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***NECK PAIN: THE ROLE OF 24 HOURS TRAPEZIUS MUSCLE
ACTIVITY, WORKLOAD AND SUBJECT BEHAVIOR***

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Abstract

Neck pain is highly prevalent in different occupational groups. Two occupational groups that are highly affected of neck pain are nurses and office employees. In both occupations, within one year, more than every second employee suffers from neck pain. Rest time of the trapezius muscle has been shown to be important for the development of neck pain. Also the activity levels of trapezius muscle, expressed as percentiles, are often used to examine the development of neck pain. Nevertheless, the factors involved in the development of neck pain, as well as the mechanism leading to neck pain are not yet clear. Therefore, a focused prevention is not possible. This dissertation aimed first in clarifying two methodological issues of electromyographical (EMG) measurements of trapezius muscle activity. Afterwards, parameters discussed to influence trapezius muscle rest time and activity were analyzed for nurses and office employees. Finally a model explaining the mechanism leading to neck pain should be developed. The overall aim of this thesis was to get a step closer to a purposeful prevention of neck pain.

In the first experiment, the normalization procedure that is often used for trapezius muscle EMG was proven for its accuracy. It was found that too low or too high normalization values may cause falsified measuring values. Therefore, it was proposed to only use normalization values limited to a defined range. In the second study it was evaluated if trapezius muscle EMG measurements during sleep are influenced by sleep stages. Trapezius muscle rest time and activity were found to be independent of sleep stages.

The following two experiments evaluated the influence of shift work on trapezius muscle rest time and activity and on the circadian rhythm of heart rate. The work organization was found to be highly potent to influence trapezius muscle rest time, trapezius muscle activity, and heart rate. In particular, shift work as well as the organization of shift work was shown to have an impact on trapezius muscle rest time and activity. Enough time off between shifts and moderate workload during night shifts were proposed.

In office employees, trapezius muscle rest time and activity during a full day of computer work, leisure time and sleep was evaluated. It was interpreted from the findings that a parameter in the subjects, called personal characteristics, was strongly related to trapezius

muscle rest time and activity. Furthermore, subjects without chronic neck pain seem to be able to almost completely relax the trapezius muscle during sleep. The influence of physical activity during lunch break on trapezius muscle rest time and activity needs to be further investigated since a tendency was found that subjects with more physical activity during lunch break had shown more trapezius muscle rest time and less trapezius muscle activity in the afternoon. Trapezius muscle rest time and activity was not found to systematically change in the progression of a day of office work. During leisure time the peak activity of arm acceleration was higher than during work and trapezius muscle rest time and activity was not significantly different.

Based on mentioned studies and findings from literature, a model explaining the development of neck pain and including the parameters acting on trapezius muscle and the processes inside the muscle could be developed. However, some of the proposed mechanisms still have to be confirmed, particularly the proposed low-frequency fatigue.

The two parameters work organization and personal characteristics could have been shown to be able to significantly change trapezius muscle rest time and activity. Combining these findings with the proposed model, it can be concluded that the prevention of work-related neck pain should not only focus on physical and psychosocial risk factors, but also on the work organization. How to implement the finding about the importance of the personal characteristic in prevention of neck pain is not yet clear.

Zusammenfassung

Nackenbeschwerden sind in verschiedenen Berufsgruppen weit verbreitet. Zwei sehr stark betroffene Berufsgruppen sind Pflegefach- und Büroangestellte. In beiden Berufsgruppen leidet innerhalb eines Jahres jeder zweite Angestellte an Nackenbeschwerden. Es konnte gezeigt werden, dass die Erholzeit des Trapezmuskels relevant ist für die Entwicklung von Nackenbeschwerden. Weiter sind auch die Aktivitätslevels, ausgedrückt als Perzentile, ein häufig verwendetes Mass um die Entwicklung von Nackenbeschwerden zu untersuchen. Die Parameter, die in die Entwicklung von Nackenbeschwerden involviert sind, sowie der genaue Mechanismus, der zur Entstehung von Nackenbeschwerden führt, sind jedoch noch unklar. Deshalb ist eine fokussierte Prävention von Nackenbeschwerden momentan nicht möglich. Das erste Ziel dieser Dissertation bestand darin, zwei methodologische Schwierigkeiten elektromyographischer Messungen (EMG) des Trapezmuskels zu lösen. Danach wurden in den Berufsgruppen der Pflegefach- sowie der Büroangestellten Parameter untersucht, welche die Erholzeit und die Aktivität des Trapezmuskels beeinflussen könnten und schliesslich sollte ein Modell, das die Entstehung von Nackenbeschwerden beschreibt, entwickelt werden. Das Ziel dieser Dissertation war es, einen Schritt näher zu einer zielgerichteten Prävention zu gelangen.

Im ersten Experiment wurde die Normalisierungsprozedur, die bei EMG-Messungen oft eingesetzt wird, überprüft. Es konnte gezeigt werden, dass zu hohe oder zu tiefe Normalisierungswerte zu einer Verfälschung der Messergebnisse führen können. Als Lösungsvorschlag wurde empfohlen nur Normalisierungswerte innerhalb eines definierten Bereiches zu verwenden. In der zweiten Studie wurde untersucht, ob EMG Messungen in der Nacht von den Schlafstadien beeinflusst werden. Die Resultate zeigten, dass sowohl die Erholzeit als auch die Aktivität des Trapezmuskels unabhängig von den Schlafstadien sind.

Die folgenden zwei Experimente untersuchten den Einfluss der Schichtarbeit auf die Erholzeit und die Aktivität des Trapezmuskels sowie auf die zirkadiane Rhythmik der Herzfrequenz. Die Gestaltung der Arbeitsorganisation erwies sich als wirkungsvoller Parameter, um die Erholzeit und die Aktivität des Trapezmuskels sowie die Herzfrequenz zu beeinflussen. Im Speziellen konnte ein Einfluss der Schichtarbeit und der Organisation dieser auf die Erholzeit und die Aktivität des Trapezmuskels nachgewiesen werden. Daher wird eine ausreichend lange Pause zwischen zwei Schichten und eine reduzierte Arbeitsbelastung in Nachtschichten empfohlen.

Bei Büroangestellten wurden die Erholzeit und die Aktivität des Trapezmuskels während eines gesamten Arbeitstages, der Freizeit und des Schlafes untersucht. Die Ergebnisse wurden so interpretiert, dass ein Parameter, die sogenannte persönliche Charakteristik, stark mit der Erholzeit und der Aktivität des Trapezmuskels in Verbindung stand. Des Weiteren konnte gezeigt werden, dass Probanden ohne chronische Nackenschmerzen während des Schlafes den Trapezmuskel nahezu komplett entspannen konnten. Eine Tendenz, dass ein erhöhtes Level physischer Aktivität während der Mittagspause zu mehr Erholzeit und weniger Aktivität des Trapezmuskels am Nachmittag führen kann, konnte gefunden werden. Deshalb wird empfohlen, den Einfluss physischer Aktivität während der Mittagspause und der Freizeit auf die Erholzeit und die Aktivität des Trapezmuskels weiter zu untersuchen. Im Verlauf eines Arbeitstages konnte keine Veränderung der Erholzeit und der Aktivität des Trapezmuskels nachgewiesen werden. Die maximale Armbeschleunigung war in der Freizeit grösser als bei der Arbeit, während die Erholzeit und die Aktivität des Trapezmuskels sich nicht signifikant unterschieden.

Basierend auf den durchgeführten Studien und Erkenntnissen aus der Literatur konnte ein Modell entwickelt werden, das den Mechanismus der Entstehung der Nackenschmerzen erklären soll. Dieses Modell enthält sowohl die Prozesse innerhalb des Muskels, als auch die Faktoren, die auf den Arbeitnehmenden einwirken. Einige der vorgeschlagenen Mechanismen, insbesondere die Entstehung der Ermüdung in den tiefen Frequenzen, müssen jedoch noch bestätigt werden.

Es konnte gezeigt werden, dass die beiden Parameter Arbeitsorganisation und persönliche Charakteristik die Erholzeit sowie die Aktivität des Trapezmuskels signifikant verändern können. Kombiniert man diese Erkenntnisse mit dem vorgeschlagenen Modell, folgt, dass die Prävention arbeitsbedingter Nackenbeschwerden sich nicht nur auf die physischen und psychosozialen Risikofaktoren konzentrieren, sondern auch die Arbeitsorganisation miteinbeziehen sollte. Wie die Erkenntnisse der Wichtigkeit der persönlichen Charakteristik in die Prävention von Nackenbeschwerden eingebaut werden sollen, ist noch unklar.

Preface

This thesis was entirely performed at the Sensory-Motor Systems Lab, Institute of Robotics and Intelligent Systems, ETH Zurich, Switzerland. Chapter 2 until Chapter 5 are manuscripts that were published in international journals and Chapter 6 and Chapter 7 were submitted to international journals. Chapter 4 and 5 are the results of a collaboration with the Graduate School of Health Sciences in Osaka (Japan) and the Kyoto Institute of Technology (Japan):

Chapter 2: Nicoletti, C., Läubli, T., 2013. Normalization of trapezius muscle EMG with submaximal reference contractions: Difficulties and solution approaches *Zbl Arbeitsmed* 63, 250–253. With kind permission of Springer Science+Business Media.

Chapter 3: Müller, C., Nicoletti, C., Omlin, S., Brink, M., Läubli, T., 2015. Relationship between sleep stages and nocturnal trapezius muscle activity. *J. Electromyogr. Kinesiol.* 25, 457-462. We thank Elsevier and the Journal of Electromyography and Kinesiology for allowing the inclusion of this publication in the doctoral thesis.

Chapter 4: Nicoletti, C., Muller, C., Tobita, I., Nakaseko, M., Laubli, T., 2014. Trapezius muscle load, heart rate and time pressure during day and night shift in Swiss and Japanese nurses. *Ind. Health* 52, 225-234. With kind permission of Industrial Health.

Chapter 5: Nicoletti, C., Muller, C., Hayashi, C., Nakaseko, M., Tobita, I., Laubli, T., 2015. Circadian rhythm of heart rate and physical activity in nurses during day and night shifts. *Eur. J. Appl. Physiol.* 115, 1313-1320. (Erratum: Nicoletti, C., Muller, C., Hayashi, C., Nakaseko, M., Tobita, I., Laubli, T., 2015. Erratum to: Circadian rhythm of heart rate and physical activity in nurses during day and night shifts. *Eur. J. Appl. Physiol.* 115, 1321.) We thank the European Journal of Applied Physiology for allowing the inclusion of this publication in the doctoral thesis.

Chapter 6: Nicoletti, C., Läubli, T. Comparison of trapezius muscle rest time and activity during work, leisure and sleep in female office employees: a within day analysis. Submitted to *BMC Musculoskelet Disord.*

Chapter 7: Nicoletti, C., Läubli, T. Trapezius muscle activity and body movement at the beginning and the end of a workday in female office employees. *Ind. Health*, in revision.

Objectives

The overall objective was to get a step closer to a purposeful prevention of neck pain. The contribution of this dissertation is to find parameters related to trapezius muscle rest time and activity and to critically analyze the findings from literature that trapezius muscle rest time is crucial to avoid the development of neck pain. Finally, a clear model explaining the mechanism of the development of neck pain should be developed.

The most commonly used method to evaluate the activity of trapezius muscle is the electromyography (EMG). Although frequently used, there are some uncertainties concerning the optimal methodology. Therefore, the first two manuscripts (Chapter 2 and 3) cover methodological issues of EMG measurements.

To identify parameters that could be related to trapezius muscle rest time and activity, two different professions both with a high prevalence rate of neck pain, but highly different workloads were considered. The third and the fourth manuscript (Chapter 4 and 5) analyzed special parameters of the profession of the nurses. The fifth and the sixth manuscript (Chapter 6 and 7) analyzed parameters in the profession of the office employees and had an additional emphasis on the trapezius muscle rest time and activity during leisure time and sleep.

Finally, a model explaining the mechanism that could lead to neck pain, including the happenings on the muscular level, the parameters of the working conditions of the different professions, leisure time and sleep, was developed. As the manuscript including this newly developed model is not yet written the model is included and explained in the introduction (Chapter 1.4) and mentioned again in the general discussion (Chapter 8.1) and the outlook (Chapter 9).

1. Introduction

1.1 Prevalence and impact of neck pain

Neck pain is highly prevalent in the working population (Picavet and Schouten, 2003). Reported prevalence rates of neck pain strongly vary between different publications. A review about prevalence rates of the world population (Fejer et al., 2006b) showed a mean value of lifetime prevalence of neck pain of 49%, a mean value of one-year prevalence of 37% and a mean one-week prevalence rate of 13%. A study in the British population (Palmer et al., 2001) showed a one-year prevalence rate of 34% and a one-week prevalence rate of 20%. In the Dutch population a one-year prevalence rate of 16% for men and 25% for women was reported (Picavet and Schouten, 2003). Like all MSDs (musculoskeletal disorders), neck pain reduce the quality of life of the affected person (Scuffham et al., 2010). In the United States of America (USA), neck pain is the number four in the list of diseases that cause years lived with disability (Murray, 2013). In other words, in the USA, the number of years lived with a disability is the fourth highest due to neck pain. Furthermore, the health costs are substantial. In the Netherlands in the year 1996, the direct and indirect costs of neck pain were 686.2 million Dollar, which means 1% of the total healthcare expenses (Borghouts et al., 1999). Neck pain can lead to a loss of productivity, too (van den Heuvel et al., 2007). This is not only due to sickness absence but also to a reduced productivity of the employees working with neck pain. van den Heuvel et al. (2007) found that 68% of the productivity loss due to neck pain was caused by workers that were working but were less productive and only 32% was due to sickness absence. Due to these different impacts MSDs not only affect the person suffering from them, but also related people, the company the person works for and the economy.

The prevalence of neck pain shows different characteristics in different groups of the population. Neck pain is more prevalent in women than in men (Baran et al., 2011; de Zwart et al., 2001). In addition, prevalence of neck pain varies with age. It was shown to ascend until the age range of 35 to 49 years and to decline afterwards again (Hoy et al., 2010). Finally the prevalence of neck pain differs between the occupational groups too. Two occupational groups that are strongly affected from neck pain are nurses and office employees. In nurses the one-year prevalence rate of neck pain was reported as 52% (Harcombe et al., 2009) and 55% (Warming et al., 2009). With 51% (Harcombe et al., 2009) and 55% (Wu et al., 2012), similar prevalence rates were reported for office workers. In other words, within one year, more than every second nurse or office employee is affected of neck pain.

1.2 Current knowledge about the development of neck pain

To study the development of neck pain most authors focus on the activity of the trapezius muscle, due to several reasons. First the trapezius muscle is the prevalent site of pain in the neck/shoulder area and secondly it is one of the muscles that is easily accessible by the commonly used method surface electromyography (EMG) (Sommerich et al., 2000). Furthermore, specific behavior patterns of this muscle were proposed that could explain the frequent development of pain (trapezius myalgia) in the trapezius muscle (Hagg, 1991a).

In some occupational tasks, e.g. computer work, the load on the trapezius muscle is rather small (Zennaro et al., 2003). During a task that only uses a small amount of the maximal force of a muscle, only some of the subunits of the muscle, the motor units, are activated (Wilmore and Costil, 2004). The motor units of the slow twitch fibers are always activated first. Only if the required force is too high to be provided through the aerobic metabolism of the slow twitch fibers, the motor units of the anaerobe fast twitch fibers will be activated as well (Wilmore and Costil, 2004). If such a low-level force has to be maintained over a certain period of time, the activated motor units can get overexerted (Hagg, 1991a). Some authors mentioned a rotation of motor units in long-lasting low-level activity that enables the fatigued motor units to recover (Bawa and Murnaghan, 2009). However, in the trapezius muscle of some individuals this rotation does not seem to happen (Zennaro et al., 2003).

The exact mechanism responsible for the development of neck pain in occupations with a low or median physical strain is not fully understood (Walton et al., 2013). The most promising hypothesis is the so-called Cinderella hypothesis (Hagg, 1991a). Hagg proposed that during a long-lasting low-level strain always the same muscle fibers are activated. Based on the famous fairytale of Cinderella, he proposed that one muscle fiber has to be active over the whole period and has to perform all the work, while the others stay inactive. If this period of continuous activity is too long and the muscle fiber has no chance to rest it may become overloaded (Hagg, 1991a). This theory is based on the concept of recruiting motor units in a defined order based on their sizes and without a replacement of fatigued fibers (Henneman and Olson, 1965; Wilmore and Costil, 2004).

Different findings support this Cinderella hypothesis. Zennaro et al. (2003) found motor units in the trapezius muscle of some individuals that were indeed active nearly a complete computer task. Additionally, the type of workload was shown to have an influence. Falla and Farina (2007) found a spatial shift of activity within trapezius muscle during a dynamic

activity, but no shift was found during a static activity of the muscle (Farina et al., 2008). Using muscle biopsies, Andersen et al. (2008) showed structural changes in muscle fibers in subjects suffering from trapezius myalgia. In these subjects so-called megafibers of type I muscle fibers were found more often than in healthy subjects. It is assumed that these megafibers developed because the muscle tried to react on the high strain. However, the capillarization of the megafibers was relatively poor and therefore, this adaptation seems to be pathologic and does not allow an aerobic metabolism (Andersen et al., 2008). Similar findings were reported by Hagg (2000), who showed an increased area of type I muscle fibers and an reduced amount of capillaries per area of type I muscle fibers in subjects with trapezius myalgia compared to controls. In accordance, Rosendal et al. (2004) showed an increased lactate level in the interstitium of the trapezius muscle in subjects with trapezius myalgia. Furthermore, they found an increased level of 5-HT (serotonin) and glutamate. Andersen et al. (2008) proposed that the pain in the trapezius muscle might result from an acidosis based on the anaerobic metabolism of the type I megafibers and Rosendal et al. (2004) assumed that the combined effect of lactate, 5-HT and glutamate could cause or increase pain. For high repetition tasks in a rat model, significantly increased levels of inflammatory cytokines were found in muscles and tendons (Barbe et al., 2013). Additionally, if such tasks were combined with a high force condition, parameters of tissue degradation were found (Barbe et al., 2013). Wilander et al. (2014) have shown elevated levels of some inflammatory biomarkers in the serum of subjects with work-related neck or shoulder pain. Despite the unclearness of the development of neck pain, already different approaches for prevention were done. However, as reviews showed, prevention resulted in little success so far (Bongers et al., 2006; Hoe et al., 2012; Verhagen et al., 2013).

This chapter shows that the mechanism of the development of neck pain is still unclear, even though, several studies were already conducted. As the mechanism of the neck pain development is unclear, it is additionally not known which the important parameters that should be avoided are. Considering the high prevalence rates of neck pain (Fejer et al., 2006b; Palmer et al., 2001) and the little success of prevention (Bongers et al., 2006; Hoe et al., 2012; Verhagen et al., 2013), it is, in our opinion, difficult or even impossible to prevent neck pain purposeful until now.

1.3 Main measures used

1.3.1 EMG

Basics

The commonly used method to evaluate the activity of the trapezius muscle is surface EMG. This is the only non-invasive method to receive direct information on muscle involvement (Mathiassen et al., 1995). Surface EMG measures the potential differences of the electric field on the skin between two or more electrodes. These electrical fields are generated by the action potentials that generate muscle contractions (Barbero et al., 2012). In this thesis, bipolar surface EMG was used. Thus the electric potential differences between two electrodes, placed on the skin over the area of the muscle, were measured. Thereby it is important to attach the electrodes at a suitable position on the skin along the muscle. If the electrodes are placed too close to the tendon or to the motoric endplate no good signal can be obtained (Barbero et al., 2012). SENIAM (2015) provides information about the best place to attach the electrodes. To measure the pars descendens of the trapezius muscle the electrodes of the bipolar surface EMG are preferable placed on the line connecting the acromion and the cervical vertebra 7 (C7). The revised recommendation by SENIAM (2015) advocates that the midpoint of the two electrodes should be at 50% of this line and the distance between the electrodes should be 20 mm. However, in the studies reported in this dissertation the midpoint of the two electrodes was chosen to be 2 cm medial of the midpoint of the line connecting the acromion and C7.

