEIN and JOHNSON, 2006; HÜNTING *et al.*, 1981). The ergonomics of the environment and the nature of the task determine postures, movements, and the repetitive character of task execution (MARKLIN *et al.*, 1999). Design work, Internet navigation and the use of interactive software programs require excessive mouse use, or the use of other pointing devices (FAGARASANU and KUMAR, 2003). Thus, JOHNSON *et al.* (1993, as cited by KEIR *et al.*, 1999) found that mouse use constituted 65% of the graphics/drawing task in an experiment with three different routine tasks.

COOPER and STRAKER (1998) compared the shoulder muscle load due to mouse use with the load due to keyboarding and discovered increased load on the anterior deltoid and decreased load on the trapezius for computer mouse use. Now, while a graphic designer may spend most of his working time using a computer mouse, a secretary may use both the keyboard and the computer mouse in a balanced ratio. In consequence of the different tasks they have to fulfill and the different manners in which they use their tools, they might develop different types of MSDs (DENNERLEIN and JOHNSON, 2006; HÜNTING *et al.*, 1981). KEIR *et al.* (1999) implemented the assessment of the influence of the task on carpal tunnel pressure by comparing the pressures measured when participants performed a point-and-click task with the pressures measured when they performed a drag-and-drop task, and found that pressures during the dragging task exceeded those measured during the pointing task.

3 - Research questions and hypotheses

The present study compared the load of three differently designed computer mice (a traditional mouse, a joystick-like vertical mouse, and a slightly modified vertical mouse) on the musculoskeletal systems of the forearm and the shoulder by means of EMG.

While experimenting with the Anir mouse prior to the actual experimental setup, we found the forearm position when using the Anir mouse for tasks requiring swift and expansive movements rather uncomfortable, as the fixed mouse handle forces the arm in awkward positions when the abduction angle of the upper arm increases. Also, when moving the elbow forwards and sideways, considerably more muscle activity in the anterior deltoid was experienced using the Anir mouse as compared to the traditional mouse. With the use of the modified slightly flexible ergo mouse, on the other hand, such movements became smoother and seemed less strenuous for the shoulder muscles. This experience is consistent with the findings illustrated in *Figure 2.7* and *Figure 2.8*. Thus, for the assessment of the shoulder muscle activity in addition to the upper trapezius assessed in the study of AARÅS and RO (1997) the anterior deltoid (COOPER and STRAKER, 1998; ISO 9241-9, 2000) was selected.

AARÅS and RO (1997) used a single task (tracing) for the assessment of workload in their study. ISO 9241-9 (2000) states that "input devices should be tested for the tasks for which they are intended to be used" (p. 35). Therefore, the tasks selected for this study represent a variety of typical every day tasks for computer mouse users: Drag-and-drop is typical for word processing, point-and-click is representative for Internet navigation and tracing is commonly used in many design tasks, to cite only a few examples.

The objective of the experiment was to find out (1) how muscle load would differ for shoulder and forearm muscles when using the three differently designed computer mice, (2) whether different mice might yield different results in terms of muscular load for different tasks, and (3) if the usage of the Sico mouse prototype would add to lessen overall or specific muscular load by allowing a sideward movement of the mouse handle.

Expected results were (1) reduced muscle activity in the forearm muscles when using the ergo mice as compared to the traditional mouse and increased activity in the shoulder muscles, (2) increased activity for the 3M mouse (compared to the Sico mouse) in the anterior deltoid for the point-and-click task because of the expansive movements required, and (3) decreased muscle activity in the forearm and deltoid when using the Sico mouse as compared to the 3M mouse.

4 - Methods

4.1 Electromyography - EMG

4.1.1 *The use of electromyography for the assessment of muscle load*

Surface electromyography (sEMG) is a common method for the evaluation of muscular activity. Using sEMG enables the researcher to find out which muscles are active to what degree and to estimate muscle force. Thus, correctly employed, sEMG "assists in evaluating the relative risk of a work task" (ANKRUM, 2000, p. 530). The amount of effort an action or force exerts on a muscle is called muscle load. ISO 9241-9 (2000) proposes EMG recording to assess the muscle load imposed by frequently or continuously used input devices, as EMG is empirically related to the force exertion for a given posture. EMG measures the level of muscle activity occurring over a period of time. "The most reliable biomechanical load comparisons are measures from identical muscle groups and the same postures across devices" (p. 46). The present study is designed to compare identical muscle groups *within* subjects while they are coping with different tasks across different computer mice. This first expenditure estimate in terms of muscle activity could lead to further investigation about the efficiency of differently designed computer mice in terms of performance and the coping with different tasks.

4.1.2 *EMG basics*

As soon as muscle fibers or bundles of muscle fibers contract, action potentials are generated. They can be measured with electrodes, and then be recorded with sufficiently sensitive amplifying equipment (ROHMERT and LAURIG, 1993). In contrast to medical research where examiners use needle electrodes for EMG, occupational researchers use mainly surface electrodes, which are non-invasive and do not hurt the participants. These - usually self-adhesive - electrodes are placed over the central part of the muscle (CORLETT, 2005) to assess the level of muscle activity over a period of time. Findings report a high correlation between EMG activity and muscular force, for static as well as for dynamic activities (HAGBERG, 1981, as cited by CORLETT, 2005) which makes sEMG a perfectly suitable method for the assessment of musculoskeletal load.

Surface electromyographic signals are the temporal and spatial summation of motor unit action potentials (MUAPs) providing information in a frequency range from only a few Hz to approximately 1500 Hz. The main energy, however, can be found in the band below 70 Hz (STRASSER, 1999). EMG "can also ... show the presence of muscle fatigue, a state when the skeletal muscle is unable to maintain the required force of contraction" (HAGBERG, 1981, as cited by CORLETT, 2005, p. 475). Fatigue

processes of the muscles lead to an increase in the low frequencies of the signal and a decrease of higher frequency components. However, the changes in the frequency domain are not important enough to reliably correlate them with graduation of muscular fatigue. Therefore researchers in the fields of ergonomics and work medicine preeminently take an interest in the amplitudes of the bioelectrical activity (STRASSER, 1999).

During the relaxation phase of a muscle, the EMG baseline should be more or less noise-free. The EMG signal is very sensitive. Its range starts from only a few micro-volt, making it liable to external noise sources or other artifact sources such as baseline offsets (constant baseline shifts), ECG artifacts (when measuring close to the heart), or increased (50/60 Hz) baseline noise due to interfering power hum, to only mention a few hazards. However, proper skin preparation and correct electrode positioning help to avoid most artifacts. Prior to electrode fixation parallel to muscle fibers with an inter electrode distance of approximately 20 mm, the skin has to be thoroughly cleansed with alcohol and shaved where necessary. To increase selectivity and avoid the risk of dislocation when the muscle is moving, it is advisable to choose middle belly portions of the muscle for electrode placement. If dynamic movements are assessed, all leads should be well fixed (e. g. with duct tape) to avoid lever forces on the electrodes (KONRAD, 2005).

To display and analyze signals in a computer, they have to be converted from analog voltage to digital signals. For proper conversion of the expected amplitude range for most kinesiological setups a 12 bit A/D board will suffice. Very small signals might need a higher amplification to achieve a better amplitude resolution. Another important technical item in EMG research is the signal sampling frequency. According to the Nyquist theorem, in order to accurately convert the complete spectrum of the signal, the sampling frequency has to be at least twice as high as the signal bandwidth. If this sampling condition is not satisfied aliasing effects will occur because frequencies higher than the Nyquist limit will fold into the frequency range below the limit. Now, almost all of the EMG signal power is located in the band between 10 and 250 Hz so that scientific recommendations (SENIAM, ISEK) require an amplifier band setting of 10 to 500 Hz. Therefore a sampling frequency of at least 1000 Hz is advisable, i. e. the double band of EMG (KONRAD, 2005).

One method for EMG analysis is the integrated EMG (IEMG), a measure of the power of the signal. Hereby the signal is integrated over a time interval.

Integrating circuits accumulate the root mean square (rms) values of the signal, recording them until a certain selected total value has been reached and then starting the addition again. The visual record shows a series of triangular waves, with equal peaks, but spaced more closely where the EMG signal is greater. Counting the peaks per unit time or calculating the rms value, again

per unit time, provides values representative of the muscular activity.
(CORLETT, 2005, p. 477)

The rms algorithm is defined for a time window. Values range from 20 ms for fast movements (jump, reflex) to 500 ms for slow or static activities. A value between 50 and 100 ms works well for most EMG experiments (KONRAD, 2005).

Under static load the electromyographic activity (EA), the envelope of the rectified and integrated raw EMG signal, correlates with the exerted force. EA is a suitable parameter when it comes to physiological costs of manual work e. g. quantifying the effort and muscular activity which has to be put into a task under given working conditions or differentiating between more or less effectively designed working devices (STRASSER, 1999) like it was the case in this study.

The amplitude mean value of a selected analysis interval is probably the most important EMG-calculation, because it is less sensitive to duration differences of analysis intervals. The mean EMG value best describes the gross innervation input of a selected muscle for a given task and works best for comparison analysis. The Area is the true mathematical integral under the EMG amplitude for a certain analysis period. Depending on the point of view, it has the benefit or drawback of being directly dependent on the time duration selected for an analysis (KONRAD, 2005).

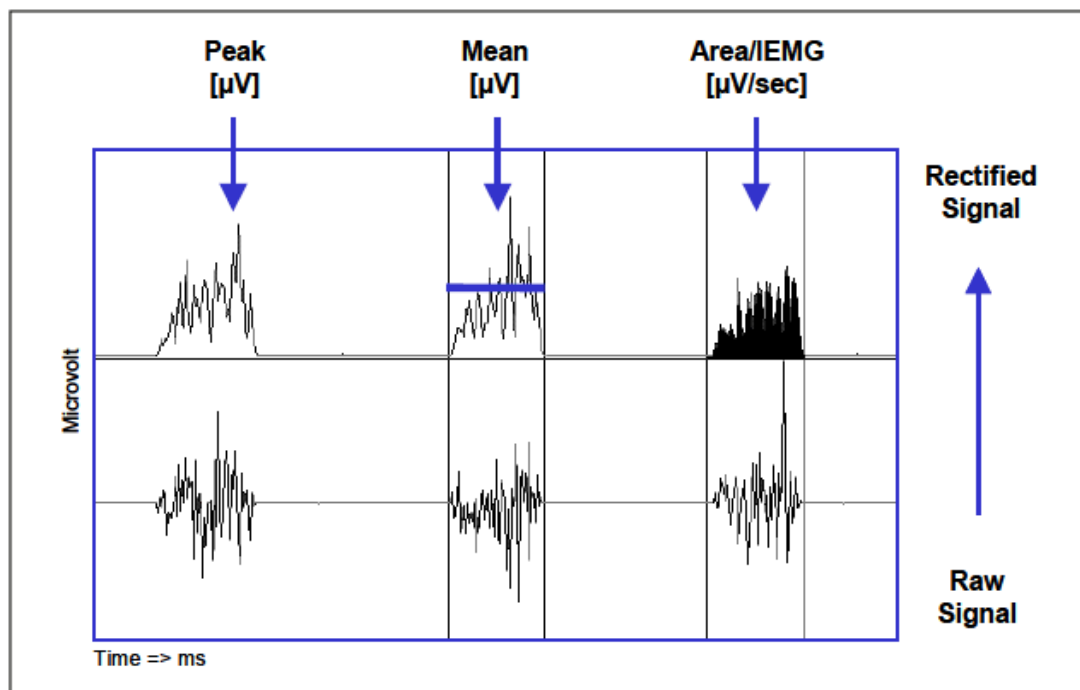


Figure 4.1 EMG standard amplitude parameters (KONRAD, 2005, p. 39)

4.1.3 EMG study design

When designing an EMG study several crucial points have to be considered: Even among participants performing precisely the same task, there is a substantial inter-individual variation in terms of EMG signal output (BALOGH *et al.*, 1999, as cited by NORDANDER *et al.*, 2003). SCHNOZ *et al.* (2000) report substantial individual differences in trapezius muscle activity for a simple finger motor task at different rates and different trunk postures, ranging from insignificant in some participants to 28% for the dynamic component in others. Similarly, KONRAD (2005) points out that the microvolt scaled amplitude "can strongly vary between electrode sites, subjects and even day to day measures of the same muscle site" (p. 29) making inter-individual comparison difficult.

