Doctoral Thesis

On the role of trapezius muscle activity and relaxation in the development of neck and shoulder pain

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ON THE ROLE OF TRAPEZIUS MUSCLE Activity AND RELAXATION IN THE DEVELOPMENT OF NECK AND SHOULDER PAIN

A dissertation submitted to
ETH ZURICH
for the degree of
DOCTOR OF SCIENCES

presented by
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Kurzfassung


Die dritte Studie beschäftigt sich mit der wichtigsten Erholungsphase des menschlichen Körpers, dem Schlaf. Es wurde überprüft, ob die nächtliche Trapezius-Aktivität mit der Charakteristik des menschlichen Schlafs, den Schlafphasen, zusammenhängt. Ebenfalls wurde die Bedeutung der nächtlichen muskulären Entspannung auf das subjektive Schmerzempfinden untersucht.


Die vorliegende Dissertation verbessert das Verständnis für einige Mechanismen, die zu erhöhter Trapeziusaktivität und damit zu Schmerzen führen können. Hauptsächlich unterstreichen die Resultate aber die Bedeutung einer ausreichenden muskulären Erholung zur Vorbeugung der Schmerzentstehung.
Abstract

In industrialized countries musculoskeletal disorders (MSDs) are among the most common work-related diseases. Most frequently affected are the back, shoulder and neck region. Because of the high prevalence rates, MSDs are the leading cause for physician visits, hospitalizations and other health and social care utilization. These health problems cause considerable social and financial consequences.

The pathophysiology for the development of musculoskeletal complaints probably lies in the overloading of single motor units and the resulting damage in the muscle fibers. Also a variety of physical and mental risk factors are known that promote the development of MSD.

This thesis examines the impact of various risk factors on the muscular activity. Emphasis is placed on the occurrence and avoidance of prolonged and uninterrupted muscle activity, because this can lead to the aforementioned overload. The focus was placed on the neck and shoulder region, and therefore on activity measurements of the Trapezius muscle.

In an initial study within this dissertation, an alternative input device was compared with the computer mouse. Besides the muscular strain in the shoulder, additional emphasis was put on the performance achieved with both devices. For a successful implementation of an alternative input device in the working environment, economic criteria such as work performance must as well be considered besides the aspect of health promotion.

In the second study the relationship between phasic muscle activation in the Trapezius and the typing on a computer keyboard was demonstrated. The biomechanically unnecessary activation of shoulder muscles during keying tapping with supported forearm could be one of the main reasons for the widespread occurrence of neck pain related to computer work.

The third study deals with the main recovery phase of the human body: sleep. It was investigated whether the nocturnal Trapezius muscle activity was related with the sleep stages used to characterize human sleep. The study also revealed the importance of nocturnal muscle relaxation on the subjective perception of pain.
Finally, the fourth study examined an occupational group with a particularly high proportion of musculoskeletal complaints: hospital nurses. Trapezius muscle activity, movement behavior and subjective ratings of mental strain were compared between day and night shift. With such comparisons, new information on the interaction between various risk factors and the development of MSD can be obtained. Additionally, new recommendations for a healthier work design could be derived.

This thesis attempts to improve the understanding of some mechanisms leading to increased Trapezius activity and pain. Mainly, the results underscore the importance of sufficient muscle relaxation for the prevention of neck and shoulder pain.
1. General Introduction

This chapter provides an overview of the muscle physiology, its musculoskeletal disorders (MSD)-related pathophysiology and discusses the extent of the problem of work-related MSD.

1.1. Musculoskeletal disorders (MSDs)

Musculoskeletal disorders are the representation of pain developed by overload or injury of the musculoskeletal system. In modern society, sick leave due to MSDs has been reported a major health and social problem (Buckle 2005). Among all musculoskeletal disorders, back, neck and shoulder pain are the most frequent (Macfarlane et al. 1998; Strine and Hootman 2007).

Prevalence and costs

In the US, with a 3 month prevalence of 31%, back and neck pain is a huge public health problem and a common source of disability in the general population (Strine and Hootman 2007). In a systematic review of the literature, a one year prevalence of 83% has been reported for back pain (Jeffries et al. 2007). In the year of 2000, Walker et al. estimated a life-time prevalence of 84% for back pain.

Hestbaek et al. (2003) pointed out that approximately 90% of the patients suffering from back pain seek for medical care within four weeks. About 80% of them recover sufficiently to return to work within six weeks. This very high recovery rate is overshadowed by the high recurrence rate: In a prospective study of subjects suffering from shoulder pain, approximately 50% experienced recurrent episodes within a 18 months follow up (Winters et al. 1999). In patients with back pain, a recurrence rate of 60% has been observed (Hestbaek et al. 2003).

Due to the high prevalence rates, neck and back pain are among the leading causes for seeking medical care and sick leave, resulting in great financial consequences because of workers’ compensation, medical cost and productivity loss. Neck and back pain constitute the most common disorders causing sick leave and early retirement (Borg et al. 2001). As reported by the Center for Disease Control and Prevention (2001) in the US, these disorders are the second leading cause of disability and the leading cause of job-related disability,
costing the American society more than US$50 billion each year. In Switzerland, work-related pain in back, shoulder and upper limbs has been estimated to cost CHF10 billion a year due to loss of productivity and job absence (Läubli and Müller 2009).

**Risk factors**

Because of the high numbers of MSDs and their profound economic impact, many studies have been conducted to identify its causes and essential risk factors. A number of systematic reviews pointed out the great variety of possible risk factors which basically fall into two categories; physical and psychosocial factors. (Bongers et al. 1993; Bernard 1997; Waersted 2000; van Rijn et al. 2010):

**Physical risk factors**

Several physical risk factors are associated with the development of MSD; heavy lifting and forceful manual exertion, rapid work pace, manual material handling and mechanical pressure concentrations are factors with obviously high strain on the human body (Burdorf and Sorock 1997; Elders et al. 2003). Additional established risk factors for MSD development are whole body vibration, bad ergonomic conditions and awkward body positions and repetitive movement (Burdorf and Sorock 1997; Kädefors et al. 1999; Vieira and Kumar 2004).

In 1991, Hägg introduced his Cinderella hypothesis, proposing that the over-exertion of small motor units is one of the main causes for muscle pain development (see chapter 1.2 for details). Thus, the lack of regeneration time has become an increasingly important risk factor (Hermens and Hutten 2002; Thorn et al. 2007; Leonard et al. 2010).

**Psychosocial factors**

Similar to the physical risk factors, a great number of psychosocial risks are related to the onset of back and neck pain: monotonous tasks, low social support, low job satisfaction, high mental demands, high work load and insufficient work life balance are the most important factors (Bongers et al. 1993; Hoogendoorn et al. 2000; Linton 2001; Hämmig and Knecht 2008).

The appearance of work-related MSDs in professions with low physical demands illustrates the importance of psychosocial factors (Waersted 2000).
Additionally, there is some evidence that individual characteristics such as age or gender may be independent risk factors, but may also influence the relationship between physical and psychosocial factors and MSD development. Burdorf and Sorock (1997) showed increased prevalence for back pain dependent on higher age. Messing et al. (2009) pointed out that there are minor gender differences concerning the risk factors for developing musculoskeletal disorders. However, it must be stated that individual factors are of minor importance compared to the aforementioned physical and psychosocial risk factors (Veiersted and Westgaard 1994; Messing et al. 2009).

The enormous amount of plausible causes for pain development makes it difficult to decide which factors should be considered as the most important. However, the origin of MSD has to be considered as multifactorial. We recently demonstrated that the number of risk factors prevalent may be more important than their respective nature (Läubli et al. 2010). With the questionnaire data of a representative sample of the Swiss working population we detected a highly significant linear relationship between the number of risk factors and the prevalence of MSDs.
1.2. (Patho)Physiology of the muscle
(Silbernagl and Despopoulos 1991; Stegemann 1991; Thews et al. 1999)

Regardless of the external risk factors, the final mechanisms that lead to musculoskeletal pain must happen in the muscle. Hence, a profound understanding of the muscle physiology and the possible pathophysiological pathways that lead to pain is of great importance.

Anatomy and Physiology
A muscle is a contractile tissue which is able to produce force and cause motion. Three types of muscles exist in the human body:

Smooth muscle: Is found in the walls of organs and structures, e.g. stomach, skin, blood vessels. Smooth muscles are not under conscious control.

Cardiac muscle: Only found in the heart, cannot be voluntary contracted, but is structurally related to a skeletal muscle.

Skeletal muscle: Can be activated voluntarily and is anchored to a bone by tendons. It is used to effect skeletal movement. When investigating musculoskeletal disorders, only skeletal muscles are of interest. In the following parts of this thesis, the term ‘muscle’ is always used to describe a skeletal muscle.

A muscle contains muscle tissue, nerves, connective tissue and blood vessels. It is a compound of muscle fibers with a diameter of 10-100 µm. A muscle fiber is generated by the fusion of several muscle cells. Its length can range from 1mm to the entire length of a muscle (several centimeters). Most of the volume in a muscle fiber, named as sarcoplasm, is taken by the myofibrils. These are elongate clusters of contractile elements with a diameter of 1 µm. Additionally the sarcoplasm contains glycogen and fat particles, enzymes, other proteins and specialized organelles such as mitochondria and the sarcoplasmatic reticulum. The myofibrils contain the apparatus (sarcomere) that produces muscle contraction. A sarcomere is a complex of primarily two types of proteins: myosin and actin (Figure 1). When energy is supplied, myosin and actin are able to shift in relation to each other, causing a shortening of the muscle. The contraction of a sarcomere is triggered by the release of calcium (Ca$^{2+}$) from the sarcoplasmatic reticulum.
Within the muscle, two important structures for the control of movement and position exist:

**Muscle spindle**: Receptor that is located in the body of the muscle in between the muscle fibers. Muscle spindles register information about muscle length and changes in length. This information is transmitted to the central nervous system by sensory neurons. The responses of the muscle spindles are used to determine the position of body parts, to control the target length during a voluntary contraction and to trigger reflexes in order to prevent overstretching of the muscle.

**Golgi tendon organ**: Tension sensitive receptor located in the tendon of skeletal muscles. If the required force gets too high, the golgi tendon organ triggers an inhibitory feedback to the agonist muscle to protect it from possible injury.

---

Neuromuscular activation

The muscle fibers are innervated by electrical impulses, transmitted by a motoneuron axon. Generally, each muscle fiber is connected with one motoneuron axon on a specific point, called the motor end plate. A functional group of muscle fibers including the innervating motor neuron is called motor unit (MU). The activation of a specific motoneuron causes the contraction of all fibers within the motor unit.

Two main groups of muscle fibers can be discriminated, whereof a MU only contains fibers of one type:

*Type I (slow twitch)*

Type I fibers are generally small fibers, with slow contraction speed. They are very fatigue resistant and work mainly with an oxidative metabolism.

*Type II (fast twitch)*

In general, type II fibers have a wider diameter than type I fibers. Their contraction speed is faster, but they are less resistant to fatigue. They predominantly perform glycolysis for energy supply.

Rest potential

During muscular rest the cell membrane is polarized, maintaining a negative interior charge of -70mV. This electrical gradient across the membrane is created by reaching an equilibrium of sodium (Na⁺) and chloride (Cl⁻) mostly outside and potassium (K⁺) mostly inside the cell membrane. This electrical gradient during muscular rest is called rest potential.

Action potential

To activate a muscle contraction, an impulse form the (central) nervous system propagates through the motoneuron to the motor end plate. This impulse causes

Figure 2: Course of the membrane potential during muscle activation with refractory period. The dashed red line represents the threshold for the action potential.
the release of acetylcholine (ACH) in the synapse between motoneuron and muscle fiber. ACH diffuses through the synapse and binds to receptors on the muscle cell membrane. The binding of ACH opens chemically regulated ion gates, causing Na\(^+\) to enter the cell. With increasing Na\(^+\) concentration inside the membrane, the membrane depolarizes. At a threshold -55mV additional channels open, resulting in a rush of Na\(^+\) into the cell. This mechanism causes a fast and complete depolarization of the membrane and triggers the release of calcium (Ca\(^{2+}\)) from the sarcoplasmatic reticulum. The membrane potential overshoots +30mV and is propagated along the membrane through the whole muscle fiber (action potential). During the following period of repolarisation, the membrane potential undershoots to approximately -80mV (refractory period). In this period, the muscle fiber cannot be activated again (Figure 2).

The electrical activation of the muscle can be detected with Electromyography (see chapter 2.1).

**Motor unit firing rate**

The force a MU is able to generate depends on its activation rate. The number of discharges of a MU in time is called firing rate. A strong relationship between average firing rate and average force generation has been shown by Conwit et al. (1999).

The maximum firing rate depends on the muscle size. In smaller muscles, the activation frequency reaches up to 60 peaks per seconds, whereas in larger muscles it reaches a plateau at 20-25 peaks per second.

During sustained contractions the firing rate decreases independently from the resulting force. There are possible optimization processes, causing the firing rate to adapt to a more economic activation frequency. During prolonged contractions, the firing rate also decreases because of muscular fatigue. Fatigued muscle fibers need longer restoration time before they can be activated again. Hence, measuring the firing rate is a good indicator for muscle fatigue during sustained contractions.
Motor unit recruitment

A muscle consists of various MUs of different types and sizes. To achieve a required muscle force, only the lowest amount of MUs needed is activated. According to the Henneman size principle, small type I units are the first to be activated, independently of the absolute force required (Henneman 1981). With increasing force demands, additional and larger MUs are recruited successively. At last, large type II units are recruited (Figure 3). During a fatiguing task, the amount of MUs recruited increases in order to maintain a constant force level.

![Figure 3: Recruitment and discharge pattern of 5 MUs during a graded contraction from 0 to 50% of the maximum voluntary force. (a) Course of the force development. (b) Firing rate of the different MUs. Recruitment and discharge of each MU takes place around the same force level. EMG measurement of the first dorsal interosseus muscle (Kamen and De Luca 1989).](image)

Pathophysiology

In 1991, Hägg introduced the Cinderella hypothesis to explain the development of muscle pain (Hägg 1991). Based on the Henneman size principle he suggested that during sustained muscle contraction several low-threshold motor units are continuously active. This results in an overload of the MU followed by muscle fiber damage. According to the Henneman size principle low-threshold MUs are the first to be activated. During sustained muscle activation these MUs might suffer from insufficient relaxation, leading to small injuries. This theory has been supported by several studies (Forsman et al. 1999; Zennaro et al. 2003) and is used to explain the development of work-related MSDs. In a recent experiment we were able to
detect the occurrence of MUs in the masseter muscle that were active during a prolonged biting task (Cinderella units, Figure 4).

Figure 4: Example of continuously active MUs of one subject performing a 30min biting task at 3% MVC (maximal voluntary contraction). Intramuscular EMG was recorded unilaterally with eight fine-wire electrodes. (A) Activity of MUs in time. (B) Shape of the same MUs in the three channels recorded. (C) Firing rate of MU Nr. 3 during a 30min biting task. (D) Waterfall plot of MU Nr. 3. (Farella et al. 2011)

The occurrence of long lasting low level muscle activity possibly leading to an overexertion of Cinderella units has been shown for a great variety of working conditions: e.g. repetitive or monotonous tasks, high mental load and insufficient relaxation time (Sjøgaard and Søgaard 1998; Waersted 2000; Visser and van Dieën 2006).

The pathogenesis for muscle pain caused by Cinderella units was elucidated during recent years. Due to the constant overload of single MUs, unfavorable muscle adaption processes take place. Andersen et al (2008) reported significantly higher proportions of type I
megafibers with poor capillarization in MSD patients. This mechanism goes along with an altered metabolism in form of Ca$^+$ accumulation and reduction of muscle oxygenation, increased shear forces and trigger points, causing muscle damage and inflammation (Hägg 2000a; Maas et al. 2004; Visser and van Dieën 2006; Larsson et al. 2007).

The Trapezius muscle

In all experiments described in this thesis, the upper part of the Trapezius muscle (m. Trapezius descendens) was examined. As pain in neck and shoulder belong to the most frequent types of MSDs (Borg et al. 2001), we decided to focus on this body region. Several studies showed the relationship between muscle load in the upper Trapezius and pain development (Veiersted et al. 1993; Jensen et al. 1993a; Hägg and Aström 1997). Beside its relevance for MSD development, the Trapezius muscle has the advantage of being a relatively big and superficial muscle. This makes it easily accessible for muscle activity recordings.
1.3. Objectives and relevance of the experiments

Given the high prevalence of musculoskeletal disorders and its financial consequences, it is of great interest to reduce the causing risk factors. Regarding the huge variety of possible risk factors, it is difficult to decide which are the most important and how to measure their effect. As there is great evidence for the pathophysiological mechanism in the muscle and its strong relationship with parameters measurable by electromyography, the effect of the different risk factors can be assessed by evaluation of the resulting muscle activity. As described in the introduction, prolonged low-level muscle activity and the lack of muscle relaxation seem to be the most important EMG parameters related to MSD. Hence, these parameters should be used to discriminate between subjects and situations that might be predisposed to MSD development.

1. Muscular load and performance compared between a pen and a computer mouse as input devices

During recent years, computer work time has increased (Dolton and Pelkonen 2004) and there is great evidence for the relationship between the use of a computer mouse and neck and shoulder pain (Blatter and Bongers). Thus, it is of great interest to provide alternative input devices that reduce the muscular load and therewith the risk of developing MSD.