Normalization

To reach a good comparability of the EMG over several measurement days of a subject and over different subjects the signal has to be normalized (Allison et al., 1993; Mathiassen et al., 1995). Reasons therefore are a slightly different position of the electrodes on different days (Allison et al., 1993) and a difference in the subcutaneous fat layer between the subjects (Nordander et al., 2003). Different normalization procedures are used in literature. Normalization can be done against a maximal reference exertion (MVE) or against a submaximal reference exertion (RVE) (Mathiassen et al., 1995). Furthermore the submaximal reference contraction can be done with or without additional weight (Mathiassen et al., 1995). All studies in this thesis used submaximal reference contractions without additional weight. The normalization to a submaximal reference contraction has some advantages over the normalization to a maximal reference contraction. As shown by Hansson et al. (2000), normalization to an RVE value instead of an MVE value reduced the sensitivity to individual differences and increased the sensitivity of the EMG signal to the performed task. Therefore, normalization to an RVE value can reduce undesired variability. Also Nordander et al. (2003)

found a better agreement of the EMG amplitude to the normalization with an RVE value than an MVE value.

As a posture for the normalization to an RVE procedure, Mathiassen et al. (1995) proposed to hold both arms in a horizontal position laterally extended in 90° abduction. This posture is often used in literature and could be shown to reduce the variability in the RVE value compared to similar positions (Läubli, 2013). Läubli (2013) showed that the resulting value from normalization to the described RVE normalization procedure results in approximately 17% of the maximal voluntary force. Based on the recommendations of Mathiassen et al. (1995) the reference contraction in the studies reported in this dissertation were held three times for 20 s with 40 s break in between. Afterwards the mean of the most stable 10 s of the three contractions was calculated and used to normalize the EMG signal and express it in % RVE.

Parameters analyzed in the EMG

In the EMG, different parameters were chosen to be analyzed. According to different authors (Holte and Westgaard, 2002; Nordander et al., 2000; Sandsjö et al., 2000) and based on the above mentioned Cinderella hypothesis (Hagg, 1991a) trapezius muscle rest time is an important parameter. Trapezius muscle rest time is defined as a percentage of the measurement duration with a completely or almost completely relaxed trapezius muscle (Hagg and Astrom, 1997). Different limits in the EMG signal to define rest time are discussed (Hansson et al., 2000). In the studies in this dissertation rest time is defined as the amount of time with an EMG signal below 5% RVE. The argumentation to see trapezius muscle rest time as an important parameter in the EMG signal is based on the introduced Cinderella hypothesis. Considering that during a long-lasting low-level activity always the same muscle fibers are active, missing rest time could lead to an overload of certain muscle fibers. Further parameters often used are the different percentiles of trapezius muscle activity (Akesson et al., 2012; Holte and Westgaard, 2002; Ostensvik et al., 2009). The 10th percentile of trapezius muscle activity is frequently used. It is defined as the data point, where 10% of all measured data points are below. Therefore, it gives a measure of the “general tension” or the static activity of the muscle, thus of the activity that was maintained over 90% of the measurement duration. The 50th percentile is defined as the data point where 50% of the measured values are below. Thus it can be used as a measure of the median muscle activity. Finally the 90th percentile is defined as the data point where only 10% of the values are above. It can be seen as a measure for the peak activity or the maximal load (Jonsson, 1982).

Beside the percentiles of trapezius muscle activity and the rest time as a temporal aspect of the muscle activity the, spatial aspects of trapezius muscle activity have to be mentioned as well. The concept of analyzing the spatial distribution of trapezius muscle activity with surface EMG is relatively new. Falla and Farina (2007) and Farina et al. (2008) found a shift of activity within the trapezius muscle during a dynamic activity, but no shift during a static activity of the muscle. Occurring simultaneously, a temporal and a spatial constraint activity of trapezius muscle are proposed to be able to force some muscle fibers to be continuous active over a longer period of time. This could lead to an overload or even pain of these fibers (as proposed in an accepted proposal to the Swiss National Science Foundation; see Outlook). The spatial aspect of trapezius muscle is an interesting new concept. However, it was not yet part of the studies in this dissertation.

Measurement duration

To assess the activity of trapezius muscle in occupational settings, in our opinion, it is important to conduct field studies with long measurement duration. Since no review article was found a short, non-systematic literature research was conducted, considering field studies about trapezius muscle activity with measurement durations of at least two hours. Twenty studies were found, whereof only ten dealt with office employees or nurses. Out of these ten studies only 6 evaluate trapezius muscle rest time. And only three of them finally reported full-shift trapezius muscle rest time differentiated for the occupational groups. These publications are discussed in the Chapter 1.5.

1.3.2 Heart rate

Heart rate as a parameter for physical and psychosocial load

The heart rate value during rest differs between subjects (Agelink et al., 2001) and within a subject between various times of the day (Ruger and Scheer, 2009). Increases from the given resting values can be due to physical (Grandjean, 1991) or psychosocial loads (Fisher and Newman, 2013). It can be argued that the variability of the heart rate, as a sensitive measure of stress (Salavecz et al., 2010), should be analyzed as well. As the main focus of this dissertation was the trapezius muscle activity, heart rate variability was not assessed.

Circadian rhythm of heart rate

Heart rate is one of the physiological parameters following a circadian rhythm (Ruger and Scheer, 2009), which leads to lower heart rate values during night than day. During a period of 24 hours the heart rate can be described as a cosine curve with a maximum value at noon to

afternoon and a minimum at 3 to 6 am (Clarke et al., 1976; Huikuri et al., 1990). The circadian rhythm of heart rate is regulated by many factors that result in a complex system (Bollinger and Schibler, 2014). Thereby, the master circadian system in the suprachiasmatic nucleus acts as an internal pacemaker. Furthermore, environmental factors strongly influence the circadian rhythm (Ruger and Scheer, 2009). The most important environmental factor is the light-dark cycle (Ruger and Scheer, 2009). If the dark-light cycle and the internal pacemaker are shifted, a circadian misalignment occurs (Bonde et al., 2012; Ruger and Scheer, 2009). This can lead to a reduction of the normally high melatonin secretion during night (Bonde et al., 2012).

Heart rate artifacts in EMG

The EMG signal of the neck muscles can be contaminated by the heart rate (Clancy et al., 2002). As shown by Mekhora and Straker (1999) the EMG signal was significantly different after the removal of heart rate artifacts. We observed that these artifacts lead especially during nights, when the muscle activity is low, to a misinterpretation of the EMG signal. If the heart rate was recorded using electrocardiography (ECG), the removal of the heart rate from the EMG signal is possible e.g. by a technique developed in our group (Lustenberger et al., 2009). Thereby, a 150 ms window was removed, if a peak in the EMG and the ECG signal was detected at the same time. The missing 150 ms were filled with the mean of the values before and after the removed values. If the heart rate is recorded with a Polar watch (Polar, Finland), as it was the case in some of the studies included in this dissertation, no ECG signal is recorded and a removal of the ECG artifacts is not possible. In this situation different authors recommended the use of a high pass filter with a cutoff frequency between 10 Hz and 60 Hz (Drake and Callaghan, 2006; Redfern et al., 1993).

1.4 Framework for a better understanding of work-related neck pain

Workloads that are discussed to cause neck pain

Despite the high prevalence of neck pain and various studies examining the development of neck pain, the underlying mechanism and the responsible loads for the development of neck pain are still unknown (Walton et al., 2013). Several reviews were conducted (Paksaichol et al., 2012; Palmer and Smedley, 2007; Waersted et al., 2010) and all of them only found limited evidence for most of the assessed parameters. Paksaichol et al. (2012) assessed 47 parameters. Out of these 47 parameters clear evidence was only found for two, namely female gender and previous history of neck pain. Palmer and Smedley (2007) found in three of the 19 examined

parameters moderate evidence. All of them were related to repetitive tasks. As clear evidence for most of the discussed parameters affecting the development of neck pain is still missing, several authors call neck pain as “multifactorial caused” (Hayes et al., 2012; Horneij et al., 2004; Petit et al., 2014; Valachi and Valachi, 2003). The existing literature indicates that neck pain is indeed caused by a multifactorial pathway, which means that most often neck pain results when specific factors are present (Bongers et al., 2006). Nevertheless, the term “multifactorial” does not allow for purposeful prevention. Therefore, a model explaining the development of neck pain is strongly needed.

The loads or strains on the trapezius muscle that are discussed to result in neck pain can be differentiated into four groups: physical risk factors, psychosocial risk factors, organizational risk factors and individual risk factors (Caruso and Waters, 2008; Paksaichol et al., 2012). Some of the physical risk factors discussed are irregular head or body posture (Eltayeb et al., 2009), repetitive movements, high physical workload (Palmer and Smedley, 2007), time sitting since the last break (Hush et al., 2009), and hours per day working with a computer (Eltayeb et al., 2009; Griffiths et al., 2012). Discussed psychosocial loads are high job demands, low job control, high job strain, low job support (Palmer and Smedley, 2007), relations with colleagues (Janwantanakul et al., 2010), high mental workload (Schleifer et al., 2008), and high psychological stress (Paksaichol et al., 2012). Individual factors are female gender, previous history of neck pain, older age, physical leisure activity, duration of employment in the same job, and smoking (Paksaichol et al., 2012). In addition, recent findings showed that especially in younger ages genetic factors can significantly influence the development of neck pain (Fejer et al., 2006a; Stahl et al., 2013). Finally, discussed organizational factors are long working hours (Caruso and Waters, 2008), rest breaks (Palmer and Smedley, 2007), and shift work (Nicoletti et al., 2014b).

A proposed model of the development of neck pain

As an instrument to enable purposeful neck pain prevention, we developed a model that shows single factors which are proposed to be involved in the development of neck pain. Additionally, the impact of these factors on the muscular level is presented (s. Figure 1.1). This model consists of two parts, whereas the first part describes the development of acute neck pain. This part should be applied when a healthy person starts working at a new workplace and it explains the mechanism that is responsible if the person develops acute neck pain, e.g. in the evening after work. The second part describes the further development of the acute neck pain. It attempts to explain why a person develops chronic neck pain or why a person is able to adapt to the workload and why the acute neck pain then disappears.

The starting points of the model are the two EMG parameters spatial and temporal invariable activation of trapezius muscle. We propose that different parameters can lead to these two possibilities of invariable muscle activation in a working subject. For the development of temporal invariable activation of trapezius muscle some literature exists already, but the findings are rare as most of the studies only evaluated different percentiles of trapezius muscle activity but not trapezius muscle rest time. We grouped the factors that are discussed to have an influence on the temporal invariable activation of trapezius muscle in the four groups constrained/immobile work postures (Akesson et al., 2012), high physical workload (Akesson et al., 2012; Jensen et al., 1993; Nordander et al., 2004), time pressure (Nicoletti et al., 2014a), and cognitive and visual demands (Schleifer et al., 2008). All these single factors are discussed to lead to a temporal invariable muscle activity or in other words they are discussed to cause an uninterrupted activation of trapezius muscle over a long time span. Based on previous work (Nicoletti et al., 2014b) we propose an additional factor, a personal state and/or trait anxiety, that might lead to a temporal invariable activation of trapezius muscle. This factor means that some kind of personal state or trait could influence the activity of the trapezius muscle. Thus, it is hypothesized that a kind of a “tense” persons exists. The difference between state and trait is meant as a temporal limited way to react (state) or a character trait that persists during the whole lifespan. Individual differences in muscle activity during the same task were already described by Westgaard and Bjorklund (1987) and Zennaro et al. (2003) in laboratory tasks. The second EMG parameter, the spatial invariable activation of trapezius muscle has been examined rarely. Some evidence was found for the parameters constrained/immobile postures and physical workload (Falla and Farina, 2007; Farina et al., 2008). Even if this is not part of this thesis, we strongly recommend to further analyze the spatial invariable activation of trapezius muscle and factors leading to it. We propose that if at least one factor leading to a temporal invariable activation of trapezius muscle and at least one factor leading to a spatial invariable activation of trapezius muscle are present, a constraint spatio-temporal activity of the motor unit pool develops. Thus the muscle is active over a longer period of time (temporal) and this activity is produced by the same muscle fibers over the whole time (spatial). Such an activity results in a potentially harmful condition for some muscle fibers activated over the whole timespan without having rest. If such a constraint spatio-temporal activity of the motor unit pool happens, it is crucial, how long this state is maintained. Again, different factors determine the further progression. We propose one factor to be the work organization. If the employee has the chance to take a break in regular time intervals, the load can be reduced and the muscle should be able to relax. However, it was shown that not all persons are able to relax the trapezius muscle during a work break (Veiersted, 1994). Therefore, we suggest that again a

personal factor or a personal pattern of the sensory-motor system influences the activity level of the muscle (called personal state and/or trait anxiety in the model). We propose that a part of the constraint spatio-temporal activity of the motor unit pool is not due to the discussed factors like constraint posture, physical workload, time pressure, cognitive or visual demands, but due to a personal factor. These amounts of the constraint muscle activity will also be preserved during breaks and hinder the muscle to relax. Thus, after a constraint spatio-temporal activity of the trapezius muscle happened for a short period of time, the work organization and the personal state and/or trait anxiety determine if the muscle has the chance to rest. If this happens, the muscle fibers will relax after a short term activity (they find some rest time in terms of temporal activity in the EMG) and they have enough time to recover before the next activation. Thus no overload or pain should develop. But if the work schedule or the personal characteristics do not allow the activated muscle fibers to relax, they can get overloaded and even acute neck pain might develop. The exact mechanism leading from a long-lasting constraint spatio-temporal activity of some muscle fibers to a painful overload is not fully understood to date. In chapter 1.2 some theories are mentioned. We propose that low-frequency fatigue could be involved as it is induced by low-level non-exhaustive exertions. It is reported to be a fatigue of the low-threshold motor units and it sustains over several hours after completion of the task (Adamo et al., 2002; Blangsted et al., 2005; Sogaard et al., 2003). Furthermore, this fatigue is subjectively not perceived (Adamo et al., 2002; Blangsted et al., 2005). Adamo et al. (2002) suggested that low-frequency fatigue may accumulate and increase the risk for MSDs, as it is not perceived. Therefore, we propose low-frequency fatigue to be the missing link between a constraint spatio-temporal activity of the motor unit pool and the development of acute overload or even acute pain. Such an acute overload is the negative endpoint of the first part of the model. At this point in our model, a person several weeks or months after starting the work, will suffer from neck pain in the late afternoon during work and maybe also in the evening after the work.

If a muscle is regularly exerted to a level that it hurts, structural changes may happen (Wilmore and Costil, 2004). We propose that these changes can either lead to a (positive) adaptation of the muscle. This adaptation will enable the muscle to recover and to get used to the load. As long as the work task stays equal, no further overload should occur. However, such changes might be negative and lead to a maladaptation. An example for a maladaptation could be the above described growth of type I muscle fibers, whereby the capillarization per area gets worse (Andersen et al., 2008) resulting in a still overloaded muscle or a muscle which may be even more overloaded. Therefore, the pain will remain and chronify after a certain amount of time. We suggest here again some factors that determine if an acute overload leads to an adaptation

or to a maladaptation. As discussed in Chapter 1.5.3, we suggest that an active leisure time behavior could have a positive influence on the adaptation of the muscle. As shown by different authors (Fejer et al., 2006a; Stahl et al., 2013), genetics influences the prevalence of neck pain. Furthermore, we propose again an influence of personal state and/or trait anxiety. The activity of trapezius muscle during sleep is suggested to be important as well. Sleep is an important relaxation period (Adam and Oswald, 1984) and covers several hours of our day.

The proposed model describes the development of neck pain and the possible ways to maladaptation and chronification. If the model can be ascertained it would give starting points for primary prevention (first part of the model) and for secondary prevention (second part of the model). If our model is accurate, primary prevention could be done by modifying the loads triggered by constraint or immobile postures, by physical workload, by time pressure, by cognitive or visual demands or by the work organization (e.g. the work schedule). The individual, internal factors are something that seems difficult to change.

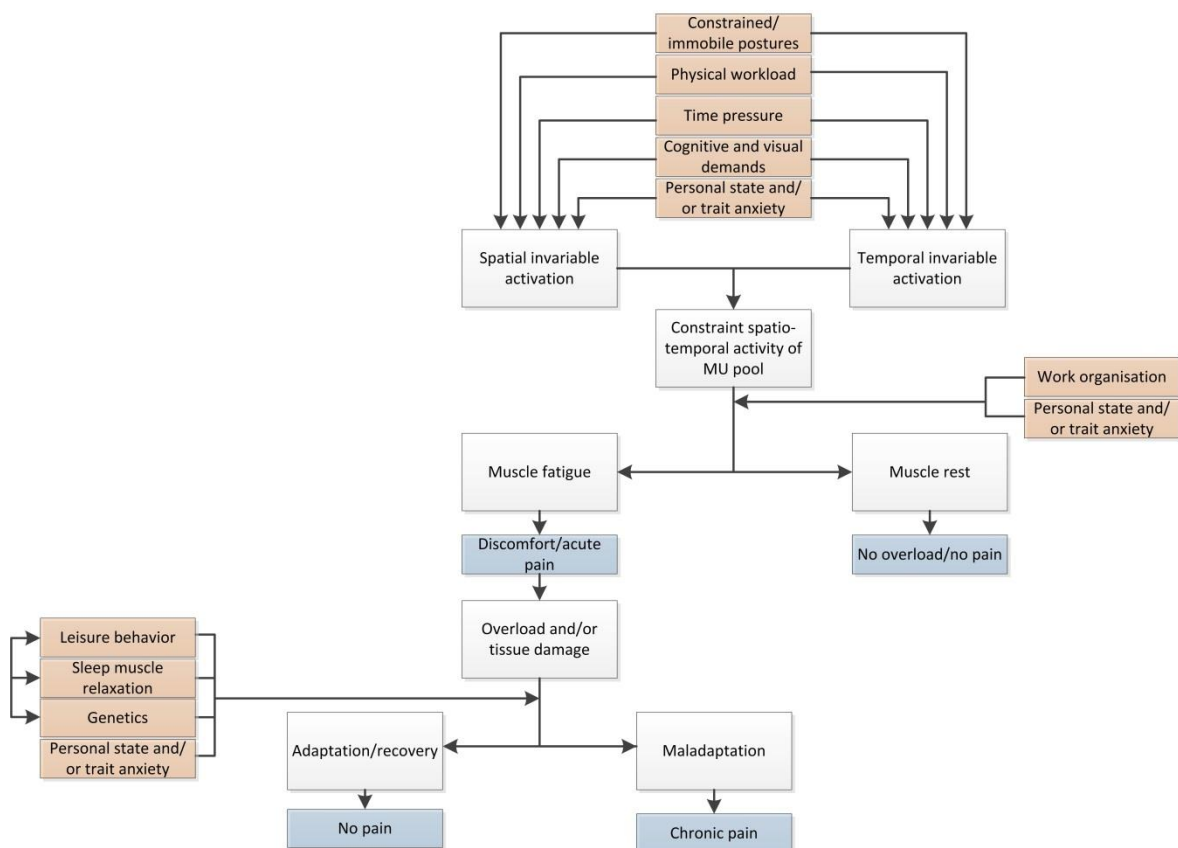


Figure 1.1: Proposed model of the development of neck pain. The white boxes are mechanisms on the muscular level, the orange boxes are parameters that act on trapezius muscle and the blue boxes are possible outcomes.

1.5 Risk factors and prevalence of neck pain in the studied occupational groups

1.5.1 Neck pain in nurses

Nurses are one occupational group that is strongly affected by neck pain. The one-year prevalence in nurses is higher than 50% (Harcombe et al., 2009; Warming et al., 2009). This may be one of the reasons that in Switzerland, on average, nurses only work for 13.5 years on the job (Dolder and Grünig, 2009). Furthermore, Hasselhorn et al. (2008) reported that in many European countries enough educated nurses would live, but not enough of them work in their profession.