As a consequence, various approaches to resolve this issue have been proposed, one of them being the normalization of the EMG parameters to a reference value, which can be the maximum voluntary contraction (MVC) value of a reference contraction performed by an individual during the experiment. Another approach would be normalization to the internal mean value, to a given trial, or to the level of a sub-maximal reference activity. The aim, these methods have in common, is to eliminate the influence of a certain unstable detection condition and to rescale the data from microvolt to percent of the adopted reference value to allow for a direct quantitative comparison of EMG values between subjects.

However, "valid MVC data can only be produced with healthy subjects ... prepared (trained) for the MVC test series. This may make the methodological organization of a study very demanding and time consuming" (p. 33) and even in healthy subjects, some uncertainties like the questions whether the subject is able to perform a valid trial, whether the test exercise correctly 'caught' the respective muscle, etc. may be left unresolved. Another drawback is the recording of small amplitudes as "on the microvolt level, it is impossible to estimate the neuromuscular demand because these data are too strongly influenced by the individual signal detection condition. Any 'normative' amplitude data published in microvolt values must be used with very special care" (p.33).

For the present study only intra-individual differences were of interest. Consequently, we used a within design so that the above mentioned issues could be neglected. If conditions are to be compared, like the EMG output when using different devices for the same task, the question whether muscles are more or less active is addressed. When the same subject and muscle is assessed without removing the electrodes between trials, the muscle activity of the same muscle can directly be compared in different test positions and curve characteristics can be described (KONRAD, 2005).

4.2 Participants

LAURSEN and JENSEN (2000) assessed the influence of age on computer work and found a significantly greater trapezius muscle activity in older participants compared to younger ones, as well as a tendency to greater activity of the neck extensor muscles and the deltoid muscle. Due to this fact participants in a relatively narrow range of age were selected for the present study.

After informed consent 9 healthy male volunteers participated in the experiment (age $\bar{x} = 24.7$ years [SD 5.55]; BMI $\bar{x} = 23$ [SD 1.66]; computer work in hours/week $\bar{x} = 26.8$ [SD 17.73]; sports in hours/week $\bar{x} = 5$ hrs [SD 2.37]). All participants were right-handed, familiar with computer mouse usage, and reported no prior musculoskeletal pain in the forearm or shoulder region.

After the experiment had taken place, participants completed a demographic questionnaire and received 15 Euro as compensation for taking part in the study.

4.3 Independent variables

4.3.1 Tasks

The experimental tasks used for this study were designed to allow for the assessment of an important variety of movements used in every day computer work: Task 1 [CYC] required high velocity and precision at the same time because the task had to be performed at maximum possible speed and the mouse had to be positioned within a fraction of a millimeter to click off little circles. Such movements are characteristic for Internet navigation or computer game playing.

Task 2 [TXT] was designed as an example for a typical word processing task and included drag-and-drop which implied the depressing of the right mouse button while the mouse was moved (LAURSEN and JENSEN, 2000).

Task 3 [FIG] was a task representative for graphic design work (tracing) which demanded great accuracy as the mouse had to be moved in a predetermined way. To put emphasis on physical differentiation of muscle load and avoid distracting the participants, all tasks were designed to require minimum mental demands.

Figure 4.2 depicts the positioning of the three tasks within the dimensions "speed" and "accuracy".

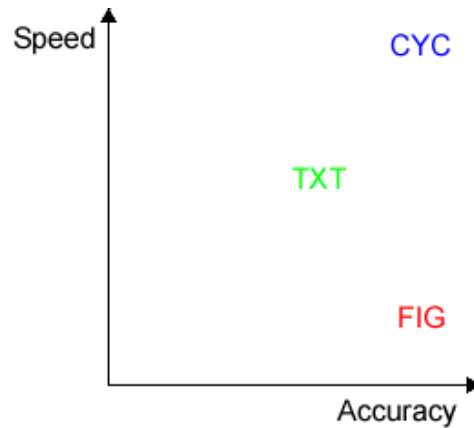


Figure 4.2 Task positioning within the dimensions speed and accuracy

Participants performed each of the three tasks with each of the three mice: For task 1 (point-and-click) 150 little circles were presented one after the other, distributed in set order all over the screen. As soon as one circle was clicked off the next one appeared. Task 2, the word processing task (drag-and-drop), consisted of one and a half page where 35 couples or triples of words were highlighted at a random location. Participants were instructed to select all these fragments with the mouse and change their color to red and their weight to bold until they reached the end of the text. In a second step they had to cut these previously processed words and paste them line by line into a list inserted below the text until the list was complete. Task 3 consisted in tracing various geometrical figures in an interactive flash movie (made with Macromedia Flash MX v. 6.0) from the left to the right (*Figure 4.3*) (all tasks are included in the digital appendix).

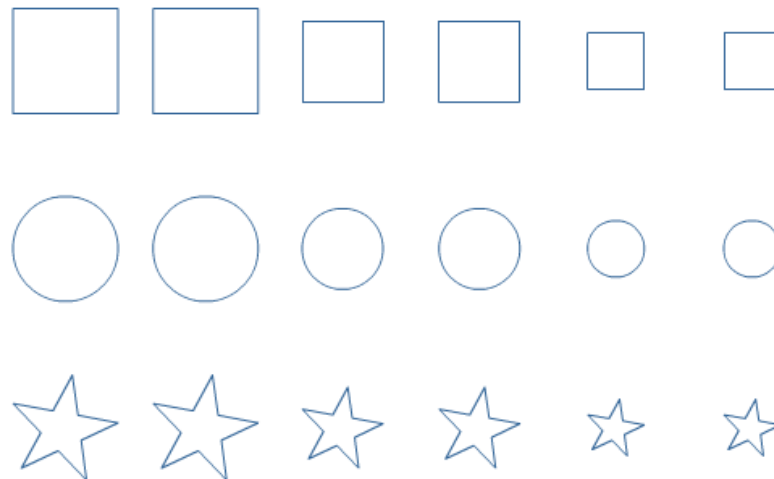


Figure 4.3 Screenshot of figure tracing task

Participants were instructed to complete the drag-and-drop and the tracing task at a speed they normally used with attention (for the figure tracing task) to careful tracing of the lines. They were instructed to work at maximum speed when performing the point-and-click task. Time was not restricted: each task had to be fully executed. This resulted in differences in total trial length over participants and tasks.

4.3.2 Computer mice

Three differently designed computer mice were used in the experiment: a traditionally designed computer mouse (*Figure 4.4*) with disabled scroll wheel (masked with duct tape), designed to be held with a pronated hand position, an ergonomic (vertical) mouse by 3M (*Figure 4.5*), held with a neutral hand position (the ulnar side of the hand and wrist is resting on the mouse), and a slightly modified 3M mouse with a piece (10 mm height) of foamed rubber (*Figure 4.6*) inserted at the basis of the handle to allow for approximately 20° lateral buckling of the mouse handle (measurements of foamed rubber at maximum deflection: 14 mm; at maximum compression: 2 mm).



Figure 4.4 Traditional mouse with disabled scroll wheel

3M ergo mice are available in medium and large size. A medium sized mouse was used to insert the foamed rubber piece, which evened out the difference to the large sized ergo mouse so that at the end both ergo mice [Sico and Ergo] had the same size and height. The ergo mice had a lateral button which was not used by the participants. They were asked to ignore it.



Figure 4.5 3M vertical mouse (Anir mouse)



Figure 4.6 Foamed rubber at basis of the Sico mouse

4.3.3 Muscles

The muscular activity was registered by means of surface EMG from four muscles (*Figure 4.7 - Figure 4.10*) of the right forearm and shoulder. According to HÄGG and MILERAD (1996, cited by AARÅS and RO, 1997) both static load and fatigue effects are usually larger on the extensor muscles (due to their stabilizing functions) compared with the flexor muscles of the forearm. Therefore two extensor muscles were chosen to measure the EMG activity of the forearm: the extensor carpi ulnaris (ECU) [channel 1] acting to extend and abduct the hand in the wrist, and the extensor digitorum (ED) [channel 2], responsible for dorsal extension and acting as antagonist of the flexor muscles (STRASSER *et al.*, 2004).

Increased abduction and flexion of the upper arm in the shoulder joint are important risk indicators for MSD in the neck and shoulder region (AARÅS, 1994a). To assess the load on the shoulder and neck muscles the deltoideus pars anterior [channel 3], involved in the forward moving of the arm, and the trapezius pars descendens [channel 4] "which is responsible for the drawing up or keeping the shoulder in position, and which normally has to be regarded as a bottle-neck muscle in sedentary work" (STRASSER *et al.*, 2004, p.111) and which is most often associated with myalgia (ANKRUM, 2000) were chosen.



Figure 4.7 *Extensor carpi ulnaris*



Figure 4.8 *Extensor digitorum*

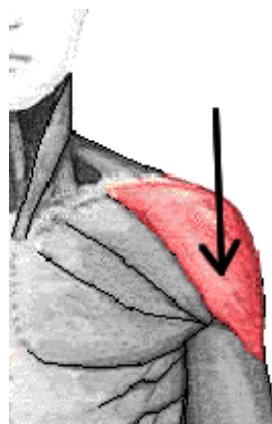


Figure 4.9 *Deltoideus pars clavicularis*

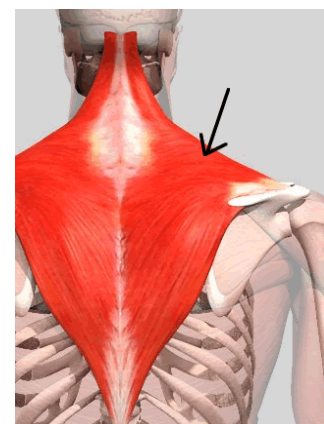


Figure 4.10 *Trapezius pars descendens*

4.4 Dependent variables

The dependent variables were the EA of the four muscles assessed in this study in μV .