The aim of this experimental study was to compare a pen as an alternative input device to a computer mouse while taking learning effects into consideration. To convince employers to provide new technologies to their workers, not only health outcomes can be taken into consideration. It is important as well to demonstrate the benefits in performance. While introducing a new device and comparing it to an existing one, learning effects play an important role. Motor learning of the subjects influences their muscle activity and also the performance using the new device.

Lastly, an alternative input device cannot succeed if the workers feel less convenient working with it than with the computer mouse.

In the present study we investigated 20 subjects performing a test program on five consecutive days with mouse and pen and evaluated both devices in terms of muscle activation, performance and subjective rating.
2. Evidence for repetitive strain in the Trapezius muscle during a tapping task

Similar to mouse use, a relationship between keyboard use and MSD in neck and shoulder has been found (Feuerstein et al.). As working on a keyboard is often performed with supported forearm, the reasons for possible elevation in Trapezius activity was unclear. We therefore performed this study to elucidate the relationship of phasic Trapezius activity to the tapping of a key. Furthermore, the influence of different key characteristics was investigated.

A first evaluation of the data collected during this experiment has already been published in the thesis of Tomatis (2009). Due to the fact that new literature questioned some of our findings (Waersted et al. 2010; Samani et al. 2011) we decided to completely re-analyze our data to address these concerns. By performing a cross-correlation analysis with a different pre-processing of the EMG data and by introducing the calculation of effect size we were not only able to show the actual presence of phasic Trapezius activation, but also how strong this activation contributes to the measured overall activity during the key tapping.

With this study we aimed for a better understanding of Trapezius muscle activation during a supported key tapping and its relevance for the development of MSD.

3. Nocturnal Trapezius muscle activity

With the introduction of the concept of work-life-balance (Hämmig and Knecht 2008) and the evidence of its relationship with MSD development, the balance between muscular load and relaxation during work as well as during leisure time has received more and more attention. The most important recovery phase of the human body is sleep. Hence, it can be speculated that nocturnal Trapezius relaxation plays an important role in the prevention or development of neck and shoulder pain.

Although there is some evidence of increased nocturnal Trapezius activity in pain-afflicted subjects (Mork and Westgaard 2004), very little information exists about the mechanisms of Trapezius activation and relaxation in relation to sleep.

Thus, we aimed for a better understanding of the relationship between neck and shoulder pain, subjective mental and physical load and nocturnal Trapezius activity. Moreover, we
elucidated the dependency between Trapezius activation and objective sleep parameters such as sleep stages.

An initial pilot study was conducted to gain further knowledge about nocturnal EMG measurement, to identify reasonable evaluation parameters and to detect special activation patterns of interest.

In a second step, a bigger field study was carried out including full Polysomnography to determine the relationship between Trapezius muscle activity and sleep stages.

Lastly, the EMG data was re-evaluated according to the results of the field study and combined with the subjects’ perceived hardening in neck and shoulder.

The results of this study should contribute to a better understanding of the mechanisms of nocturnal Trapezius activity and its relation to neck and shoulder pain. Furthermore, our results may help to identify patients with elevated risk of MSD development.

4. Comparison of Trapezius relaxation, movement behavior and mental load in Japanese hospital nurses during day and night shift

MSD in neck and shoulder is a great problem in hospital nurses and one of the main reasons for sick leave (Harcombe et al. 2009). The work of a hospital nurse is usually characterized by high physical and mental demands as well as irregular working hours, including night shifts. Recent shortage in qualified personnel and financial pressure in the health care sector worsens the problem. Although there is evidence for the relationship between night shift work and MSD development (see Caruso and Waters (2008) for review) comparison of muscle activity in the Trapezius between day and night shift has never been performed.

We therefore aimed for a better understanding of Trapezius muscle strain related to the type of shift, type of movement and mental demands in nurses. Measurements of Trapezius EMG and movement behavior with a movement recording system were performed and enhanced with subjective ratings of mental demands and fatigue.

The findings of this study contribute to a better understanding of the mechanism leading to an increased risk for MSD development when working on night shift. Furthermore, our results could be used to make suggestions for a better work design in hospitals and which risk factors should be reduced primarily.
2. Methods

This chapter provides an overview of the main measurement methods used in the experiments. It describes the basic principles of data acquisition and evaluation for each method. Specific information about the methods used can be found in the methods section of each experiment.

2.1. Electromyography

Electromyography is traditionally used in kinesiology and biomechanics to determine whether a muscle is active or not. The Electromyogram (EMG) represents the electrical activity associated with the innervation of a muscle. There are two main EMG measurement methods:

*Surface EMG:* Non-invasive method which is the algebraic summation of all motor units’ action potentials spread along a muscle at a given point in time.

*intramuscular EMG:* Invasive method which allows the detection single motor unit’s action potentials at a given point in time.

In the experiments conducted for the present thesis, only surface EMG was used. Surface EMG has some important advantages compared to intramuscular EMG: As it is noninvasive, there is no risk of causing pain or infections to the subjects and the method is applicable by non medical personnel. An important fact for the experiments conducted in this thesis is that surface EMG allows the measurement over long periods of time and also during work tasks or sports. A disadvantage of surface EMG is that only the total amount of muscle activation in a certain region can be measured, whereas intramuscular EMG can be used to assess the activity of specific single motor units as it is hardly influenced by the activity of the surrounding muscles (cross-talk).
**Surface EMG detection**

There are two main possibilities to measure surface EMG: *monopolar* and *bipolar* detection (Figure 5). During monopolar detection, the absolute electrical potential below one electrode is measured in respect to an indifferent (field free) point that is usually a bone close to the skin. During bipolar detection the difference of the potential between two electrodes covering the same active zone is calculated. Thus, the resulting signal represents the propagation of the action potential in the muscle. An important advantage of bipolar EMG detection is that it is less prone to electrical noise from the surrounding.

For the experiments presented in this thesis, only bipolar EMG detection was used.

![Diagram of monopolar and bipolar EMG recording](image)

Figure 5: monopolar and bipolar EMG recording

As described in chapter 1.2, the muscle is electrically innervated. The action potential generated at the motor end plate is propagated along the muscle fiber membrane. When placing two electrodes close to each other, the action potential arrives at different time points below each electrode. As all motor end plates of a muscle are located in the same region (innervation zone), potential differences get higher, as more MUs are activated. This also has implications for the electrode placing. The best signal is achieved at a position in the middle of the muscle body, but in some distance from the motor end plates. There, the highest EMG amplitudes are detected (Figure 6).

---

*Figure originally provided by David Groh, University of Nevada, Las Vegas; adapted for this thesis*
Figure 6\(^3\): Effect of electrode placing on amplitude of the EMG signal. (A) Directly above the innervation zone, (B) midline of the belly of the muscle between innervations zone and muscle-tendon connection (preferred placing), (C) lateral edge of the muscle, (D) on the muscle-tendon connection.

**EMG processing and evaluation**

EMG signals can be contaminated by electrical noise from the surrounding. In Switzerland for example, the main hum of the electrical current is 50 Hz. Thus, the raw EMG signal is generally band-stop filtered at 50Hz. Additional high- and low-pass filter may be used to remove noise-induced signal with no physiological origin (SENIAM).

Bipolar detection measures potential differences caused by a propagating signal between two electrodes. The resulting raw EMG oscillates between positive and negative values, with mean amplitude of zero. It is therefore necessary to perform a rectification on the signal to preserve its energy. During rectification, the negative polarity of the raw EMG is inverted to positive polarity.

---

\(^3\) Figure originally provided by David Groh, University of Nevada, Las Vegas; adapted for this thesis
**Root mean square (RMS)**

RMS is generally used to rectify and smooth the raw EMG signal with a moving average window as described in Equation 1:

\[
RMS(x) = \sqrt{\frac{\sum_{i=-\frac{w}{2}}^{\frac{w}{2}} EMG(x + i)^2}{w}}
\]

Equation 1: Calculation of RMS at position x, w=window length, EMG=raw EMG signal

The advantage of a RMS procedure is that outliers in the raw EMG signal, e.g. caused by mechanical noise, are mostly filtered. From the RMS EMG, various parameters can be calculated to describe the muscle activity. The resulting amplitude is a measure for the amount of muscle activation (Figure 7).

There are many factors that influence the frequency and amplitude of the EMG signal:

- **Muscle fiber type**: Fast twitch fibers have higher conduction velocity, higher firing rate and higher amplitude.
- **Size of the MU**: Larger MUs result in higher EMG amplitude.
- **Depth of muscle fiber**: The resulting amplitude decreases with increasing distance between the electrode and the muscle fibers.
- **Other tissue**: the skin as well as sub-cutaneous fat behaves like low-pass filters. With increasing amount of fat tissue, EMG amplitude decreases.
- **Muscle temperature**: higher muscle temperature leads to a faster conduction velocity and therefore to higher frequencies in the EMG.

For these reasons, the absolute amplitude does not provide information about the force generated. To describe the relationship between muscle activation and force, standard contractions with defined forces have to be conducted before each measurement.

The same reasons impede the comparison of different subjects by the absolute amplitude. The state of the art to compare EMG values of different persons is the normalization with standard contractions (Figure 7). Two main normalization procedures exist (Mathiassen et al. 1995):
Normalization with a maximal voluntary contraction (MVC): Subjects perform a standardized (static) contraction with the goal of maximal muscle activation. The maximal amplitude is then taken as reference values. All further EMG values from this subject are then expressed as percentage of MVC.

Normalization with a reference voluntary contraction (RVE): Similar to the MVC normalization, each person performs a standardized (static) contraction. The target is not a maximal activation, but to maintain a given force. The mean amplitude during the reference contraction is taken as reference value. The person’s EMG is then expressed as percentage of RVE (Figure 7). The advantage of RVE is that it is easier to achieve, as MVC is very dependent on the subjects motivation. Furthermore there is some risk of injury when performing a MVC contraction.

Figure 7: EMG data of two subjects during standardized contractions with equal force requirement. Data of subject one on the left, from subject two on the right side. (A) Raw data, (B) RMS data, (C), RMS normalized with RVE. In the normalized data, similar values can be seen for both subjects during the equal force output.
2.2. **Polysomnography (PSG)**

Sleep is a vitally important function of the human being. During sleep the human body recovers from daytime’s physical and mental strain. A biological watch in the brain determines a sleep-wake cycle of approximately 24 hours (Brunner et al. 1990). Sleep itself is also divided in four to five sleep cycles of 90-110 minutes per night (Figure 8). PSG is widely considered the gold standard for sleep recording (Hume 2008). Polysomnographic recordings allow to divide sleep into different stages as they occur in a normal night, namely in ‘rapid eye movement’ (REM) sleep and nonREM sleep. NonREM sleep can be further divided in the four sleep stages S1, S2, S3, and S4. The sleep stages S3 and S4 (slow wave sleep) and REM are known to be very important for the restorative power of sleep whereas W (the wake stage) and S1, do not or only very little contribute to recuperation (Wesensten et al. 1999).

![Figure 8: Sleep profile of one night, determined with the classification system by Rechtschaffen and Kales (1968). Data of one subject from the field study described in chapter 3.3.2.](image)

The different sleep stages are discriminated by a variety of parameters measured with electroencephalogram (EEG), electrooculogram (EOG), electromyogram (EMG) of the chin, electrocardiogram (ECG), respiratory movements, finger pulse amplitude and position in bed. As validation studies on various automated sleep analysis systems have reached contradictory conclusions (Drinnan et al. 2006), best result are achieved by visual scoring of sleep stages by trained scorers. Sleep stages are usually assigned to epochs of 30 seconds according to the Rechtschaffen & Kales manual (Rechtschaffen and Kales 1968). The resulting sequence of sleep stages is also known as sleep profile (Figure 8).
3. Experiments

3.1. Muscular load and performance compared between a pen and a computer mouse as input devices

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Introduction

Work-related musculoskeletal disorders of the upper extremities have become a problem with increasing incidence and prevalence rate (Visser et al. 2004) There seems to be a relationship between computer work and disorders of the upper extremities (Birch 2000, Atkinson et al. 2004, Chang et al. 2007, Haynes 2009). Jensen et al. (2002) and Blatter et al. (2002) reported that people with an extensive daily computer and mouse use developed musculoskeletal disorders more frequently than people with less mouse use. Jensen et al. (1998) also reported that musculoskeletal disorders occur more frequently in the arm and hand of the body side using the computer mouse. Current developments in the software industry lead to increased mouse use and decreased time of keyboard usage (Jensen et al. 1998). Computer work is generally characterized by a static posture in combination with repetitive moments. Intensive computer mouse usage is characterized by repetitive movements, a static pronation of the hand and forearm as well as a low, but continuous muscle load (Jensen et al. 1998). According to Schnoz (2006), this prolonged static and pronated position is one of the central problems of computer mouse employment, as these conditions can lead to strain and disorders. Aarås et al. (2002) developed a computer mouse that allowed a more neutral hand position. Subjects that used this mouse for six months had reduced pain in neck, shoulder and forearm while performance remained equal to using a normal mouse (Aarås et al. 2002). An alternative approach to reducing muscle load during computer mouse work is the employment of a pen-based system. Equally to the aforementioned mouse a pen provides a reduced pronation of hand an forearm (Schnoz 2006). There are many recent studies available that deal with alternative input devices to the computer mouse (Ichikawa et al. 1999, Kotani et al. 2003, Schnoz 2006, Park et al. 2006, Dang et al. 2009, Hwang et al. 2009). Künzi et al. (2007) compared a different pen model, which is basically a pen-shaped mouse with an optical sensor and therefore does not need a
tablet for determination of position. The advantage of this system is that it can be operated on almost every surface independently from a fixed tablet and therefore subjects can place their forearm in their most comfortable position. In the study of Künzi et al. (2007) a performance index based on Fitt’s law was used to measure performance on simple pointing tasks. The goal of the present study is to compare the computer mouse and a similar type of pen regarding the time needed to carry out standardized, daily computer work-based manipulations.

To be able to compare any measured factors between the mouse and a new input device, learning effects have to be considered as well. Card et al. (1978) proposed a logarithmic learning progress in performance, using an unknown input device. Subjects reached a plateau after 5 days of practicing. Another description of the learning curve was described by Gerard et al. (1994) after testing a new ergonomic keyboard. The improvement in performance during the first two hours was described with an exponential equation. Muscle activity was measured as well, but not investigated for learning effects. Kotani et al. (2003) compared a pen-tablet system with the computer mouse over five days. After three days, subjects completed tracking and pointing tasks with the same performance as with the mouse. Muscle activity was measured in the forearm and the Trapezius, but showed no difference during the five days. No data could be acquired for the initial learning period because subjects had many opportunities to exercise with the pen before and between the test sessions.

Apart from objectively measurable indicators, the subjective perception is one of the factors determining fatigue (Simonson and Weiser 1976). The Borg-scale is often used to quantify perceived exertion, especially in medicine and sports physiology (Hummel et al. 2005). According to Kankaanpää et al. (1997), there is a linear relationship between the rating with the Borg-scale and the measured muscle activity. Moreover, Borg and Kaijser (2006) recommend using the Borg CR10 scale more frequently in the research field of perceived exertion.

In summary, the aim of the present study was to compare the two input devices mouse and I-pen in performance, muscle activity and subjective ratings, taking into consideration the learning process over five days. The I-pen, being the newer device, was expected to show higher improvement than the mouse. By quantifying these improvements, a better comparison of the two devices should be possible.
Methods

Subjects

Twelve men and eight women (aged 19-49 years) participated in the study. All subjects were right-handed, had at least five years of experience in PC use and reported no history of I-pen or pen-tablet use. Subjects were paid the amount of 100 Swiss Franks for completing the experiment. The data of all subjects could be included in the analysis.

Figure 9: The two input devices used in this study: (a) I-pen, (b) mouse

Apparatus

A Windows XP professional notebook (1.7 GHz) ran the test-program and measured the time to complete the tasks. An 8-channel pre-amplifier and an 8-channel amplifier (both fabricated by T. Schärer, Signal and Information processing Laboratory, ETH Zürich) were used to record electromyographic activity (EMG). The filter settings were as follows: high-pass with 30 Hz, low-pass with 300 Hz, notch filter with 50 Hz. A 12-bit A/D card from national instruments (NI PCI-6023E) was installed in a 1.10 GHz PC with Windows XP professional in order to sample and store the EMG data. To this purpose, a program was written in Matlab (Version R2007a). The sampling frequency was set to 2000 Hz. The electrodes used were bipolar Ag/AgCl electrodes from Medtronic (pre-gelled surface electrodes, 9x6 mm recording area). Two types of input devices were tested in this study (Figure 9): mouse and I-pen. The mouse was a 2-button Logitech optical mouse with scroll wheel, bundled with the notebook on a USB-port. The optical sensor had a resolution of 800 dpi. The size of the mouse was approximately 110 mm in length, 60 mm in width and 35 mm in height. The weight was 90 grams. The I-pen used was an I-pen Pro II wireless (resolution of 800 dpi) produced by Finger Systems Inc. The length of the I-pen was 150 mm, the grip diameter approximately 20 mm and its weight was 40 grams. The I-Pen has a force sensitive tip for left mouse click and a multifunctional button on the top back for scrolling and right
mouse click (used with forefinger, Figure 10). The subjects were instructed to sit in a relaxed, upright position. Height adjustment was possible by adjusting the chair. The height was adjusted on the first day for each subject and then fixed for the following days.