Nurses are exposed to many occupational loads that are discussed to be related to the development of neck pain. First of all, nurses are exposed to high physical loads. Nurses have to transfer and lift patients, to work in awkward positions or to work in the same position for a long time, to lift and move heavy equipment (Tinubu et al., 2010), and the perceived exertion is high (Alexopoulos et al., 2003). Secondly, the psychosocial loads are high for nurses, too. Reported psychosocial loads are a high stress level (Conway et al., 2008; Mehrdad et al., 2010), high time pressure, emotional exhaustion (Freimann et al., 2013), working with confused patients (Tinubu et al., 2010), psychological support of patients during physical care (Salerno et al., 2012), boring tasks (Smith et al., 2004b), and high job demands (Alexopoulos et al., 2003). Regular confrontations with the death of patients and with emergencies are proposed to be important psychosocial loads that are not present in other professions, but no publications on these factors were found. Furthermore, the organizational loads in nursing are high. Organizational loads could be not having enough staff in a shift (Smith et al., 2004b), not being able to take a break (Tinubu et al., 2010), long working hours, mandatory overtime (Trinkoff et al., 2006), and shift work, often including night shifts (Lipscomb et al., 2002). Only two studies reporting full-shift trapezius muscle rest time in nurses were found (Holte and Westgaard, 2002; Westgaard et al., 2001). They showed a trapezius muscle rest time of 9.2 s/min (15.3% of measurement duration) and 11.6 s/min (19.3% of measurement duration). As they were from the same authors and were published within two years, the sample of the two studies may overlap.

Rotating shift work including night shifts is known to be associated with different health risks (Conway et al., 2008; Costa, 1996). It is assumed that these health risks are associated with a disruption in the circadian rhythm that happens because of shift work (Bonde et al., 2012). Actually, the most important health risk seems to be the higher prevalence of breast cancer

(Bonde et al., 2012). But also other types of cancer, like colorectal cancer (Schernhammer et al., 2003), lung, bladder, pancreatic cancer, or non-Hodgkin's lymphoma (Parent et al., 2012) seems to be related to rotating shift work. Further health problems associated with shift work are overweight (Zhao et al., 2012), ischemic stroke (Brown et al., 2009), insomnia (Guo et al., 2013; Oyane et al., 2013), chronic fatigue (Oyane et al., 2013), diabetes, hypertension (Guo et al., 2013), and burnout (Estryn-Behar et al., 2008). The association between shift work and neck pain is still unclear. An association between night shifts and MSDs was shown by Läubli and Müller (2009). However, this correlation was to MSDs in general and not specific to neck pain. It is known that higher risk for a work-family conflict is associated with neck pain (Hammig et al., 2011; Kim et al., 2013) and that shift work can increase the risk of a work-family conflict (Camerino et al., 2010). An own study (Nicoletti et al., 2014b), conducted as Master Thesis and evaluating the influence of different shifts on neck pain, found no clear evidence, but a hint that night shift could indeed be related to neck pain. The perception of neck pain, mental well-being at work, and time pressure were similar during day and night shifts, despite that the most strenuous work activities were less frequent and the least strenuous work activities more frequent during night shift than day shift. Furthermore, trapezius muscle rest time was longer and median trapezius muscle load was lower during night shifts than day shifts.

As described, nurses are exposed to high physical, high psychosocial as well as high organizational loads. Several of them are discussed to be related to neck pain (see above). However, to the best of my knowledge, the cause of the high prevalence of neck pain is still unknown. Therefore, no scientific based recommendations for prevention can be given.

1.5.2 Neck pain in office employee

With a one-year prevalence between 50% and 60%, neck pain has a similar frequency in office employees than in nurses (Harcombe et al., 2009). However, the loads office employees are exposed to are quite different than in nurses. In office employees the required physical force levels are rather small. Office employees often spend a mayor part of their working time in a sitting position and a lot of office employees are able to regularly stand up and take a little break. During computer work at adjusted workstations an activity of the trapezius muscle is not necessary (Zennaro et al., 2003). Nevertheless, some subjects show muscle activity (Zennaro et al., 2003). Some subjects in the cited study even showed a long-lasting activity of single muscle fibers. Also Farina et al. (2008) reported spatial invariable muscle activity during a static muscle load, which may be the case during computer work and which may lead to pain. Office employees may be exposed to stress (Hush et al., 2009) and to high cognitive loads

(Kalinienė et al., 2013). Additional psychosocial loads like social support and decision authority (Eltayeb et al., 2009) are reported, too. Based on own experience, the organizational loads in office work seems to be small. Office employees are mostly not exposed to shift work and they can often choose their exact working hours. In my opinion, if the physical, psychosocial and organizational loads of office employees are compared to nurses, an occupational group with similar amount of neck pain (Harcombe et al., 2009), the loads seem much smaller. Two studies reporting trapezius muscle rest time over a full working day in office workers were found (Holte and Westgaard, 2002; Nordander et al., 2000). They reported a trapezius muscle rest time of 13.4 s/min (22.3% of measurement duration) in one study and 13% of measurement duration for female office worker and 11% of measurement duration for male office worker in the other study.

To the best of my knowledge and despite a certain amount of studies existing, no clear explanation, how neck pain develops within these working conditions that are characterized through small physical loads, exists (Paksaichol et al., 2012). Therefore, no scientific based recommendations for prevention can be given (Hoe et al., 2012; Verhagen et al., 2013).

1.5.3 Influence of leisure time and sleep behavior

Even the topic of this dissertation is work-related neck pain, leisure time and sleep should not be left behind. Beside this dissertation, only one data sample that allows the analysis of trapezius muscle activity during leisure time and sleep was found (Holte and Westgaard, 2002; Mork and Westgaard, 2004, 2006).

In the proposed model (Figure 1.1) an important factor in developing neck pain is the “personal state and/or trait anxiety”. We propose that this parameter could be located in the sensory-motor system of the subject and determine how a subject reacts on a certain load. Therefore, these parameters should not only be present during work, but also during leisure time and maybe during sleep. So the proposed model requires the analysis of leisure time and sleep. To be able to properly analyze the trapezius muscle activity during sleep, first its dependency on sleep stages was evaluated, as sleep can be divided in different stages (Rechtschaffen and Kales, 1968). Furthermore, it may be possible that the behavior during leisure time influences the development of neck pain or the recovery from a possible overload of the trapezius muscle during work. Some studies showed clues for a positive influence of physical activity during leisure time on the development of neck pain. Hildebrandt et al. (2000) found some evidence that physical activity during leisure time could reduce musculoskeletal disorders. Rasmussen-Barr et al. (2013) found a better recovery from neck pain in women with

more physical activity during leisure time. Furthermore, a change in muscle activation pattern of the trapezius muscle during active breaks during the workday was found that could have a positive influence on the development of neck pain (Samani et al., 2009; Sundelin and Hagberg, 1989).

After this introductory information, the published and submitted manuscripts will follow. The first study (Chapter 2) was conducted to evaluate the limitations of the normalization of trapezius muscle EMG data. Based on this study, subjects with possible unreliable measurements were excluded in the following studies. The second study (Chapter 3) evaluated the methodological aspects of trapezius muscle activity measurements during sleep and allowed us in a following study to analyze the trapezius muscle activity during sleep without identifying the sleep stages. The third and the fourth study (Chapter 4 and 5) focused on trapezius muscle rest time and activity in nurses and tried to find possible reasons for a reduced trapezius muscle rest time or an augmented trapezius muscle activity. Study five and six (Chapter 6 and 7) focused on trapezius muscle rest time and activity in office employees during work, leisure time, and sleep. Furthermore, possible factors influencing trapezius muscle rest time and activity should be identified.

2. Normalization of trapezius muscle EMG with submaximal reference contractions: difficulties and solution approaches (study 1)

Normalisierung der EMG-Aktivität des M. trapezius mithilfe submaximaler Referenzkontraktionen: Schwierigkeiten und Lösungsansätze

Normalization of trapezius muscle EMG with submaximal reference contractions: difficulties and solution approaches

Zusammenfassung: Submaximale Referenzkontraktionen (RVE) sind bei elektromyographischen (EMG) Messungen des M. trapezius eine international empfohlene Normalisierungsmethode. Die vorliegende Publikation zeigt mögliche Schwierigkeiten dieser Methode und Lösungsansätze auf. Das EMG von 20 Pflegefachangestellten wurde erfasst und mittels submaximaler RVE normalisiert. Es ergab sich ein signifikanter Zusammenhang der Erholzeit und des 10. Perzentils des EMG zu RVE. Dies kann zu einer systematischen Verfälschung der Resultate führen. Mögliche Wege diese Verfälschung abzuschwächen sind das Einbeziehen von RVE in das statistische Modell, eine Verschiebung der gesamten Verteilung oder den Ausschluss von Messungen ausserhalb einer von uns vorgeschlagenen Bandbreite für RVE.

Abstract: Submaximal reference contractions (RVE) are the state of the art for the normalization of electromyographical (EMG) measures of trapezius muscle. The paper shows difficulties and solution approaches of this method. The EMG of trapezius muscle was measured in 20 nurses and was normalized with submaximal RVE. A significant correlation of rest time and RVE as well as a correlation of the 10th percentile of activity and RVE was found that can cause a systematic falsification of results. Possible solution approaches are the inclusion of RVE into the statistic model, adding a constant value to the data, or exclusion of measures beyond a proposed bandwidth of RVE.

2.1 Einleitung

Nackenbeschwerden sind in vielen Berufsfeldern ein häufiges Phänomen (Harcombe et al., 2009). Sie resultieren oftmals in einer erheblichen Reduktion der Lebensqualität (Punnett and Wegman, 2004) und können die betroffenen Personen in vielen beruflichen, aber auch alltäglichen Tätigkeiten einschränken. Weiter sind diese Beschwerden auch in wirtschaftlicher Hinsicht ein Problem (Rissen et al., 2000) und betreffen besonders Frauen (Hammig et al., 2011). Eine signifikante Rolle für die Entwicklung von Nackenbeschwerden spielt die Aktivität des M. trapezius (Aaras, 1994).

Die Oberflächen-Elektromyographie (EMG) ist die einzige nicht-invasive Methode, die eine direkte Erfassung der Muskelaktivität erlaubt. Sollen verschiedene Tage oder Probanden verglichen werden, ist eine Normalisierung des EMG unerlässlich (Mathiassen et al., 1995). Es

stehen zwei Möglichkeiten zur Verfügung: Die maximale oder die submaximale Normalisierung durch Referenzkontraktionen. Laut Hansson et al. (2000) und Nordander et al. (2003) haben die submaximalen Referenzkontraktionen Vorteile gegenüber den Maximalen. So soll die Variabilität zwischen den Probanden gesenkt werden können. Mathiassen et al. (1995) empfehlen während der submaximalen Referenzkontraktion die Arme in der Frontalebene, gestreckt in 90° Abduktion zu bringen. Die Hände sollten entspannt werden. Das Ziel dieser Publikation ist es, Schwierigkeiten, die bei submaximaler Normalisierung auftreten können anhand einer eigenen Studie aufzuzeigen und erste Lösungsansätze zu präsentieren.

2.2 Methodik

An der Studie nahmen 20 Pflegefachangestellte (weiblich, 34 ± 10 Jahre) aus vier Schweizer Spitälern teil. Sie hatten ein Arbeitspensum von mindestens 80% und wiesen keine Erkrankung des Bewegungsapparates auf. Die Studie wurde von der kantonalen Ethikkommission Zürich (KEK) bewilligt. Alle Probandinnen gaben ihr schriftliches Einverständnis.

Die Messungen fanden pro Probandin während 3 Schichten (2 Tages- und eine Nachtschicht) statt. Gemessen wurde das Oberflächen-EMG des M. trapezius descendens auf der dominanten Seite. Basierend auf den Empfehlungen von SENIAM (2012) wurden die Elektroden auf der Linie von Akromion zu C7 platziert. Der Mittelpunkt zwischen den beiden Elektroden befand sich 2 cm medial des Mittelpunktes dieser Linie. Die Distanz zwischen den beiden Elektroden betrug 2 cm. Die Referenzelektrode wurde auf C7 platziert. Vor Beginn der Arbeit wurden submaximale Referenzkontraktionen (RVE) ohne Zusatzgewicht durchgeführt. Dabei wurden die Arme dreimal für 20s in der Frontalebene, gestreckt in 90° Abduktion gehalten, mit 40s Pause zwischen den einzelnen Ausführungen. Diese Referenzkontraktionen folgten der Beschreibung von Mathiassen et al. (1995), mit leichten Modifikationen. Diese Modifikationen betreffen einerseits die Positionierung der Elektroden. Mathiassen et al. (1995) platzierten diese 2cm lateral des Mittelpunktes der Linie von Akromion zu C7. Weiter führten sie die Referenzkontraktionen viermal während 15s mit mindestens einer Minute Pause dazwischen durch. Auch der Forderung, die Referenzkontraktionen sitzend durchzuführen, konnte aufgrund der räumlichen Gegebenheiten nicht immer nachgekommen werden.

Das EMG wurde mithilfe des PS11-UD (Thumedi, Thum-Jahnsbach, Deutschland), mit einer Abtastfrequenz von 2048 Hz, erfasst. Folgende Filter wurden eingesetzt: Hochpassfilter bei 12 Hz, Bandsperrfilter bei 50 Hz, 100 Hz, 150 Hz, 200 Hz, 250 Hz, 300 Hz und 350 Hz, ein Tiefpassfilter (aktiv von 7 bis 13 Hz) und ein Tiefstfrequenzfilter (aktiv von 0.5 bis 1.7 Hz). Ausgegeben wurden Effektivwerte (RMS) während 250ms. Es wurden

Silber/Silberchlorid (Ag/AgCl) Elektroden (35 x 26mm) verwendet (Kendall Arbo, Covidien, England). Die Haut wurde vor dem Kleben der Elektroden mit abrasiver Hautvorbereitungspaste (Nuprep, Weaver und Company, Aurora, CO, USA) behandelt.

Das RMS wurde mithilfe der bereits beschriebenen submaximalen Referenzkontraktionen normalisiert. Aus dem normalisierten EMG wurde die Erholzeit sowie das 10., 50. und 90. Perzentil der Aktivität berechnet. Die Erholzeit wurde definiert als der Prozentsatz der Schicht, in dem das EMG unter 5% RVE lag.

Die Korrelationen wurden mithilfe von IBM SPSS Statistics 20 berechnet. Das in Abschnitt 3.2 erwähnte gemischte Modell wurde in SAS 9.2 berechnet. Eine Probandin verließ die Studie nach der ersten Messung, zwei Tagesschichten mussten aufgrund der schlechten Qualität der Daten ausgeschlossen werden.

2.3 Ergebnisse

Schwierigkeiten

Die RVE-Werte ($95.7 \pm 48.8\mu\text{V}$) schwankten zwischen $28.5\mu\text{V}$ und $225.6\mu\text{V}$. Ein schwacher Zusammenhang der Erholzeit ($R^2=0.15$; $n=56$; Abbildung 2.1) und des 10. Perzentils ($R^2=0.27$; $n=56$) zu RVE war ersichtlich. Das 50. Perzentil ($R^2=0.005$; $n=56$) und das 90. Perzentil ($R^2=0.009$; $n=56$) zeigten keinen Zusammenhang zu RVE.

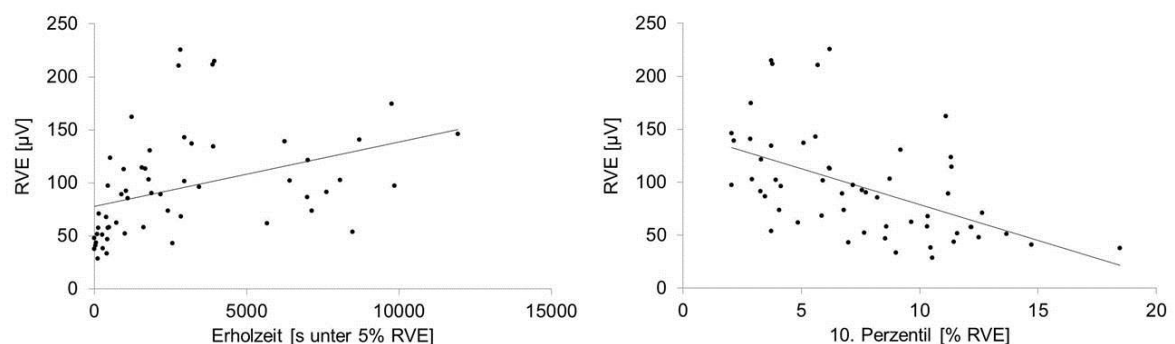


Abbildung 2.1: Zusammenhang der Erholzeit in % der Schicht und des 10. Perzentils (% RVE) des M. trapezius zum Wert der Referenzkontraktionen (RVE).

Figure 2.1: Correlation of rest time (% of shift) and the 10th percentile (% RVE) of trapezius muscle to reference contractions (RVE).

Ein ähnliches Phänomen, das ebenfalls auf Schwierigkeiten bei der Normalisierung hindeutet, ergab sich beim Vergleich der EMG-Parameter zwischen Tag 1 und Tag 2. Die Werte der Erholzeit ($R^2<0.01$; $n=34$; Abbildung 2.2) und des 10. Perzentils ($R^2=0.12$; $n=34$) korrelierten

nur schwach zwischen Tag 1 und Tag 2. Die Werte des 50. ($R^2=0.62$; $n=34$) und des 90. Perzentils ($R^2=0.31$; $n=34$) korrelierten stärker.

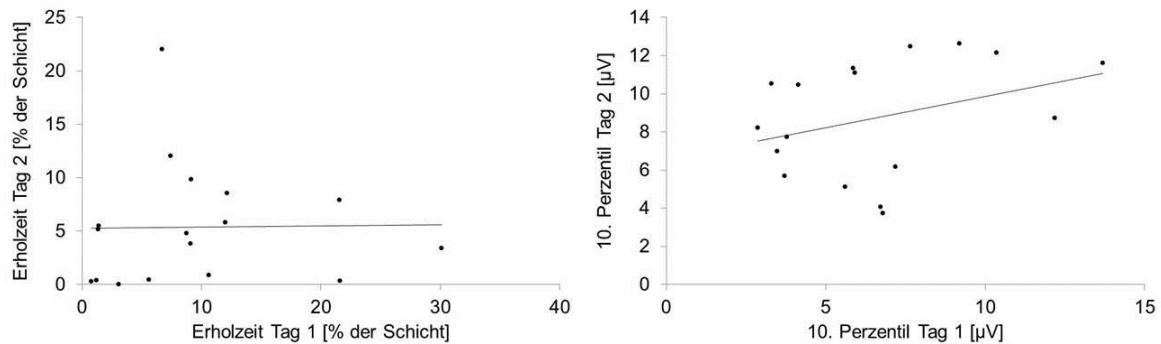


Abbildung 2.2: Zusammenhang der Erholzeit in % der Schicht und des 10. Perzentils in % der Referenzkontraktionen (RVE) des M. trapezius zwischen Tag 1 und Tag 2.

Figure 2.1: Correlation of rest time (% of shift) and the 10th percentile (% of reference contractions (RVE)) of trapezius muscle between day 1 and day 2.

Lösungsansatz 1

Um den Einfluss von RVE zu berücksichtigen, wurde RVE bei der statistischen Analyse als Kovariate in das Modell miteinbezogen. Dies ergab das folgende gemischte Modell zum Vergleich der Tages- mit der Nachtschicht: Erholzeit = Schicht, Tag, RVE

Dabei war mit „Schicht“ die gemessene Arbeitsschicht bezeichnet, also Tag 1, Tag 2 oder Nacht. „Tag“ bezeichnete lediglich, ob es sich bei der Messung um eine Tages- oder Nachtschicht handelte. Analog wurden die Modelle für die Perzentile aufgestellt.