4.5 Experimental design

The experiment was a 3 (mouse) \times 3 (task) \times 4 (muscle) factorial design with repeated measures on all factors. The factors - with their respective levels in brackets - were computer mouse (conventional mouse by DELL [*Norm*], an ergo mouse by 3M [*Ergo*], and the modified ergo mouse [*Sico*] described in the 'computer mice' section-4.3.2), task (click away little cycles appearing on the screen [*CYC*], word processing [*TXT*], and tracing outlines of geometric figures [*FIG*]), and muscle from which EMG activity was recorded (extensor carpi ulnaris [*ECU*], extensor digitorum [*ED*], deltoideus pars anterior, and trapezius pars descendens). The four muscles were treated as factors to achieve a clearer picture of the interaction effects as mouse and task effects always depend on the respective muscle used.

To control for transfer between tasks and the use of different mice and to counterbalance order effects from the repeated measurements a Greco-Latin square design was used. A Greco-Latin square is a combination of two orthogonal Latin squares, a Latin square being defined as "a balanced two-way classification scheme" (WINER, BROWN and MICHELS, 1991, p. 674). In a 3 \times 3 design, for example, each letter (a, b, c) occurs only once in each column and in each row.

Two Latin squares are called orthogonal, if their composite leads to a new arrangement where each combination of the factorial levels appears just once, as illustrated below (*Figure 4.11*).

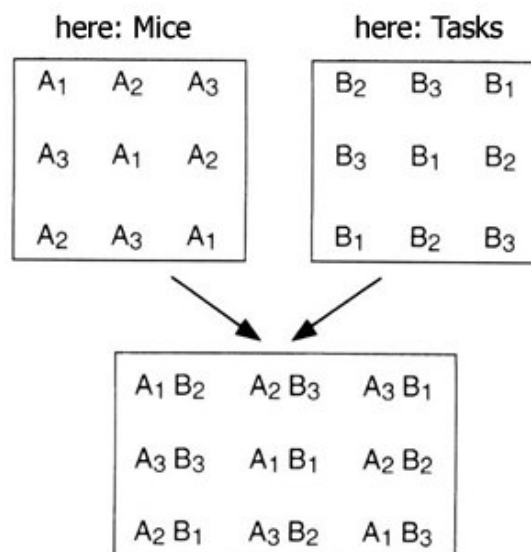


Figure 4.11 Orthogonal Greco-Latin square (BORTZ and DÖRING, 2002, p. 543)

It is possible to conduct studies according to this scheme whenever the number of factorial levels of all factors is equal and the construction of two orthogonal Latin squares is possible (BORTZ and DÖRING, 2002).

As this was a first study the number of participants was limited to 9. A higher number of participants would be preferable in further studies. Each of the 9 participants was randomly assigned to one of the Greco-Latin squares (*Table 4.1*). Each of the squares was unique so that the intended balance was ensured. The first number in each sub-square stands for the number of the mouse; the second number is reserved for the task number respectively. The order of the trial procedure was from left to right and from the top to the bottom.

Table 4.1

Experimental Design

Greco-Latin Square	subject #									
<table><tr><td>(1,1)</td><td>(2,2)</td><td>(3,3)</td></tr><tr><td>(3,2)</td><td>(1,3)</td><td>(2,1)</td></tr><tr><td>(2,3)</td><td>(3,1)</td><td>(1,2)</td></tr></table>	(1,1)	(2,2)	(3,3)	(3,2)	(1,3)	(2,1)	(2,3)	(3,1)	(1,2)	1
(1,1)	(2,2)	(3,3)								
(3,2)	(1,3)	(2,1)								
(2,3)	(3,1)	(1,2)								
<table><tr><td>(3,1)</td><td>(2,3)</td><td>(1,2)</td></tr><tr><td>(2,2)</td><td>(1,1)</td><td>(3,3)</td></tr><tr><td>(1,3)</td><td>(3,2)</td><td>(2,1)</td></tr></table>	(3,1)	(2,3)	(1,2)	(2,2)	(1,1)	(3,3)	(1,3)	(3,2)	(2,1)	2
(3,1)	(2,3)	(1,2)								
(2,2)	(1,1)	(3,3)								
(1,3)	(3,2)	(2,1)								
<table><tr><td>(3,2)</td><td>(2,1)</td><td>(1,3)</td></tr><tr><td>(1,1)</td><td>(3,3)</td><td>(2,2)</td></tr><tr><td>(2,3)</td><td>(1,2)</td><td>(3,1)</td></tr></table>	(3,2)	(2,1)	(1,3)	(1,1)	(3,3)	(2,2)	(2,3)	(1,2)	(3,1)	3
(3,2)	(2,1)	(1,3)								
(1,1)	(3,3)	(2,2)								
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(1,3)	(3,2)	(2,1)								
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(3,3)	(1,1)	(2,2)								
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(2,2)	(3,3)	(1,1)								
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4.6 Experimental set-up

OKSA, DUCHARME and RINTAMÄKI (2002) compared EMG activity and fatigue of the forearm muscles in thermoneutral and cold conditions and found higher muscle activity and accelerated muscle fatigue in cold conditions as compared with the warmer conditions (HOLEWIJN and HEUS, 1992). Thus, temperature in the laboratory was controlled and kept around 24°C throughout the experiment to minimize any experimental error due to temperature.

For grounding purposes, it was necessary to record an ECG, which is not discussed in this study [channel 0], with electrodes placed over the upper sternal border, the lower sternal border and the left mid-axillary line.

The electrodes were applied in the following way: The ED [channel 2] was palpated for the active muscle mass approximately three quarters of the distance from the elbow to the wrist while the participants extended their fingers. The ECU [channel 1] was palpated on the ulnar side of the arm a few centimeters below the ED. The position for the electrodes assessing the deltoideus pars clavicularis [channel 3] was palpated on the shoulder, centered (anterior) vertically, below the lateral end of the clavicle. For the trapezius pars descendens [channel 4] the electrodes were placed half-way between the angle of the acromion and the seventh cervical vertebrae, after palpating for the muscle belly.

Muscle activity was measured using a non-invasive EMG system. Self-adhesive Ag/AgCl surface electrodes were placed in pairs on the skin overlying the above mentioned muscles. The electrodes (24 mm in diameter) were oriented parallel to the muscle fibers with an interelectrode distance of 20 mm. Prior to electrode application, the skin over each muscle was dry shaved where necessary, cleansed with alcohol (96%) and rubbed until it appeared slightly red, a procedure applied to reduce the impedance at the skin electrode interface (CLANCY, MORIN and MERLETTI, 2002). EMG signals were sampled at 1000 Hz per channel, amplified (gain of 1000) and band-pass filtered (10–400 Hz) using BIOVISION cable-integrated amplifiers. The signals were monitored in real time for quality control.

Signals were then passed through a BIOVISION input-box (integrated power supply 2×1,5V) connected to a PocketPC with a PCMCIA 16 bit A/D card for analysis. EMG data was registered with the PLab software (v 1.0, Stiegele Datensysteme GmbH, Germany) and monitored with PView light (v. 1.0). The electrodes were not removed throughout the study, so that a direct comparison between the muscles loads in microvolt when using the three types of computer mice would be possible (AARÅS and RO, 1997).

For verification of the EMG positioning and the quality of the signal and standardization, participants were asked to sit down - before the experiment proper - in a relaxed posture with both hands and forearms resting on the table. After visual inspection of

the EMG signal and finding the muscles relaxed to a maximum extent, the resting EMG was recorded simultaneously from all muscles over a couple of seconds.

The working area (*Figure 4.12*) consisted of a conventional straight edged desk with a desk pad used as substitution for a mouse pad given the relatively wide motion range an ergonomic mouse needs, a standard keyboard (to simulate a realistic working place) with keypad and a height adjustable 17" flat screen. Before starting to work, participants were seated on an office chair, individually adjusted to enable them to place the feet flat on the ground. The mouse was at elbow height so that its use did not require shoulder flexion. Participants were centered in front of the monitor and the keyboard, the keyboard center defined by the notch between the "B" and "N" keys. In the beginning of the experiment they rested their forearms, but not the elbow, on the desk. They could, however, choose their natural and comfortable working position during the experiment. All participants - except participants 8 and 9 - left their forearms on the desk throughout the experiment.



Figure 4.12 *Laboratory setting*

Each trial was initiated by a verbal prompt and ended when the trial was accomplished. After each trial, data were checked and saved to the hard drive of the laptop for backup, a process that took between 20 and 40 seconds. During this time participants rested.

Each one of the three tasks was performed with each of the three mice according to the Greco-Latin-Square design described above (*Table 4.1*). All tasks were performed solely by using the mouse and all participants were experienced traditional

mouse users. Prior to the actual experiment participants trained on two occasions with the ergonomic 3M mouse: first they came in to practice half an hour on the above mentioned tasks to familiarize themselves with the vertical mouse. A few days later they came in a second time to perform a complete test run of the projected experiment, whereby experimental tasks were explained and instructions were given verbally. Participants were randomly assigned to the Greco-Latin squares. One to two weeks later they came in for the actual experiment and were assigned the Greco-Latin square following the square used during the trial condition.

4.7 Statistical analysis

The raw EMG signals were visualized and the data were exported as ASCII (.txt) files with MGraph (v. 1.00, Stiegele Datensysteme, Germany). They were converted from V to μV for further analyses.

After visual inspection of the raw data and manual artifact removal all negative amplitudes of the signal were converted to positive amplitudes in MATLAB (R2007a) by inverting the negative spikes to plus to be able to apply standard amplitude parameters like mean value to the curve (the mean value of a raw EMG is 0).

EMG activity was integrated over the total time of the respective trial intervals.

$$EA = \frac{1}{T} \int_t^{t+T} |EMG(t)| dt$$

Resulting mean values (microvolt per millisecond) were imported into SPSS for Windows (v. 15.0) where the ANOVAS were run. As a matter of principle SPSS computes a MANOVA as soon as a within design is involved. So, whether an ANOVA or a MANOVA is computed makes no interpretive difference in this case.

One ANOVA was run where all factors (mouse, task, muscle) were included as repeated measurements, and a second ANOVA where all values were transformed to logarithmic values (to reduce within-cell variances; for details compare digital appendix, A.1 and A.6).

Editing of the images was completed with Macromedia Fireworks MX (v. 6.0).

5 - Results

5.1 Muscle activation

As mentioned before, the electromyographic activity (EA) correlates with the exerted force (i. e. muscle load) (STRASSER, 1999).

Over all three computer mice and tasks, the EA of the extensor carpi ulnaris was the highest ($\bar{x} = 41.79$ [SD 17.39]), followed by the extensor digitorum ($\bar{x} = 26.26$ [SD 14.99]), the deltoid ($\bar{x} = 15.35$ [SD 14.14]), and the trapezius ($\bar{x} = 8.98$ [SD 5.19]).