Figure 10: Subject holding the I-pen while completing the test program

Tasks investigated
A program in JavaScript was written to measure the performance achieved while working with the two input devices. The aim of the program was to simulate common computer work using only the mouse or I-pen. 12 pre-existing tasks (Schnoz 2006) were chosen and modified for this study’s purposes. Finally, the program included 4 tasks of single-clicking, double-clicking and drag-and-drop respectively, in a fixed order as shown in Table 1. The tasks had to be performed continuously, with automatic change from one task to another. Estimated overall time needed to complete the program with the mouse was 15 minutes.
Table 1: Descriptions of the 12 tasks performed using the computer mouse and the I‐pen.

<table>
<thead>
<tr>
<th>Task no</th>
<th>Mouse action</th>
<th>Objective</th>
<th>Number of actions per task</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>single‐clicking</td>
<td>sorting symbols</td>
<td>120</td>
</tr>
<tr>
<td>2</td>
<td>double‐clicking</td>
<td>clicking on a circle, appearing at two fixed places</td>
<td>40</td>
</tr>
<tr>
<td>3</td>
<td>drag and drop</td>
<td>drag boxes in a square</td>
<td>25</td>
</tr>
<tr>
<td>4</td>
<td>single‐clicking</td>
<td>clicking on a circle, appearing randomly on the screen</td>
<td>40</td>
</tr>
<tr>
<td>5</td>
<td>double‐clicking</td>
<td>sorting numbers</td>
<td>45</td>
</tr>
<tr>
<td>6</td>
<td>drag and drop</td>
<td>sorting symbols</td>
<td>100</td>
</tr>
<tr>
<td>7</td>
<td>single‐clicking</td>
<td>clicking on a circle, appearing at two fixed places</td>
<td>40</td>
</tr>
<tr>
<td>8</td>
<td>double‐clicking</td>
<td>sorting symbols</td>
<td>120</td>
</tr>
<tr>
<td>9</td>
<td>drag and drop</td>
<td>complete a puzzle</td>
<td>~20</td>
</tr>
<tr>
<td>10</td>
<td>single‐clicking</td>
<td>sorting numbers</td>
<td>45</td>
</tr>
<tr>
<td>11</td>
<td>double‐clicking</td>
<td>clicking on a circle, that appears randomly on the screen</td>
<td>40</td>
</tr>
<tr>
<td>12</td>
<td>drag and drop</td>
<td>drag boxes in a square</td>
<td>25</td>
</tr>
</tbody>
</table>

Electromyographic measurements

Muscle activity of the Trapezius muscle was measured with surface EMG. The Trapezius-EMG has been shown to be a reliable measure of contraction levels, discomfort and risk factors of musculoskeletal disorders caused by computer mouse use (Aarås and Ro 1997; Harvey and Peper 1997; Baker et al. 1999; Kotani and Horii 2003). Two electrodes were placed on the Trapezius following the recommendation of Seniam (2006). The center point of the two electrodes was 2 cm medial from the midpoint between acromion and C7. The reference electrode was placed on C7. The skin had been previously shaved and prepared with a peeling paste. The EMG recorded during the computer tasks was normalized relative to a reference voluntary electrical activation (RVE) value. At the beginning of each session, RVE was determined with the method of Mathiassen et al. (1995). Thereby, three submaximal reference contractions of 15s each with a break of 30s were performed. Of these three contractions, a mean value was calculated and taken as RVE. The EMG recorded during the tasks was then normalized calculating it as relative values to the RVE. For each
task, the root mean square (RMS)-EMG was calculated using a moving average window of 50 ms. A low level EMG activity was defined and calculated as 5\textsuperscript{th} percentile ($P_{0.05}$) of the RMS-EMG. For higher level EMG activity the mean from the RMS-EMG was taken. As an indicator of energy consumption during the session, cumulative RMS was calculated, summing up muscle activity every 50ms for each task separately. As the values for the cumulative RMS were summed up over the whole tasks, they are not only dependent on the magnitude of EMG-activity but also on the amount of time needed to complete the tasks.

**Procedure**

Subjects were tested on five consecutive days, always at the same time. The design used in this study was a repeated measures design with three factors. Independent variables included task (1 to 12), input device (mouse or I-pen) and day (one to five), dependent variables included performance, muscle activity and Borg ratings. On every day, subjects performed the test program once with each device. The subjects were allowed to rest between the two trials. The order of the device use was chosen randomly on the first day and fixed for the following days. A learning session of ten minutes with the mouse was granted on the first day before the test session. To be able to describe the learning process with the new input device, only a short learning session of one minute at the most was allowed on the first day, for the subjects to understand how the I-pen works. On the following days, only the test sessions were performed, without any additional opportunities for practicing. Performance was defined as time needed to complete the tasks. Time measurement started with the first click on the first task and ended with the completion of the last task. Time was taken for each task separately as well as for the completion of the whole program. Subjects were asked to rate their subjective effort in shoulder and forearm immediately after completing the program using the mouse or the I-pen. The specific wording associated with the Borg scale was: “Please rate your subjective effort in shoulder and forearm while working with the mouse/I-pen.”
Statistics

To describe the learning effects in performance, regression parameters were calculated using a logarithmic curve estimation procedure in SPSS. The following equation was used for curve fitting:

\[ T = T_1 - b \log(\chi) \]

\( T \): Time to complete the task on the \( \chi \)th trial; \( T_1 \): time for the first trial; \( b \): an empirically determined constant; \( \chi \): test session.

To evaluate the main effects of the variables (input device, task and day) on performance, EMG-data and subjective ratings, a repeated ANOVA (analyses of variance) with logarithmic design was performed. The regression parameters were evaluated with two-sided ANOVA. Significance was assumed for \( p \leq 0.01 \).
Results

Performance

Figure 11 shows the improvement in performance during the five days. Time to completion was significantly shorter with the mouse for all tasks (F=204.4, p<0.01). Based on the statistical analysis of variable b, the logarithmic model (the logarithmic equation used for curve fitting, $T=T_1-b\log(\chi)$, as described in “Statistics” in the method section) chosen to describe the learning curve showed great significance with $F=36.63$ and $p<0.01$.

Figure 11: Time needed to complete each task on days one to five. Mean values with standard deviation for (a) mouse and (b) pen
Along with the time needed for every task, overall time was measured. Figure 12 shows the mean time needed to complete the whole test program with mouse and I-pen. Performance was significantly better with the mouse than with the I-pen (F=204.4, p<0.01). Analogous to the single tasks, overall time showed a significant logarithmic decrease over the five sessions (F=83.89, p<0.01). Analysis of the parameters $T_1$ and $b$ resulted in significantly lower values for $T_1$ for the mouse (F=128.13, p<0.01), but higher values for $b$ for the I-pen (F=35.35, p<0.01). An increased $b$ results in higher learning rates. Both devices showed significant differences between the twelve tasks for $T_1$ (F=227.1, p<0.01) and $b$ (F=22.3, p<0.01).

![Figure 12: Time to complete the test program with mouse and pen. Average over all subjects with standard deviation](image)

**Muscle activity**

As an indicator for the total muscular load, the RMS was summed up for each task separately (Figure 13). Due to the use of the logarithmic model, standard deviation is displayed with a logarithmic scale. The twelve tasks showed significant differences with F=211.25 and p<0.01. The summed up RMS values for the I-pen were significantly higher than those for the mouse (F=37.86, p<0.01). Analysis showed no significant changes over the five sessions for either the I-pen or the mouse (F=1.85, p=0.13).

The analysis of $P_{0.05}$ of the RMS (Figure 14) resulted in no significant differences between the two devices (F=1.34, P=0.26). Further analysis showed no changes over the five days (F=1.54, p=0.2) and no significant differences between the twelve tasks (F=0.99, p=0.46). The mean of the RMS is shown in Figure 15. No differences were found for the two devices (F=1.09,
and the twelve tasks ($F=1.18$, $p=0.3$). Further, no changes could be determined over the five test days for both devices ($1.89$, $p=0.12$).

![Graph showing summed up RMS for mouse and pen](image)

**Figure 13:** Summed up RMS for (a) mouse and (b) pen. Average over all subjects with standard deviation

**Borg**

Subjective ratings of stress in hand and shoulder while working with mouse and I-pen were measured with the Borg CR10-scale (Figure 16). Analysis revealed no difference between the two devices in shoulder ($F=2.31$, $p=0.15$) and hand ($F=0.59$, $p=0.45$). For hand-stress, the ratings showed no differences over the five sessions for either device ($F=1.53$, $p=0.2$). Analysis of shoulder stress, however, resulted in significantly decreasing ratings over the five sessions ($F=17.83$, $p<0.01$) for both devices.
Discussion

Performance

The data acquired during the test program show a better performance with the mouse than with the I-pen over all five days. As expected, the curve regression showed higher learning rates for the pen. The logarithmic learning model turned out to be a precise description of the learning effects, even though an extrapolation to calculate the theoretically reachable performance may not be valid for very high “x” (>1000 days), because the logarithmic function has no threshold and therefore slowly decreases to minus infinity with x.
theoretically growing to infinity. The dramatic improvement in performance with the mouse is surprising. Even though the subjects were well trained in working with a computer mouse and the tasks were based on common computer work, great improvement was still possible. Kotani et al. (2003) compared a pen-tablet system with a computer mouse over five days. In a tracking and a pointing task, the pen outperformed the mouse on the third day. Some learning effects were determined for the mouse too, but only to a small extent (Kotani and Horii 2003). Analogous results were found by Gerard et al. (1994) while comparing a normal with a newly developed ergonomic keyboard. There was only a small amount of improvement with the standard keyboard, but a very high learning progress with the new one.

![Figure 15: Mean RMS-EMG in percentage of RVE for each task with (a) mouse and (b) pen use. Average over all subjects with standard deviation.](image-url)
Our data show that the type of the evaluated task has a great influence on the varying performance with mouse and pen. In most former studies that compared mouse and pen, only simple tracking and pointing tasks were performed (Ichikiwa et al. 1999, Kotani et al. 2003, Künzi et al. 2007). In these studies, the pen outperformed the mouse. Our tasks were based on daily computer work and therefore more complex to perform. As can be seen, the complexity of the task seems to have a higher influence on the performance than the different handling of the two devices. The same results were shown by Schnoz (2006) who compared a pen-tablet system with a computer mouse. With tasks similar to those in the present study, performance was very similar for both devices, with slightly better results for the pen-tablet.

Our findings lead to the question of what performance measure should be used to evaluate different input devices. In many studies on this topic, Fitt’s law is used to measure performance (MacKenzie 1992, Ichikawa et al. 1999, Künzi et al. 2007, Wobbrock et al. 2008). With Fitt’s law, a performance index is calculated based on demanded precision, distance to target and time to completion needed (MacKenzie 1992). Therefore, only single movements are evaluated. In our study we focused on the time needed to complete complex tasks and therefore did not consider single movements. The different methods of measuring performance can lead to different evaluations of the two input devices. Kotani and Horii (2003) reported a better performance for a pen-tablet when measuring the overall time, but the time needed for single movements did not differ between pen and mouse. Analogous results were reported by Künzi et al. (2007). They found a better performance with the mouse regarding Fitt’s law, but a better performance with the I-pen regarding the overall time. As it was the goal of our experiment to compare the I-pen and the computer mouse in common computer work, the overall time should be used as the measure for performance. For longer-lasting computer work the duration of single movements does not seem to have great influence on the performance. The limitations lie in the combination of single movements and the pauses between them. After 5 days of exposure to the I-pen and the chosen tasks, we can say that working with the computer mouse allows a slightly better performance for complex and long-lasting computer tasks than working with the I-pen.
Figure 16: Borg ratings of the two devices for (a) hand and (b) shoulder. Average over all subjects with standard deviation

Muscle activity

Looking at Figure 14 and Figure 15 a trend in the data could be observed over the five days. Nevertheless there is a very high standard deviation and therefore a great variation in the EMG data. It has to be taken into consideration that the x-axis only shows a range from 0 to 4 %RVE. Therefore the effect size of the differences between the 5 days is very small and not statistically significant (p=0.02). What is more, one has to pay attention not to overestimate the standard deviation. There are known challenges in collecting EMG data over several days, especially with multiple RVE determinations (Ball and Scurr 2010). But Burnett et al. (2007) showed a high validity comparing Trapezius EMG data from several days normalized with the procedure performed in this study.

As an indicator for the total load while working with the two devices, we integrated the RMS-EMG of the Trapezius over the total time. Analysis showed no change over the five test days. As the cumulative RMS is dependent not only on the level of muscle activity as well as on the time needed to complete the tasks, we expected to find an increasing average RMS. This assumption could not be confirmed in our statistical analysis. Kotani and Horii (2003) reported no changes in average EMG while testing a pen-tablet system over five days. Those results seem similar to ours, but it must be taken into consideration that the test sessions by Kotani and Horii (2003) had a fixed duration with a flexible numbers of tasks to be completed, while in our study the number of tasks was fixed with flexible time to complete them. Nevertheless, the conclusion can be drawn that subjects optimize their working speed but not the necessary the muscular load. Our results show higher values in the integrated
RMS-EMG for the I-pen than for the mouse. This difference most likely stems from the significantly longer time needed to complete the tasks with the I-pen. Kotani and Horii (2003) did not find any differences in average muscle activity of the Trapezius between computer mouse and a pen-tablet system. The same findings were reported by Künzi et al. (2007) in evaluating %MVE (percent of maximal voluntary electrical activation). According to the manufacturer of the I-pen, the more natural hand position during use of the I-pen should reduce the muscular load on the Trapezius. Zipp et al. (1983) investigated the effects of lower arm pronation on Trapezius EMG. Their results showed that a pronation of the lower arm reduced by 10 degrees already caused significantly lower muscle activity in neck, shoulder and arm muscles during keyboard work. These findings were used by Aarås and Ro (1997) to develop a new computer mouse. This mouse led to reduced pronation of the lower arm during computer work. Surprisingly, they found no difference in Trapezius EMG between the new and a standard mouse. Similar results were found by all aforementioned studies, including ours. These findings seem contradictory to Zipp et al. (1983). An explanation was published recently by Brown et al. (2007). They investigated various input devices on performance and arm position. According to their results, most subjects’ pronation of the lower arm was reduced by an average of 43° from the horizontal baseline while working with the computer mouse. Therefore, the differences in pronation of the lower arm between a standard mouse and other input devices such as the I-pen seem to be smaller than expected, which could explain the lack of difference in Trapezius EMG.

According to the Cinderella hypothesis of Hägg (1991), one of the causes for work-related musculoskeletal disease are tasks with low muscular load but continuous low activity of small motor units (Forsman and Thorn 2007). We decided according to El Ahrache et al. (2005) to calculate the fifth percentile of the RMS-EMG as the dimension for this low activity. The statistical evaluation did not show significant change of P_{0.05} over the five days for either the mouse or the I-pen.

Another indicator for musculoskeletal disorders is the average muscle activity (Nieminen 1989; El Ahrache et al. 2005). Over the five test days no changes of mean activity were found in either device.

Independently of the average muscle activity, the percentiles remain on a constant level. Taking into account the model of ordered recruitment by Henneman (1985), this leads to the conclusion that working with either of the two devices requires activation of only small
motor units. Therefore, subjects stay in a state of low level muscle activation of the Trapezius, in which the level of RVE contraction muscle activity is not exceeded.

**Borg scale**

Over the course of the five sessions, the ratings of perceived exertion in the hand differed from the ones in the shoulder. The Borg scale values for the shoulder showed a significant logarithmic decrease, while the values for the hand stayed constantly at a low level. Because muscle activity did not change during the sessions, ratings of perceived exertion in the shoulder seem to correlate only with the duration of work, but not with the height of muscular load. Contrary results were found by Kankaanpää et al. (1997) and Hummel et al. (2005). Both studies determined a linear correlation between measured muscle activity and ratings with the Borg scale. A possible explanation for this difference is that the subjects in the present study performed the tasks with only low-level muscle activity. Harvey et al. (1997) and Künzi et al. (2007) postulated that the correlation between Borg-scale and EMG is not valid in low-level muscle activity. Therefore, the perceived exertion while working with either mouse or I-pen depends in this study only on duration of work.

The obvious reason why there was no significant decrease in the ratings of the hand is that subjects already rated their perceived exertion in the lowest region of the Borg scale in the first session. Therefore, the subjects’ variation due to the day’s form was bigger than any decrease over the testing period could have been.

Differences in perceived exertion between mouse and I-pen were found neither for the shoulder nor for the hand. The same result was found by Künzi et al. (2007) when comparing mouse and pen. Previous studies showed different results in subjective assessment of the two input devices. In one of the experiments by Schnoz (2006), subjects judged the pen to cause less exertion. In contrast to these results, the mouse attained more positive values than two different types of pen models in the study by Ichikawa et al. (1999). An explanation for these contradictory results could lies in the large diversity for both input devices. As varying types of pen and mouse models were used in the different studies, the results of the subjective evaluation of the input devices are expected to depend strongly on the different models used for comparison. This theory is supported by Ichikawa et al. (1999), where a considerable difference in subjective evaluation can be seen between the two investigated pen models.
Conclusion

Our results show that even for easy and very common computer tasks, improvements in performance are possible with both devices. It is not surprising, that the I-pen, being the newer device, showed more improvement than the mouse. But the main effect for these improvements is that people learn how to complete the tasks more efficiently, independently of the device. Therefore, the effects of motor learning can hardly be separated from learning how to complete the tasks. With enough learning time, a nearly equal performance with both devices should be possible, since the difference in performance at the initial trial was 26% and at the final trial it decreased to 18%.