Lösungsansatz 2

Eine gute Lösung zur Reduktion des Zusammenhangs der Erholzeit und des 10. Perzentils zu RVE schien die Verschiebung der gesamten Verteilung um den konstanten Faktor 20 darzustellen: $EMG_{faktornormalisiert}(x) = (100 * EMG(x)) / (RVE + 20)$.

Durch Anwenden dieser Verschiebung konnte der Zusammenhang der Erholzeit ($R^2=0.07$) sowie des 10. Perzentils ($R^2=0.13$) zu RVE gesenkt werden. Der Zusammenhang zwischen dem 50. Perzentil ($R^2=0.09$) und RVE sowie jener zwischen dem 90. Perzentil ($R^2=0.17$) und RVE stieg jedoch an. Dass eine solche Verschiebung der gesamten Verteilung um den Faktor 20 zu keiner wesentlichen Verfälschung der Daten führt, konnte anhand der Abbildung 2.3 gezeigt werden. So korrelierte die normalisierte Erholzeit sehr stark mit der faktornormalisierten Erholzeit ($R^2=0.95$).

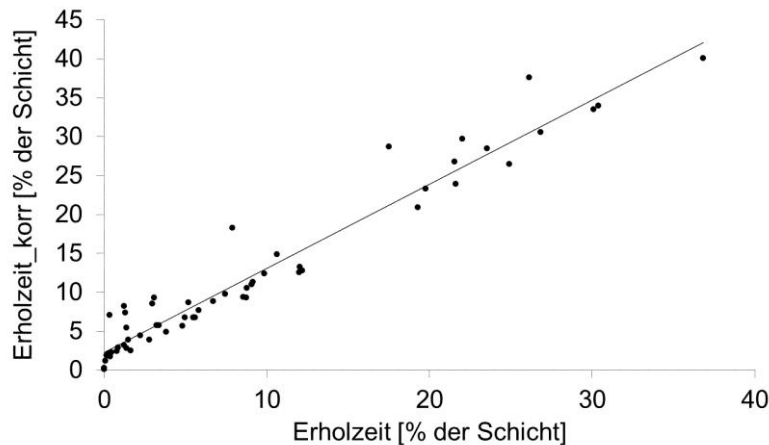


Abbildung 2.3: Zusammenhang der Erholzeit (in % der Schicht) der normalisierten Daten zu der Erholzeit (in % der Schicht) der faktornormalisierten Daten (Erholzeit_korr).

Figure 2.3: Correlation of rest time (% of shift) of the normalized data to rest time of the factor normalized data (rest time_corr).

Lösungsansatz 3

Um den Zusammenhang der EMG-Parameter mit RVE im tiefen Bereich der EMG-Aktivität abzuschwächen und im hohen Bereich auf einem tiefen Niveau zu halten, wurden nur Messdaten von Probanden berücksichtigt, deren RVE-Werte innerhalb eines Bereichs von $55\mu\text{V} \leq \text{RVE} \leq 140\mu\text{V}$ lagen. Dadurch wurde der Zusammenhang der Erholzeit ($R^2=0.06$; $n=38$) sowie jener des 10. Perzentils ($R^2=0.16$; $n=38$) zu RVE abgeschwächt. Der Zusammenhang des 50. Perzentils ($R^2=0.02$; $n=38$) sowie jener des 90. Perzentils ($R^2=0.10$; $n=38$) zu RVE wurde nur leicht verstärkt. Diese Methode führte auch zu einer Verstärkung der Korrelation der Erholzeit ($R^2=0.18$; $n=14$) und des 10. Perzentils ($R^2=0.17$; $n=14$) zwischen Tag 1 und Tag 2. Beim 50. Perzentil ($R^2=0.66$; $n=14$) und beim 90. Perzentil ($R^2=0.31$; $n=14$) blieb die Korrelation zwischen Tag 1 und Tag 2 gleich gross.

2.4 Diskussion

Durch eine Normalisierung mit submaximalen Referenzkontraktionen kann das EMG des M. trapezius verfälscht werden, was zu einer systematischen Verfälschung der erhaltenen Resultate führen kann. Von einer solchen Verfälschung betroffen waren vor allem die tiefen Bereiche der EMG-Aktivität, das heisst die Erholzeit und das 10. Perzentil. Da keine Literatur zu diesem Thema gefunden wurde, wurde nach eigenen Lösungsansätzen gesucht. Der erste Lösungsansatz half die Schwierigkeit abzuschwächen, die folgenden zwei sollten helfen die Schwierigkeit zu lösen. Abgeschwächt werden konnte die Schwierigkeit, indem RVE in die statistischen Auswertungen einbezogen wurde. Eine mögliche Lösung der Schwierigkeit

bestand darin, die gesamte Verteilung von RVE um den Faktor 20 anzuheben, falls nur Parameter im tiefen Bereich der EMG-Aktivität, beispielsweise die Erholzeit oder das 10. Perzentil, berechnet werden. Werden Parameter über den gesamten Bereich der EMG-Aktivität benötigt, stellte die Beschränkung von RVE auf den Bereich zwischen $55\mu\text{V}$ und $140\mu\text{V}$ eine gute Lösung dar.

Zwischen RVE und der Erholzeit, sowie RVE und dem 10. Perzentil ergab sich ein Zusammenhang, welcher zu einer systematischen Verfälschung der Resultate führen kann. Bezüglich der Erholzeit schienen die sehr tiefen RVE die grosse Schwierigkeit zu sein. Als Beispiel hierfür wird von einem RVE von $20\mu\text{V}$ ausgegangen. Ein solches RVE führt während der Normalisierung zu einer Anhebung der gesamten Verteilung um den Faktor 5. Das in der vorliegenden Studie verwendete Messgerät gab in vollständiger Ruhe den Minimalwert $1\mu\text{V}$ aus. Diese entspricht nach der Normalisierung einem Minimalwert von $5\mu\text{V}$, was nach Definition der Erholzeit ($< 5\%$ RVE) gar keine Erholzeit mehr zulässt. In solchen Fällen, in denen lediglich die Erholzeit und tiefe Perzentilwerte gebraucht werden, kann eine Faktornormalisierung hilfreich sein.

Der Zusammenhang der Perzentilwerte im hohen Aktivitätsbereich zu RVE wurde durch die Faktornormalisierung jedoch verstärkt. Dies führte zu der Vermutung, dass nicht nur sehr tiefe, sondern auch sehr hohe RVE problematisch sein könnten. Dies wiederum führte zu der Entwicklung von Lösungsansatz 3, welcher bei der Erholzeit, sowie bei Perzentilwerten über den gesamten Aktivitätsbereich, akzeptable Werte lieferte. Durch die Beschränkung von RVE auf den Bereich von $55\mu\text{V}$ bis $140\mu\text{V}$, konnte eine allzu starke Veränderung der Messwerte verhindert werden, wobei trotzdem eine Normalisierung stattfand.

Für die grosse Streubreite von RVE und vor allem für die vielen tiefen Werte gibt es verschiedene Erklärungen. Als Erklärung für die vielen tiefen Werte, muss darauf hingewiesen werden, dass die Messungen der vorliegenden Studie ausschliesslich bei Frauen durchgeführt wurden. Das Unterhautgewebe ist bei Frauen oftmals dicker als bei Männern und somit die Distanz von dem Muskel zu den Elektroden grösser (Bilodeau et al., 2003). Diese grössere Distanz kann das Signal abschwächen (Nordander et al., 2003) und führt bei Frauen häufig zu einer tieferen Aktivität im Oberflächen-EMG als bei Männern. Die bereits in der Einleitung erwähnte Häufung von Nackenbeschwerden bei Frauen (Hammig et al., 2011) zeigt jedoch auf, dass solche Messungen gerade bei Frauen relevant sind und dass eine Lösung der Normalisierungsschwierigkeiten gefunden werden muss. Weiter ist es möglich, dass bei gewissen Messungen die Elektroden zu nahe an der motorischen Endplatte geklebt wurden, was das Signal abschwächen kann (Veiersted, 1991). Eigene Erfahrungen unter Verwendung der jeweils aktuellen Empfehlungen von SENIAM oder leicht modifizierten Varianten davon zeigten, dass die Lokalisierung der motorischen Endplatte im M. trapezius nicht einfach ist und

von Person zu Person zu variieren scheint. Die leichten Modifikationen bei der Ausführung der Referenzkontraktionen gegenüber den Empfehlungen von Mathiassen et al. (1995) sollten nicht zu den beobachteten Schwierigkeiten geführt haben.

Als allgemeine Erklärung für die grosse Streubreite von RVE, muss gesagt werden, dass einige Probandinnen Probleme bei der Ausführung der Referenzkontraktionen aufwiesen. So wurden die Arme von einigen Probandinnen zu weit kranial oder kaudal gehalten. Auch die Positionierung in der Transversalebene führte bei manchen Probandinnen zu Problemen. Laut Veiersted (1991) wird RVE bereits durch geringe Positionsänderungen der Arme beeinflusst. Die Probandinnen, die Probleme mit der Positionierung aufwiesen, wurden von der Versuchsleiterin korrigiert, bis eine möglichst korrekte Armposition erreicht war. Trotzdem waren leichte Variationen in der Armposition wohl mit ein Grund, dass das RVE zwischen den Probandinnen so stark variierte.

Es wird empfohlen bei EMG-Messungen am M. trapezius descendens die Elektroden solange neu zu kleben, bis während submaximalen Referenzkontraktionen ohne Zusatzgewicht ein RVE zwischen $55\mu\text{V}$ und $140\mu\text{V}$ erreicht wird. Das Neukleben der Elektroden sollte um den anfänglich definierten Punkt der Lokalisation erfolgen, wobei der Abstand zwischen den beiden Elektroden gleich bleiben sollte. Durch zusätzliches Einbeziehen von RVE in das statistische Modell können die Schwierigkeiten weiter entschärft werden.

Weitere Forschung auf diesem Gebiet ist dringend nötig, da die Normalisierung über submaximale Referenzkontraktionen bei dem EMG des M. trapezius sehr häufig angewendet wird, eine Normalisierung von Daten jedoch niemals zu einer Verfälschung dieser führen sollte.

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3. Relationship between sleep stages and nocturnal trapezius muscle activity (study 2)

Abstract

Objective: Former studies report a relationship between increased nocturnal low level trapezius muscle activity and neck or shoulder pain but it has not been explored whether trapezius muscle relaxation is related to sleep stages. The goal of the present study was to investigate whether trapezius muscle activity is related to different sleep stages, as measured by polysomnography.

Methods: Twenty one healthy subjects were measured on four consecutive nights in their homes, whereas the first night served as adaptation night. The measurements included full polysomnography (electroencephalography (EEG), electrooculography (EOG), electromyography (EMG) and electrocardiography (ECG)), as well as surface EMG of the m. trapezius descendens of the dominant arm.

Results: Periods with detectable EMG activity of the trapezius muscle lasted on average 1.5% of the length of the nights and only in four nights it lasted longer than 5% of sleeping time. Neither rest time nor the length of periods with higher activity levels of the trapezius muscle did significantly differ between sleep stages.

Conclusions: We found no evidence that nocturnal trapezius muscle activity is markedly moderated by the different sleep stages. Thus the results support that EMG measurements of trapezius muscle activity in healthy subjects can be carried out without concurrent polysomnographic recordings.

3.1 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 the neck and shoulder (Hagg, 1991b), muscle relaxation and recovery during sleep might play an important role for pain development. Former studies 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. Additionally, 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. A recent study by Alsaadi et al. (2011) also showed a moderate relationship between self-reported sleep disturbances and the intensity of low back pain in patients.

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

The aforementioned studies either concentrated on electromyography (EMG) parameters over the whole night or on special EMG events occurring during the night without simultaneous polysomnographic sleep recordings. Thus, it remains unclear how trapezius muscle activity is related to sleep as such, whether e.g. deeper sleep is characterized by lower trapezius muscle activity. Sleep can be described by polysomnographic (PSG) recordings that allow dividing sleep into different stages as they occur in a normal night, namely in rapid eye movement (REM) sleep (with its typical rapid eye movements) and nonREM sleep. NonREM sleep can be further divided in the four sleep stages S1, S2, S3, and S4 (Rechtschaffen and Kales, 1968). 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, on the other hand, do not contribute to recuperation, or only very little (Wesensten et al., 1999). The present study aims to elucidate the relationship between trapezius activity and sleep stages determined by PSG.

3.2 Methods

Study protocol

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

Thirty subjects were measured in a period of six months, 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). The measurements took place in the subjects' homes. 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 Zürich. 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 200 Swiss Francs upon completion of the study.

Subjects

The study sample was selected to represent the Swiss population between the ages of 18 and 66 years as close as possible. Exclusion criteria for this study were:

- 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 am 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 (with strain gauges), finger pulse amplitude (with a finger pulse oximeter) and position in bed were recorded continuously during the night. To diagnose sleep disordered breathing, the respiratory movements were recorded as well. To derive the polysomnogram (sleep profile), each experimental night was divided into 30s- 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 (Caffarel et al., 2006), we decided for a visual scoring of sleep stages. Two trained scorers independently assigned sleep stages in every 30s-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 was assigned to each scorer. Finally each scorer cross-checked the scored nights of the other scorer. As in recommendations of the American Academy of Sleep Medicine (Iber et al., 2007) S3 and S4 are not discriminated anymore, we chose to set these two stages equal after the final scoring of each night.

Sleep disturbance index

As the subjects also participated in a study about environmental noise and sleep (Brink et al., 2011), there might be some concerns about the subjects' sleep quality. Therefore a noise specific sleep disturbance index (SDI) developed by Griefahn et al. in 2008 was used to

compare the sleep quality of the present study's participants with reference values from quiet and noisy nights (Griefahn et al., 2008).

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 (Mork and Westgaard, 2006; Westgaard et al., 2002).

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 carry pouch around the waist.

Electrode placement

One pair of pre-gelled silver-silver chloride bipolar electrodes (sensor size 9x6 mm, Alpine Biomed ApS, Skovlunde, Denmark) was attached to the subject, who sat in an upright position, according to SENIAM (2006). 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 inter-electrode distance was 2 cm with a reference electrode placed on the process spinae of C7 (Fig. 3.1). 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.



Fig 3.1: EMG electrode placing and wiring on the trapezius

Electrocardiography (ECG)

The 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). 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 below the cardiac apex with the ground electrode placed on the spine of C7. The skin preparation procedure was the same as used in the EMG measurement.

ECG contamination in the EMG signal was found in several subjects and nights. These heartbeat artifacts occurred temporarily with different durations ranging from a few to several minutes. 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. Thus, it is important to remove possible artifacts before analysis.

Questionnaires

In the morning after waking up, the subjects completed recurring questionnaires concerning their self-reported sleep quality. These questions had to be answered on a visual analog scale (VAS) ranging from 0 (“my sleep was calm”) to 10 (“my sleep was very restless”). 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 visual analog scale from one to five, whereby one was a negative answer and five a positive.

Data processing

Nocturnal trapezius EMG raw data were processed using Matlab 2010a (Mathworks). First, an offset correction of the signals was conducted, subtracting the baseline shift. Then, the signals were band stop filtered from 45 to 55 Hz to eliminate 50 Hz mains hum (Butterworth 3rd order). A peak detection and gating technique was used to eliminate heartbeat artifacts from EMG using Matlab 2010a (Mathworks). Areas of the trapezius EMG with possible ECG contamination were identified by visual inspection. Within the selected areas, all EMG peaks with amplitude between 30 μ V and 800 μ V (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 (within a window of 10ms) peaks were eliminated from the EMG by deleting a 50ms 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 (Mekhora and Straker, 1999). The gap was then backfilled with a constant value that was the mean of the last 10 EMG values prior and first 10 EMG values after the gap. See Lustenberger et al. (2009) for more details. 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 according to the recommended procedure of Mathiassen et al. (1995) with specific adjustments for our study: three RVCs of 20 sec duration with 30 sec breaks between were made instead of four RVC of 15 sec duration and breaks of 1 min. The RVC was recorded before each experimental night while the subject sat in an upright position, palm down and with 90° arm abduction. For each of the three RVCs of the RMS EMG signal, the mean amplitude from the middle 10 seconds was determined. These resulting amplitudes were identified as reference voluntary electrical activations (EMG_{RVE}). The mean from these three EMG_{RVE} values was then calculated, resulting in one value of the reference voluntary electrical activation (RVE) that was used to normalize the processed nocturnal trapezius RMS (Mathiassen et al., 1995). In further parts of this paper, the normalized EMG values are expressed as percentages of RVE (%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 were segmented into intervals of 30 seconds (“epochs”), corresponding to the time discretization 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

A threshold of 10% RVE was chosen to describe muscle relaxation (rest time) and the threshold >25% RVE was used to describe muscle activity during sleep. For each epoch, the relative time with an EMG value <10% RVE and >25% RVE was calculated. For each subject, experimental night and for the entirety of all epochs belonging to the S1, S2, S3/S4, REM, or W sleep stages in a night, the mean duration of muscle rest time and the mean muscle activity was calculated. The two parameters can thus take values between 0% (no rest time at all or no muscle activity at all) to 100% (meaning, that in all epochs of a sleep stage, muscle activity was below or above the respective percentage of RVE).

The mean noise level of the device itself was 10.9 μV (± 0.49 μV standard deviation (SD); referred to the input). Careful visual inspection of the acquired data showed that during the field measurements the noise level occasionally reached a maximum of 30 μV . This means that in some periods, only values higher than 30 μV could clearly be recognized as EMG signal. This noise level is rather high compared to modern technology and was accepted because the system offered a sufficient duration of registration with a high sampling rate, and was powered by low-weight batteries. As we used the 10% RVE as a limit for defining the resting periods, we only analyzed subjects with an RVE value ≥ 350 μV and therefore the detection limit always was above the noise level.

All statistical analysis was performed with SAS (SAS Stat Version 9.2, SAS Institute, Cary, NC, USA). Following the recommendations by Bagiella et al. (2000) the procedure mixed was used to evaluate the significance of effects due to sleep stages, persons measured and order of night. Variability between nights was very large compared to the variations between subjects. Thus, the single nights were used to estimate the variance/covariance “within subjects”. Since the persons were specifically selected for the purpose of a study on sleep disturbances due to church bell’s noise they were considered a fixed factor. Significance was assumed for $p \leq 0.05$.

3.3 Results

Sample description

Thirty study participants were measured within the six months of the field study period. Nine subjects had to be excluded during the study as they showed symptoms of sleep apnea or excessive snoring which were not detected beforehand or because of an RVE value $\leq 350 \mu\text{V}$. This resulted in a final sample of 21 subjects of which 10 (47.6%) were female and 11 (52.4%) male. Six subjects were aged between 18 and 33 years, seven between 34 and 49 years, seven between 50 and 65 years and one subject was 66 years old. The mean age was 41 years.

As the first night of each subject was an adaption night and therefore disregarded in the analysis, 63 nights remained for analysis. Due to different incidents, such as unexpected shutdown of measuring devices or loss of electrode contact or due to too small RVE values, 22 more nights had to be excluded. This results in 41 valid nights. The number of evaluated sleep stages is shown in Table 3.1.

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

Average self-reported sleep quality (rated on a 0 to 10 VAS) was 3.2 ± 1.9 for the first, 3.6 ± 2.4 for the second and 4.6 ± 2.2 for the third experimental night.

Table 3.1: Mean duration of the experimental nights and the sleep stages, appearances of the sleep stages, rest time (mean duration with a trapezius muscle activity <10% RVE) and active time (mean duration with a trapezius muscle activity <25% RVE) in relation to the length of the experimental nights or of the sleep stages with the appropriate statistics.