Table 5.1
Descriptive Statistics of Muscle Activation by Mouse and Muscle

	mouse	Mean	Std. Deviation	N
ECU	Norm	48.675781	22.2330973	27
	Sico	38.215948	12.8923105	27
	Ergo	38.501733	14.0343153	27
	Total	41.797821	17.3966954	81
ED	Norm	40.625822	14.6678484	27
	Sico	19.403874	8.4466711	27
	Ergo	18.764926	9.1684102	27
	Total	26.264874	14.9968535	81
Deltoid	Norm	4.160285	2.0376454	27
	Sico	21.466056	15.5700465	27
	Ergo	20.427478	13.1707205	27
	Total	15.351273	14.1456313	81
Trapezius	Norm	6.269737	4.5024849	27
	Sico	11.000804	5.4116828	27
	Ergo	9.697100	4.5985620	27
	Total	8.989214	5.1971229	81

Table 5.1 illustrates that - with exception of the trapezius - the values of the EA differed considerably between the traditional mouse and the ergo mice. The traditional mouse put more load on the forearm muscles whereas the ergo mice put more load on the deltoid. Only minor differences were found in the trapezius.

5.2 Analyses of Variance

As mouse and task effects depend on the respective muscles, a three-way repeated measures ANOVA (Table 5.2) was run to test for the effects of the three different mice and tasks and the effects of the different muscles as well as their combined effects. *P* values less than .05 were considered significant.

Table 5.2

Tests of Within-Subjects Effects - interaction effects and main effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
task	194.271	2	97.136	2.169	.147
	716.690	16	44.793		
muscle	50121.342	3	16707.114	26.733	.000
	14999.011	24	624.959		
mouse	568.295	2	284.148	4.052	.038
	1122.136	16	70.133		
task * muscle	980.373	6	163.395	3.682	.004
	2130.367	48	44.383		
task * mouse	416.951	4	104.238	2.406	.070
	1386.195	32	43.319		
muscle * mouse	15115.992	6	2519.332	14.462	.000
	8361.873	48	174.206		
task * muscle * mouse	660.459	12	55.038	3.296	.001
	1603.240	96	16.700		

a Computed using alpha = .05

The within subjects ANOVA of the mean EMG parameters revealed a significant three-way interaction effect (task by muscle by mouse) $F_{(12,96)} = 3.296$, $p = .001$, and significant interaction effects for task by muscle $F_{(6,48)} = 3.682$, $p = .004$, and muscle by mouse $F_{(6,48)} = 14.462$, $p = .000$. Main effects mouse $F_{(2,16)} = 4.052$, $p = .038$, and muscle $F_{(3,24)} = 26.733$, $p = .000$ were also significant.

The electromyographic data obtained in this study were normally distributed (Table 5.3; for details see digital appendix, A.5). Nevertheless, a logarithmic transformation (\log_{10}) was performed to reduce the within-cell variances. Thus ANOVAs were run with the original as well as with the transformed data. Overall results equaled the original results with the exception that task became a significant main effect ($F_{(2,16)} = 4.066$, $p = .037$) and no interaction effect was found for task by mouse ($F_{(4,32)} = 1.545$, $p = .213$) for the transformed values, whereas with the original data this effect was close to significant (for details see digital appendix, A.1).

Table 5.3

Tests of Normality

	Kolmogorov-Smirnov(a)			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
ECU	.171	9	.200(*)	.949	9	.680
ED	.240	9	.142	.889	9	.195
Deltoid	.171	9	.200(*)	.924	9	.429
Trapezius	.139	9	.200(*)	.977	9	.948

* This is a lower bound of the true significance.

a. Lilliefors Significance Correction

5.2.1 Effects grouped by muscle

On the following pages the results are presented according to individual muscles.

The amplitude of the EMG signal for the extensor carpi ulnaris was largest for all tasks when using the traditional mouse (*Figure 5.1*). The Sico mouse yielded the least activity for the tracing task [FIG], where it outstripped the Ergo mouse. The Ergo mouse yielded the least activity for the point-and-click task [CYC] compared to the other computer mice. In the word processing [TXT] task results were alike for both ergonomic mice.

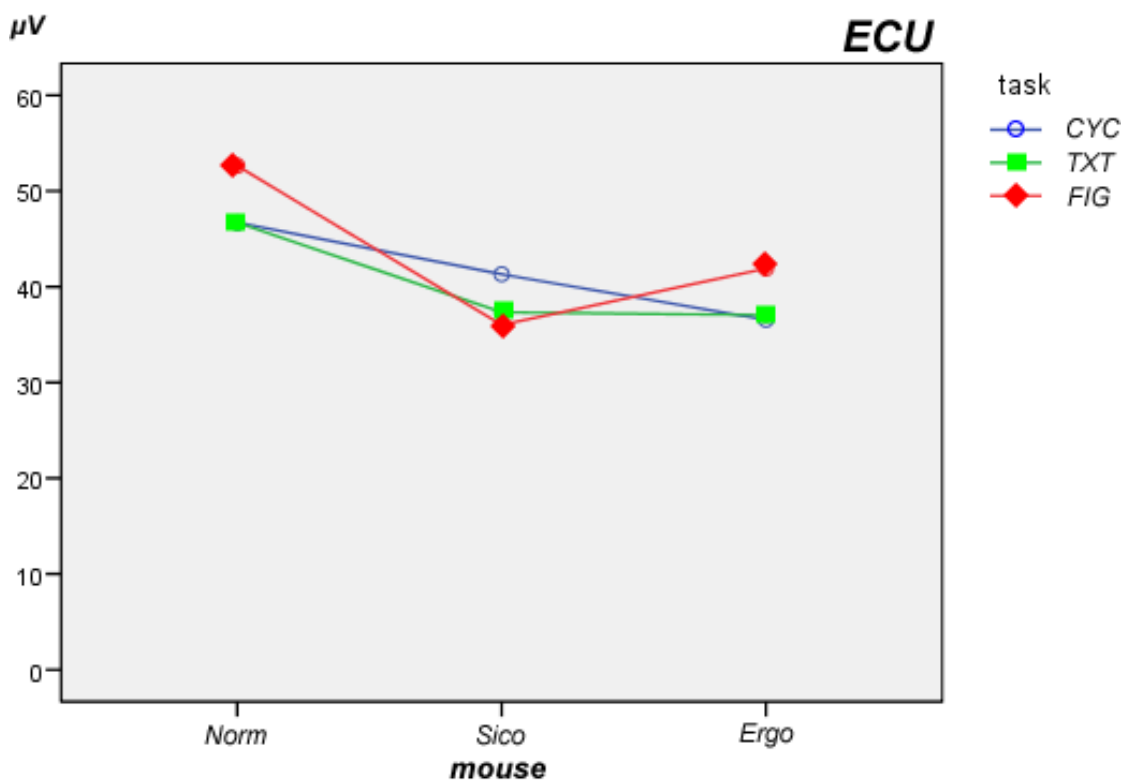


Figure 5.1 EA of mouse by task by extensor carpi ulnaris

As *Figure 5.2* illustrates, important differences in the EA were found for the traditional computer mouse in the extensor digitorum as compared to the ergonomic computer mice. The two ergonomic mice clearly outperformed the traditional mouse for each of the three tasks. The Sico mouse achieved slightly better results than the Ergo mouse in the tracing task [FIG].

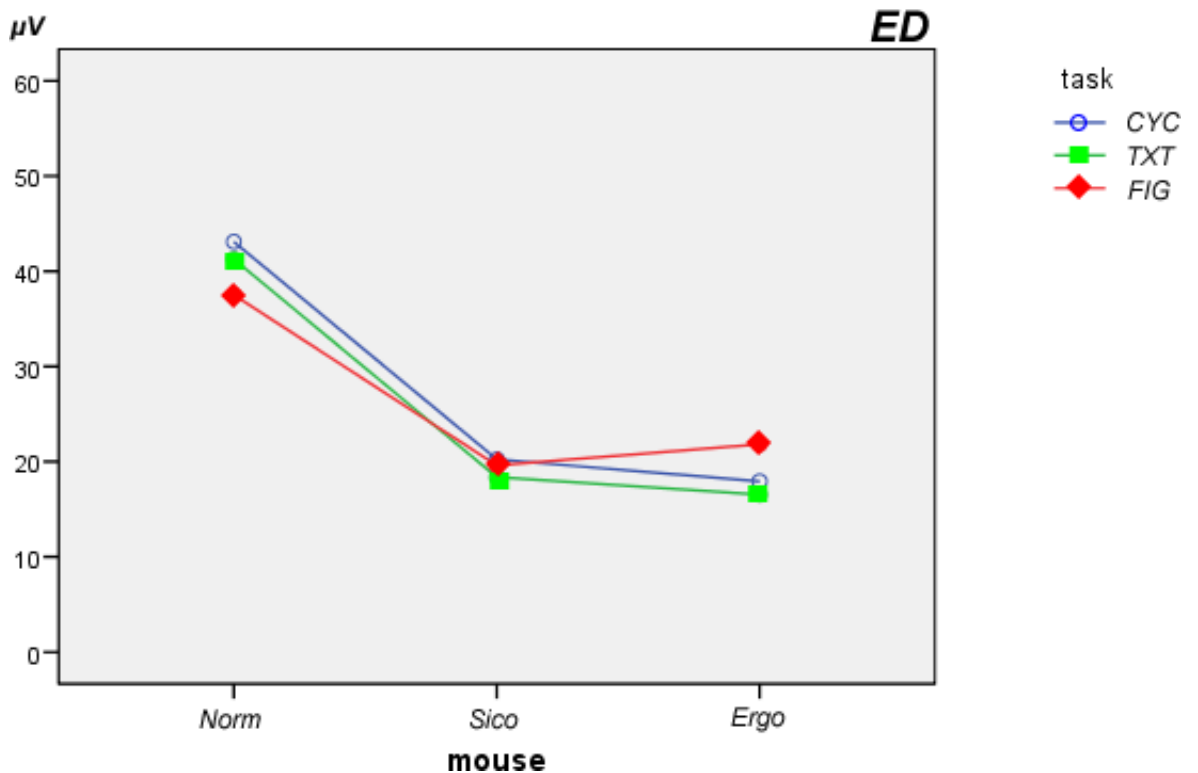


Figure 5.2 EA of mouse by task by extensor digitorum

The traditional mouse yielded the lowest muscle load in the deltoid (*Figure 5.3*) with each of the three tasks. Both the Ergo and the Sico mouse performed best with the tracing [FIG] task. The muscle load for the point-and-click [CYC] and drag-and-drop [TXT] tasks increased when using the ergonomic mice as compared to the traditional mouse. A Tukey HSD multiple comparison test showed significant differences (.031) between the tracing task and the point-and-click task in the deltoid. There was a discrepancy between the original data and the logarithmically transformed data for the deltoid which will be discussed in detail in paragraph 5.2.4 .