Muscle activity in the Trapezius does not change throughout the learning process. Since performance improved at the same time, we can say that there is no correlation between performance and muscle activity. During the course of the learning process, only performance is optimized but not the Trapezius muscle load or the muscular energy consumption. Regarding the muscular load while working, both devices are equal.

The level of perceived exertion in the shoulder diminished with the learning process of the performance. As muscle activity stays constant over the five days, the subjective rating depends only on the duration of performed work. Therefore, the Borg scale does not correlate with muscle activity in low level muscular load.

For both shoulder and hand, no differences in perceived exertion were found between mouse and I-pen. Furthermore, the perceived exertion while working with the I-pen is the same as the mouse from the beginning.

In conclusion, computer mouse and I-pen are equal in Trapezius muscle load and perceived exertion, while the mouse shows some advantages in performance. Based on our findings, the I-pen doesn’t reduce risk factors for MSD, such as muscular load or perceived exertion. Therefore we think that the I-pen could be used complementary to the standard computer mouse, as it does not bring any advantages in working speed or reducing muscular load but could provide more variation in posture and arm movement. Such variation can help to prevent work-related MSDs in daily computer work (Delisle et al. 2009).
3.2. Evidence for repetitive strain in the Trapezius muscle during a tapping task

The data of this experiment has previously been used for the thesis of Tomatis (2009). Due to new findings in literature and our improvements in data processing and analysis, the experimental data was fully re-analyzed, resulting in the following study. Fundamental changes have been made in data processing (time and amplitude normalizing), statistical methods (calculating of effect size, adjustment of cross-correlation), results presentation and the overall focus of the study (introduction and discussion).

Introduction

Musculoskeletal complaints in the neck and upper extremity, particularly Trapezius myalgia, are common events in modern society. There is evidence for a possible causal relationship between computer work and musculoskeletal diseases in the neck and arm (Ming and Zaproudina 2003; Wahlstrom 2005; Gerr et al. 2006). Trapezius myalgia is mostly associated with static work in front of a computer with a fixed posture, stressful jobs, and insufficient rest (Madeleine 2010). It has been suggested that individuals with a poor computer working technique work with higher muscle activity in the forearm and shoulder (Lindegard et al. 2003). Wrist and arm postures, finger movements, speed of movements, and force applied while keying are examples of variables included in this construct (Kadefors and Läubli 2002; Wahlstrom 2005; Gerr et al. 2006).

Good ergonomic conditions, the time spent working with computers, and the influence of input devices are the most important aspects regarding work-related musculoskeletal diseases in the upper body. Observing subjects working with keyboards a previous investigation showed that absence or presence of neck pain could be predicted by assessing if a neck flexion greater than 20 degrees was present (Baker et al. 2008). A correct placement of the visual unit is therefore extremely important. A relationship between duration of computer use and prevalence of musculoskeletal problems has been previously reported (Ming et al. 2004; Bhandari et al. 2008). Subjects with more severe upper extremity symptoms apply more force while using the keyboard (Feuerstein et al. 1997). Additionally, reduced intramuscular coordination between extensor and flexor arm muscles is present when using keys with high force characteristics (Tomatis et al. 2009). One of the functions of the Trapezius muscle is the stabilization of the shoulder; hence it allows the stabilisation of
the arm. Recent findings suggest that pain-induced changes in Trapezius activity also change the coordination of the wrist extensor and flexor muscles (Falla et al. 2004; Samani et al. 2011). Therefore a dependency between forearm muscles and Trapezius activation during key tapping is very plausible. We hypothesize that by applying higher forces or because of bad forearm muscle coordination (i.e. high co contractions of agonist and antagonist muscles) while working with different key characteristics, higher muscle activation might be found in the Trapezius muscle, since in computer operators pain in the forearm muscle is often accompanied by Trapezius myalgia.

This study focuses on Trapezius muscle load using input devices (keys with different force-displacement characteristic) and with supported forearm. In subjects with musculoskeletal diseases higher average Trapezius activity and reduced rest time (prolonged periods without muscle relaxation) during work were already described (Vasseljen and Westgaard 1996; Hägg and Astrom 1997; Sandsjo et al. 2000; Thorn et al. 2007). The contribution of all upper limb joints, including the shoulder, to single-finger tapping has been investigated by Dennerlein et al. (2007) with motion analysis, showing that the shoulder contributes to a small extent to the tapping movement. As only the joint movement was recorded but not the muscle activity, we suggest that the muscle activation related to the tapping might be observable to a higher extent than the actual joint movement. We intended to identify phasic activity during tapping by assessing activity in the Trapezius muscle during repetitive and fast tapping tasks. Specifically, the objectives were: 1) to determine whether the Trapezius is phasically active during supported key tapping, 2) to determine if the Trapezius activity depends on the forearm activity, and 3) to determine if the strain intensity depends on the characteristics of the key.
Methods

Subjects
Thirteen right-handed subjects (seven women and six men) were included in the study, with the following anthropometric characteristics (mean ± SD): age 29.7 ± 11.4 years (ranging from 20 to 57 years), height 171.8 ± 9.7 cm (ranging from 155 to 187 cm). All subjects worked at least 5 hours per week at the computer. None of the subjects suffered from neck, shoulder, arm, or wrist pain.

The ethics committee of the ETH Zurich approved the study protocol, and informed consent to the procedure was obtained from all subjects.

The subjects were allowed to stop at any time in case of pain or fatigue.

Experimental design
The subjects sat with the right forearm supported on a table, the wrist sustained on a keyboard support, and the prone hand and fingers extended above the keyboard. The subjects had the possibility to adjust the chair to sit more comfortably.

The subjects were asked to depress the key with the index finger at a frequency of 4 Hz during 120 seconds while keeping the finger on the key. The pace was provided by audio signals. This tapping-task was repeated once for each of the ten keys with different characteristics (Table 2) in random sequence (Tomatis et al. 2009) to avoid an order effect.

The surface electromyogram (sEMG) of the finger extensor (m. extensor digitorum) and flexor (m. flexor digitorum) and of the Trapezius (m. Trapezius descendens) muscle was recorded, as was the key on-off signal.

Key characteristics
The keys differed in their force-displacement characteristics: 5 keys had the same displacement (3 mm) but differing in forces, and the other 5 had the same force (0.588 N), but different displacements (Table 2)

Table 2: Key force-displacement characteristics and labels

<table>
<thead>
<tr>
<th>Key-name</th>
<th>40p</th>
<th>60p</th>
<th>80p</th>
<th>100p</th>
<th>120p</th>
<th>1mm</th>
<th>2mm</th>
<th>3mm</th>
<th>4mm</th>
<th>5mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Make-force [N]</td>
<td>0.39</td>
<td>0.59</td>
<td>0.78</td>
<td>0.98</td>
<td>1.18</td>
<td>0.59</td>
<td>0.59</td>
<td>0.59</td>
<td>0.59</td>
<td>0.59</td>
</tr>
<tr>
<td>Key displacement [mm]</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>
**Electrodes**

Conventional surface bipolar Ag/AgCl electrodes (20 mm apart, pre-gelled, 9x6 mm recording area, Medtronic, Switzerland) were used to record the sEMG signals. Before applying the electrodes, the skin was shaved and prepared with a peeling paste. Bipolar electrodes were placed at a point 2/3 of the distance from C7 and the acromion (Jensen et al. 1993b). Both the extensor and flexor application points on the forearm were found by palpation. A reference electrode was placed on C7.

**Hardware**

An eight-channel pre-amplifier (GAIN=100) and an eight-channel amplifier with manual adjustment for amplification (10-50), a 30 Hz high-pass filter, a 300 Hz low-pass filter and a 50 Hz notch filter (Signal and Information Processing Laboratory ETH Zurich, Switzerland) were used to record the measurements. No ECG artefacts were observed by visual inspection. A 12-bit A/D card (NI PCI-6023E, National Instruments, Austin, Texas) was installed on a 1.10 GHz personal computer (Windows XP) to sample and store the data. Data was stored at 2048 Hz using custom software programmed with Matlab (Version 7.0.1, Mathworks, MA, USA).

**Data analysis**

The sEMG signals of the muscles extensor digitorum, flexor digitorum and Trapezius were rectified and processed with a 6<sup>th</sup> order Butterworth low pass filter at 5 Hz to obtain linear envelopes, which provide information on the timing and duration of the burst, as well as details on muscle activation characteristics.

Using the onset signal of the key-tap, the linear envelopes obtained from each channel were cut from one key onset signal to the next one. To remove timing variability between the cycles, the envelope length was time normalized to 1000 samples per cycle, using a re-sampling procedure.

For each condition and each subject, the limits for the outliers were defined as the 10<sup>th</sup> and 90<sup>th</sup> percentile of the amplitude range for every cycle. Outliers were excluded from the further analysis. For each session with a specific key characteristic approximately 400 until 500 cycles could be used. The normalized cycles were overlaid and the average activity level
within a cycle was determined. At each point in time the mean and its standard deviation were calculated. The mean range over the tapping cycles was compared to its maximal standard deviation. The resulting quotient was used to describe the effect size of the observed Trapezius activation (Leonhart 2004). The maximal amplitude of the averaged signal was used to characterize the phasic component of the Trapezius activity. Therefore the mean of the averaged signal was shifted to zero and the amplitude was normalized by setting the maximum to 100%. Thus, the resulting signal ranges from approximately -100% to a maximum of 100%.

Statistical methods

Statistical analysis was performed using SAS (Version 9.1, SAS Institute Inc., NC, USA).

To check if the activity bursts of the forearm and Trapezius muscles are time-correlated during the tapping cycle, cross-correlation was used.

Mixed models statistics (proc mixed) were used to calculate exact p-values and significances. The correlation coefficients determined by cross-correlation were regressed on the predictors key and order of key. Subjects were set as a random factor. Significance was assumed for p ≤ 0.05.
Results

**Objective 1: Phasic activation of Trapezius muscle**

Results showed a phasic activation of the Trapezius muscle during the tapping cycle (Figure 17). The calculated effect size was ≥0.5 in 67% of the cases (graphs), where a case is defined as all repetitions for one key and one subject (Table 3).

Figure 17: a-c. Depiction of the overlaid sEMG activities of the forearms and Trapezius muscles during the tapping cycle of one subject. The thick white line represents the mean. The cycle period lasts approximately 250ms divided into 1000 normalized units.
**Objective 2: Trapezius activity depends on forearm activity**

The size of the correlation coefficient determined by the cross-correlation between forearm and Trapezius muscle activity ranged between 0.75 and 0.98 (mean 0.93 ± 0.05) for both the extensor and flexor muscle. The significance of the cross-correlation for each subject and key is indicated in Table 3.

Table 3: Effect size and significance of cross-correlation for each subject and key. Grey: effect size >0.50, white: effect size <=0.50; Significance: * P<0.01, ** P<0.001

<table>
<thead>
<tr>
<th>Person</th>
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<th>60p</th>
<th>80p</th>
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<td>2.99**</td>
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<tr>
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<td>1.05**</td>
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<td>0.51**</td>
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<td>0.94**</td>
<td>0.13**</td>
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<td>1.34**</td>
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</tr>
<tr>
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<td>1.23**</td>
<td>0.74**</td>
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<td>0.82**</td>
<td>0.90**</td>
</tr>
</tbody>
</table>

Phasic activity of the Trapezius muscle was nearly always detectable, but at significantly different time-points within the tapping cycle for the participating subjects (Figure 18).
Figure 18: Depiction of the burst of activation of all subjects during the tapping cycle obtained with the key characteristic 120 kp. Every cycle has been normalized for time and amplitude.

**Objective 3: Dependency of Trapezius activity to key characteristics**

Mixed models statistics were used to examine the relationship between the timing of the Trapezius activation and the different key characteristics. Trapezius activity did not strongly depend on key characteristic neither for flexor muscle nor for extensor muscle (Table 4).

Table 4: Results of the mixed models statistic used to calculate the influence of different subjects and keys on the correlation coefficient of the flexor and extensor muscles.

<table>
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<th>Flexor</th>
<th>Variable</th>
<th>Degrees of freedom</th>
<th>F</th>
<th>p</th>
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<td>&lt;0.01</td>
</tr>
<tr>
<td></td>
<td>Key</td>
<td>9</td>
<td>1.71</td>
<td>0.10</td>
</tr>
<tr>
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<td>Order</td>
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</table>

<table>
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<th>Variable</th>
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<td>&lt;0.01</td>
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<tr>
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<td>0.11</td>
</tr>
<tr>
<td></td>
<td>Order</td>
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<td>0.53</td>
<td>0.47</td>
</tr>
</tbody>
</table>
Discussion

Objective 1: Phasic activation of Trapezius muscle

One of the aims of this study was to provide evidence for repetitive strain in the Trapezius muscle during a tapping task. In 67% of the studied cases a burst of activation was detected with an effect size ≥0.5.

Increased phasic Trapezius EMG activity during finger- or key-tapping was shown. In 2000, Schnoz et al. found elevated dynamic and static Trapezius muscle activity during finger tapping at different rates and trunk postures that were not only explainable by mechanical reasons such as maintenance of body posture. In addition, Zennaro et al. (2003) found continuous active motor units during 30 minutes of key tapping, supporting the Cinderella hypothesis (Hägg 1991).

To exclude a possible correlation with the movement of the upper arm, we chose a setup with supported forearm and supported wrist. Under those conditions, shoulder and arm are almost immobile: no movement was visible during the tapping task. Nevertheless, we detected repetitive activation of the Trapezius muscle in correlation with activation of the forearm muscles. The observed activity shows a phasic pattern and is highly time-correlated with the key on-off signal. Many studies showed generally increased EMG values during key tapping, describing a more or less static EMG component, for which the source remained unclear (Zennaro et al. 2003; Leonard et al. 2010; Madeleine 2010). In the experiment conducted, the tapping was performed with only one finger at a given speed. Therefore the phasic activation of the Trapezius could easily be measured. Thinking about a more realistic work task, most workers would use a ten finger system while working with a keyboard. Using all fingers with some variation in speed should result in overlaying phasic activation patterns. Therefore we hypothesize that a great part of the generally increased activity described in the aforementioned studies could be explained by the phasic activation as seen in our experiment. A possible explanation for the detected activity could be anticipatory postural adjustments (APAs) to stabilize the position of the segments of the body during movement (Massion 1992). APAs are unconscious muscular activities preceding the voluntary movement aiming to prevent the changes in posture produced by the focal movement itself (Caronni and Cavallari 2009). In the year of 2009, Caronni and Cavallari conducted an experiment to investigate the role of APAs during index finger tapping. They showed that with the hand resting prone, APAs in Trapezius muscle could not be observed. In contrast
they found an inhibition of the Trapezius prior to the finger tap in the prone position. As the subjects in the present study also performed the key tapping with the index finger in a prone position, APAs may not fully explain the activity found in our study. Another explanation for the observed activity in the Trapezius can be found in the literature describing motor learning:
Darainy and Ostry (2008) showed that following an arm movement learning task co-contraction of the shoulder still remained constant. In the initial phase of learning a new movement, very high activity can be observed in all muscles related to the movement, but co-contractions decrease with the learning progress (Thoroughman and Shadmehr 1999). According to Darainy and Ostry, these co-contractions do not disappear throughout the learning process but still form a central part of the means by which the nervous system regulates movement, also in highly skillful subjects. It seems that even though in our experimental setup subjects were experienced keyboard users and performed the tapping task with supported forearm, the activation of the Trapezius is not needed from a biomechanical point of view, but also cannot be avoided because it is part of the motor program controlling the movement.

**Objective 2: Trapezius activity depends on forearm activity**

The Trapezius activity was found to be dependent on the forearm activity: cross-correlation ratios between forearm and Trapezius activity were high for both extensor and flexor muscles. Comparable results have been found by Schnoz et al. (2000) who showed that dynamic co-activity of the Trapezius muscle occurs during computer mouse use and is time linked with the mouse clicking. A recent publication of Samani et al. (2011) showed that artificially induced pain in the Trapezius can lead to changes in the coordination of wrist flexor and extensor muscles. Thus, there seem to be strong interactions between the motor control of forearm and Trapezius muscles, influencing each others’ activation patterns. This hypothesis is supported by Alizadehkhaiyat et al (2007), showing that a weak shoulder may predispose other joints, e.g. the elbow, to injuries caused by overuse. This relationship might also explain the high inter-individual differences in the timing of the burst of Trapezius activation that were found in the present study. Various individual conditions could influence the interactions between forearm and Trapezius muscle activity:
e.g. shoulder strength (Alizadehkhaiyat et al. 2007), shoulder pain (Samani et al. 2011), muscle imbalance in shoulder or forearm (Lewis et al. 2005) or level of forearm muscle coordination (Tomatis et al. 2009). These differences could explain why some subjects may be predisposed to easier MSD development caused by the mechanisms described by Sjogaard et al. (1998).