	Mean duration [min] (mean \pm std)	Number of appearance of sleep stages (mean, min., max.)	Rest time (mean \pm std)	Active time (mean \pm std)
Night 1	322 \pm 93	78/32/144	97.2 \pm 6.8	0.012 \pm 0.02
Night 2	329 \pm 79	86/54/150	98.5 \pm 3.8	0.083 \pm 0.27
Night 3	329 \pm 75	78/53/157	99.7 \pm 0.8	0.019 \pm 0.04
p ^a	0.24	0.44	0.31	0.81
F ^a	1.46	0.83	1.18	0.21
Stage 1	36 \pm 22	26/5/48	98.9 \pm 3.2	0.036 \pm 0.11
Stage 2	172 \pm 56	26/12/61	99.0 \pm 2.9	0.038 \pm 0.18
Stage 3/4	20 \pm 24	6/0/27	98.9 \pm 4.6	0.076 \pm 0.40
REM	82 \pm 34	8/1/17	98.4 \pm 6.5	0.004 \pm 0.02
Awake	17 \pm 15	14/4/31	98.3 \pm 5.5	0.040 \pm 0.15
p ^b	<0.001	<0.001	0.65	0.31
F ^b	87.55	58.58	0.62	1.20

Legend: ^a p and F values for differences between different nights; ^b p and F values for differences between different sleep stages

EMG and sleep stages

The mean duration of the measured nights and sleep stages, the number of appearances of the sleep stages, the trapezius muscle rest time and the length of muscle activity during the nights and during the sleep stages are shown in Table 3.1. Periods with detectable EMG activity of the trapezius muscle lasted on average 1.5% of the length of the nights (full measuring periods) and only in four nights levels above 5% were observed. Muscle rest time for every sleep stage and every night is depicted in Figure 3.2.

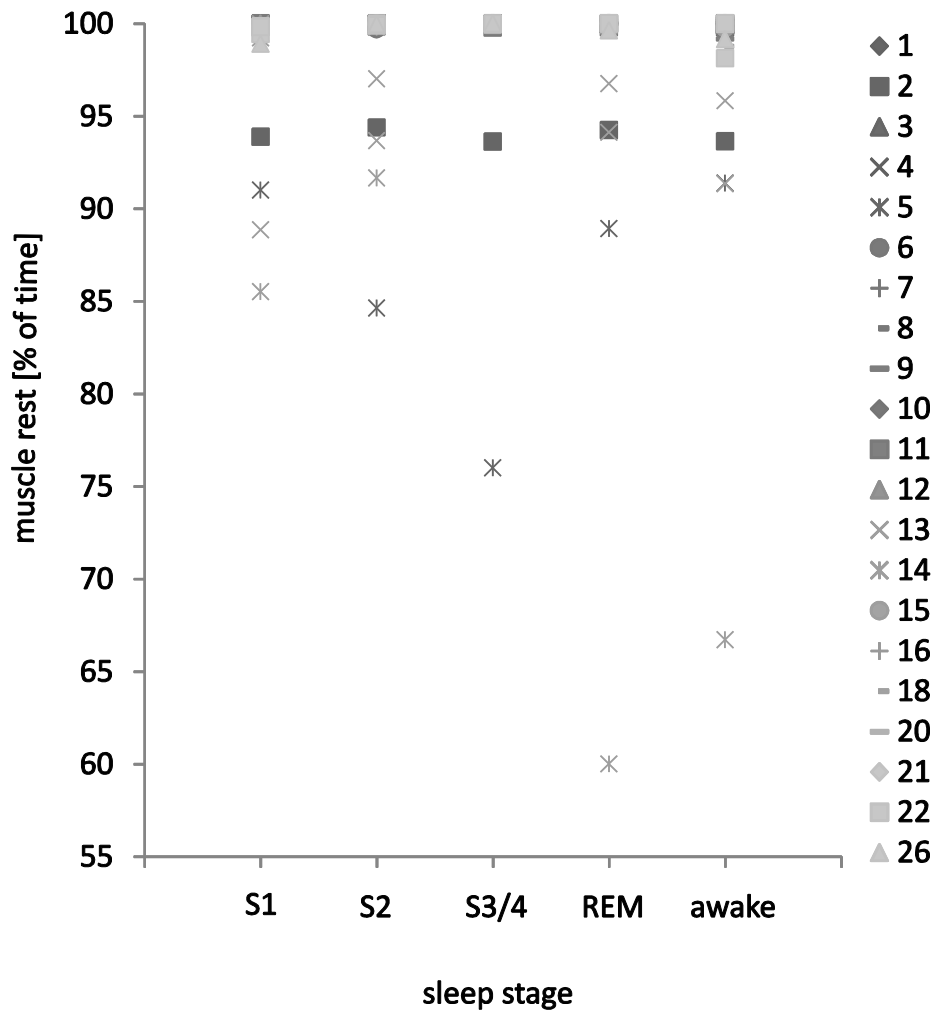


Fig 3.2: Mean muscle rest time over all nights for each subject and sleep stage. Subjects are determined by a code of digits

No differences were found in the mean duration of the recorded sleeping times between the first, second or third measured night of a subject (see Table 3.1). The number of single appearances of a sleep stage also did not significantly differ between the three nights evaluated. As expected the average length, as well as the number of occurrences of the different sleep stages S1, S2, S3, REM, and awake differed significantly. Statistical analysis showed no difference in rest time and in the length of time with muscle activity for the sleep stages. Also no differences in rest time or the length of time with muscle activity were found between the three measured nights of a subject. Between subjects rest time did not significantly differ ($F=1.2$, $p=0.30$), but the length of time with muscle activity proved to be significantly different between the examined subjects ($F=14.0$, $p<0.001$).

3.4 Discussion

The aim of this study was to describe the relationship between sleep stages and trapezius EMG activity. As there is evidence that sustained activity of low-threshold motor units plays an important role in MSD development (Sjogaard and Sogaard, 2014), we focused on muscle rest time or in other words, the absence of EMG activity. The study was performed in a sample of the Swiss population and at the subject's homes, i.e. in a natural environment. The results of the SDI imply that our subjects had the same level of sleep disturbance as was reported in reference participants during a quiet night in the laboratory (Griefahn et al., 2008).

Our results suggest that there is no significant relationship between the present sleep stage and the examined parameters of muscle relaxation or muscle activity in the trapezius muscle in healthy subjects. The results are somewhat surprising, as it is well known and also crucial for sleep stage scoring, that many muscles show reduced activity especially during the REM stage compared to all other stages (Iber et al., 2007; Rechtschaffen and Kales, 1968). It has to be taken into account that any change from any sleep stage to REM sleep occurs on an already very low EMG activity level. Even though we chose with 10% RVE a threshold just above the measurement noise level in most of the subjects, a possible reduction in trapezius activity in REM sleep still could have taken place below this limit and therefore not influence the amount of rest time calculated in our analysis.

Nevertheless, great differences between nights were found, ranging from 78% until 100% rest time during one night. It seems that other factors are much more important for trapezius rest time than sleep stages themselves.

Based on our findings analysis of nightly trapezius EMG activity –such as muscle rest time or occurrence of low level activity- in healthy subjects can be made disregarding standard sleep stage parameters. Further studies are needed to confirm these results for subjects with MSDs. Then it would support the results of former studies showing a relationship between increased low level nocturnal trapezius activity and neck or shoulder pain (Mork and Westgaard, 2004, 2006; Westgaard et al., 2002), 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, 1984) 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 as healthy controls. Therefore the mechanisms resulting in increased nocturnal EMG activity in MSD patients are of great interest for prevention and treatment and should be further investigated.

Limitations

The subjects self-reported sleep quality was best for the first night, but did not greatly differ between the nights. Therefore and in addition to the adaption night, the disturbance caused by the measurement equipment should not have influenced the subject's muscle relaxation time. More subjects and experimental nights would be needed to validate these between-days differences.

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. Jackson et al. (2009) showed that the inter-subject variance between different days is about 12% for normalized EMG data. As we concentrated on muscle rest time 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. Another concern can be the used threshold value of 10% RVE and the frequency band of the device starting at 70 Hz. This was necessary because of the unknown level of interferences in the bedrooms of the subjects. Furthermore, the results were obtained with surface EMG. Therefore they are of high practical value for researchers working with surface EMG. For other areas of the muscle or for researchers working with intramuscular EMG the results may not be transferable.

3.5 Conclusion

The findings of the present study support the case that future experiments performing long-time trapezius EMG measurement in healthy subjects can 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 regarding equipment and trained scorers and might lead to additional discomfort for the subjects.

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4. Trapezius muscle load, heart rate and time pressure during day and night shift in Swiss and Japanese nurses (study 3)

Abstract

The aim of the present study was to analyze the activity of the trapezius muscle, the heart rate and the time pressure of Swiss and Japanese nurses during day and night shifts. The parameters were measured during a day and a night shift of 17 Swiss and 22 Japanese nurses. The observed rest time of the trapezius muscle was longer for Swiss than for Japanese nurses during both shifts. The 10th and the 50th percentile of the trapezius muscle activity showed a different effect for Swiss than for Japanese nurses. It was higher during the day shift of Swiss nurses and higher during the night shift of Japanese nurses. Heart rate was higher for both Swiss and Japanese nurses during the day. The time pressure was significantly higher for Japanese than for Swiss nurses. Over the duration of the shifts, time pressure increased for Japanese nurses and slightly decreased for those from Switzerland.

Considering trapezius muscle activity and time pressure, the nursing profession was more burdening for the examined Japanese nurses than for Swiss nurses. In particular, the night shift for Japanese nurses was characterized by a high trapezius muscle activity and only few rest times for the trapezius muscle.

4.1 Introduction

The nursing profession is challenged with high physical loads, high mental loads and special organizational factors such as shift work. These factors lead to high physiological and psychological burden in nurses all over the world (Caruso and Waters, 2008; Hui et al., 2001; Salerno et al., 2012; Smith et al., 2004a; Tezel, 2005).

The prevalence of musculoskeletal disorders (MSDs) in nurses is high, especially in the neck and lower back. The reported prevalence of neck pain by nurses varies between 40% according to a study among Australian nurses (Lusted et al., 1996) and 60% in a study in the Netherlands (Bos et al., 2007).

The development of neck pain is closely linked to the activity of the trapezius muscle (Aaras, 1994; Hanvold et al., 2012). The most accepted method of measuring this activity is surface electromyography (EMG) (Mathiassen et al., 1995). The periods without measurable EMG activity, so-called rest time, seem to be an important factor in preventing neck pain (Veiersted et al., 1993). The long periods of continuous muscle activity, on the other hand, have been shown to lead to neck pain (Ostensvik et al., 2009). As an explanation, the Cinderella Hypothesis (Hagg, 1991b) proposes that long-lasting, low-level contractions always activate the same muscle fibers. When these fibers become overexerted, muscle pain develops.

One burden of the nursing profession is the rotating shift work (Conway et al., 2008) that is associated with health problems such as burnout (Estryn-Behar et al., 2008), cancer (Bonde et al., 2012) and MSDs (Läubli and Müller, 2009). Working in a rotating shift system often leads to work-family conflicts (Camerino et al., 2010), which in turn are associated with neck pain (Hammig et al., 2011). In addition, physiological and organizational parameters and psychological loads such as time pressure can also lead to a reduced rest time of the trapezius muscle (Birch et al., 2000; Lundberg et al., 1994) and are therefore risk factors for neck pain.

Currently there are many studies about the workload of nurses in different countries (Abbey et al., 2012; Myny et al., 2012). Some of them found correlations of work schedules and self-reported physical work load to MSDs, others just reported the workloads of nurses in many different countries (Abbey et al., 2012; Heiden et al., 2013; Myny et al., 2012; Pekkarinen et al., 2013; Salerno et al., 2012; Trinkoff et al., 2006). Caruso and Waters (2008) noticed, physiological data are still missing. Therefore, in the present study we analyzed the activity of the trapezius muscle, the heart rate and the time pressure during day and night shifts in Swiss and Japanese nurses¹. Related literature described similar levels of self-reported workloads in different countries, hence we hypothesized that the country the nurses work in had little influence on the results. We also hypothesized that the workload is higher during day shift than during night shift. Therefore, we expected trapezius muscle activity, heart rate and time pressure to be higher during the day shift in comparison with the night shift

4.2 Subjects and Methods

Subjects

17 Swiss and 22 Japanese nurses (10 of one dataset and 12 of another) participated in this study (Table 4.1). The educational level of all participating nurses was equivalent to a registered nurse. All nurses were female with at least one year of work experience in the same job. Swiss subjects worked either part-time ($\geq 80\%$) or full-time while Japanese subjects worked only full-time. The following exclusion criteria were defined: clinical findings of MSDs, skin disease, and intake of muscle relaxants. In the Swiss dataset, subjects with cardiovascular, psychological or neurological diseases or medication use were excluded. In

¹ It is foreseen to publish an in-depth analysis of the circadian pattern of heart rate and of the workload over 24 hours, based on the same datasets.

both Japanese datasets, subjects with shoulder and neck pain due to injury or systemic disease, BMI>30 and subjects using tranquilizing medication were excluded. The Swiss part of the study was approved by the ethical committee of the canton of Zurich (Switzerland) and all Swiss subjects gave their written informed consent. The Japanese part of the study was approved by the ethical committee of the Japan Health and Welfare Organization (580-1 Horikawacho, Saiwaiku, Kawasakishi, Kanagawa 212-0003). Furthermore, the ethical committee of the Graduate School of Health Sciences, Jikei Institute (Osaka, Japan) approved the work of the master students on this project and the ethical committee of the participating hospitals accepted the completion of the study in their hospital. All Japanese subjects gave their written informed consent. Subjects were instructed according to the Helsinki declaration, participated voluntarily and were free to discontinue their participation at any time without explanation.

Table 4.1: Characterization of the Swiss and the two Japanese datasets: For the Swiss and the both Japanese datasets the period of data collection, the number of subjects, the age of subjects (mean and standard deviation), the ward the subjects worked on, the time frame of the day and the night shift and the order of the measured shifts are shown.

Dataset	Swiss data	Japanese data 1	Japanese data 2
Data collection	6.2011-11.2011	10.2010-2.2011	11.2011-2.2012
N	17	10	12
Age	33.5 ± 10.1	30.8 ± 8.9	31.5 ± 8.7
Ward	Orthopedic ward (n=8) Intensive care (n=6) Emergency department (n=2) Post anesthesia care unit (n=1)	Cardiology ward	Orthopedic ward (n=7) Circulation and lung (n=3) Surgery (n=2)
Day shift	7.00-16.00	08.00-16.30	08.30-17.00
Night shift	21.30-7.00 (n=8) /23.00-7.30 (n=6) /22.00-6.00 (n=2) /20.00-6.30 (n=1)	00.00-8.30	00.30-09.00
Order of the measured shifts	Randomly; only one shift per day	Day shift and later on the same day night shift	Day shift and later on the same day night shift

Apparatus

Surface EMG and heart rate of Swiss subjects were collected with the PS11-UD (THUMEDI GmbH & Co. KG, Thum-Jahnsbach, Germany) with a sampling rate of 2048 Hz. Data were filtered in the device with an analog 3rd-order highpass filter with a cutoff frequency of 4 Hz (-3 dB) and a 10th-order anti-aliasing filter adjusted to 650 Hz (-3 dB). Additionally, a digital highpass filter at 12 Hz, a digital band replacement filter at 50 Hz, 100 Hz, 150 Hz, 200 Hz, 250 Hz, 300 Hz and 350 Hz, and two algorithms, which used low and very low frequencies (7-13 Hz and 0.5-1.7 Hz) were applied. The flatness (ripple) of the device's transfer function is ± 0.1 dB from 20 Hz-500 Hz. With Matlab R2011b, a root-mean-square procedure was conducted with a window width of 250ms, downsampling the processed data to 4 Hz. For more information, see Nicoletti et al. (2014b). The electrodes used were pre-gelled Ag/AgCl electrodes (Kendall Arbo, England).

Bioplar EMG of the Japanese data 1 was collected with the Muscle Tester Me3000P (Mega Electronics Ltd, Koupio, Finland). Data with a sampling rate of 2000 Hz were band pass filtered with a frequency band from 20 to 500 Hz and preprocessed with a root-mean-square procedure with a window width of 100 ms. The electrodes used were pre-gelled Ag/AgCl electrodes (Ambu Neuroline, Denmark).

Bipolar EMG of the Japanese data 2 was collected with the YS_BioMeas (RMS4, Yuui-Koubou Ltd., Japan). The effective frequency range went from 8 to 1000 Hz. The raw EMG signals were amplified ($\times 1000$), notch-filtered (central frequency 55 Hz) and a root-mean-square procedure was conducted with a window width of 50 ms. EMGs were recorded at a resolution of 16 bits with a sampling rate of 50 Hz. The electrodes used were pre-gelled Ag/AgCl electrodes (Ambu Neuroline, Denmark).

In the Swiss dataset, heart rate was measured using a two-electrode electrocardiogram (ECG) that was also part of the PS11-UD. After internal processing (moving average mean of 7 R-R intervals) the heart rate was given. Values smaller than 30 bpm or higher than 200 bpm and areas with a standard deviation larger than 40 bpm over 7 values were excluded. In both Japanese datasets, heart rate was measured with a heart rate watch (Polar CS600, Polar, Finland).

Procedure

Each subject was measured during a day and a night shift on the same ward (Table 4.1; Swiss subjects were measured during two day shifts, but only data of the first day shift were used for this publication). In Swiss nurses, only one shift per day was measured. The order of day and night shift was selected randomly. In Japanese nurses, the night shift was measured later on the same day than the day shift. The measurement device was applied before the start of the shift. The position of the EMG electrodes was the same in all three datasets, based on the recommendation of SENIAM (2012). The electrodes were placed on the line from the acromion to the cervical vertebra 7 (C7) with the midpoint of the two electrodes 2 cm medial of the midpoint of this line. The distance between the two electrodes was 2 cm. A reference electrode was placed on C7, except in the Japanese data 2 which was placed on the thoracic vertebra 3 or 4 (TH3/TH4). The measuring device was worn around the waist and the cables were fixed on the skin to reduce movement artifacts.

In Swiss data, heart rate was collected with a two-electrode ECG. One electrode was placed on the left side of the chest wall below the breast while the other was placed below the clavicle. For the Japanese data, the belt of the heart monitoring watch was worn around the chest and the watch was worn around the wrist.

Subjects performed submaximal reference contractions at the beginning of every shift, slightly modified from the description of Mathiassen et al. (1995). Subjects held their arms in a horizontal position, laterally extended in 90°abduction. In Swiss data, subjects held this position for three 20 s periods, with a 40 s break between periods. In both Japanese datasets, the break between the three contractions was 30 s.

At the beginning and at the end of every shift, subjects answered a question about time pressure on a scale from 1 to 5, whereby “1” meant “great time pressure” and “5” meant “far too little work”.

Analysis

All data were processed with Matlab R2011b. Japanese data 1 was downsampled from 10 Hz to 5 Hz while Japanese data 2 was downsampled from 50 Hz to 5 Hz. EMG data were normalized using the mean value of the three submaximal reference contractions, called the reference voluntary electrical activation (RVE). After this normalization, values were expressed as % RVE. Data points above 1000% RVE were removed. Afterwards, the rest time

(defined as % of shift duration with EMG below 5% RVE) and the 10th, 50th and 90th percentiles of EMG activity were calculated.

In heart rate data of Swiss nurses, heart rate was filtered with an internal procedure of the PS11-UD (see “Apparatus”). In both Japanese datasets, heart rate was filtered with a peak detection procedure and face validity. The scale of the question about time pressure was inverted, so that a higher value indicated more time pressure. After inverting “1” meant “far too little work” and “5” meant “great time pressure”.

Statistics

Mixed model analysis was used for statistical analyses (SAS 9.2). The dependent variables used were the rest time of trapezius muscle, the 10th and the 50th percentile of EMG activity and the heart rate. The shift (night or day) and the nation (Switzerland or Japan) as well as the interaction shift*nation were part of the model. The subject was a random factor. For comparing the two Japanese datasets, the same model, only including the two Japanese datasets as two different samples (“nation”), was calculated. In order to compare the time pressure values at the beginning and at the end of the shift, a mixed model including the shift (night or day), the nation (Switzerland or Japan), the time of the diary value (beginning or end of the shift) as well the interactions time*nation, time*shift and time*shift*nation was calculated.