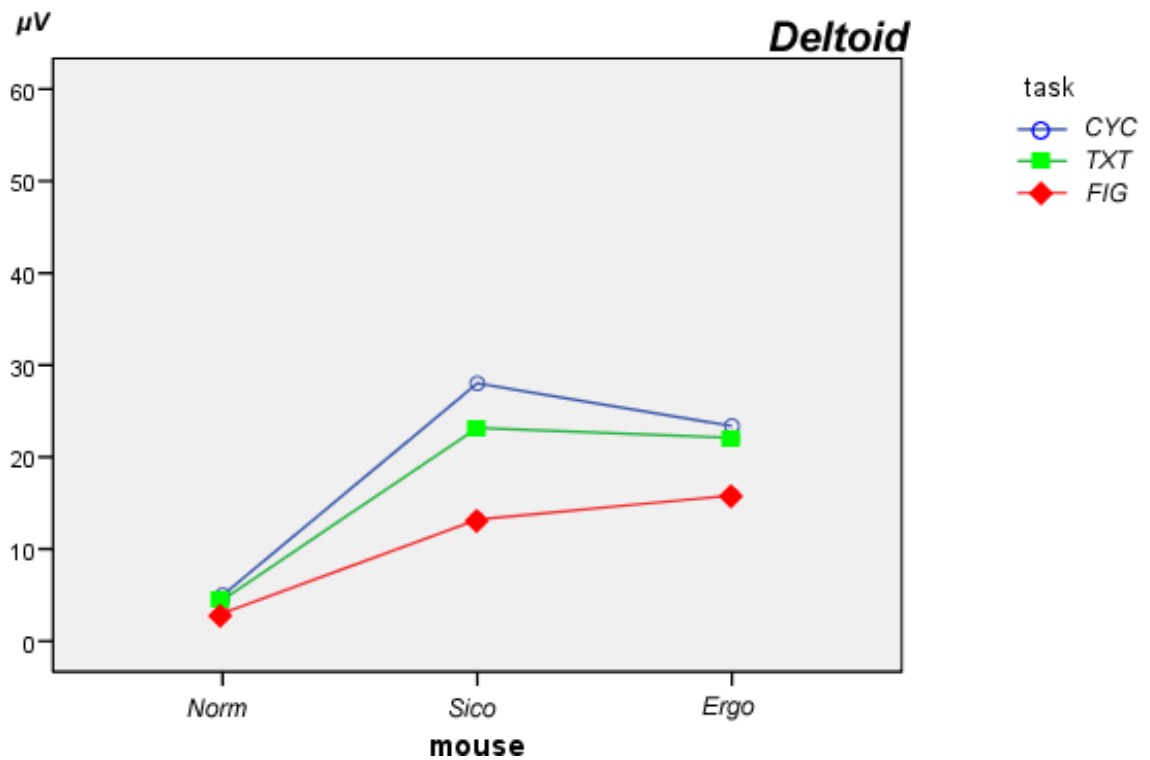


Figure 5.3 EA of mouse by task by deltoid

In the Trapezius (*Figure 5.4*) the traditional mouse yielded the least EA and the word processing [TXT] task demanded the greatest activity when participants used the ergonomic mice. Overall activity was very low.

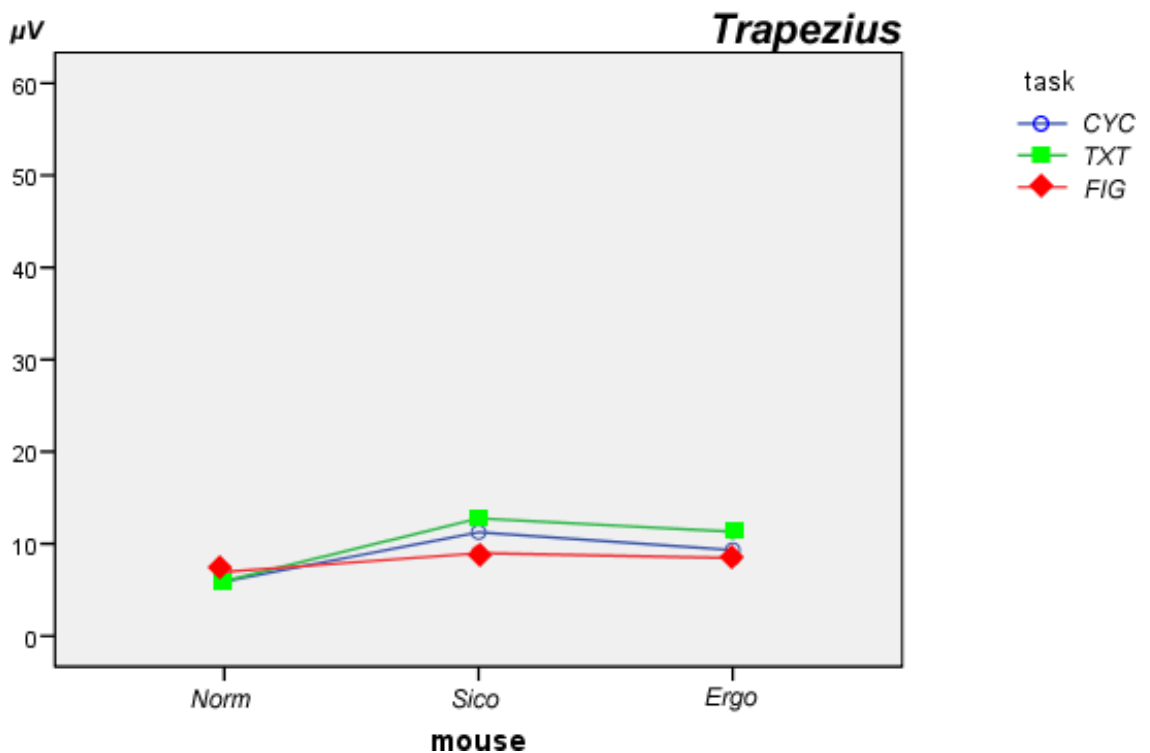


Figure 5.4 EA of mouse by task by trapezius

5.2.2 Effects grouped by mouse

As *Figure 5.5* clearly illustrates, overall activity was much higher in the forearm muscles and lower in the shoulder muscles when using the traditional mouse compared to the Sico and Ergo mice. The use of the traditional mouse provoked only very little activity in the shoulder muscles, but yielded much larger activity in the forearm muscles as compared to the ergonomic mice.

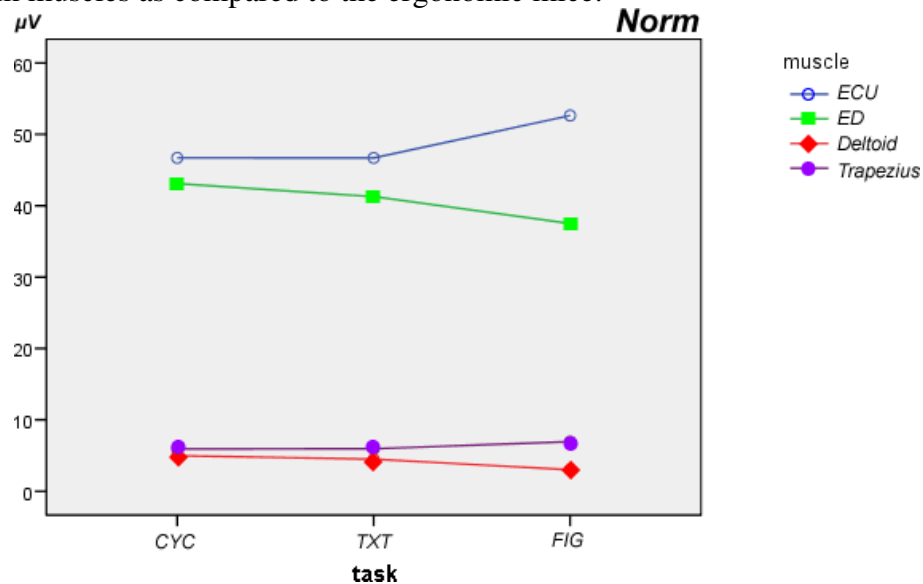


Figure 5.5 Effects for the traditional mouse

The distribution of the muscle load was more balanced for the ergonomic mice (*Figure 5.6* and *Figure 5.7*). These mice yielded considerably higher activity in the deltoid and lower activity in the forearm muscles than the traditional mouse, especially in the extensor digitorum.

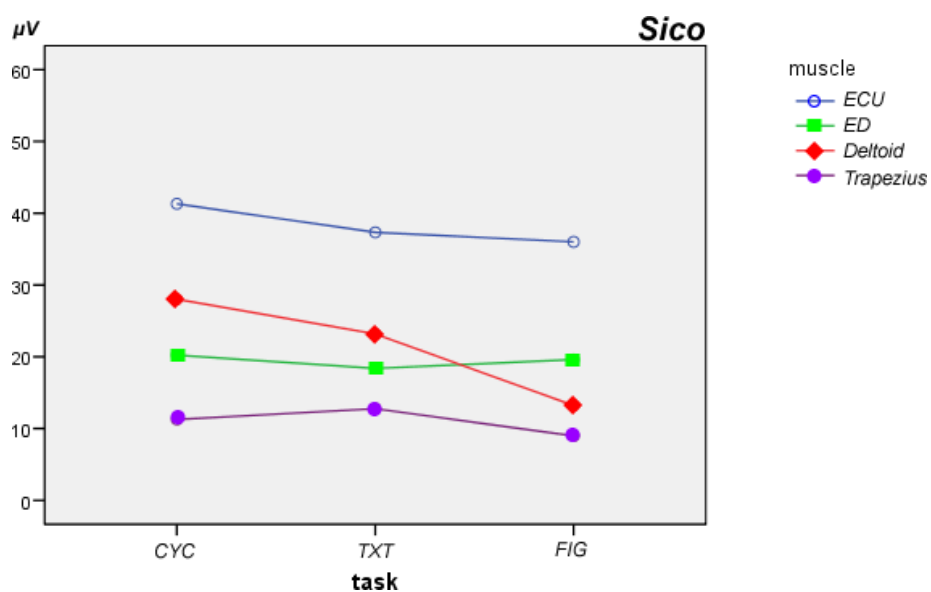


Figure 5.6 Effects for the Sico mouse

The point-and-click [CYC] task put more muscle load on the deltoid than the tracing [FIG] task, when the participants used the Sico and the Ergo mice. The difference was even more important with the Sico mouse. The drag-and-drop [TXT] task yielded slightly lower activity than the point-and-click [CYC] task, especially with the Sico mouse.

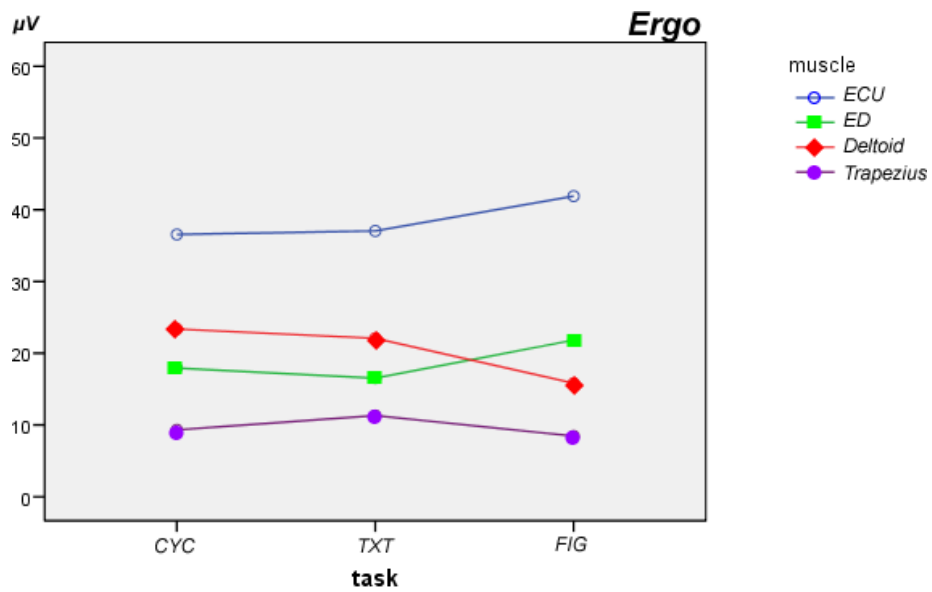


Figure 5.7 Effects for the Ergo mouse

5.2.3 Effects grouped by task

Results indicate that the Sico mouse yielded slightly lower EA than the Ergo mouse in the extensor carpi ulnaris and in the deltoid, when participants performed the tracing [FIG] task and higher EA when they performed the point-and-click [CYC] task.