**Objective 3: Dependency of Trapezius activity to key characteristics**

No significant relationship between key characteristic and phasic Trapezius activity was observed.

During recent years, computer work time has increased (Dolton and Pelkonen 2004). Already in 2002, Kadefors and Läubli estimated that more than half of the population in Europe was using a computer at work. Extended periods of time are spent using input devices and, if some keyboards induce more muscular activity, the risk of MSD development could increase. To be able to reduce possible risk factors, the effect of different key characteristics on the Trapezius activity is of great interest.

As shown in Table 3, our experiments could not show any relationships between phasic Trapezius activity and key characteristics. Therefore, within our experimental conditions, a different keyboard does not seem to influence phasic Trapezius activity. It has to be taken into consideration, that we only analyzed the time component of the muscle activity. There might be some changes in Trapezius EMG amplitude induced by the different key characteristics. Further analysis should be made to provide more information about possible differences in EMG amplitude.

**Limitations**

There might be some concerns about the subject’s body position, as it was not fully controlled. As aforementioned, a comparable activation pattern of the Trapezius muscle was found in most of the subjects, leading to the conclusion that the observed activity is mainly caused by the tapping process and not by posture. Nevertheless a possible influence of the posture on the Trapezius activation and time shift cannot be fully excluded and has to be considered as a limitation of the study.

Cross-correlations were used to assess the dependency between Trapezius and forearm muscle activity. This procedure provides only a linear relationship between the timing of the
measured EMG activation patterns. Even though the correlation parameter were very high (0.93±0.05), the effect might be overestimated. Principal component analysis (PCA) would be an alternative to gain more detailed information about the dependencies of muscle activation timing and could be used in future studies.

**Conclusion**

Our experiments showed significant phasic Trapezius activation during a tapping task with supported wrist and forearm. This Trapezius activity is highly correlated with the finger flexor and extensor activation. The causes for this activity and whether it could be seen as a primary cause for developing pain should be further investigated. The reason for the different patterns in the timing of activity that were observed among the analyzed subjects have not been extensively investigated and should be further analyzed.
3.3. Nocturnal Trapezius activity

Introduction

Human sleep is generally considered as the most important regeneration phase for the whole body, including the recovery from physical and psychological demands (Adam and Oswald 1984). As the overexertion of low-threshold motor units is a common model to explain musculoskeletal disorders in neck and shoulder (Hägg 1991), muscle relaxation and recovery during sleep might play an important role for pain development. An earlier study showed increased overall nocturnal activity in the Trapezius muscle in subjects with shoulder and neck pain compared to pain-free controls (Mork and Westgaard 2006). In 2002, Holte and Westgaard showed that pain-afflicted subjects showed significantly higher Trapezius muscle activity during leisure time (including sleep) than pain-free subjects. Steingrimsdottir et al. (2005) found the presence of self-reported sleep disturbances to be a strong individual predictor of increased Trapezius muscle activity during standardized cognitive and motor tasks.

There is also evidence of long-term rhythmic muscle activity during the night, possibly influencing pain development (Westgaard et al. 2002; Mork and Westgaard 2006).

It has been shown that besides physical load also mental stress induces muscle activity at low levels, therefore it can be speculated that daytimes physical and mental load influence nocturnal muscle activity (Veiersted and Westgaard 1994; Waersted et al. 1994; Waersted 2000; Lundberg 2002).

The aforementioned studies either concentrate on electromyographic (EMG) parameters over the whole night or on special EMG events occurring during the night without simultaneous polysomnographic sleep recordings. Thus, it remains unclear whether Trapezius muscle activity is related to sleep as such, as it is objectively determined by measurements of EEG activity.

Moreover, all existing studies performed single day measurements, allowing inter-individual analysis only. A repeated measurement design could increase the understanding of the influence of differences in the individual physical and mental strain on nocturnal Trapezius muscle activity. The aim of the present study was to investigate the relationship between mental and physical load, perceived hardening or pain in neck and shoulder and the presence of nocturnal Trapezius muscle activity or relaxation. Additionally, the influence of
objective sleep parameters derived by sleep monitoring on Trapezius activity has been elucidated.

**General Methods**

This section describes the methods used for all following experiments investigating nocturnal Trapezius muscle activity. Specific methods are described in each experiment’s methods section.

**Surface EMG**

Muscle activation of the Trapezius during sleep was measured by surface EMG. Shoulder muscle load is commonly measured by bipolar surface EMG of the Trapezius descendens (Jensen et al. 1993b; Aaras 1994).

**Portable EMG tool**

A small, portable 2-channel device (manufactured by Stefan Erni, Clinic for Masticatory Disorders, Removable Prosthodontics, and Special Care Dentistry, University of Zurich, Switzerland) was used to measure nocturnal Trapezius activity (channel 1) and heart ECG (channel 2). The device contained a built-in 70-400 Hz band-pass filter, an acquisition frequency of 2000 Hz, a 10 bit resolution and an amplifier gain of 4000. The subjects wore the apparatus in a bum bag around the waist (Figure 20).

**Electrode placing**

Pre-gelled silver-silver chloride bipolar electrodes (sensor size 9x6 mm, Alpine Biomed ApS, Skovelunde, Denmark) were attached to the subject, who sat in an upright position, according to Hermens et al. (1999). Hence, these electrodes were placed at 2/3 of the line from the lateral edge of the acromion toward the spinous process of the 7th cervical vertebra (C7) to generate an EMG signal of the Trapezius descendens (SENIAM 2006). The interelectrode distance was 2 cm with a reference electrode placed on the process spinae of C7 (Figure 19). Electrodes’ positions of each subject were noted to reproduce the same conditions for all measuring nights. Previous to the attachment of electrodes, the skin was cleaned with an abrasive paste (Nuprep, Weaver and Company, Aurora, USA) to enhance skin conductivity. Then, the electrodes and corresponding cables were fixed with eudermic
tape in order to avoid their shifting or falling off during sleep. The signal was recorded unilaterally on the dominant arm.

Figure 19: Electrode placing and wiring on the Trapezius

Figure 20: EMG device and bum bag with waist belt

Electrocardiography (ECG)
EMG of neck and trunk muscles is frequently contaminated by heart muscle electrical activity (Clancy et al. 2002). Thus, it is important to record ECG in addition to EMG in order to remove possible artifacts.

Two electrodes (same type as EMG electrodes) were placed across the chest as seen in Figure 21 with 1 ground electrode placed on the spine of C7. The electrode placing procedure was the same as used in the EMG measurement.

Figure 21: Electrode placing across the chest for ECG measurement

Data processing
Nocturnal Trapezius EMG raw data was processed using Matlab 2010a (Mathworks). First, an offset correction of the signals was conducted, revising the baseline shift. The signals were then band stop filtered from 45 to 55 Hz to eliminate 50 Hz mains hum. RMS (root mean square) values were calculated and smoothed using a 100 ms moving average window.
**Reference contraction**

The signal was normalized using a reference voluntary contraction (RVC). This contraction was performed each night at the beginning of the measurement according to the recommended procedure of Mathiassen et al. (1995) with specific adjustments for our study: 3 RVCs of 20 sec duration with 30 sec breaks in between were made instead of 4 RVC of 15 sec duration and breaks of 1 min. The RVC was recorded while the subject sat in an upright position, palm down and with 90° arm abduction. For each of the 3 RVCs, the mean amplitude from the middle 10 seconds was calculated. These resulting amplitudes were identified as reference voluntary electrical activations (EMG\textsubscript{RVE}). The mean from these 3 EMG\textsubscript{RVE} values was then calculated, resulting in one reference value (RVE) that was used to normalize the processed nocturnal Trapezius RMS (Mathiassen et al., 1995). In present study, normalized EMG values are expressed as percentages of RVE (%RVE).

### 3.3.1. Pilot study: Nocturnal Trapezius activity and physical and mental load

To gain more experience in nocturnal Trapezius EMG measurement and the relationship between nocturnal muscle activity and physical and mental load we conducted a pilot study. 16 healthy subjects (8 male and 8 female, aged 21-30 years), students or postgraduates, were measured during two nights. To avoid a “first night effect” (Agnew et al. 1966), one habituation night was given. To achieve some variability in the subjects’ mental load, one of the nights was just before an examination day (stress night), whereas the other night preceded a normal day (normal night). The study was approved by the ETH ethics committee and all subjects gave informed consent. Full details about the subject selection, study protocol and data evaluation can be found in Lustenberger (2009).

**Methods**

**Surface EMG**

Surface Trapezius EMG on the dominant arm as well as ECG were measured and processed as described in the general methods section above. The filtered and processed EMG values are expressed as percentage of RVE.
Questionnaires
During the measuring period, the subjects completed recurring questionnaires in the evening as well as in the morning. The evening questionnaire consisted in questions about the subject’s physical and mental load during the preceding day. The morning questionnaire asked about sleep quality and sleep disturbances caused by the measuring equipment. These questions had to be answered on a visual analog scale ranging from 0 to 10. Personal information about the subjects was collected by a questionnaire asking for basic sociodemographic variables.

Data analysis and Statistics
To quantify muscular rest of m. Trapezius during sleep, time fraction of the sleep period with RMS values in EMG lower or equal to 5% RVE was calculated and expressed as percentage for each night. Hansson et al. (2000) described the RMS values below 5% RVE or 1% MVE (EMG at maximal voluntary electrical activation (MVE), RVE is roughly about 15-20% MVE) as a good indicator for muscular rest. Cumulative time fraction, expressed as percentage of the night, was calculated for 5%, 25% RVE, 50% RVE, 75% RVE and 95% RVE for normal and stress night, to demonstrate the distribution of different activity levels during sleep. (Lustenberger 2009).

To test for significant differences between normal and stress night, evaluation parameters (EMG parameters, sleep parameters, questionnaires) were subjected to a Wilcoxon test for paired samples.

The relationship between EMG parameter differences and evening questionnaire scale differences for the normal and stress night was estimated using Spearman correlation. In addition, EMG parameters for both nights were compared with evening questionnaire scales for both nights (Spearman correlation).

All statistical tests were conducted using SPSS 17.
Results and Discussion

32 successful nocturnal m. Trapezius EMGs were recorded. The EMG data of two nights (both from the same subject) had to be excluded from the analysis, because of bad signal quality, resulting in 30 valid nights for evaluation.

Electrocardiography (ECG) contamination

ECG contamination in EMG was found in several subjects and nights (Figure 22). These heartbeat artifacts occurred temporarily with different durations ranging from a few to several minutes. EMG of neck and trunk muscles is frequently contaminated by heart muscle electrical activity (Clancy et al. 2002). This phenomenon occurs due to proximity of the collection sites to the heart and the volume conduction characteristics of the ECG through the torso (Drake and Callaghan 2006). ECG contamination may influence the EMG data, especially in low-level activity that occurs during sleep. Mekhora and Straker (1999) reported a significant difference in RMS values before and after elimination of ECG from low-level static Trapezius EMG. It is therefore important to remove possible artifacts before analysis. The contamination that occurred in our data was irregular and not continuous. Hence, no commonly used filter or pattern recognition technique could be applied.

Figure 22: a) Amplification of the ECG contaminated EMG. b) Amplification of ECG, heartbeats are simultaneous with peaks in EMG (red, dashed line).
For that reason, a peak detection and gating technique based on the recommendations of Mehkohra and Straker (1999) was developed (Lustenberger 2009) and enhanced to eliminate heartbeat artifacts peak by peak from the raw EMG signal using Matlab 2010a (Mathworks). Areas of the sleep EMG with possible ECG contamination were identified by visual inspection. Probable heartbeat artifacts are clearly visible in the EMG peaks (Figure 22). Within the selected areas, all EMG peaks with amplitude between 30 µV and 800 µV (threshold values determined by visual inspection) were identified. The same procedure was performed with the measured ECG signal. The detected peaks in the Trapezius EMG were then compared with the peaks from the ECG signal. Simultaneous peaks were eliminated from the EMG by deleting a 50 ms window that included the ECG artifact. A 50ms window appeared to be sufficient, because only a short and relatively high ECG peak was found in the EMG data, not the full QRS complex that would cause the removal of a longer window (Mehkohra and Straker 1999). The gap was then backfilled with a constant value that was the mean of the last EMG value prior and first EMG value after the gap. Visual inspection of the extracted EMG parts before and after the elimination of heartbeat artifacts (Figure 23) suggested that this removal method is an accurate way to remove irregular ECG contamination with little information loss in EMG.

Figure 23: a) Example of ECG contamination of Trapezius EMG in one subject during the sleeping phase. b) Trapezius EMG after ECG removal.
Comparison of the filtered Trapezius EMG with the original ECG contaminated signal showed a maximum increase of the mean Trapezius EMG over the whole night by 7% due to ECG contamination. This heart beat induced differences potentially cause severe errors in the analysis of low level muscle activity or muscle relaxation, where a threshold of 5% RVE is often chosen (Hansson et al. 2000).

Muscle activity
Distribution of the nocturnal muscle activity is shown in Table 5. No significant differences between normal night and stress night for muscular rest (percentage < 5%RVE) and all other thresholds in the sleep period were found. Most of the observable nocturnal muscle activation takes place in the region below 25% RVE.

Table 5: Mean and standard deviation of the cumulative time fraction of muscle activity below the chosen thresholds for normal and stress night. Significance was calculated with a Wilcoxon test for paired samples.

<table>
<thead>
<tr>
<th>threshold</th>
<th>normal night</th>
<th>stress night</th>
<th>significance (p)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5%RVE</td>
<td>90.3 ± 16.8</td>
<td>90.7 ± 25.3</td>
<td>0.69</td>
</tr>
<tr>
<td>25%RVE</td>
<td>99.4 ± 1.1</td>
<td>97.6 ± 6.9</td>
<td>0.53</td>
</tr>
<tr>
<td>50%RVE</td>
<td>99.8 ± 0.1</td>
<td>99.6 ± 1.1</td>
<td>0.57</td>
</tr>
<tr>
<td>75%RVE</td>
<td>99.9 ± 0.04</td>
<td>99.7 ± 0.8</td>
<td>0.47</td>
</tr>
<tr>
<td>95%RVE</td>
<td>99.9 ± 0.03</td>
<td>99.8 ± 0.6</td>
<td>0.36</td>
</tr>
</tbody>
</table>

At 5%RVE great inter-individual differences can be seen, whereas already at 25%RVE the differences between the subjects are reduced to a minimum. Hence, the threshold of 5%RVE seems to be a good indicator to describe not only muscular rest as proposed by Hansson (2000) but also for general differences in nocturnal Trapezius muscle activation.

Muscle activity compared with daily mental and physical load
As only the thresholds of 5% and 25% RVE seem to be important to describe differences between the nights, Spearman correlation was used to compare muscular rest and low level activity with the questionnaire items. Correlation of low-level activity values for both nights with the factor mental stress (correlation coefficient (r) = -0.02, p = 0.92) and physical stress (r = 0.14, p = 0.48) for both nights showed no significance.
To avoid overestimation of the absolute VAS ratings and to reduce the resulting inter-individual variability, intra-individual differences between normal and stress night were calculated for the questionnaire items as well as for the EMG parameters. These differences were compared with Spearman correlation. Differences in mental load did not significantly correlate with differences in muscular rest (r = -0.29, p=0.30) or low-level activity (r=0.28, p=0.32). The same results were found for physical load (r = -0.30, p=0.27 for muscular rest; r=0.30, p=0.28 for low-level activity).

These results imply that intra-individual differences in nocturnal Trapezius activity are not influenced by daily mental or physical load. The same result has already been shown by Mork and Westgaard (2004) for inter-individual differences. There are a number of limitations in the present pilot study, concerning the study design and the questionnaire used. Because the two measurement nights were several days to weeks apart of each other, there might be some restrictions comparing the EMG parameters (Jackson et al. 2009) as well as the responses from the VAS (Lesage et al. 2011). Additionally, the effect of sleep as such (e.g. sleep stages, sleep quality) was not included in the analysis.

**Continuous low level Trapezius muscle activity**

In most of the subjects, periods of continuous low level muscle activity (>5%RVE) were observed. These periods ranged from seconds to hours and the activity was clearly not a result of ECG contamination (Figure 24). We assume, that the high variability in muscular rest as shown in Table 5 is mostly explained by the occurrence of this continuous low level activity. Visual inspection revealed that most of this activity shows a highly phasic activation pattern with stable amplitude. Frequency analysis was performed for some of the detected periods, mostly resulting in one very stable frequency component. The pattern shown in Figure 24 for example has a rhythmic activation at 10 Hz.
Figure 24: Example for not ECG contaminated continuous and phasic Trapezius activity during the sleeping period. (A) Overview, continuous activity for approximately 320 seconds. (B) Amplification of a sequence with clearly visible phasic Trapezius activity. (C) ECG signal of the same period as (B). Trapezius activity is not caused by ECG contamination. Figure taken from Lustenberger (2009).

In 2004, Mork and Westgaard already described the occurrence of prolonged low level nocturnal Trapezius activity with stable amplitude and activation frequency. They also described a significant relationship between increased muscle activity and the occurrence of clinical MSD diagnosis. An activation frequency around 10 Hz as described in Figure 24 is in accordance with the typical firing rate of low-threshold motor units (MU) of the Trapezius muscle (Westad et al. 2004). Hence we suppose that this prolonged low-level activity is caused by the constant activation of one or more MUs (we also found higher activation frequencies, indicating the activity of several MUs). According to the Cinderella Hypothesis postulated by Hägg (1991), this is the mechanism that could lead to over-exertion of single MUs and resulting in pain development.