Furthermore, an exploratory analysis was undertaken to elucidate eventual relationships between perceived time pressure and trapezius rest time or heart rate. To test if trapezius muscle rest time or heart rate were influenced by the level of time pressure before work, mixed models (separately for the factors trapezius muscle rest time and heart rate) including the covariates nation and shift were calculated. To test if the level of time pressure after work is influenced by trapezius muscle rest time or heart rate during work, the parameters heart rate and rest time were simultaneously included in the mixed model analysis with the covariates shift, nation and shift*nation.

4.3 Results

Recordings of trapezius EMG were analyzed for all 37 nurses. Heart rate data of 12 shifts and diary data of 3 shifts were missing.

Pooling of the data of the Japanese datasets

The two Japanese datasets were joined for analysis. The parameters trapezius muscle rest time ($p=0.20$; $n=22$), 10th percentile ($p=0.33$; $n=22$) and 50th percentile ($p=0.69$; $n=22$) of EMG activity, heart rate ($p=0.70$; $n=16$) and time pressure (difference between the beginning and the end of the shift; $p=0.13$; $n=20$) showed no difference between the datasets. The 90th percentile was significantly different ($p=0.01$; $n=22$) between the two Japanese datasets. As apparent in Figure 4.1d, this difference originated from three subjects with extremely high values during night shift. As these values could not be clearly explained or classified as physiologically impossible, the 90th percentile of trapezius muscle activity was not further analyzed.

Table 4.2: For the day and the night shift of Swiss and Japanese nurses the median values and standard deviation of electromyography (EMG) parameters, heart rate and time pressure at the beginning and at the end of the shifts are shown. The percentiles of EMG activity were expressed relative to the reference voluntary electrical activation (RVE). $n_{\text{Japan}}=22$, $n_{\text{Switzerland}}=17$ for EMG parameters, $n_{\text{Japan}}=16$, $n_{\text{Switzerland}}=17$ for heart rate and $n_{\text{Japan}}=20$, $n_{\text{Switzerland}}=17$ for the diary

	Japan		Switzerland	
	Day shift	Night shift	Day shift	Night shift
rest time (% of shift)	7.1 ± 7.1	5.6 ± 6.0	9.6 ± 8.2	13.8 ± 12.4
10 th percentile (% RVE)	7.0 ± 4.3	9.9 ± 7.1	6.6 ± 3.2	6.1 ± 3.3
50 th percentile (% RVE)	28.8 ± 12.2	34.2 ± 13.9	33.5 ± 13.0	28.2 ± 14.2
90 th percentile (% RVE)	82.7 ± 18.8^a (84.6 ± 19.4) ^b	100.4 ± 34.7^a (90.2 ± 24.1) ^b	91.9 ± 22.3	86.9 ± 23.8
Heart rate (bpm)	91.2 ± 9.5	83.4 ± 7.7	89.7 ± 9.2	82.2 ± 10.0
Time pressure beginning ^c	2.8 ± 1.1	2.8 ± 0.9	3.2 ± 0.7	2.9 ± 1.0
Time pressure end ^c	3.5 ± 0.8	3.5 ± 1.0	2.9 ± 0.8	2.9 ± 0.7

^a all data

^b data without the 3 subjects mentioned in part 3.1

^c reported time pressure at the beginning/at the end of the shift

Trapezius muscle activity

Table 4.2 shows the median values of the EMG parameters during day and night shift in Swiss and Japanese nurses. Using mixed model analysis, rest time of the trapezius muscle was found to be longer in Swiss nurses than in Japanese nurses (Table 4.3). Although rest time of trapezius muscle tended to be longer during the day shift than during the night shift in Japanese nurses and to be longer during the night shift than the day shift in Swiss nurses (Table 4.2), no

significant shift effect or interaction effect (shift*nation) was found. The longer rest time in Swiss nurses compared to Japanese nurses was also evident in Figure 4.1a that compared the individual trapezius rest time levels of the day and the night shifts of all the subjects and showed the regression lines. The regression lines were nearly parallel, which means that the ratio of rest time of the day compared to the night shift was the same in both countries. Although, the average level in the Swiss nurses was higher.

The 10th and the 50th percentile of EMG activity showed a significant different shift effect in the two nations (Table 4.2). The percentiles were higher during the night shift in Japanese nurses and slightly higher during the day shift in Swiss nurses (Table 4.1). This effect was also visible in the different slopes of the regression lines in Figure 4.1b and c.

Heart rate

Heart rate was higher during the day shift than during the night shift in both countries (Table 4.2). As shown in Table 4.3, this shift effect is statistically significant. No effect of the nation and no interaction effect (shift*nation) was seen. It is notable that heart rate is rather high on average, indicating a high workload.

Time pressure

The level of time pressure was significantly different between Swiss and Japanese nurses (Table 4.3). At the beginning of the shifts, the indicated levels of time pressure appeared to be similar (Table 4.2), being independent of nationality or shift type. At the end of the shifts, Japanese nurses indicated significantly more time pressure compared to the beginning of the shift and compared to the Swiss nurses.

Time pressure at the beginning of the shifts tended to predict a shorter trapezius muscle rest time ($F=2.2$, $p=0.14$) and a higher heart rate ($F=2.7$, $p=0.11$) during work. The level of time pressure at the end of the shifts was not significantly correlated with trapezius rest time ($F=0.04$) or heart rate ($F=0.6$) during the preceding work period.

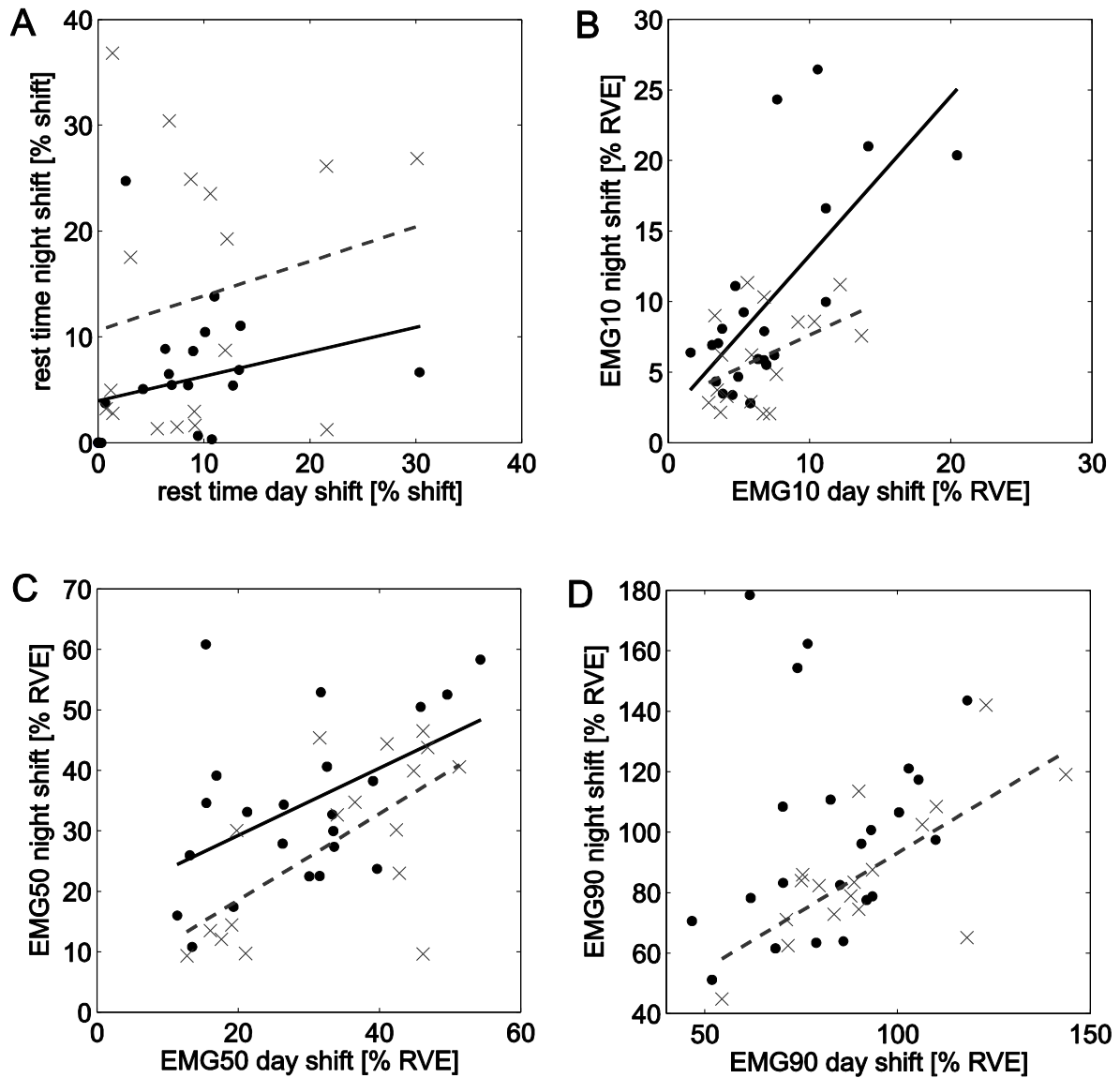


Figure 4.1: a) Trapezius muscle rest time (rest time), b) 10th percentile (EMG10), c) 50th percentile (EMG50) and d) 90th percentile (EMG90) of trapezius muscle activity during day and night shift in Swiss and Japanese nurses. These electromyography (EMG) parameters are plotted as day shift vs. night shift. Percentiles of EMG were expressed relative to reference voluntary electrical activation (RVE). Single data points of Swiss nurses are marked with a cross (x) and the regression line of Swiss nurses is shown as a dashed line. Single data points of Japanese nurses are marked with a dot (•) and the regression line of Japanese nurses is shown as a solid line. $n_{\text{Japan}}=22$, $n_{\text{Switzerland}}=17$

Table 4.3: Degrees of freedom (DoF), F and P values of mixed model analysis for Swiss versus Japanese nation, day versus night shift and shift*nation interaction are shown for rest time of trapezius muscle, 10th and 50th percentile of trapezius muscle activity, heart rate and time pressure (value at the end of the shift - value at the beginning of the shift). n_{Japan}=22, n_{Switzerland}=17 for EMG parameters, n_{Japan}=16, n_{Switzerland}=17 for heart rate and n_{Japan}=20, n_{Switzerland}=17 for the diary

Parameter	Effect	DoF numerator	DoF denominator	F	P
Rest time	nation	1	37	6.05	0.019
	shift	1	37	0.62	0.435
	shift*nation	1	37	2.74	0.107
10 th percentile	nation	1	37	2.26	0.141
	shift	1	37	2.54	0.120
	shift*nation	1	37	5.60	0.023
50 th percentile	nation	1	37	0.03	0.871
	shift	1	37	0.00	0.991
	shift*nation	1	37	7.08	0.012
Heart rate	nation	1	29	0.15	0.699
	shift	1	29	38.42	<0.001
	shift*nation	1	29	0.44	0.515
Time pressure	nation	1	109	6.35	0.013
	shift	1	109	0.40	0.528
	time	1	109	3.92	0.050
	time*nation	1	109	9.79	0.002
	time*shift	1	109	0.21	0.650
	time*nation*shift	1	109	0.18	0.676

4.4 Discussion

The rest time of the trapezius muscle was longer in Swiss nurses than in Japanese nurses. The 10th and 50th percentiles of EMG activity were the highest during night shifts of Japanese nurses. The heart rate was higher during the day shift in Swiss and in Japanese nurses. The level of time pressure at the beginning of the shifts was similar in Swiss and Japanese nurses but only significantly increased towards the end of the shift in Japanese nurses.

Trapezius muscle activity

The rest time of the trapezius muscle was longer in Swiss nurses than in Japanese nurses during the day and night shifts. The literature suggests that sufficient rest time of the trapezius muscle is the most important factor detectable by surface EMG for preventing neck pain (Hagg and Astrom, 1997; Veiersted et al., 1993) and therefore, work should allow for enough muscle rest time. It is not currently clear which amount of trapezius muscle rest time is “enough”, but the 5.3% and 7.1% of the shifts of the Japanese nurses seems to be extremely short. Even the 10% and the 13.8% of Swiss nurses may be too short.

Rest time data was compared with data from other studies. We used the threshold value of 5% RVE to define rest time of the trapezius muscle. The studies in Table 4.4 used the maximal voluntary electrical activation (MVE) for normalization. All values below 0.5% MVE were defined as rest time. Both RVE and MVE are widely used and accepted in literature (Hansson et al., 2000). A small study of ten subjects (Läubli, 2013) reported that 100% RVE corresponds to 17% MVE if the RVE is conducted without additional weight on the arms (we were not able to compare our data with data from studies using RVE with additional weight). Therefore, 0.5% MVE corresponds to approximately 3% RVE. As this is a bit smaller than the 5% RVE that we used in this study, the percentages of rest time in literature should be slightly smaller than the ones in our study. However, the published rest times (Westgaard et al., 2001) for health care workers are slightly longer than in our Swiss nurses and markedly longer than in our Japanese nurses. The health care workers recorded in Westgaard et al. (2001) were nurses (45%), nurses in home care (24%) and supervisory and support personnel (31%). The rest time of sellers also was higher than the ones recorded in our study (Akesson et al., 2012). Only the rest time of dental hygienists lay in the area of the Swiss nurses, but these values were still higher than in Japanese nurses. Based on the comparison with data from these two studies (Table 4.4), we conclude that the nursing profession is one of the professions with the shortest rest time values. Especially among Japanese nurses, trapezius muscle rest time was very short.

Table 4.4: Recorded rest time of trapezius muscle in literature in different professions.

profession	country	n	Recording time	Rest time [%]	Reference
Health care	Norway	44	Full workday	19.3	Westgaard et al. (2001)
Seller	Norway	22	Full workday	11.7	Westgaard et al. (2001)
Dental hygienist	Sweden	12	5 h 54 min	8.2	Akesson et al. (2012)

The 10th and the 50th percentiles of trapezius muscle activity showed opposite shift effects in Swiss and Japanese nurses. The values were higher during day shifts for Swiss nurses and higher during night shifts for Japanese nurses. Such a trend of increased trapezius muscle activity during night shifts in Japanese nurses was also evident for trapezius muscle rest time, but was not significant. Both measures, the 10th percentile of trapezius muscle activity and rest time, represent the continuous activity of the trapezius muscle. This continuous strain was the biggest in the night shift of Japanese nurses. Therefore, we propose to give the nurses in this shift more chances to take a break, especially in Japan. The 50th percentile characterizes the median load of the shift. Interestingly, this median load was nearly the same in the day shift of the Japanese nurses and in the night shift of the Swiss nurses as well as in the night shift of the Japanese nurses and in the day shift of the Swiss nurses. This implies that the mean overall workload seemed to be similar in Swiss and in Japanese nurses but its temporal distribution is different. The 90th percentile or the peak activity was the highest in the night shift in the Japanese nurses.

Different reasons for this higher trapezius muscle activity and the smaller rest time of the trapezius muscle in the night shift of Japanese nurses are possible. It seems that the workload during night shifts is higher in Japanese nurses than in Swiss ones. This could be caused by less staff during night shifts. As a higher activity of the trapezius muscle could be caused by physical or psychological strain (Nimbarte et al., 2012; Sjogaard et al., 2000), another possible cause could be a high psychological strain during night shifts. The same arguments can be given for the larger workload in Swiss nurses during day shifts. Another reason could be the different shift systems in the two countries. In Switzerland, after working a day shift, nurses were free at least until the next morning. If a night shift followed the day shift, nurses were free until the evening of the next day. The Japanese nurses, on the other hand, started their first night shift seven hours after finishing the previous day shift. Therefore, the time for regeneration before the night shift was short. Trinkoff et al. (2006) showed more MSDs in nurses having less than 10 hours off work between two shifts. In Japanese nurses, it is possible that trapezius muscle was not fully recovered before starting the night shift and therefore, more trapezius muscle activity was found.

As shown by Tanaka et al. (2010) and Arakawa et al. (2011) the shift system as well as the recovering periods are extremely important to avoid medical errors. Since medical errors could have severe consequences for patients, the shift system should allow the nurses to work as focused as possible. Another factor augmenting the probability of medical errors is if the nurses suffer from pain (Arakawa et al., 2011). Considering the possible development of neck

pain (Ostensvik et al., 2009), the activity of trapezius muscle should be reduced and the rest time increased. As mentioned in the introduction section of this paper, trapezius muscle rest time can be augmented by changing physiological loads (Heiden et al., 2013), psychological loads (Birch et al., 2000) or organizational factors (Conway et al., 2008).

Heart rate

The heart rate was significantly higher during the day shift than the night shift in both Swiss and Japanese nurses. The main reason for that is the circadian rhythm. As the human body is meant to have an approximately 24-hours rhythm, the heart rate is lower in the phase that is meant for recovery (Scheer et al., 2010). (more details are reported in Nicoletti et al. (2014b)).

Time pressure

The average reported levels were similar between the two countries, but we believe it is inappropriate to draw conclusions based on these absolute values. It was highly demanding to develop a questionnaire scale in Japanese and German that has a similar meaning among Swiss and Japanese nurses. The final wording was decided on after intense discussions in Switzerland, in Japan as well as among the authors. It is less difficult to compare relative changes within the two groups. In Japanese nurses we observed a significant increase between the start and the end of day and night shifts, while reported stress levels tended to decrease among Swiss nurses.

An exploratory analysis tested if higher levels of stress at the beginning of work would predict shorter trapezius muscle rest periods and a higher mean heart rate. Considering the nationality and type of shift (day or night shift), such a tendency was evident but not significant. Thus, the hypothesis that stress may increase trapezius muscle tension (Lundberg et al., 1994) was tentatively supported. This concerned the combined effect of stress and working with a high workload. It was not tested if perceived stress without any work demands would have a similar effect. On the other hand, we tested if short trapezius rest periods and/or a higher heart rate during work would predict stress levels at the end of the shift; this was not the case. This lack of a relationship leads to the question of whether the high workload visible in EMG and heart rate is appropriately sensed by the nurses. It is likely that further stressors such as unavailability of physicians, unsupportive management, interpersonal issues, and patient mental health are directly correlated with perceived stress levels (Happell et al., 2013) and have a more direct impact on the perception of time pressure than the measured trapezius muscle activity.

A possible limitation of this study was that EMG data of the three datasets was measured with three different devices. It is generally accepted that results from different studies may lead to slightly different results but these effects are known to be small if proper standardization procedures are used (Mathiassen et al., 1995). The Japanese and Swiss research team held several joint laboratory sessions to ensure identical procedures for all measures taken, including the standardization procedure. Additionally, researchers from both countries were involved in the measurements of both countries. We are thus sure that the reported difference in trapezius rest time is induced through the work situation and not the measuring device. Furthermore, we did not record the exact break times in the different shifts. But we are convinced that they are not very different and we know that in all the recorded shifts nurses were not allowed to take a nap.

Conclusion

Japanese nurses had a shorter trapezius muscle rest time compared to Swiss nurses as well as compared to published values. Especially during night shifts, their trapezius muscle rest time was short. On average, it was below 6% of the working time, indicating that opportunities to relax the trapezius muscle were limited. In Swiss nurses, night shifts seemed to allow for significantly more rest periods. The same relative load pattern was seen for the parameters describing static and average muscle activity. Heart rate was higher during day shifts and average levels above 80 beats per minute indicated a rather high workload among both Japanese and Swiss nurses.

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With kind permission of Industrial Health

5. Circadian rhythm of heart rate and physical activity in nurses during day and night shifts (study 4)

Abstract

Purpose

The study investigates if the circadian rhythm of heart rate is apparent during the working periods of day and night shifts in Swiss and Japanese nurses and if it is influenced by work organization. For a better interpretation of the heart rate, the activity profile over these working periods was monitored.