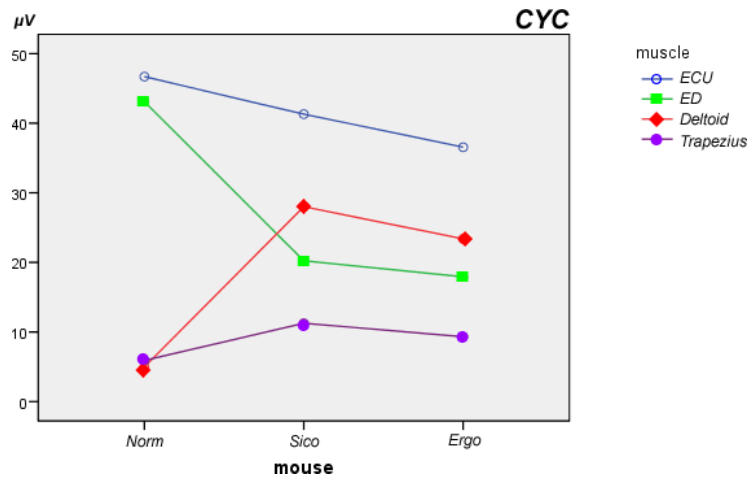


Figure 5.8 Effects for the point-and-click task

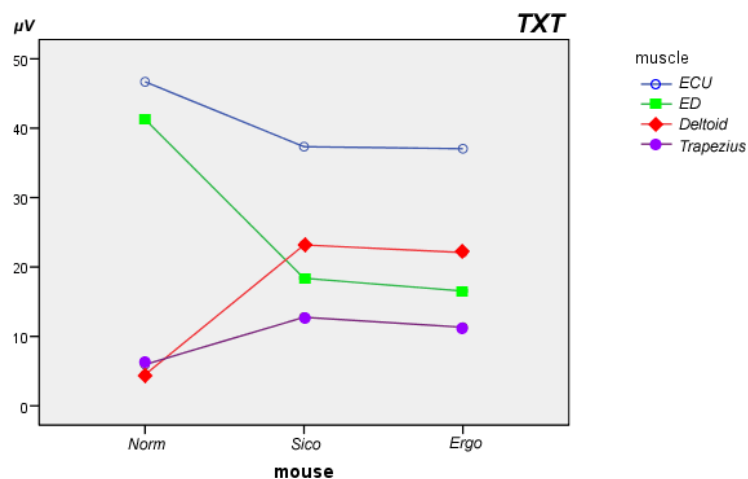


Figure 5.9 Effects for the drag-and-drop task

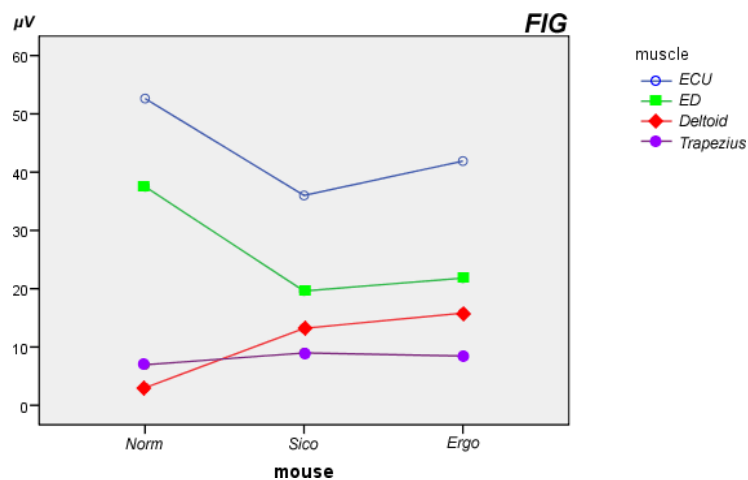


Figure 5.10 Effects for the tracing task

5.2.4 Task by mouse effects for the respective muscles

Two ANOVAs were run to assess the task by mouse effects for the respective muscles. One ANOVA with the original data and one with the \log_{10} transformed data. This time mouse and task were treated as repeated measurements and the individual muscles were fed into SPSS as measure names. *Table 5.4* shows the results of the ANOVA performed with the original data.

Table 5.4
Univariate Tests computed with original data

Source	Measure	Type III Sum of Squares	df	Mean Square	F	Sig.
task	ECU	137.897	2	68.949	.886	.431
	ED	38.840	2	19.420	.547	.589
	Deltoid	949.392	2	474.696	10.199	.001
	Trapezius	48.515	2	24.257	1.339	.290
Error(task)	ECU	1244.669	16	77.792		
	ED	567.909	16	35.494		
	Deltoid	744.659	16	46.541		
	Trapezius	289.820	16	18.114		
mouse	ECU	1917.009	2	958.505	4.723	.024
	ED	8358.103	2	4179.052	18.985	.000
	Deltoid	5086.709	2	2543.354	17.327	.000
	Trapezius	322.465	2	161.233	7.038	.006
Error(mouse)	ECU	3246.859	16	202.929		
	ED	3521.946	16	220.122		
	Deltoid	2348.637	16	146.790		
	Trapezius	366.566	16	22.910		
task * mouse	ECU	368.082	4	92.020	2.660	.051
	ED	259.066	4	64.767	2.334	.077
	Deltoid	388.866	4	97.216	4.586	.005
	Trapezius	61.396	4	15.349	1.553	.211
Error(task*mouse)	ECU	1106.865	32	34.590		
	ED	888.069	32	27.752		
	Deltoid	678.307	32	21.197		
	Trapezius	316.193	32	9.881		

a Computed using alpha = .05

Marginally significant interaction effects were found for task by mouse for the ECU ($F_{(4,32)} = 2.660$, $p = .051$) as well as for the ED ($F_{(4,32)} = 2.334$, $p = .077$). For the deltoid the interaction effect was highly significant ($F_{(4,32)} = 4.586$, $p = .005$) whereas for the trapezius no significant interaction effect was found ($F_{(4,32)} = 1.553$, $p = .211$).

Results from the ANOVA performed with the \log_{10} transformed data equaled these results with one important exception: Whereas the original data showed a significant task by mouse interaction effect for the deltoid ($F_{(4,32)} = 4.586$, $p = .005$), the transformed data showed no interaction effect at all for the deltoid ($F_{(4,32)} = .679$, $p = .612$). Here, task and mouse were both highly significant main effects (task: $F_{(2,16)} = 15.707$, $p = .000$; mouse: $F_{(2,16)} = 56.521$, $p = .000$): Participants had the lowest muscle activity with each task when using the traditional mouse and the lowest muscle activity with each of the three mice when performing the tracing [FIG] task, the second lowest with the drag-and-drop [TXT] task and the highest activity with the point-and-click [CYC] task. So, with the transformed data a mere additive effect of mouse and task was found for the deltoid (*Figure 5.11*). The discrepancy between the results probably is due to inhomogeneous between-cell variances in the original data.

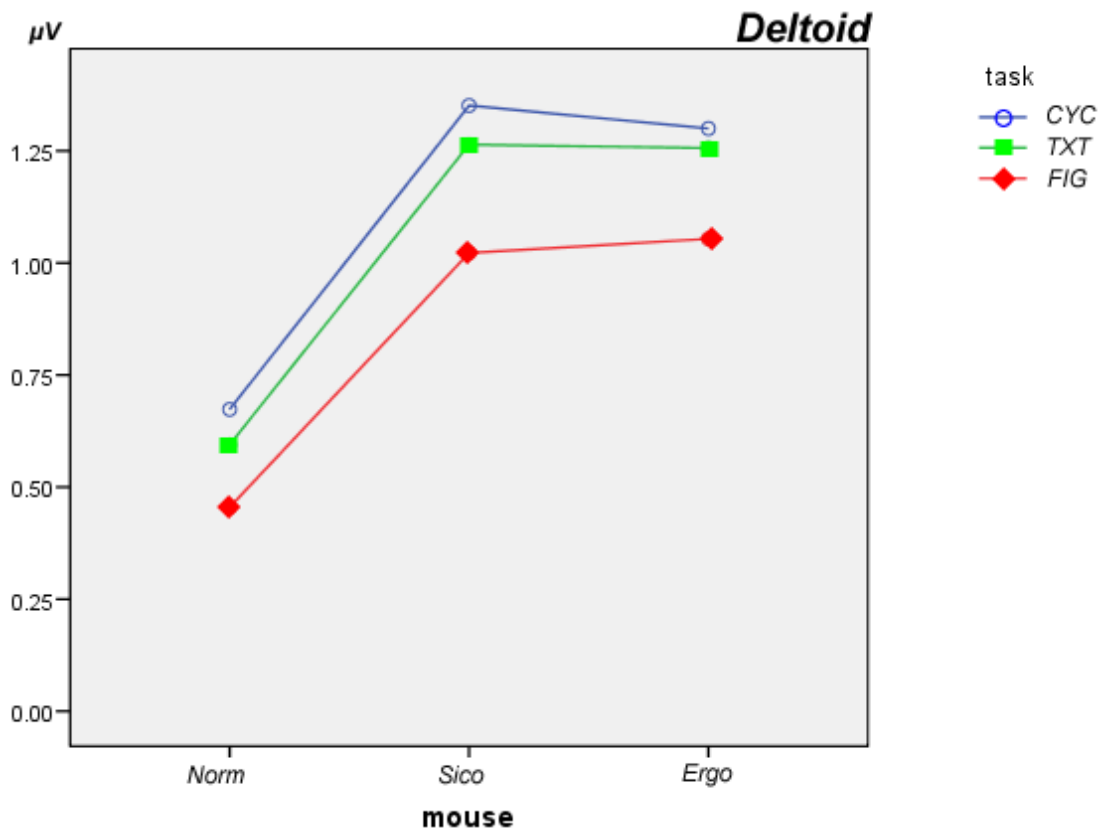


Figure 5.11 EA of the deltoid after logarithmic transformation: additive effect

5.2.5 Effects grouped by participants and muscle

The following figures show the EA by participant and muscle to demonstrate the important interindividual differences found during the experiment (charts for individual results may be compared in the digital appendix - A.2 and A.3). The lines between the points in the following figures do not indicate relationships; they are merely dis-

played for the sake of visual clarity. *Figure 5.12* illustrates the EA of the extensor carpi ulnaris by subject and mouse.