The reason for this prolonged Trapezius activity remains unclear, but there is some evidence, that it is related to the occurrence of MSD (Mork and Westgaard 2004). Furthermore, it remains unclear if sleep as such influences nocturnal Trapezius activity. For a better
understanding of nocturnal low-level muscle activity, its relationship with sleep parameters such as sleep stages should be investigated.

**Conclusion**

This pilot study shows the importance of a very careful data processing procedure, especially concerning the removal of ECG artifacts. Intra-individual differences in Trapezius activation could not be explained with mental or physical load. For a better understanding of the observed low-level muscle activity patterns as well as of the high variability in muscle relaxation, the relationship between nocturnal Trapezius EMG and sleep behavior -determined by an objective measure, such as Polysomnography- should be investigated. More and consecutive measuring nights are needed to explain intra-individual differences. A threshold of 5%RVE is a promising indicator to describe differences in nocturnal Trapezius muscle activity.
3.3.2. Relationship between sleep stages and nocturnal Trapezius muscle activity

Introduction

The pilot study gave important information for further nocturnal Trapezius EMG measurements, especially concerning the removal of ECG contamination. The prolonged low-level activity observed in several subjects is in line with the results of earlier studies (Westgaard et al. 2002; Mork and Westgaard 2004). Although this activity does not seem to be influenced by daily mental or physical load there is some evidence that it is related to pain development in MSD patients (Mork and Westgaard 2004). The mechanisms causing this activity still remain unclear. The obvious next step was therefore to investigate the dependencies between Trapezius muscle activity and sleep as such. The sleeping period is known for its restorative power (see chapter 2.2). On the other hand a great number of sleep disturbances influencing various parts of the human functions are known (Harvey et al. 2011). It is therefore very plausible that also Trapezius muscle activity is related to objective measurable sleep parameters.

We aimed to elucidate the relationship between Trapezius EMG and sleep stages determined by Polysomnography (PSG). The findings should provide a better understanding of the interactions between nocturnal Trapezius activity and sleep behavior. Furthermore, the results of the present study should contribute to an improved interpretation of the findings of existing experiments investigating nocturnal Trapezius muscle activity.
Methods

Study protocol

The present study was part of a bigger field study, investigating polysomnographically measured awakening reactions due to environmental noise (Brink et al. 2011), which allowed to use synergies in subject recruiting, data collection and the usually very sumptuous sleep stage analysis.

30 subjects were measured in the period from August 2009 until December 2009, each for four nights with the first night as an adaptation night to avoid a "first night effect" (Agnew et al. 1966; Mendels and Hawkins 1967). Subjects were visited by one or two investigators each evening before a recording night and were prepared for the PSG and EMG recordings. The study protocol was approved by the interdisciplinary ethics committee of ETH Zurich. Subjects were instructed according to the Helsinki declaration, participated voluntarily and were free to discontinue their participation at any time without explanation. Subjects were paid a remuneration of 200 CHF upon completion of the study.

Subjects

As this study was part of the study by Brink et al. (2011), the subjects were selected to the specific requirements, such as place of living, age, gender etc. Subjects suffering from sleep disturbances were excluded. The study sample was selected to represent the Swiss population between the age of 18 and 66 years as close as possible.

Exclusion criteria for this study were:

- MSD with clinical findings
- Shoulder and neck pain due to injury or systemic disease
- Intake of muscle relaxant
- BMI>30
- Skin disease in shoulder and neck area (electrode placing)
- use of tranquilizing medication
- Excessive snoring or clinically diagnosed sleep apnea
Unusual sleep-wake pattern (Subjects were required to usually maintain a steady sleep-wake rhythm with regular sleeping times covering at least the time period from midnight to 06 h in the morning)

Detailed information about the recruitment can be found in Brink et al. (2011)

**Polysomnographic (PSG) measurements**

With portable polysomnographic recorders (PD3), developed at the German Aerospace Center (DLR), the electroencephalogram (EEG) at position O2, C4 and F4, electrooculogram (EOG), electromyogram (EMG) of the chin, electrocardiogram (ECG), respiratory movements, finger pulse amplitude and position in bed were recorded continuously during the night (Figure 25). To diagnose sleep disordered breathing, the respiratory movements were recorded as well. To derive the polysomnogram (sleep profile), each experimental night was divided into 30-s epochs. To mark the beginning of the sleep period, subjects were required to press a marker button on the recorder when they switched off the lights and wanted to sleep. As validation studies on various automated sleep analysis systems have reached contradictory conclusions (Drinnan et al. 2006), we decided for a visual scoring of sleep stages. Two trained scorers independently assigned sleep stages in every 30-s-epoch according to the Rechtschaffen & Kales manual (Rechtschaffen and Kales 1968). The nights to analyze were allocated randomly, but at least one night of each subject to each scorer. Finally, each scorer cross-checked the scored nights of the other scorer (Brink et al. 2011). Because the American Academy of Sleep Medicine (Iber et al. 2007) recently recommended to not discriminate S3 and S4 anymore, we chose to set these two stages equal after the final scoring of each night.
Sleep disturbance index

Because the subjects also participated in a study about environmental noise (Brink et al. 2011), there might be some concerns about the subjects’ sleep quality. A noise specific sleep disturbance index (SDI) developed by Griefahn et al. in 2008 was therefore used to compare the sleep quality of the present study’s participants with reference values from quiet and noisy nights (Griefahn et al. 2008).

Questionnaires

During the measuring period, subjects completed recurring questionnaires concerning their self-reported sleep quality and the occurrence of neck or shoulder pain. These questions had to be answered on a visual analog scale (VAS) ranging from 0 to 10. Personal information about the subjects was collected by a questionnaire asking for basic sociodemographic variables, as well as containing questions about health, which had to be answered on a 1 (negative) to 5 (positive) scale.

Surface EMG

Surface Trapezius EMG on the dominant arm as well as ECG were measured and processed as described in the general methods section above. A peak detection and gating technique was used to eliminate heartbeat artifacts from EMG using Matlab 2010a (Mathworks), as
described in chapter 3.3.1. The filtered and processed EMG values are expressed as percentage of RVE.

*Data cutting and aligning*

RVE values were aligned with the sleep recording, using the starting times of the PD3 and the EMG device. Then, RVE data was cut into intervals of 30 seconds ("Epochs"), corresponding to the time discretisation used for the scoring of sleep stages. Sleep onset time was defined as the first occurrence of "S2" in each night. The endpoint of the measurement was set to the last epoch not scored as "W" before the end of the recording.

*Data analysis and Statistics*

For each epoch, the relative time below 5% RVE was calculated. A threshold of 5%RVE has been shown to be a good indicator for muscular rest (Hansson et al. 2000). In the present study, the proportion of time below 5%RVE is therefore considered as the amount of full muscle relaxation (relaxation time). For each subject, experimental night and sleep stage, the mean muscle relaxation time was calculated (proz5RVE). The values of proz5RVE thus range from 0% (no relaxation at all) to 100% (meaning that during the entire epoch, muscle activity was below 5% RVE).

All statistical analysis was performed with SAS (SAS Stat Version 9.2, SAS Institute, Cary, NC, USA). Mixed models (proc mixed) were used to calculate exact p-values and significances. Muscle relaxation time (proz5RVE was regressed on the predictors sleep stage and order of experimental night. The subjects were set as a random factor. Significance was assumed for \( p \leq 0.05 \).
Results

Sample description

30 people were measured within the 5 months of the field study period. 3 subjects had to be excluded during the study as they showed symptoms of sleep apnea or excessive snoring which were not detected beforehand. This resulted in a final sample of 27 subjects of which 15 (55.6%) were female and 12 (44.4%) male. 8 subjects were aged between 18 and 33 years, 10 between 34 and 49 years, 8 between 50 and 65 years and 1 subject was 66 years old. The mean age was 41 years.

Because the first night of each subject was an adaption night and therefore disregarded in the analysis, 81 nights were left for evaluation. Due to different occurrences, such as unexpected shutdown of measuring devices or loss of electrode contact, 12 more nights had to be excluded, resulting in 69 valid nights.

To check whether the participants were disturbed in their sleep by environmental noise, the SDI was calculated, resulting in a value of \(-0.28 \pm 1.91\) for this study. Griefahn et al. (2008) provide reference values for quiet (SDI = \(-0.12 \pm 1.07\)) and noisy (SDI = \(0.48 \pm 0.97\)) nights, achieved with 50 participants in the sleep laboratory.

Average self reported sleep quality was 4.1 ± 2.2 for the first, 3.5 ± 2.0 for the second and 3.9 ± 2.3 for the third experimental night, answered on a 0 (“my sleep was calm”) to 10 (“my sleep was very restless”) visual analog scale.

EMG and sleep stages

Figure 26 shows the calculated rest time in dependency of the sleep stages and experimental night.
Statistical analysis showed no significant differences for the sleep stages. Nevertheless, the factor ‘order of experimental night’ had significant influence on the measured EMG rest time. The $F$- and $p$- values calculated by the mixed models procedure can be found in Table 6. Analysis showed that the first night differed significantly from the second and third night ($F=4.49$, $p<0.01$), whereas night three and four did not differ ($F=1.37$, $p=0.17$).

Table 6: Statistical parameters calculated by the mixed models procedure.

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Degrees of freedom</th>
<th>$F$</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sleep stage</td>
<td>4</td>
<td>0.32</td>
<td>0.86</td>
</tr>
<tr>
<td>Order of experimental night</td>
<td>2</td>
<td>5.08</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

Significant inter-individual differences were found. Mean muscle relaxation over all epochs and experimental nights compared between the subjects was $33.52 \pm 25.98 \%$. This effect can be seen in Figure 27.
Visual inspection of the EMG data revealed the occurrence of prolonged low-level Trapezius muscle activity (>5%RVE) in most of the subjects as already described in chapter 3.3.1. The statistical analysis did not lead to the assumption that these periods of activity occur only during specific sleep stages. Comparison and visual inspection of these periods with the corresponding sleep profile confirmed this finding (Figure 28 and Figure 29).
Figure 28: Example of continuous low level Trapezius activity (approximately 40 minutes) in one subject compared to its sleep profile.

Discussion

The aim of this study was to describe the relationship between sleep stages and Trapezius EMG activity. Because there is great evidence that sustained activity of low-threshold motor units plays an important role in MSD development, we focused on muscle relaxation time or in other words, the absence of EMG activity. The study was performed on a representative sample of the Swiss population and at the subject’s homes, resulting in an experimental situation very close to natural conditions. The results of the SDI imply that our subjects were equally disturbed in their sleep than the reference participants during a quiet night in the laboratory (Griefahn et al. 2008). Noise-induced sleep disturbances should therefore not influence the results of the present study.

Our results show that there is no relationship between the present sleep stage and the amount of muscle relaxation in healthy subjects. There seems to be a slightly greater relaxation during slow wave sleep (S3/S4) than during the other sleep stages especially in Night 2. However this difference was not statistically significant. The results are somewhat
surprising, as it is very well known and also crucial for sleep stage scoring, that many muscles show reduced activity during the REM stage compared to all other stages (Rechtschaffen and Kales 1968; Iber et al. 2007). It has to be taken into account that these changes in REM sleep occur on an already very low EMG activity level. Even though we chose with 5%RVE a threshold just above the apparatus noise level in most of the subjects, a possible reduction in Trapezius activity in REM sleep could have taken place below this limit and therefore not influence the amount of muscle relaxation calculated in our analysis.

Nevertheless, we detected increased low-level activity also during the REM sleep in some subjects (e.g. Figure 28), a pattern that we would not expect according to the muscle inhibition mechanisms described in the literature (Rechtschaffen and Kales 1968; Iber et al. 2007). Additionally, great inter-individual differences were found, ranging from almost no relaxation to almost 100% relaxation during one night. It seems that other personal factors are much more important for Trapezius relaxation than the sleep characteristics that are measurable with PSG.

Based on our findings, MSD related analysis of nightly Trapezius EMG activity –such as muscle relaxation or occurrence of low level activity- can be made disregarding standard sleep parameters. This supports the results of earlier studies showing a relationship between increased low level nocturnal Trapezius activity and neck or shoulder pain (Westgaard et al. 2002; Mork and Westgaard 2004; Mork and Westgaard 2006), as a possible difference in the sleep pattern of MSD patients (Alsaadi et al. 2011) should not have influenced the Trapezius EMG measurements.

Sleep is generally known to be a regeneration period (Adam and Oswald) and e.g. Lobbezoo et al. (1996) showed that patients with increased daytime Trapezius EMG activity due to Cervical Dystonia had the
same amount of nocturnal muscle relaxation than healthy controls. Hence, the mechanisms resulting in increased nocturnal EMG activity in MSD patients are of great interest for prevention and treatment and should be further investigated.

Even though we provided one adaption night to avoid a “first night effect” (Agnew et al. 1966), on average the fraction of time with muscle relaxation was significantly longer in the first experimental night than in the following two nights (37.23 % in the first night compared to 29.07 % in Night two and 34.57 in Night three). This small difference must be compared to the huge inter-individual differences, ranging from almost no to almost complete muscle relaxation. The subjects self-reported sleep quality was best for the second night, but did not greatly differ between the nights. Thus, and in addition with the adaption night provided, the disturbance caused by the measurement equipment should not have influenced the subject’s muscle relaxation time. Nevertheless, a second adaption night might be needed. More subjects and experimental nights would be needed to validate these between-days differences.

**Limitations**

There are known concerns about the comparability of EMG measurements on different days (Jackson et al. 2009). We tried to minimize these differences by placing the electrodes as accurate as possible. Also Jackson et al. (2009) showed that the inter-subject variance between different days is about 12% for normalized EMG data. As we focused on muscle relaxation and did not compare EMG amplitudes during specific tasks this difference is less of a problem. Nevertheless, we admit that between-day variance is an important limitation of studies measuring EMG on different days.

**Conclusion**

Based on the findings of the present study, future experiments performing long-time Trapezius EMG measurement could include the sleeping time in the analysis, without taking into account sleep parameters derived by Polysomnography. Thus, such kinds of experiments are easier to conduct, as Polysomnography is very sumptuous in equipment and trained scorers and might leads to additional discomfort for the subjects.
3.3.3. Nocturnal Trapezius relaxation and self reported hardening in neck and shoulder

The findings of chapter 3.3.2 allowed the analysis of overall nocturnal EMG parameters, disregarding the subjects’ sleep profiles. Because Mork and Westgaard (2004) found a relationship between neck and shoulder pain and low level nocturnal Trapezius activity, we reassessed our data to compare subjective ratings of hardening with the measured activity. The aim was to explain the influence of muscle relaxation and the occurrence of low level activity on the subjects’ perceived pain in the evening and morning.

Methods
Subject selection, study design and measurement procedure were already described in chapter 3.3.2.

Questionnaire
The question of interest for this study was about the occurrence of neck and shoulder hardening. Answers were given on a 0 to 10 VAS (Figure 30). The subjects answered this question in the evening just before going to bed and in the morning just after awakening.

![VAS scale for the item “hardening in neck and shoulder.”](image)

Figure 30: VAS scale for the item “hardening of neck and shoulder.”

For the evaluation, the difference between the VAS-value from the morning and the one from the evening was calculated:

$$\text{VAS}_{\text{Difference}} = \text{VAS}_{\text{Morning}} - \text{VAS}_{\text{Evening}}$$

Thus, a negative value for $\text{VAS}_{\text{Difference}}$ represents a decrease, a positive value an increase in neck and shoulder hardening during the night.
To control for possible sleep disturbances, self reported sleep quality was asked with a similar VAS ranging from 0 = “my sleep was calm” to 10 “my sleep was very restless”.

**EMG parameter**

We showed that EMG analysis can be performed without taking sleep stages into account (chapter 3.3.2). Hence, overall muscle relaxation (activity < 5%RVE) was calculated for each night (proz5RVE$_{tot}$). The pilot study (chapter 3.3.1) revealed the occurrence of prolonged low-level activity and there is some evidence that increased nocturnal Trapezius activity is related to MSD development (Mork and Westgaard 2004). Additionally, the lack of muscular rest has also been shown to be a good indicator for MSD development (Thorn et al. 2007). Hence, for each night, we detected the longest continuous period with EMG activity greater than 5%RVE (length$_{active}$) and the longest period with EMG activity smaller than 5%RVE (length$_{rest}$).

**Statistics**

Statistical analysis was performed with SAS (SAS Stat Version 9.2, SAS Institute, Cary, NC, USA). Mixed models (proc mixed) were used to calculate exact p-values and significances. proz5RVE$_{tot}$, length$_{active}$ and length$_{rest}$ were regressed on the predictors VASDifference and order of experimental night. The order of experimental night was included, because we found some night-dependent differences for proz5RVE in 3.3.2.

To assess whether muscle relaxation is influenced not only by hardening differences but also by the absolute ‘severity’ of the hardening, we introduced the absolute rating of the hardening in neck and shoulder from the evening questionnaire (VAS$_{ev}$) into the model. The subjects were set as a random factor and significance was assumed for $p \leq 0.05$. 