Methods

Heart rate and activity profile of 18 Swiss and 24 Japanese nurses were measured during one day and one night shift. The day and the night shift data of each subject were combined, resulting in an approximately 18 hours working period.

Results

A significant time effect of the mean hourly value of the heart rate was found in Swiss nurses (change in amplitude 7.1 bpm) as well as in Japanese nurses (11.8 bpm). These effects could be modeled with cosine curves for the Swiss and Japanese subjects. For the activity level significant time effects, similar to the ones in heart rate, were found in Swiss nurses (88% of SD) but not in Japanese nurses (26% of SD).

Conclusions

We found a significant time effect in heart rate similar to the known circadian rhythm under normal sleep-wake conditions while working in the studied shift work schedules. In the Japanese nurses studied heart rate followed a circadian rhythm independently of the level of physical activity. Therefore an activity profile following the circadian rhythm, especially a reduced workload from 2 am until 4 am, is proposed. The proposed activity profile could be reached with an adapted work organization.

5.1 Introduction

All over the world, workers are involved in night work. In Europe and the USA, 15-20% of the working population is involved in shift work including night shifts (Straif et al., 2007). With an amount of more than 30%, the health care sector is one of the sectors in which shift work including night shifts is most prevalent. Shift work, especially if it includes night work, is known to be disruptive for the circadian rhythm (Bonde et al., 2012; Bracci et al., 2014; Straif et al., 2007).

On one side, the circadian rhythm is given by an internal pacemaker called master circadian system and located in the suprachiasmatic nucleus. On the other side, the circadian rhythm is strongly influenced by environmental clues, like the light-dark cycle (Ruger and Scheer, 2009).

This results in a complex system of many different regulation mechanisms (Bollinger and Schibler, 2014). If the internal rhythm, given by the master circadian system and the light-dark cycle is shifted, a circadian misalignment occurs (Bonde et al., 2012; Ruger and Scheer, 2009). This desynchronisation leads to a disturbance in melatonin secretion. During a regular night, melatonin is secreted in high levels. Exposure to light during this biological sleeping period, leads to a misalignment of the circadian rhythm and thereby to a desynchronization of the melatonin secretion (Bonde et al., 2012).

Different health problems are associated with shift work. The most prominent one is the increased prevalence of different cancer types (Parent et al., 2012; Schernhammer et al., 2003), especially of breast cancer (Bonde et al., 2012; Leonardi et al., 2012). Estryn-Behar et al. (2008) found an association of shift work including night shifts and burnout. Läubli and Müller (2009) found an correlation of shift work and musculoskeletal disorders. Associations can also be found with sleep disturbances (Flo et al., 2012; Guo et al., 2013; Oyane et al., 2013), chronic fatigue (Oyane et al., 2013), changes in behavior pattern, depression, digestive disorders and cardiovascular diseases (Costa, 1996; Vyas et al., 2012). Bonde et al. (2012) state in their review that “disruption of the circadian rhythm is assumed to be a main pathway from shift work to disease”. To reduce the disruption and therefore also the health problems, several authors propose rapidly rotating shift systems (Bonde et al., 2012; Knauth et al., 1979).

Heart rate is one of the physiological parameters underlying a circadian rhythm (Ruger and Scheer, 2009). Data of the circadian rhythm of heart rate in healthy subjects under normal sleep-wake conditions are rarely reported. The reported data show a peak about noon to afternoon and a minimum about 3 am to 6 am (Clarke et al., 1976; Huikuri et al., 1990). Besides the circadian rhythm heart rate is also influenced by physical (Grandjean, 1991) and psychological loads (Fisher and Newman, 2013). Several studies measured heart rate during shift work and also during leisure time in shift workers (Colquhoun, 1988; Goto et al., 1994; Ito et al., 2001), but working nights were rarely compared with working days. These kind of measurements are important to understand the interaction between activities at work and HR variability. However, to the best of our knowledge none of the above mentioned studies investigated the circadian rhythm and controlled heart rate simultaneously for time of the day and workload.

With this study, we have in mind the claim of Bonde et al. (2012) who declared that “it is important to identify and implement shift systems that minimize circadian disruption “. As a first step towards a shift system that reduces circadian disruption, we intend to clarify in two

work situations if over an approximately 18 hours working period, consisting of a combined day and night shift, the circadian rhythm of heart rate is apparent. We also aim to compare the changes of heart rate and of activity profiles during the different hours of the working period.

5.2 Materials and Methods

Ethics Statement

The ethical committee of the canton of Zurich (Switzerland) approved the Swiss study and all Swiss subjects gave their written informed consent. In the Japanese study, the ethical committee of the Japan Health and Welfare Organization (580-1 Horikawacho, Saiwaiku, Kawasakishi, Kanagawa 212-0003, Japan) approved this study. All Japanese subjects gave their written informed consent. Subjects were instructed according to the Helsinki declaration, participated voluntarily and were free to discontinue their participation at any time without explanation.

Subjects

18 nurses participated in the Swiss and 24 nurses in the Japanese study (Table 5.1). They were all female and had an education equal to a registered nurse (Table 5.1). All subjects worked at least for one year on the job. Swiss subjects worked either part-time ($\geq 80\%$) or full-time and Japanese subjects worked full-time. Subjects fulfilling the following criteria were excluded: clinical findings of MSDs, intake of muscle relaxants and subjects with skin disease. In the Swiss dataset subjects with cardiovascular, psychological or neurological diseases, or subjects under medication were excluded. In the Japanese datasets, subjects with shoulder and neck pain due to injury or systemic disease, subjects using tranquilizing medication and subjects with a BMI >30 were excluded. The Swiss nurses were selected based on their willingness to participate and if their regular work schedule included day and night shifts. In all subjects the unit agreed with the proposed study. In Japanese nurses agreement was obtained from a participating unit and afterwards the subjects were selected based on their willingness to participate and if they regularly worked day and night shifts. The working hours of the measured shifts are shown in Table 5.1. Additionally the shift systems differed between the two countries: in Japan the night shift started 7 h and 30 min after the end of the previous day shift. In Swiss nurses the night shift started on the next day, more than 24 h after the ending of the last day shift.

Table 5.1 Specifications of Swiss and Japanese subjects.

Data set	Swiss subjects	Japanese subjects
Data collection	6.2011-11.2011	10.2010-2.2011, 11.2011-2.2012
N	18	24
Age	31.3 \pm 8.2	31.0 \pm 8.2
Ward	Orthopedic ward (n=9) Intensive care (n=6) Emergency department (n=2) Post anesthesia care unit (n=1)	Cardiology ward (n=6) Orthopedic ward (n=9) Circulation and lung (n=5) Surgery (n=4)
Day shift	7.00-16.00	08.00-16.30 (n=6) / 08.30-17.00
Night shift	21.30-7.00 (n=9) / 23.00-7.30 (n=6) / 22.00-6.00 (n=2) / 20.00-6.30 (n=1)	(n=18) 00.00-8.30 (n=6) / 00.30-09.00 (n=18)
Order of the shifts	Randomly; only one shift per day	Day shift and later on the same day night shift

Apparatus

Heart rate of the Swiss subjects was collected with a two electrodes electrocardiogram (ECG; sampling rate 1000 Hz) using the electromyography (EMG) recording device PS11-UD (THUMEDI GmbH & Co. KG, Thum-Jahnsbach, Germany). The ECG was directly processed with the device (moving average mean over 7 R-R intervals), thus heart rate was obtained. The electrodes used were pre-gelled Ag/AgCl electrodes (Kendall Arbo, England). In the Japanese data set, heart rate was measured with a heart rate watch (Polar CS600, Polar, Finland) with a sampling rate of 2400 Hz.

For the Swiss subjects, the acceleration of the dominant upper arm was also measured with the PS11-UD. A one-dimensional accelerometer (sampling rate 8 Hz) was fixed on the upper arm. Activity of the Japanese subjects was detected using the ViM sports memory (MicroStone, Japan) with a sampling rate of 24 Hz. The ViM sports memory was fixed on the dominant upper arm. Using a built-in algorithm, it classified ten different types of movements based on registrations by a three-dimensional accelerometer and a gyroscope. The ViM sports memory analyzed consecutive three minutes intervals and calculated the temporal distribution of these ten different movement types within the 3-min intervals.

Procedure

Each subject was measured during a day and a night shift on the same ward (Table 5.1; Swiss subjects were measured during two day shifts, but for this analysis only data of the first day shift were used). For the Swiss subjects, the order of the measured shifts was random. In Japanese subjects, the day shift was always measured directly before the night shift. The night shift measured in Swiss subjects was the second or in one case the third in a row. In Japanese subjects, the measured night shift was the first in a row.

The measurement device was applied before work started. In Swiss subjects, one electrode of the ECG was placed on the left side of the chest wall below the breast and the other one below the clavicle. The accelerometer was worn at the upper arm and was fixed with tape. The measuring device was worn around the waist and the cables were fixed on the skin for reducing movement artifacts. For the Japanese data, the belt of the heart monitoring watch was worn around the chest and the watch around the wrist. The ViM sports memory was worn on the dominant upper arm.

Analysis

All data were processed with Matlab R2011b. For the heart rate data of Swiss subjects, the PS11-UD used an internal filtering procedure. This procedure removed values smaller than 30 bpm, bigger than 200 bpm and if the standard deviation of 7 values was bigger than 40 bpm. Heart rate of Japanese subjects was analyzed with the help of peak detection and visual inspection and artifacts were removed. The heart rate data of every subject was split in 3-min-intervals. For every 3-min interval the median was calculated. The data from the day and the night shift of every subject were combined, covering approximately 18 hours.

For building the line with the median value (thick line) in Figure 5.1a and b, for every 3-min interval, the median of heart rate over all Swiss (1a) or Japanese (1b) subjects was calculated. Of this median values, a moving average mean over 5 values, or 15 min, was calculated. These values were used in Figure 5.1 as median (thick line). To describe the minimum and the maximum heart rate values (thin lines) in Figure 5.1, for every hour and for every subject, the smallest and the biggest value of the twenty 3-min intervals was searched and written in a new variable with its real time. These minimum and maximum values were also averaged over all Swiss or Japanese subjects using the median. A moving average over 5 values was calculated. These values are used in Figure 5.1a and b as minimum and maximum values (thin lines). As the time intervals of the minimum and maximum values were not constant within the single

hours, the distribution of these values is not constant. For statistical purpose, the median of heart rate values over one hour was calculated for every subject (using the 3-min intervals). The first interval started at 0.30 am.

For arm acceleration of Swiss subjects, 3-min intervals were generated using the median. In Japanese data, the built-in algorithm of the measuring device calculated for every 3-min-interval the percentages of the following movement types: “normal walking”, “fast walking”, “very fast walking”, “light running”, “fast running”, “light sport” and “intensive sport”, “desk work”, “standing work” and “slow walking”. For our analysis, “normal walking”, “fast walking”, “very fast walking”, “light running”, “fast running”, “light sport” and “intensive sport” were classified as “active” and “desk work”, “standing work” and “slow walking” as “not active”. For every 3-min interval, the percentage of “active” tasks was calculated. From the resulting 3-min interval values of both countries, the mean of all Swiss or Japanese subjects was obtained. From these values, the moving average over 5 values was calculated. Afterwards, these values were z-transformed (i.e. the mean was deducted from every value and the resulting value was divided by the standard deviation) and plotted in Figure 5.3. For statistical analysis of activity data, the mean over one hour was calculated for every subject. The first one-hour interval started at 0:30 am.

Two different measuring devices were used to measure heart rate and their reliability was checked. A test person wore both devices for two hours, simulating typical activities of a nurse. A correlation of $R=0.85$ was reached. An $R=0.9$ was reached after exclusion of rare artifacts that were caused because the devices touched each others.

Statistics

General linear model analysis was used for statistical analyses of heart rate and activity (SAS 9.2). The ward the nurses worked on was used as a class variable. The Greenhouse-Geisser-Epsilon was chosen for the evaluation of significance (Bortz and Schuster, 2010). A cosine curve was fitted on the hours 1 to 24 for heart rate and activity of Swiss and Japanese subjects. The amplitude, the phase shift and the displacement of the cosine curve were fitted. The period was set to 0.25, because we fitted the model to a 24 hours rhythm.

5.3 Results

Combined day and night shifts were used for heart rate analysis (separately for the 18 Swiss and 11 Japanese subjects) and for the analysis of activity (separately for the 18 Swiss and 23

Japanese subjects). In Swiss data, $5.9\% \pm 11.9\%$ of heart rate data per subject were excluded and in Japanese data it was $1.8\% \pm 2.8\%$.

Heart rate

Figure 5.1 show the heart rate over the combined day and night shift period for (a) Swiss and (b) Japanese nurses. The dots represent the single 3-min values of all subjects. The thick line shows the moving average mean value of the 3-min intervals of the subjects. The two thinner lines indicate the moving average of minimum and maximum values of every hour of the subjects. A highly significant time effect of the hourly median values of heart rate was found for the Swiss ($F=6.57$, $p<0.001$ with Greenhouse-Geisser-Epsilon) as well as for the Japanese nurses ($F=7.65$, $p<0.001$ with Greenhouse-Geisser-Epsilon).

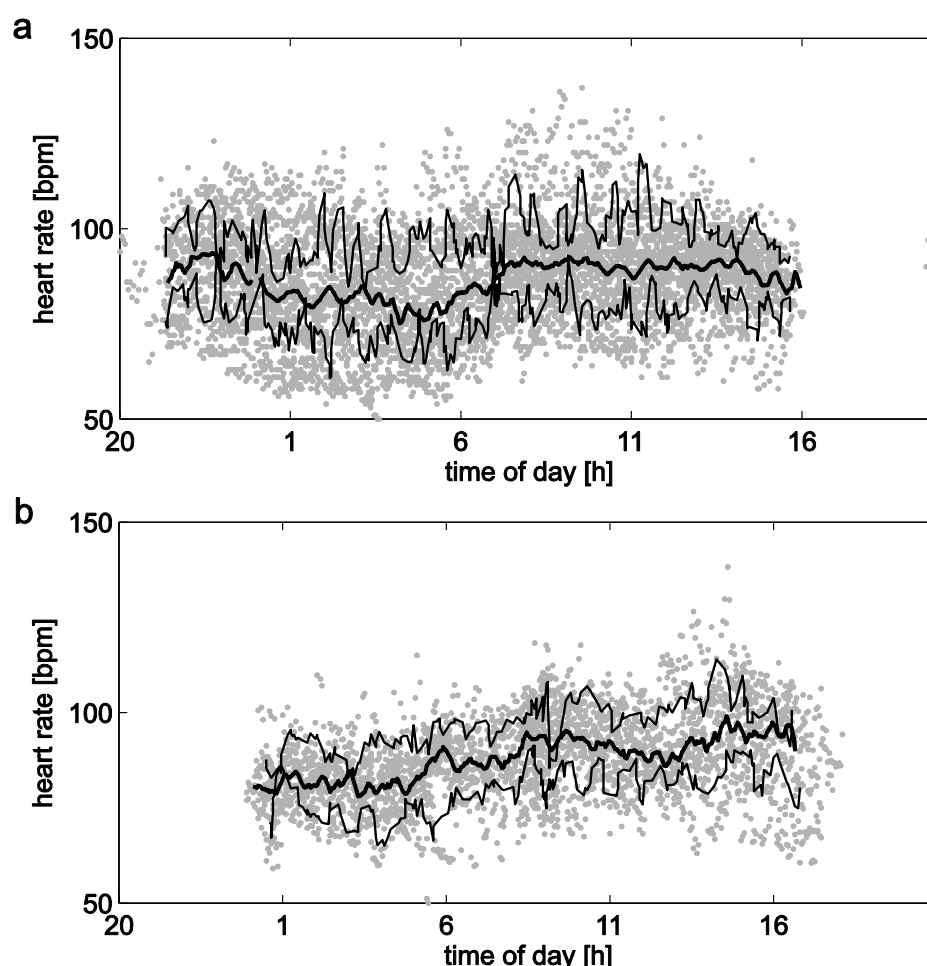


Fig. 5.1 3-min averaged heart rate values of the combined day and night shift of a) Swiss and b) Japanese subjects. The 3-min-averaged heart rate values are shown as dots (•). The thick line shows the moving average mean values of the subjects and the thin lines show the moving average minimum and maximum values of the subjects

Additionally, a cosine curve was fitted on the heart rate data of the Swiss
 $hr(t) = -3.5 \cdot \cos(0.25 \cdot t + 12.2) + 86.1$ ($R^2 = 0.05$, $F = 8.03$) and of the Japanese subjects
 $hr(t) = -5.9 \cdot \cos(0.25 \cdot t + 12.4) + 86.4$ ($R^2 = 0.18$, $F = 19.7$).

The one-hour mean values of the heart rate of the subjects and the fitted cosine curves are shown in Figure 5.2a for the Swiss and 2b for the Japanese nurses. Both groups showed a drop in heart rate in the early morning. The subjects showed the minimum around midnight to 3 am and a wide maximum between 12 am and 3 pm.

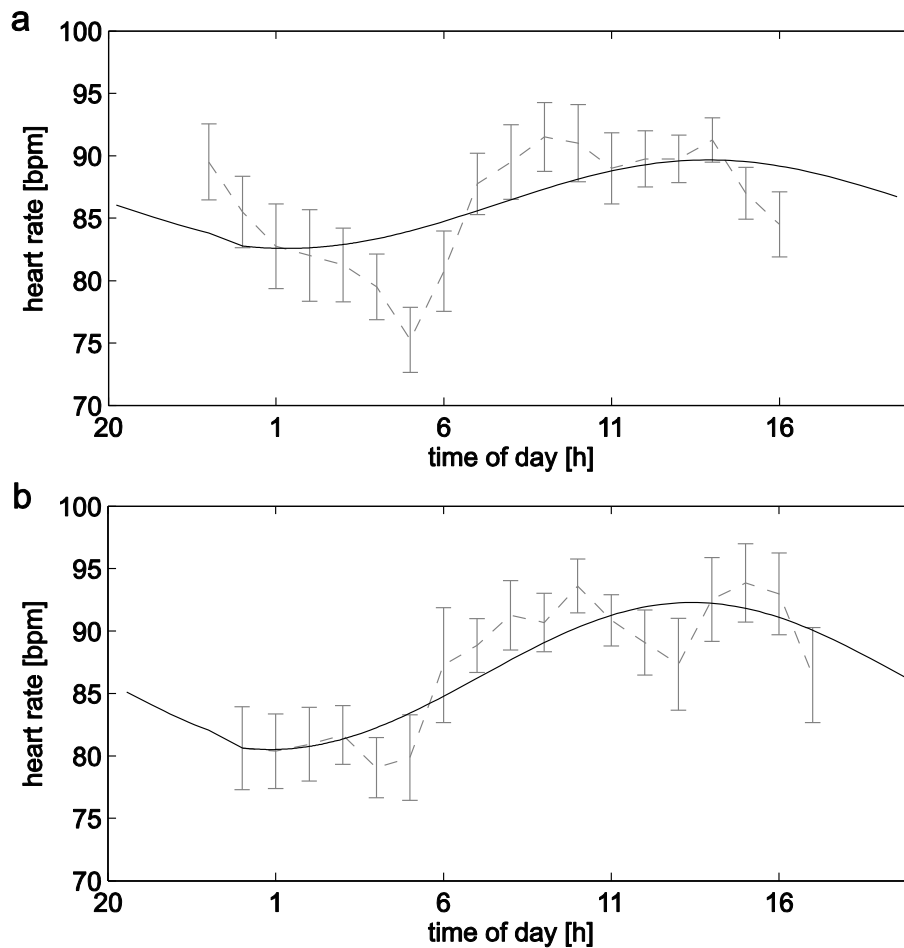


Fig. 5.2 Heart rate and the fitted cosine curve of a) Swiss and b) Japanese subjects. Hourly mean values of heart rate of the subjects with the standard error are shown as a grey dashed line and the fitted cosine function as a black solid line

Activity

No difference in activity between the different wards within a country was found (Japanese part $p = 0.9$ with one-way anova, Swiss part $p = 0.4$ (for trapezius muscle activity and details in Swiss nurses see Nicoletti et al. (2014b))) thus it is justified to jointly analyse the nurses from

different wards within the countries. Analyzing the activity pattern of the Japanese nurses no significant differences between the different hours of the day were found ($F=1.04$, $p=0.36$ with Greenhouse-Geisser-Epsilon). In the data of Swiss nurses, significant time dependent differences of activity were found ($F=5.22$, $p<0.001$ with Greenhouse-Geisser-Epsilon).