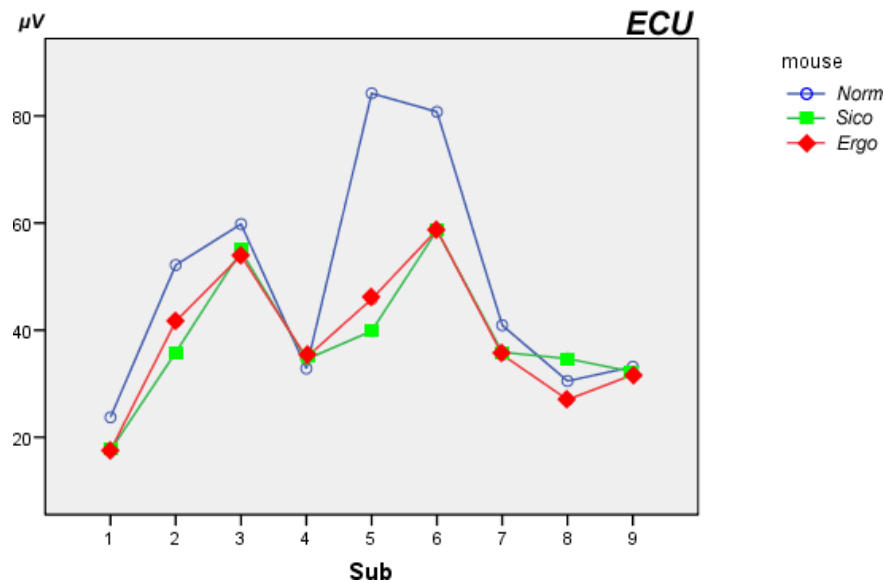


Figure 5.12 EA by subject by mouse in the extensor carpi ulnaris

In general, there was little difference between the three mice in the extensor carpi ulnaris though a tendency towards lower activity for the Ergo and the Sico mouse could be observed. Only subjects 5 and 6 had a *considerably* higher activity when using the traditional mouse as compared to the ergo mice. *Figure 5.13* illustrates the advantage of the Ergo and Sico mouse over the traditional mouse in the ED for some subjects and shows that other subjects achieve almost equal or even the same results (subject 9) with each of the three mice.

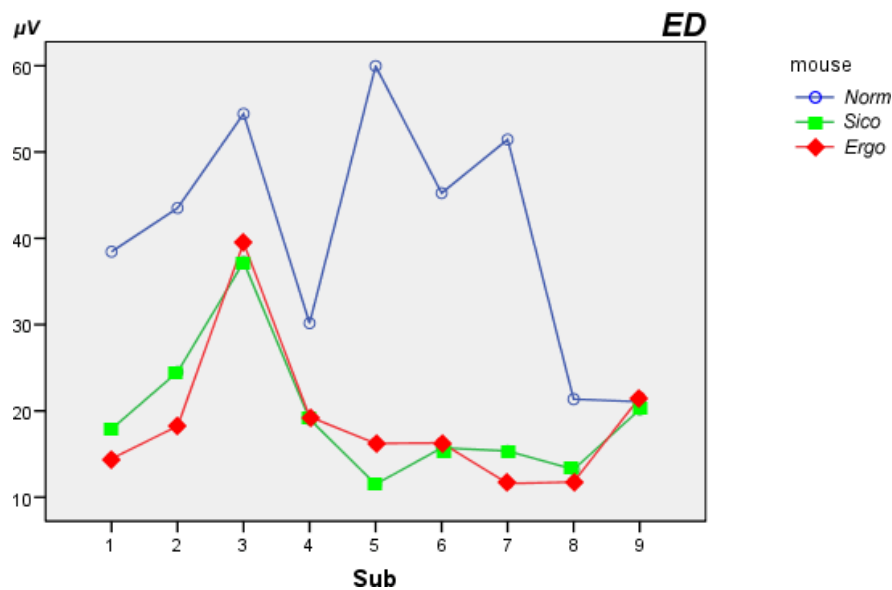


Figure 5.13 EA by subject by mouse in the extensor digitorum

The muscular activity in the deltoid (*Figure 5.14*) was lowest for all subjects when using the traditional mouse. Subjects performed on an almost identical level with the Ergo and the Sico mouse. Participants 4 and 8 performed on a rather similar level with all three computer mice.

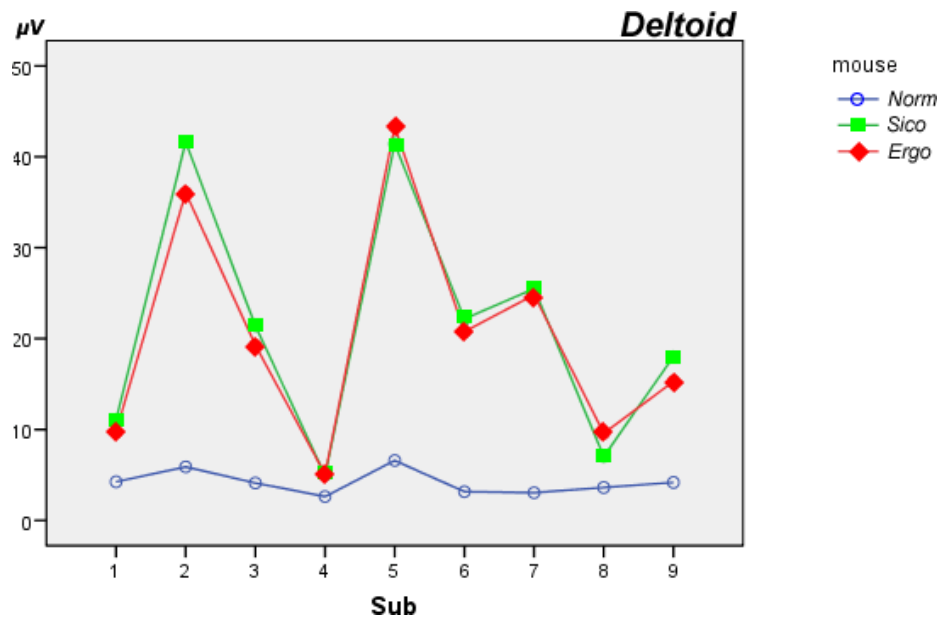


Figure 5.14 EA by subject by mouse in the deltoid muscle

Trapezius activity was lowest for the traditional mouse except for subjects 3 and 8. The comparatively high trapezius activity in subject 8 and 9 for the traditional mouse might be explained by the already reported lacking forearm support in these subjects (VISSER *et al.*, 2000; COOK *et al.*, 2004; SILLANPÄÄ *et al.*, 2003).

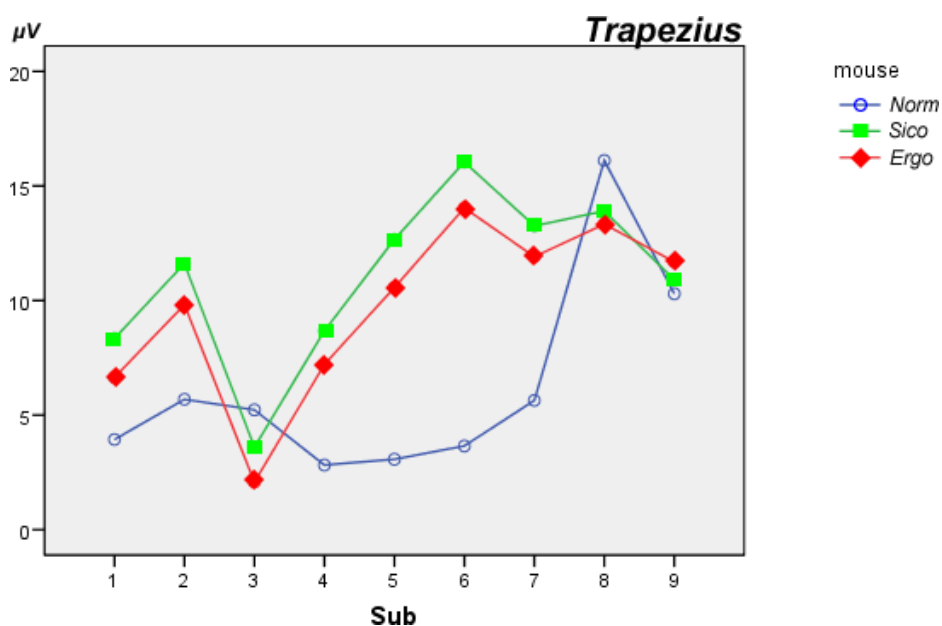


Figure 5.15 EA by subject by mouse in the trapezius muscle

5.2.6 Time on task

The detailed assessment of the time on task was not the subject matter of this thesis. However, out of interest and to gain a first impression of the topic, an ANOVA was run to assess the time participants spent on different tasks with the different mice. There was a significant difference in time on task between the point-and-click [CYC] and the drag-and-drop [TXT] task on one hand and the tracing [FIG] task on the other hand: With the traditional mouse participants used significantly less time than with the ergo mice for the CYC ($F_{(2,24)} = 10.63$, $p = .000$) and TXT ($F_{(2,24)} = 12.98$, $p = .000$) tasks while no difference in terms of lead time was found between the three mice for the tracing [FIG] task (Table 5.5; for details see A.4 in the digital appendix).

Table 5.5

Time on task ANOVA

			Sum of Squares	df	Mean Square	F	Sig.
CYC * Mouse	Between Groups	(Combined)	15831.185	2	7915.593	10.633	.000
	Within Groups		17866.667	24	744.444		
	Total		33697.852	26			
TXT * Mouse	Between Groups	(Combined)	33776.074	2	16888.037	12.986	.000
	Within Groups		31212.000	24	1300.500		
	Total		64988.074	26			
FIG * Mouse	Between Groups	(Combined)	5625.407	2	2812.704	.918	.413
	Within Groups		73530.889	24	3063.787		
	Total		79156.296	26			

These results are surprising as participants were equally trained with the ergo mice for each of the three tasks.

5.2.7 Main findings

Main findings of the present study are: (1) A significant three-way-interaction for mouse by muscle by task. (2) Muscle load on the extensor digitorum is clearly reduced and also has a tendency to decrease on the extensor carpi ulnaris with the use of ergonomic mice whereas (3) muscle load increases on the deltoid. The opposite is the case when using the traditional mouse: (4) Muscle load increases on the forearm muscles and (5) decreases on the deltoid. (6) The overall muscle load on the trapezius is very low, regardless which mouse is being used.

6 - Discussion and Conclusions

The main objective of this study was to evaluate the effect of three differently designed computer mice on the load of forearm and shoulder muscles in computer users. To meet this objective, the muscle activation of two forearm muscles, the extensor carpi ulnaris and the extensor digitorum, and of two shoulder muscles, the deltoid pars clavicularis and the trapezius pars descendens, was assessed by means of sEMG.

The present study confirms the findings of AARÅS and RO (1997) who detected a significant reduction in muscle load on the extensor digitorum and a clear tendency towards reduced muscle load on the extensor carpi ulnaris when participants used the Anir mouse compared to a traditional mouse. Just as in our experiment these authors found very low trapezius load for the traditional as well as for the Anir mouse. The deltoid was not investigated in their study.

The significant reduction in the extensor digitorum muscle activity when using the ergonomic mice might be due to the fact that the mouse button here is depressed with the thumb instead of with the index finger so that the extensor digitorum is not affected by clicking movements. Long-term studies should investigate the consequences of high muscle activity in the thumb and related muscles when such vertical ergonomic mice are used.