80
Results

The relationship of $\text{VAS}_{\text{Difference}}$ and $\text{proz5RVE}_{\text{tot}}$ is shown in Figure 31. The observable tendency of decreasing $\text{VAS}_{\text{Difference}}$ with increasing $\text{proz5RVE}_{\text{tot}}$ was statistically confirmed with $F=10.52$ and $p<0.01$. The order of the experimental night did not influence overall muscle relaxation ($F=1.38$, $p=0.27$).

![Graph showing the relationship between VAS Difference and proz5RVE tot.](image)

Figure 31: Difference between evening and morning in subjective rated hardening in neck and shoulder compared to the percentage of muscle relaxation over the whole night. A negative value on the y-axis represents a decrease, a positive value an increase in hardening over the night.

In addition to the overall muscle relaxation, the longest period with continuous muscle relaxation ($\text{length}_{\text{rest}}$) as well as the longest period with continuous muscle activity ($\text{length}_{\text{active}}$) was regressed on the neck and shoulder hardening differences. Analysis showed great significance for $\text{length}_{\text{rest}}$ ($F=13.87$, $p<0.01$). This effect is illustrated in Figure 32. Only weak significance was found for $\text{length}_{\text{active}}$ ($F=4.08$, $P=0.05$).
Figure 32: Difference between evening and morning in subjective rated hardening in neck and shoulder compared to the longest continuous period of muscle relaxation. A negative value on the y-axis represents a decrease, a positive value an increase in stiffness over the night.

By using only differences in subjective rating of hardening in neck and shoulder, the effect might be overestimated. Thus, the model was calculated again, including perceived hardening in the evening (VAS_{ev}) in the regression. Values for VAS_{ev} reported by the subjects ranged from 0 to 9, with a mean of 3. The comparison of the different models can be found in Table 7.

Table 7: Comparison of the F- and p-values determined with the different regression models for each EMG parameter. A: model only including VAS_{difference} and experimental night; B: enhanced model with VAS_{ev}.

<table>
<thead>
<tr>
<th>Predictor</th>
<th>proz5RVE_{tot}</th>
<th>length_{rest}</th>
<th>length_{active}</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
<td>p</td>
<td>F</td>
</tr>
<tr>
<td><strong>Regression model A</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VAS_{difference}</td>
<td>10.52</td>
<td>&lt; 0.01</td>
<td>13.87</td>
</tr>
<tr>
<td>Experimental night</td>
<td>1.38</td>
<td>0.27</td>
<td>2.07</td>
</tr>
<tr>
<td><strong>Regression model B</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VAS_{difference}</td>
<td>4.98</td>
<td>0.03</td>
<td>12.83</td>
</tr>
<tr>
<td>VAS_{ev}</td>
<td>0.29</td>
<td>0.60</td>
<td>1.17</td>
</tr>
<tr>
<td>Experimental night</td>
<td>1.20</td>
<td>0.31</td>
<td>2.48</td>
</tr>
</tbody>
</table>
To control whether major sleep disturbances were influencing the Trapezius activation, the effect of self reported sleep on the EMG parameters was determined with mixed models statistics. With $p=0.97$ for $\text{length}_{\text{active}}$, $p=0.52$ for $\text{length}_{\text{rest}}$ and $p=0.52$ for pro$\text{zSRVE}_{\text{tot}}$ self reported sleep quality did not influence any of the EMG parameters.

**Discussion**

We could show a highly significant relationship between changes in the perceived hardening of neck and shoulder over the night and Trapezius muscle relaxation. The strongest dependency has been found for the longest continuous relaxation period and differences in hardening. The studies of Mork and Westgaard (2004; 2006) already described the relationship between self reported neck and shoulder pain and increased nocturnal muscle activity. In contradiction to our results, they found the subjects’ absolute pain levels to be a good predictor for increased Trapezius EMG. In the present study on the other hand, the absolute hardening did not influence any of the EMG parameters, but the difference in hardening between evening and morning did so with high significance. It has to be taken into account, that we asked for hardening or pain in the very moment (evening and morning) but the question used by Mork and Westgaard was about neck and shoulder pain during the last six months. According to Dionne et al. (2008) a valid rating of the perceived pain can only be given for the last month. A classification in pain-afflicted and pain-free subjects on the basis of the self-reported pain during the last six months might therefore lead to a classification bias. On the other hand, asking only for the occurrence of pain in the very moment as we did might be too limited, because the development of MSDs is a longer lasting process (Kolb et al. 2011). Hence there are some obvious restrictions comparing these study populations.

Nevertheless the present as well as all prior studies showed the occurrence of prolonged low-level nocturnal Trapezius activity and its relationship with perceived tension (Westgaard et al. 2002; Mork and Westgaard 2004; Mork and Westgaard 2006). Additionally, we found that the presence of Trapezius muscle relaxation seems to be a protection factor for perceived pain. These results are in line with the findings from daytime EMG measurements related to MSD development (see chapter 1.2). It has been postulated and proven many times that long lasting low level muscle activity is highly correlated with the development of
MSD (Hägg 1991; Jensen et al. 1993a; Falla et al. 2004; Andersen et al. 2008). In recent years, not only the increased activity during work, but also the muscle recovery in breaks or leisure time has been paid more attention. Holte and Westgaard (2002) showed that pain-afflicted subjects had increased muscle activity during leisure time compared to pain-free subjects. It has been shown that the lack of muscular rest time during work is associated with MSD development Thorn (2007).

Although we found great significance between the EMG parameters and differences in perceived hardening, a high variety can be seen in Figures 31 and 32. As described in chapter 3.3.2, great inter-individual differences in muscle activity were found. Hence, the relationship between EMG and perceived hardening explains some of the variance, but there are a number of other factors influencing either the muscle activity or the subjective rating of neck and shoulder hardening. Perceived hardening has previously been described as a sensation of elevating shoulders together with a variety of autonomic responses that included elevated heart rate, respiratory and perspiration responses, possibly biasing the subjective rating (Holte et al. 2003).

It is not sure whether the same mechanisms in muscle activation occur during sleep and during day. Sleep is generally considered as a regeneration period and e.g. Pompeiano (1967) described the inhibition of muscle activity especially during REM sleep. Great difference between awake and sleep have been shown for cervical dystonia, where patients and healthy controls differed greatly in the daytime Trapezius activation, but this differences disappeared during sleep (Lobbezoo et al. 1996).

On the other hand, a number of clinical symptoms exist that result in unnatural nightly muscle activity. Very well known examples are the restless-leg syndrome (Salas et al. 2010) that expresses in periodic leg movement during the sleep or the phenomenon of bruxism (Bader and Lavigne 2000) that is characterized by the grinding of the teeth and typically includes the clenching of the jaw.

The reasons for the observed nocturnal Trapezius activity and its relationship to perceived tension remain speculative. Westgaard et al. (2002) postulated that low level muscle activity during the night might be caused by pre-motor input to motoneurons from the autonomic nervous system, in particular from the sympathetic nervous system. Hence, subjects with
neck and shoulder pain might have an elevate level of the autonomic arousal that manifest in elevated Trapezius activity (Mork and Westgaard 2004). One underlying mechanism could be the so called plateau potentials that are long lasting depolarizing potentials in motor neurons (Kiehn and Eken 1998). After initiation of a plateau potential, a motoneuron can fire action potentials in the absence of continuous synaptic excitation, resulting in long lasting low-level muscle activation. If there is a causal relationship between nocturnal plateau potentials and perceived hardening remains questionable.

Body posture during sleep may also influence the occurrence of prolonged low-level Trapezius activity. In the present study subjects were not observed during their sleep. We therefore could not control for their body position. However, muscle activity related to the controlling of body position typically shows a more phasic activation with great changes in amplitude (Yamazaki et al. 2003), while the low-level activity herein described is of very stable and rhythmic nature and more likely caused by the aforementioned mechanisms. Laboratory studies with video recordings would be needed to test this hypothesis.

In our experiment, the subjects’ subjective hardening was very sensitive to the muscular rest during the night. One interesting aspect within this result is that the measurable muscle relaxation and the subjective rating difference of shoulder and neck pain corresponded very well, but did not correlate at all with the self reported sleep quality. Thus, it seems that the subjects were able to discriminate between their overall sleep quality and the specific relaxation in the Trapezius muscle. A causality between nocturnal Trapezius activity and pain-afflicted subjects was discussed by Westgaard et al. (2002) and Mork and Westgaard (2004). We can state that the amount of muscle relaxation during the night influences the subjective feeling of hardening. There seems to be some causal relationship of muscle relaxation influencing at least short time pain reception. The fact that the absolute rating of perceived tension in the evening was not correlated with nocturnal muscle activity or relaxation leaves the question open, if the nocturnal muscle activity is a cause or a consequence of neck and shoulder pain. However, it is likely that the mechanisms influencing Trapezius muscle activity during the night are part of a more complex physiological response with activation of various physiological systems that in summation are more critical to pain development. That the risk of developing MSD in neck and shoulder
cannot be reduced to a single factor but is the summative risk of various risk factors has also been described by Läubli et al. (2010).

**Conclusion**

Nocturnal Trapezius muscle activation and relaxation are strongly related to perceived changes in hardening or pain in neck and shoulder, but independent from objective sleep parameters derived by Polysomnography. Although the underlying mechanisms remain unclear, a lack of muscle relaxation and the occurrence of prolonged low-level activity during the night should be considered as risk factors for MSD development. We state that asking for perceived hardening before and after sleep provides valid information of the person’s nocturnal muscle relaxation. This information in addition with other known risk factors could help to identify and discriminate persons with increased risk for MSD development from others.
3.4. Comparison of Trapezius relaxation, movement behavior and mental load in Japanese hospital nurses during day and night shift

Introduction

Musculoskeletal disorders are a problem with high prevalence and incidence rate among hospital nurses (Josephson et al. 1997; Harcombe et al. 2009). The work of hospital nurses is often characterized by high physical demands (lifting and transferring of patients and medical equipment, awkward postures), high mental loads (time pressure, lacking room of maneuver) and irregular working hours (Smith et al. 2006; Trinkoff et al. 2006; Caruso and Waters 2008). The situation becomes even more problematic with the actual shortage of nurses and the high financial pressure on hospitals. This results in increasing workload for the employees.

In 2010 we started a project in collaboration with the Graduate School of Health Sciences, Jikei Institute, Osaka, Japan with the aim to assess the physical and mental demands of hospital nurses. The final goal of the project is to gain a profound understanding of the risk factors leading to MSDs in hospital nurses. Comparison of data from different hospitals in Japan and Switzerland will be used to identify the most important risk factors. Furthermore, the comparison should contribute to the development of recommendations for a healthier work organization and the reduction of risk factors. The project includes questionnaire studies as well as experiments with physiological measurements. The present work describes a first experiment conducted with nurses working at the Mitsubishi Hospital in Kyoto, Japan.

Shift work and especially night shift work is known as an important risk factor for various health risks (Costa 2003). Estryn- Behar et al. (2008) for example showed that subjects working on night shift developed significantly higher rates of burn-outs than subjects working only on day shift. Similar relationships have been shown for other diseases such as colon and rectal cancer or ischemic stroke (Schernhammer et al. 2003; Brown et al. 2009). A recent study by Camerino et al. (2010) showed that shift work can lead to work-life conflict. The relationship between work-life conflict and MSDs has been documented by Hämmig et al. (2011). A recent review by Caruso and Waters (2008) found 23 studies investigating the relationship between shift work and musculoskeletal disorders. 14 studies reported an
increase of the occurrence of MSDs with shift work compared to normal day work. All studies were based on subjective reporting. Caruso and Water concluded that there is a lack of objective measure of physical demands. We therefore concentrated on physiological parameters to compare day and night shift work, enhanced with subjective ratings of mental demands. Pain in neck and shoulder is reported to be the most common MSD in Japanese hospital nurses (Smith et al. 2006). Thus, we decided to focus on Trapezius muscle activity.

The goal of this study was to compare Trapezius muscle activity between day and night shift. Additionally, the overall physical demand was measured by detection of the nurses’ movement behavior. The physiological measurements were enhanced with self reported pain and mental demands. Finally, Trapezius muscle activity was modeled with the movement behavior, subjective ratings and type of shift.

To our knowledge, this is the first study comparing Trapezius muscle activity between day and night shift in hospital nurses.

**Methods**

**Subjects and Study protocol**

Fifty healthy hospital nurses have been measured during the period between October 2010 and February 2011. All subjects worked in one of two cardiology wards at the Mitsubishi Hospital in Kyoto, Japan. The nurses had at least one year of professional experience. Each subject was measured during one day and one night shift. The day shift lasted from 08.00 to 16.30 and the night shift from 00.00 to 08.30. The shift plan of the Mitsubishi Hospital demands a day shift directly followed by a night shift, meaning that the subjects worked during day until 17.00, than had a break of approximately 7.5 hours and came back to the hospital again for a night shift. Most of the subjects visited their homes during the break and slept for a couple of hours. These two shifts are usually followed by a complete day off. The measurement started with a day shift and was continued on the following night shift. The main tasks of the nurses in the cardiology ward are general health care of the patients including medication, serving food and drinks, supporting the patients in their daily
needs like washing, going to toilet etc. and writing patient reports. On the two wards included in this study, no intensive or emergency patients were present.

Subjects were visited by one or two investigators prior to their working shift and prepared for the measurement. After the end of their shift the subjects were able to remove all measurement equipment by themselves. Measurement included EMG of the Trapezius descendens of the dominant side, heart rate and movement behavior. Additionally, a recurring questionnaire had to be filled out at various time-points during the measuring day or night. Subjects were instructed according to the Helsinki declaration, participated voluntarily and were free to discontinue their participation at any time without explanation.

Exclusion criteria for this study were:

- MSD with clinical findings
- Shoulder and neck pain due to injury or systemic disease
- Intake of muscle relaxant
- BMI>30
- Skin disease in shoulder and neck area (electrode placing)
- use of tranquilizing medication

**Surface EMG**

Trapezius EMG was measured unilaterally on the dominant arm with bipolar detection. Two electrodes were placed on the Trapezius following the recommendation of Seniam (2006). The center point of the two electrodes was 2 cm medial from the midpoint between acromion and C7. The reference electrode was placed on Th3 or Th4 (3rd or 4th thoracic vertebra. We used bipolar Ag/AgCl electrodes from Ambu neuroline (pre-gelled surface electrodes, 9x6 mm recording area).

Subjects wore a battery powered EMG recording device (Muscle Tester Me3000P, manufactured by Mega Electronics Ltd, Kuopio, Finland) in a bum bag around the waist (Figure 33). EMG data was recorded with a sampling rate of 2000Hz but pre-processed online and only the resulting values were saved. Pre-processing included a root mean square procedure with a moving window of 100ms. Finally, a 0.1 seconds RMS was saved on a memory card.
Reference contraction

Reference contraction was performed as described in chapter 3.3: Before each shift the subjects performed three contractions of 20 seconds duration with a break of 30 seconds in between in an upright position. The grand mean of the middle 10 seconds of each contraction was calculated and used as reference value (RVE). The EMG measured during the shift was then normalized with the RVE value and is expressed as percentage of RVE (%RVE) in the following parts of the present study.

Heart rate

Heart rate was measured with a commercially available Polar® watch (Polar® CS600). Heart rate is detected with a belt worn around the chest stored to watch with wireless transmission. Because of strong radiation interferences caused by different medical equipment on the ward, the data transmission was disturbed severely. Hence, the heart rate data was of very bad quality and had to be discarded from further analysis in this study.

Figure 33: A) Subject wearing the EMG device around the waist, electrode placing on the right shoulder. (B) Subject wearing the ViM sports memory on the right upper arm.
ViM sports memory

The subjects’ movement behavior was detected with the commercially available ViM sports memory, manufactured by MicroStone®, Japan. This device includes a gyroscope as well as a three-dimensional accelerometer. The ViM was attached to the upper arm on the dominant side (Figure 33). This device is able to count the steps made by a person and to detect and classify different types of movements. An in-built algorithm discriminates ten different movement types with the gyroscope and accelerometer data (Table 8). Data is stored in intervals of three minutes, providing the number of steps and the distribution of the ten movement types during each interval. Since there are some concerns about the accuracy of the ViM in discriminating all ten movement types (Takahashi et al. 2009b) we decided to combine similar movements to one type (Table 8).

Table 8: Movement types discriminated by the ViM sports memory and how they were combined in the present study.

<table>
<thead>
<tr>
<th>Type nr</th>
<th>Movement by ViM</th>
<th>Combined movement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-6</td>
<td>Different walking/running speeds</td>
<td>Walking</td>
</tr>
<tr>
<td>7</td>
<td>Desk work/rest (no movement)</td>
<td>Rest</td>
</tr>
<tr>
<td>8-10</td>
<td>Different work types (light to hard)</td>
<td>Working</td>
</tr>
</tbody>
</table>

Diary

Subjects completed recurring questionnaires during the whole measuring day or night. The questionnaire consisted in questions about time pressure, irritation and fatigue which had to be answered on a 0 (very) to 5 (not at all) scale. Additionally, subjects reported the occurrence of musculoskeletal pain by marking the painful regions on a drawing of the body (Figure 34). Thus, only the amount of painful body regions was gathered, but not the severity of pain.