Contrary to our hypothesis that the Sico mouse might yield lower EA in the forearm muscles and the deltoid as compared to the Ergo mouse, decreased EA in these muscles only occurred when the tracing [FIG] task was completed. With the point-and-click [CYC] task the EA was higher for the Sico mouse and with the drag-and-drop [TXT] task no difference between the two ergo mice in terms of EA showed. Also contrary to our hypothesis, the EA in the deltoid was not higher for the point-and-click task when participants used the Ergo mouse as compared to the Sico mouse. Instead the Sico mouse yielded slightly higher values here and overall activity in the deltoid was highest with this task, regardless which mouse was being used.

However, the aim of ergonomics is not the elimination of all muscle activity, but the keeping of muscle activity and related muscle load at an acceptable level. Sometimes higher muscle activity may be advantageous, as when people in sedentary jobs are encouraged to introduce muscle activity in their breaks (ANKRUM, 2000; see also MORK and WESTGAARD, 2006; AARÅS, 1994a) to prevent musculoskeletal discomfort and subsequent pain.

Altogether, the results of our study point to complex interrelationships between the pointing devices, the tasks, the respective muscles, and the participants. It is not possible to identify *the* best computer mouse in terms of muscle load. Some participants

actually achieved the same results in terms of muscle activation with each of the three mice. In the extensor digitorum this is true for participant 9 (see *Figure 5.13*). Three other participants achieved *almost* the same results with each of the three computer mice. In the deltoid (*Figure 5.14*) participants 4, 8, and 9 achieved more or less the same results with each mouse in terms of muscle activity regardless of the task they completed. This may indicate the significance of interindividual differences in the way interaction with the computer mice takes place; it could be a consequence of posture, or the method participants use to cope with the required tasks, or both. This result could also be based on physiological or cognitive (most participants stated they disliked working with the ergonomic mice) differences between participants. Further investigation should examine and control these issues by video taping the entire experimental process.

There is a tendency for participants to yield slightly lower muscle load in the forearm muscles and the deltoid during the tracing task when using the Sico mouse as compared to the Ergo mouse (*Figure 5.10*). This tendency is best visible in the extensor carpi ulnaris. Taking into account that the development of the prototype of the Sico mouse utilized in this study was limited by time and means, a more elaborate model with higher flexibility at the basis might yield even better results in terms of muscle load (KROEMER, 1972). According to CHENG and LEUNG (2007) who tested differently slanted mice (0° - 30°) activity in the extensor carpi ulnaris and the trapezius descendens decreases with an increasing inclination angle, a fact which KROEMER's (1972) findings already suggested. The higher activation found by CHENG and LEUNG (2007) for the extensor digitorum was ascribed to the fact that the height of the mice increased with their angle increasing. This fact would be avoided with the Sico mouse, as its height remains constant with increasing angle. Consequently, further testing with an improved prototype might be promising.

Muscle load for the point-and-click [CYC] task was less on the forearm muscles and the deltoid when the Ergo mouse was used. This could be a sign that different pointing devices might be suitable for different tasks, as with the tracing task [FIG] the Sico mouse yielded lower activity in these muscles. When connecting different pointing devices to the same computer via USB, users could alternate between them ad libitum, which would, additionally, have the advantage of introducing a greater variety of movements and a more frequent change of postures into computer mouse work (see AARÅS, 1994a).

KEIR *et al.* (1999) implemented the assessment of the influence of the task on carpal tunnel pressure by comparing the pressure when participants performed a point-and-click with the pressure when they performed a drag-and-drop task, and found that pressures during the dragging task exceeded those measured during the pointing task. In the present experiment both the dragging and the pointing task yielded approximately the same electromyographic activity and either of the tasks produced higher

EA compared to the tracing task which yielded significantly (Bonferroni, $p = .035$) lower activity in the deltoid than the other tasks.

The individual results (see *Figure 5.15*) and direct observation during the experiment indicate that forearm support during the use of a traditional mouse might significantly reduce the workload on the trapezius muscle. This is supported by findings from VISSER *et al.* (2000), COOK, BURGESS-LIMERICK and PAPALIA (2004), and SILLANPÄÄ *et al.* (2003). On the other hand, DELISLE *et al.* (2006) found that resting the forearms on the work surface increased the EMG amplitude of the extensor digitorum. In fact, the two participants in the present study who did not rest their forearms on the desk during the experiment showed substantially lower muscle activation in the extensor digitorum when using the traditional mouse than those participants who did rest their forearms on the desk (*Figure 5.13*, p. 46). As it is not possible to take both postures at the same time, this fact might point to the importance of frequent work posture variation.

Surprisingly, the tracing [FIG] task took the same amount of time with each of the three mice whereas the other two tasks took considerably longer with the ergonomic mice than with the traditional mouse. This might be due to the relatively narrow range of motion the tracing task demanded, compared to the more expansive movements used when accomplishing the other tasks. As the ergo mice are moved with the whole arm, expansive movements may demand more time than when the traditional mouse, essentially maneuvered with comparatively tiny forearm and wrist movements, is used. Also, the tracing task was performed at a comparatively low speed (see *Figure 4.2*), as the focus was set on the accurate execution of the task. This fact could have equaled out the advantage users had with the traditional mouse (because of their long-term experience) when "high speed"-tasks were accomplished. Further studies should assess participants' efficiency when using different pointing devices for various tasks in relation to the provoked muscle load.

To eliminate as many confounding variables as possible, the conditions for our experiment were rather artificial: For instance, users did not alternate between mouse and keyboard as it would be the case in a typical work environment and they could not adjust the resolution of the computer mice to their personal needs. In addition, all participants were experienced traditional mouse users, but the possibility to practice with the ergonomic mice prior to the actual experiment was limited, which naturally influenced performance as well as the chance of developing a sense of comfort with the unfamiliar ergonomic mice.

Moreover, according to HÄGG and KADEFORS (1996, as cited by ANKRUM, 2000, p. 531) "more skilled operators typically have less muscle tension than less skilled ones" so that "EMG readings may be artificially high and the task may be evaluated as more strenuous than it would be for an experienced worker" (ANKRUM, 2000, p. 531). In our experiment all participants were "less skilled" with regard to ergonomic

computer mouse use, so that the ergo mice might indeed have provoked higher electromyographic activity during this initial "familiarization process" than they probably would have after some weeks of customization.

Yet another essential aspect has to be mentioned: The trial length varied between 3.5 and 8 minutes each, depending on the performance of the respective participant, the task, and the mouse used. In such a short period of time muscular fatigue which has been discussed as an important source for the development of MSDs (ANDERSON *et al.*, 2003; KRYGER *et al.*, 2003; GERR *et al.*, 2004; CHANG *et al.*, 2007) is unlikely to arise. Furthermore, the population of the present study was limited to 9 rather sportive male participants. The choice of a different population (females, older adults, non-sportive, etc.) or a more random selection of participants might yield different results. KARLQVIST *et al.* (1999), for example, found that women lifted and rotated their shoulder outwards more than men when working with a computer mouse and they observed differences in working techniques between men and women and higher activity in overall EMG results. Further investigation should thus be carried out (a) in the natural work environment (b) over an extended period of time with (c) a higher number and a greater variety of participants.

A standard keyboard was chosen to approximate general working conditions in our study. The fact that the keyboard was equipped with a numeric pad constitutes an ergonomic disadvantage for the right handed users (COOK and KOTHIYAL, 1996) because the mouse has to be placed more to the right (increasing arm abduction) than it would have been the case when using a keyboard without numeric pad. COOK and KOTHIYAL (1998) report a significantly lower electromyographic activity for the deltoid when the computer mouse is placed adjacent to a keyboard *without* numeric pad. With a shorter keyboard the abduction angle of the upper arm is reduced and movements become less expansive.

In the present study, the number of gaps was not assessed. A low number of gaps are reported being a risk factor for developing musculoskeletal discomfort in the trapezius muscle (AARÅS, 1994b; AARÅS *et al.*, 2002) as constant low level muscle activity according to the Cinderella-Hypothesis (HÄGG, 1991, cited by HÄGG *et al.*, 2000) induces pain. "An increase in the number of micropauses (periods below 1% MVC) seems to reduce the incidence of ... discomfort" (AARÅS, 1994b, as cited by AARÅS and RO, 1997, p. 106). However, a more recent study by MORK and WESTGAARD (2006) suggests that there might be "two separate mechanisms of shoulder and neck pain involving the trapezius muscle" (p. 1148) as they found that pain can develop independently of muscle activity patterns during work or leisure time. Furthermore, they state that "subjects with shoulder and neck pain have significantly more trapezius activity during sleep ..., when the activity pattern is clearly influenced by the autonomic nervous system" (WESTGAARD, BONATO and HOLTE, 2002, as cited by MORK and WESTGAARD, 2006, p. 1148). MORK and WESTGAARD (2006) conclude

that there might be one mechanism relating to sustained activity of low-threshold trapezius motor units and a second mechanism operating independently.

Many different causal factors forming complex relationships will most probably influence the development of work related upper extremity disorders. It is thus practically impossible to isolate one single source of MSD. To achieve a comprehensive understanding of the underlying factors and to uncover their interrelationships it is necessary to make use of the experimental knowledge gathered in the laboratory and to conduct extensive and holistic studies in order to collect diversified data in the actual work environment, thereby combining a great variety of research instruments like EMG, pressure tests, questionnaires, etc.

Keeping all this in mind, the design of *the* optimum pointing device presents a real challenge to the ergonomist as the use of a product might in fact reduce muscle load in one part of the body while simultaneously increasing muscle load in another part of the body, as was demonstrated in the present study. In addition, even if a product has outstanding qualities, it might be difficult to convince a broad group of users to benefit from its advantages, because they might not like the design or feel uncomfortable when they first touch it - so that they are not willing to test it over a longer period of time.

7 - References

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8 - Digital Appendix: DVD

The associated DVD contains, among others, a program (**PViewSetup.exe**) for visualization of the included ECG/EMG raw data files (.mcf). The version included in this DVD dates from June 2008. The most recent version available can be downloaded at http://www.stiegele.eu/d/downloads_d.htm.

SPSS output files mentioned in the text

- A.1 Original data and Log10 transformed data - within and univariate tests.spo
- A.2 Plots of interaction effects by subject.spo
- A.3 Histograms of mean EA by mouse by task and by subject.spo
- A.4 Time on task.spo
- A.5 Tests of Normality.spo
- A.6 Plots of interaction effects with log10 transformed data.spo

Additional SPSS output files

ANOVA and plots with Log10 transformed data without the Deltoid.spo
Plots of interaction effects by subject by muscle and by task.spo
Plots of mouse by muscle by task interaction effects.spo

Associated SPSS data files

sub_1_GLM.sav ... sub_9_GLM.sav
intra_sub_for_GLM.sav
intra_sub_for_GLM_log10.sav
intra_sub_log10_sin_Deltoid.sav
mean_all_sub.sav
mean_all_sub_log10.sav
skewness_test.sav
time_on_task_mouse_by_task.sav

Material used in the experiment

Task 1: CYC.exe
Task 2: TXT.doc
Task 3: FIG.swf
Demographic questionnaire