Figure 34: Drawing of the body used in the diary, adapted from Kuorinka et al. (1995). If the subjects perceived pain, they marked the affected region(s)
The questionnaire had to be answered on the following nine points in time during the shift (similar for day and night shift):

1. immediately after awakening
2. before shift start (after arriving at the hospital)
3. at “morning break” (half time between shift start and lunch)
4. before lunch break
5. after lunch break
6. at “afternoon break” (half time between lunch and end of shift)
7. after handover of the patients
8. after work (before leaving the hospital)
9. before going to bed

Subjects had to indicate the exact time of answering the questions in the diary. Time point 2 was also the start and time point 8 the end of EMG, heart rate and ViM recordings.

Data cutting and aligning
The exact starting times of the EMG device and the ViM were noted and used to align the data. EMG values were cut into the same 3-minutes intervals like the ViM data. Each interval therefore contained the corresponding EMG values and the distribution of the three movement types walking, rest and working (as percentage of the interval). EMG and ViM data was cut into six parts for comparison with the subjective parameters gathered by the diary. These parts corresponded to the periods between time points 2 to 8 when the diary was filled out.

Data analysis and statistics
In chapter 3.3 we showed the influence of muscle relaxation on perceived hardening in neck and shoulder. The importance of (lacking) muscle relaxation for the development of MSDs has been widely shown (Hägg 1991; Thorn et al. 2007). We therefore also focused on muscle rest time in the present study. We already successfully used a threshold of 5%RVE as an indicator for muscle rest in our previous studies (chapters 3.1 and 3.3). This threshold is also proposed by Hansson et al. (2000). In the present study, the proportion of time below 5%RVE is therefore considered as the amount of muscle relaxation (relaxation time). Muscle
relaxation time (proz5RVE) was calculated for each 3-minutes interval determined by the ViM sports memory. The variable proz5RVE can thus take values between 0% (no relaxation at all) to 100% (meaning that during the entire period, muscle activity was below 5% RVE).

All statistical analysis was performed with SAS (SAS Stat Version 9.2, SAS Institute, Cary, NC, USA). Mixed models (proc mixed) were used to calculate exact p-values and significances.

Two different models were calculated:
Firstly we tested the dependencies between muscular rest, type of movement and day or night shift. Hence, proz5RVE was regressed on the two predictors shift type and amount of the three different movement types (walking, rest, working) in each 3-minutes interval. The subjects were set as a random factor.

In a second step the questionnaire data was included in the model. Therefore, mean values for proz5RVE and the three movement types were calculated for the six periods according to the times of filling out the diary. Because the answers to the questionnaire were given retrospectively, they were compared with the physiological parameters from the preceding periods. For example proz5RVE of the period between time point 2 and 3 (start of measurement to morning break) was compared with the questionnaire data from time point 3 (morning break). The subjects were set as a random factor again.

Additionally, Wilcoxon test for paired samples was used to compare single parameters between day and night shift and differences between the periods where determined with a Kruskal-Wallis test.
Significance was assumed for $p \leq 0.05$. 
Results

Sample description

50 female nurses were measured during one day and one night shift. Because of various problems during the data recording (noise from surrounding medical devices, unintended shutdown of the measurement devices, bad electrode contact) a great amount of the recordings had to be discarded. Finally, 31 complete recordings (15 day shifts, 16 night shifts) of 18 subjects (mean age 30.4 ± 8.3 years) were included in the analysis.

EMG, movement and shift type

The relationship between shift type, movement type and muscle relaxation was calculated with the first model. Results showed that the type of shift (day or night) greatly influences muscle relaxation (F=157.58, p<0.01). The parameter estimate was -39.7 for day shift compared to night shift. The model parameters determined by the mixed models procedure for the different movement types can be found in Table 9.

Table 9: Parameter estimates and F- and p- values determined by the mixed models statistics regressing prozSRVE with the different movement types.

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Parameter estimate</th>
<th>F-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walking</td>
<td>-0.13</td>
<td>0.13</td>
<td>0.72</td>
</tr>
<tr>
<td>Rest</td>
<td>1.73</td>
<td>3.63</td>
<td>0.06</td>
</tr>
<tr>
<td>Working</td>
<td>2.25</td>
<td>5.81</td>
<td>0.02</td>
</tr>
</tbody>
</table>

The difference between day and night shift in muscle relaxation is demonstrated in Figure 35: Subjects had a significantly higher amount of muscle relaxation during the day than during the night shift. Great inter-individual differences were found in muscle relaxation as indicated by the high standard deviation in Figure 35 and statistically confirmed with F=2.95 and p<0.01 for the random effect ‘subject’.
Figure 35: Muscle relaxation compared between day and night shift in each of the six periods determined by the diary. Mean over all subjects with standard deviation.

Model with six periods and diary data

Dividing the EMG and ViM data into six periods -according to the time points of the diary- revealed that the amount of muscle relaxation differed between day and night shift in all but the last period (Figure 35). The amount of time spent in the different movement types as shown in Figure 36 did not differ between day and night shift (Wilcoxon’s p=0.92 for working, p=0.14 for walking and p=0.45 for rest). Significant differences in the distribution of the movement types during the six periods were found by the Kruskal-Wallis test for walking (p=0.02) and rest (p=0.03) but not for working (p=0.4). Similarly, significant differences in muscle relaxation time were found between the periods (p=0.03).
Subjective rating of perceived fatigue, irritation and time pressure was measured with a 0 (very) to 5 (not at all) scale. The answers given to these questions are shown in Figure 37. To
investigate the influence of these factors, prozSRVE in the periods between time-points 2 and 8 was regressed on the answers at time-points three to eight. No significant relationship was found between muscle relaxation time and fatigue (F=0.55, p=0.48) or irritation (F=1.12, p=0.33). A non-significant tendency for the relation between increasing time pressure and decreasing muscle relaxation was found (F=4.06, p=0.09).

Figure 37: Subjective ratings of fatigue, irritation and time pressure throughout day and night shift. The rating scale ranges from 0 (very) to 5 (not at all). Mean values over all subjects. At time point 1 (after awakening) only the question about fatigue was answered.

Comparison of the subjective ratings between day and night showed no differences for fatigue, irritation and time pressure (Wilcoxon’s p=0.2, 0.53, 0.79). The Kruskal-Wallis test resulted in certain tendency for a change in perceived fatigue, irritation and time pressure between the different time-points (p=0.08, 0.07, 0.06).

The question about pain provided the information of how many body parts were affected. The mean rating of perceived pain was 1.5 ± 0.5 during day shift and 1.7 ± 0.3 during night shift. Comparison of perceived pain showed no significant differences neither between day and night (p=0.5) nor in the course of the shift (p=0.18). Because any region of the body
could be affected, comparison between Trapezius EMG and perceived pain was considered as not valid.

**Discussion**

The main aim of this study was to compare Trapezius EMG between day and night shift. A great difference between the shifts was found for muscle relaxation time. Subjects had significantly less Trapezius relaxation time during the night shift. In contrast, the amount of the different movement types did not differ between day and night shift. The type of the shift was by far the strongest predictor for the measured muscle relaxation, as seen in Figure 35. The movement type ‘working’ also showed some influence on the Trapezius EMG. The factor ‘rest’ showed tendency to relate to muscle relaxation time (p=0.06). However, the parameter estimates determined by the mixed models procedure are very low for both factors (Table 9), meaning that despite the significance, the effect on Trapezius relaxation is only marginal. It is not surprising that the movement type ‘walking’ showed no relation with the muscle relaxation, as walking itself does not necessarily induce activity in the Trapezius muscle. Additionally, a great variety of walking speeds were merged together. Walking at very fast speed possibly reduces Trapezius muscle relaxation because of the accompanying arm swing, but walking at low speed or walking while carrying some load probably results in very different Trapezius activation patterns.

We can state that the movement behavior of the subjects explains only very little of the great difference in muscle relaxation between day and night shift. It seems that the distribution of the different movement types contributes to the variance in Trapezius activity in the course of the shift, but the main reason for the differences between day and night must lay in other factors.

It is well documented that high mental loads provoke reduced muscle relaxation in the Trapezius muscle (Waersted 2000; Lundberg 2002). Nevertheless, the subjective ratings of fatigue and irritation were not significantly correlated with the amount of muscle relaxation in our experiment. The occurrence of time pressure showed tendency to relate with decreased Trapezius relaxation, but did not reach significance. This result is somewhat surprising as we expected at least the factor ‘time pressure’ to correlate significantly with
the Trapezius relaxation. Time pressure is widely known to induce high Trapezius muscle load and this relationship is often used in tests assessing human stress (see Karthikeyan et al. (2011) for a review). However, no differences between day and night were found for the subjective ratings. Although the statistic tests revealed a non-significant tendency of decreasing muscle relaxation with increasing time pressure, this effect does not explain the differences in Trapezius activity between day and night. But it might explain some of the variance in muscle relaxation in the course of the shift.

In terms of movement behavior and perceived mental load the working conditions on the cardiology wards in the Mitsubishi Hospital do not seem to differ between day and night. This makes it difficult to find explanations for the immense differences in Trapezius muscle relaxation.

A possible cause could be the insufficient recovery time between the two shifts. Higher Trapezius activity or decreasing relaxation time during equal force output is generally considered as an indicator for muscle fatigue (De Luca 1997; Hägg et al. 2000b). The nurses investigated had only a break of approximately 7.5 hours between the day and night shift. This time might be not enough for the Trapezius muscle to recover completely. Thus, the smaller amount of Trapezius relaxation during the night shift could represent a general fatigue of the muscle. This hypothesis is supported by the study of Trinkoff et al. (2006) who reported a significant relationship between low back pain and less than 10 hours break between two work shifts. This problem is exacerbated as working on night shift per se causes higher strain to the human body than working during day shift (Solonin et al. 2011).

In contradiction to this hypothesis, the reported subjective fatigue did not differ between day and night. Kimura et al. (2007) showed that perceived muscle recovery does not necessarily correspond to objective measurable recovery. In a fatiguing task, the subjects’ rating of fatigue was highly related with objective muscle fatigue measured with EMG. The same task was repeated after some recovery period. On the retry, subjects reported complete recovery, but the measurement still showed significant muscle fatigue. It seems that people are able to report changes in muscle fatigue, but not the absolute level of fatigue. The perceived recovery could therefore be overrated.

Hence, measures should be taken to avoid augmented muscle fatigue during night shift. It has been shown by Takahashi et al. (2009a) that reduction of overall fatigue can prevent
MSD development. They demonstrated that nurses who take a nap during the night shift had significantly lower amounts of MSD complaints than nurses who do not take a nap.

The course of the subjective ratings is very stable during day and night shift for all subjects (Figure 37). We observed a quite fixed schedule of work tasks during the shift on the cardiology wards at the Mitsubishi Hospital. This schedule can be maintained because most of the patients are long-term stationary patients recovering from heart surgery. It seems as the subjective ratings during the shift mainly represent the work schedule. The work load and tasks seem to be equally distributed on the different nurses during day as well as during night shift. On the other hand, significant differences in the movement behavior (‘rest’ and ‘walking’) were found between the subjects in each of the six periods. Hence, we hypothesize that the subjective rating of the nurses was mostly influenced by the type of work and less by their actual physical or mental strain. This might be an explanation, why the subjective parameters did not correlate with the Trapezius relaxation time.

Self reported pain did not differ between day and night shift. This finding indicates that neither of the shift types caused a higher strain to the subjects. This result is in line with the outcomes from the other questionnaire data and the ViM recordings but not with the measured Trapezius muscle relaxation time. However, comparison between self reported pain and Trapezius activity cannot be done because the question about pain is too unspecific. The value gathered by this question only represents the number of painful body parts, whereas the EMG measurement is highly specific on the Trapezius muscle. A more specific question about the severity of hardening or pain in the shoulder should be used in future studies.

Limitations
The ViM sports memory used to measure the movement behavior was attached on the upper arm. The discrimination in the different movement type is made with the data from a gyroscope and a three-dimensional accelerometer. Comparing this data with EMG parameters from the Trapezius muscle might be limited, because one could think of arm movements that do not necessarily affect the activity of the Trapezius descendens. Additionally, a high workload in awkward or static positions might be miss-classified as ‘rest’,
because only information on motion but not on body position is used to determine the movement types. Further studies therefore should use sensors determining body position (e.g. trunk position) and motion data to discriminate different types of work. Measurement of heart rate should also be included to determine between static positions with high or low workload. 

The allocation of EMG and movement parameters in periods between the different time-points of answering the questionnaire might not be accurate enough. It is plausible that the answers given by the subjects just represent their subjective feeling at the very moment whereas the EMG and ViM data represent a longer period. This effect should be paid attention when designing similar studies in the future.

**Conclusion**

The Nurses measured in this study have similar workloads during the day and night shift. Nevertheless, the overall muscle relaxation was significantly lower during the night shift. This effect should be considered as a risk factor for MSD development. The measurement of the movement behavior and the subjective parameters asked by questionnaire contribute to the description of the Trapezius relaxation throughout the shift, but not to the explanation of the differences between day and night. Because it is likely that subjects have to work in a state of augmented muscle fatigue, measures for a better recovery between the working shifts should be taken. This would mean to change the shift plan to another system with a break of more than 10 hours between the shifts. An urgent measure that could be introduced is to provide the possibility to take a nap during the night shift.
4. General Discussion and Conclusion

This thesis attempts to contribute to the understanding of the physiological mechanisms related to MSD development and prevention, focusing on the region of neck and shoulder.

In modern society, computer work time has increased (Dolton and Pelkonen 2004). Already in 2002, Kadefors and Läubli estimated that more than half of the population in Europe was using a computer at work. Because keyboard and mouse use have been identified as possible risk factors for MSD development in neck and shoulder, numerous efforts have been made to design ergonomic input devices (Aarås and Ro 1997; Schnoz et al.). This includes various types of keyboards as well as alternative pointing devices which are mostly pen-like systems. The aim of an ergonomic design of input devices usually is to reduce muscular load by adjusting weight, size or resistance of the device or by enabling a working position were the finger, hand and arm joints are in a more neutral position (Aarås et al. 2002; Forsman and Thorn 2007; Delisle et al. 2009). Working in a more neutral position should reduce the muscle load and therefore lower the risk of pain development. However we could not show any differences in Trapezius muscle load between working with a pen or a standard computer mouse. Working in a more neutral arm position did not influence the strain in the shoulder. Similarly, we found no difference in Trapezius muscle activation while tapping on keyboards with different key characteristics. Neither the resistance nor the displacement distance of the key contributed to a significant reduction of phasic muscle activation. Moreover we could show that Trapezius activation is mostly related to the actual tapping on the keys, regardless to the different types of keys. It is likely that most of the Trapezius muscle strain is caused by the typical movements performed while using an input device and only very little influenced by its characteristics. Hence, we conclude that ergonomic input devices might provide an improvement in performance, especially in very specific computer work tasks, but that the overall muscular strain is mostly dependent on the device usage time.

After Hägg proposed his Cinderella hypothesis in 1991, the occurrence of long-lasting low level muscle activity and the resulting lack of muscular rest time have been paid more and more attention. Since then, a great variety of mental and physical risk factors have been
identified to be related with this sort of muscular over-exertion. It is likely that the final development of musculoskeletal pain is a cause of the number of risk factors prevalent and not necessarily their respective nature (Läubli et al. 2010). For the sake of a better understanding of the physiological mechanisms leading to MSD not only single work tasks should be evaluated but also the overall strain during a subjects’ day, including leisure time. A good balance between work and leisure time has been found to be a crucial factor for MSD prevention (Hämmig et al. 2011). This relationship has also been demonstrated by Mork and Westgaard (2006). They showed that workers with MSD in neck and shoulder had the same amount of muscle activity during the work than pain-free subjects. But in leisure time, the muscle activation was significantly increased in the patients compared to the controls. This effect is even observable in increased muscle activation during the night (Mork and Westgaard 2004).

Sleep is generally considered as the most important recovery phase for the human body (Adam and Oswald 1984). The presence of long-lasting low-level nocturnal Trapezius activity we observed in our experiments may result in an insufficient recovery of the muscle. This hypothesis is supported by the fact that subjects with less nocturnal muscle relaxation time reported an increase in perceived hardening in neck and shoulder in the morning. The improvement of nocturnal muscle relaxation could therefore be a measure for MSD prevention and rehabilitation. Because Trapezius activation is not dependent on actual sleep characteristics described by sleep stages, its causes should further be investigated.

The importance of sufficient muscle recovery is also supported by the results from our study on hospital nurses. Although the physical and mental workload during day and night shift was very similar, the nurses experienced a much lower amount of Trapezius relaxation while working during the night. Regarding the very short leisure time between day and night shift (< 8 hours) it is likely that this difference in muscle relaxation is caused by insufficient muscle recovery.

Thus, it is important to aim for sufficient muscle relaxation and to avoid muscle over-exertion. Considering the diversity of risk factors related to the development of MSD (Canjuga 2009), prevention and intervention strategies should be of interdisciplinary nature as well.
Outlook

Assessment of physical and mental strain in hospital nurses during day and night shift is continued in various hospitals in Switzerland and Japan. Because increased muscle activity during work, leisure time and sleep has been shown to be an important risk factor, further measurements should be performed over a full 24 hours day or even longer. Additionally, enhanced measurement systems to quantify physical load and to objectively measure mental load will be introduced. A profound understanding of the balance between muscle load and relaxation and its relation to pain development is needed to provide new suggestions for MSD prevention.
5. Bibliography


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6. Curriculum Vitae

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Publications


Conferences