Figure 5.3 shows the z-transformed values of activity and heart rate of Swiss and Japanese data. In Swiss data, the curves of heart rate and activity were similar. In Japanese data, as shown by the statistical analysis, activity presented no time dependent effect.

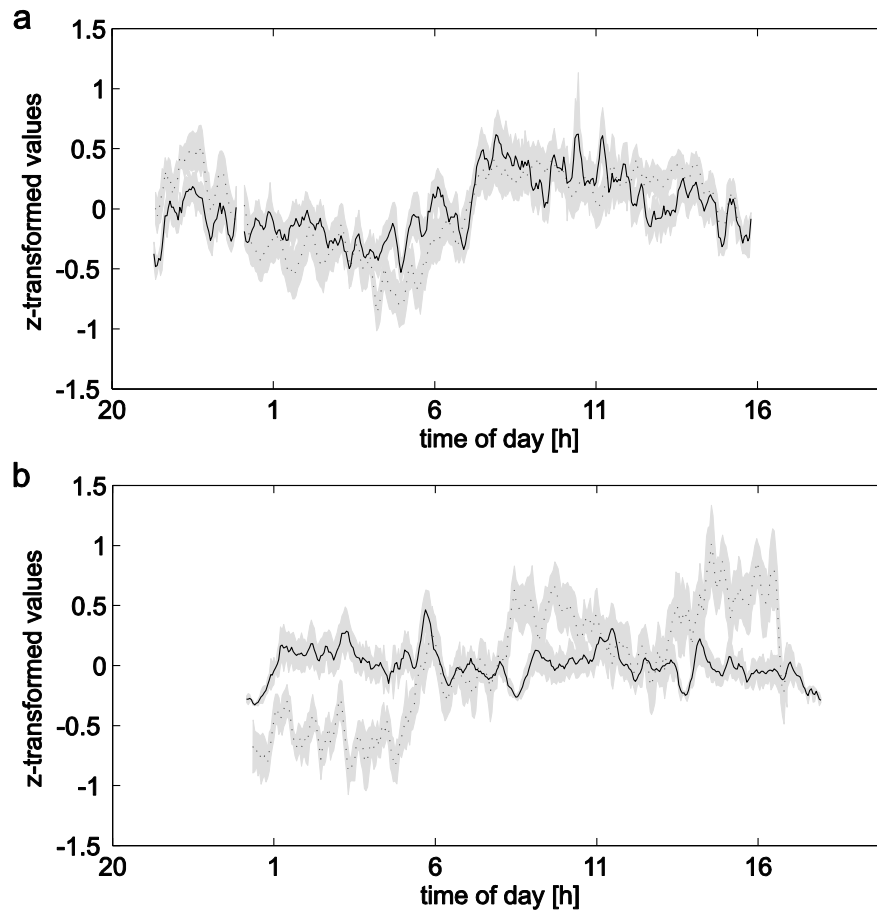


Fig. 5.3 Z-transformed values of heart rate and activity of a) Swiss and b) Japanese nurses. Heart rate is shown as a grey dashed line and activity as a black solid line. For both parameters the standard error is shown as a grey area

We additionally fitted a cosine curve on the activity of Swiss subjects

$\text{activity}(t) = -0.12 \cdot \cos(0.25 \cdot t + 13.0) + 0.61$ ($R^2=0.10$, $F=18.45$, change in amplitude 87% of the standard deviation)

For the Japanese subjects fitting a cosine curve with a periode of a full day did not give a significant result ($R^2=0.01$, $F=1.81$, change in amplitude 26% of the standard deviation). As already seen above, the activity of the Japanese nurses did not follow a 24-hour rhythm

($F=1.81$). In the Swiss nurses we found a significant 24-hour rhythm ($F=18.45$) with a similar phase shift as in the heart rate (with a phase of 13 for the activity and 12.2 for the heart rate).

5.4 Discussion

In the early morning a significant drop in heart rate was observed in the Japanese as well as in the Swiss nurses that can be explained by the circadian rhythm. In the Japanese nurses, the circadian drop was present in spite of a continuously high activity level.

Swiss and Japanese nurses showed a significant time dependent variation in heart rate during work. This time dependent variation was similar to the common circadian rhythm under normal sleep-wake conditions (Clarke et al., 1976; Huikuri et al., 1990). The amplitude of the rhythm is smaller in the Swiss than in the Japanese nurses. This may be due to the work schedule, as the measured night shift was the second one in Swiss, but the first one in Japanese nurses. Considering the fitted cosine curve, the Swiss as well as the Japanese nurses showed a minimum in heart rate from midnight till 3 am. The data additionally showed a local minimum at 5 am in the Swiss nurses and at 4 am in the Japanese ones. Especially in the Swiss nurses, where heart rate was at least 5 bpm lower than in every other point in time, it is probable that at 5 am the nurses had a period with less work. Especially because at 5 am the activity level of the Swiss nurses also was quite low. In the Japanese nurses, the drop at 4 am is smaller and may also be due to chance.

Goto et al. (1994) found in nurses a significantly lower heart rate during night shift than during day shift. Ito et al. (2001) concluded in their study that only a small contribution of the internal clock to the circadian rhythm was apparent, but a large contribution of activity. Ito's study, used heart rate data of 10 Japanese nurses but did not include the work activities of the nurses in the analysis. They only included a division in sleeping, working or leisure time. In Ito et al. (2001), heart rate had the smallest values at 4 am and the highest at 2 pm with a difference of approximately 25 bpm that is a bigger difference than in our study. Furthermore, heart rate variation was similar to the typical circadian variation. Colquhoun (1988) examined 8 hours sessions of sedentary shift work and with an increasing number of consecutive night shifts he found an adjustment of the heart rate to the timing of the shift and an elevation in heart rate after big meals. So a rhythm of heart rate, similar to the circadian rhythm seems to be maintained during shift work but may be disturbed by special duties or with increasing number of night shifts.

In Japanese nurses, the averaged heart rate seems to be independent of the activity. The activity level during the night shift was high, maybe even slightly higher than during day shift. Despite the high activity, heart rate was rather low. As a methodological point for further research, we state that the activity level during night shift could be underestimated only using heart rate. Therefore, additional parameters of activity, like accelerations or changes in positions should be recorded.

Bearing in mind the cancer problematic discussed in the introduction, the demands on the activity level during the night shifts should be reconsidered. The review of Bonde et al. (2012) mentioned various factors that causes circadian disruption and therefore could result in an elevated risk for breast cancer in night shift workers. The review mentioned the type of shift system, behavioral and lifestyle factors and environmental factors. The light exposure during night shifts seems clearly to be the most important factor, as it regulates the secretion of melatonin. Considering our results, we propose to see the activity level during night shifts as a possible additional influencing factor. When the activity level during night is as high as during day shift, but heart rate could not rise, additional disturbances of the circadian system are possible. Indeed, some evidence can be found that in long-term night work or if travelling over time zones, a high activity level during the biological night force the change of circadian rhythm (Atkinson et al., 2007). Therefore, we propose to adapt the workload during shift work to the circadian rhythm. Activity during night, especially from 2 am to 4 am should be reduced. Using more staff could be one possibility to reach this. In Swiss nurses, a period with less work seem to exist at about 5 am. This raises the question if it would be possible to shift this period to the time with the minimum of the circadian rhythm, which means from 2 am until 4 am. Further research in this field is strongly needed.

Also other reasons support the adaption of workload to the circadian rhythm. Santhi et al. (2007) showed a decline in cognitive processes during the night. Riedel et al. (2011) found between 2 am and 4 am a critical period with a significantly increased activity adjusted risk to experience a work-related accident. Thus, between 2 am and 4 am work duties should be minimized as much as possible to reduce work accidents.

It seems that the organization of shift work can influence the amount of circadian disruption and therefore it should be possible to reduce the disruption of the circadian systems by means of work organization. Based on the results it can be concluded that a high amount of activity during night shifts could augment the circadian disruption. Further studies are needed to clarify this and investigate which additionally factors of the work organization could have an

influence on the circadian disruption. A often studied method to reduce workload during night shifts is napping. A review (Ruggiero and Redeker, 2014) showed that napping can reduce sleepiness and can improve the sleep-related performance. But the review also showed that naps can lead to sleep inertia. Furthermore Edwards et al. (2013) showed that nurse managers perceive some conflicts related to napping and that 70% of the interviewed managers see drawbacks of the napping. Additionally, opportunities for napping do not exist in every hospital. Therefore another solution to reduce the load and the misalignment due to night shifts is strongly needed.

We are aware, that this is only a small study containing some limitations. The study design was not meant to be a statistical comparison between the effect of different shift schedules but was meant to shed light on the interplay between heart rate and physical activity during night work in two examples. Both data sets were independently analyzed and are displayed in a similar way. Based on a close cooperation between the research teams of the two countries that included reciprocal site-visits we are sure, that we could avoid large differences in the selection of nurses and in the interpretation of the measures taken. Using different measuring devices complicates comparisons of absolute levels of the activity and eventually heart rate, but as generally known does not hinder the analysis of the course within single subjects or here within the Swiss and Japanese nurses. Of course results from two culturally different countries are reported. This seems brave but literature reviews also do not pay great attention to the fact that studies are compiled from many countries. Additionally, we did not record the exact sleep schedule of the participants, the menstrual cycle or the menopausal status, the consumption of tea, coffee or tobacco and the illumination levels. Further research controlling all these parameters is strongly needed. However, we obtained clear and statistically highly significant results and we are convinced that they objectively describe some aspects of the physiological workload in Swiss and Japanese nurses. The study highlights some unsolved issues on the potential interactions between activity levels and heart rate during night work that should be considered in the organization of shift work.

Conclusion

We conclude that a significant time dependent variation in heart rate, similar to the known circadian rhythm under normal sleep-wake conditions, can be retained in nurses working night and shift work. In the example of the Japanese nurses heart rate followed a circadian rhythm independently of the level of physical activities and adaptation to the workload seems to be disturbed. Therefore an activity profile according to the circadian rhythm, which better corresponds to the physiological needs, is proposed. Especially during the critical period from

2 am to 4 am work demands should be eased, taking into account the known increased risk of work accidents during this time, and to counteract against disturbances of the circadian rhythm. The organization of the shift work seems to have an influence on the disruption of the circadian system and has to be further examined.

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Conflict of interest

The authors declare that they have no conflict of interest.

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6. Comparison of trapezius muscle rest time and activity during work, leisure and sleep in female office employees: a within day analysis (study 5)

Abstract

Background Neck pain is known to be highly prevalent among computer operators and its occurrence was linked to a reduced resting time of the trapezius muscle during work. With regard to leisure time and sleep such a correlation only was studied by a single research group.

Methods This study evaluated the activity of the trapezius muscle over a full day. In 20 female office employees trapezius muscle rest time and activity, arm acceleration and heart rate were compared between work and leisure, as well as work and sleep.

Results Trapezius muscle rest time was similar at work ($19\% \pm 14\%$ of time) and at leisure ($24\% \pm 16\%$ of time). During sleep the trapezius muscle was mostly relaxed ($97\% \pm 1\%$ of time). Between work and leisure a significant correlation of the 10th ($R=0.65$) and the 90th percentile ($R=0.66$) of trapezius muscle activity was found, while no significant correlation was evident for the trapezius muscle rest time ($R=0.40$) and for measures of arm acceleration. Between work and sleep the 10th percentile of trapezius muscle activity ($R=0.65$) was significantly correlated.

Conclusions The significant correlations found in the behavior of trapezius muscle activity during work and leisure and partly at sleep may be explained through a personal characteristic of the subjects. Nevertheless the observed personal pattern of trapezius muscle activity did not impede a sufficient relaxation of the trapezius muscle during sleep. Further studies are needed to test if this also will be the case in subjects with work-related neck pain.

6.1 Background

In office work, one of the most prevalent musculoskeletal disorders (MSDs) is neck pain. With prevalence rates between 51% and 58%, more than every second office employee is affected (Baran et al., 2011; Harcombe et al., 2009; Wu et al., 2012). Up to now, the mechanism of the development of neck pain as well as the risk factors for the development of it are not fully understood (Walton et al., 2013). Especially in office work, where the load on the neck muscles is rather small, the high prevalence rates of neck pain are hard to explain (Paksaichol et al., 2012). Possible factors that are discussed are psychosocial factors like low control at work and high job strain (Palmer and Smedley, 2007), organizational factors like number of working hours using a computer per day (Eltayeb et al., 2009), individual factors like gender (Hush et al., 2009) and physical factors like a sustained static muscle activation (Farina et al., 2008). On the muscular level, an important parameter that was found to be related to neck pain is the activity of trapezius muscle (Aaras, 1994; Hanvold et al., 2012). This activity can be measured non-invasively with surface electromyography (EMG) (Mathiassen et al., 1995).

Especially if periods without activity, the so-called rest time, are missing, neck pain has been reported (Hagg and Astrom, 1997; Veiersted et al., 1993).

Beside the work, the activity of the trapezius muscle during leisure and sleep could be relevant. Only little literature investigated the activity of the trapezius muscle during these periods of the day. For leisure, only one study resulting in several papers was found: Holte and Westgaard (2002) showed a higher trapezius muscle rest time during leisure than during work for different occupational groups. For secretaries however they showed a higher trapezius muscle rest time during work than during leisure. In Mork and Westgaard (2006) they reported a higher trapezius muscle rest time during work than leisure only in subjects that showed many periods with an EMG amplitude $>2\%$ of the maximal force. These results are from the same study sample. Nevertheless, leisure time could be an important factor influencing the load on the trapezius muscle. Several authors propose an active behavior during leisure with the aim to reduce musculoskeletal disorders (Hildebrandt et al., 2000) and specifically neck pain (Rasmussen-Barr et al., 2013).

Similarly for the sleep period, only data from one study sample were found. The study population, consisting of office workers and teachers with and without neck pain showed a wide variation of the amount of trapezius muscle rest time during sleep (Mork and Westgaard, 2004). Subjects suffering from neck pain showed a higher level of trapezius muscle activity and less trapezius muscle rest time than the subjects without neck pain. In another publication it is reported that sustained activity on the level of 10% of the maximal voluntary activation was found (Westgaard, 1999). A recently published study of our group revealed that during sleep most of the examined healthy subjects showed a high amount of trapezius muscle relaxation (Muller et al., 2015). Furthermore, trapezius muscle activity was not significantly correlated with sleep stages evaluated by somnography.

Better knowledge is needed about the natural behavior of trapezius muscle activity and the factors that are influencing it at work, leisure and during sleep. The role of personal traits and environmental factors needs to be better understood. Additionally relationships with pain development should not only be investigated during work but also during leisure and sleep. Therefore, the aim of this study was to compare trapezius muscle rest time and activity during work, leisure and sleep.

6.2 Methods

Subjects

Twenty female office employees (38 ± 12 years) participated in the study. All the subjects were employed as office workers with a weekly working time of at least 80% and worked at least since one year on the job. Subjects fulfilling one of the following criteria were excluded: skin disease, clinical findings of a musculoskeletal disorder, drug abuse, intake of psychotropic drugs or intake of muscle relaxants. The study was approved by the ethical committee of the Federal Institute of Technology Zurich (Switzerland) and all subjects gave their written informed consent. Subjects were instructed according to the Helsinki declaration, participated voluntarily and were free to discontinue their participation at any time without explanation.

Procedure

In the morning before the start of work, the measuring devices were applied. The EMG electrodes were placed on the dominant arm on a line from the acromion to the cervical vertebra 7 (C7), based on the recommendations of SENIAM (2012). The midpoint of the two electrodes was 2 cm medial of the midpoint of this line. The electrode-electrode distance was 2 cm. The reference electrode was placed on C7. For the electrocardiogram (ECG), one of the electrodes was placed on the left side of the chest wall below the breast, the other one below the clavicle. An accelerometer that was used to measure arm acceleration was placed on the top third of the dominant upper arm. On the thoracic spine a position sensor was placed allowing the assessment of trunk flexion and extension. The recording device was worn around the waist. To reduce movement artifacts the cables were taped to the skin. The subjects wore the measuring device until they started to work in the next morning.

A submaximal reference contraction, slightly modified from the description by Mathiassen et al. (1995), was performed at the beginning of the measurement. The subjects hold their arms in a horizontal position laterally extended in 90° abduction for 20 s. This procedure was repeated three times with a 40 s break in between. The subjects answered a question about neck pain six times during the measuring period (at the first morning after awakening, before start of the work, before lunch break, after finishing work, before they go to sleep and after awakening in the next morning). During the measurement the subject could follow their normal daily activities. The only restriction was that they were not allowed to take a shower.

Apparatus

Bipolar surface EMG (PS11-UD, THUMEDI GmbH & Co. KG, Thum-Jahnsbach, Germany) was recorded at a sampling rate of 2048 Hz. The flatness (ripple) of the transfer function from 20 Hz-500 Hz of the device was ± 0.1 dB and the intrinsic effective noise of the entire system was about 250 nV (12-650 Hz). A two-electrode ECG was acquired with the same measuring device and was processed within the device to derive the heart rate (using the moving average mean over seven R-R intervals). Additionally a one-dimensional accelerometer and a position sensor were part of the measurement device PS11-UD (sampling rate 8 Hz). Pre-gelled Ag/AgCl electrodes (35 x 26 mm, Kendall Arbo, Covidien, England) were used and the subjects' skin was prepared with abrasive paste (Nuprep, Weaver and Company, Aurora, CO, USA).

Analysis

Data were processed with Matlab R2012b. Parts of the EMG signal, especially parts of the night were contaminated by artifacts from the heart rate. The used measurement device (PS11-UD) had a built in filter to filter the ECG artifacts of the EMG signal. As this filter worked with a reference signal that was acquired at the beginning of the measurement it did not correctly work after a change of the body position (e.g. lying down during sleep). So we had to work with the unfiltered raw data of the device. First of all, the offset of the EMG data was corrected. Afterwards the ECG contamination was cleared. It was found to be challenging to get rid of the ECG contamination, as the ECG had different shapes in different subjects and even within a subject after a change of the body position (s. Figure 6.1 a and c). Thus it was not possible to develop a simple algorithm that recognizes the typical shape. As recommended by several authors (Drake and Callaghan, 2006; Redfern et al., 1993) we used a high pass filter. These authors suggested cut-off frequencies between 10Hz and 60Hz. After trying different cut-off frequencies, a 3rd order Butterworth filter at 50 Hz was chosen (s. Figure b and d). The reason for this choice was the recommendation of Redfern et al. (1993) to set the cut-off frequency as low as possible to minimize data loss. No further filters were applied. A noise level of approximately 2 μ V was visible, whereby less than 1 μ V was noise of the device and the remaining noise was from the environment (50 Hz and higher). It was decided not to use further filter as we expected that additional filtering would change the signal more than the noise level of approximately 2 μ V. For quality control, the whole dataset was visually controlled. In the sleep period of one subject, a period of approximately 45 min was detected, in which the noise level was higher. This period was manually corrected. Afterwards the root mean square (RMS) of the signal was built using a non-overlapping window of 250 ms and the

EMG was normalized to the reference voluntary electrical activation (RVE) of the submaximal reference contractions. Using very small or very high RVE values can lead to an inaccurate calculation of rest time values. Therefore subjects with RVE values out of the range of 55 μV until 140 μV were excluded (Nicoletti and Läubli, 2013). The RVE value was calculated as the mean of the most constant 10 s of the three reference contractions. Afterwards, the EMG was expressed in % RVE. Data of the heart rate were processed by the device (see 2.3) and reduced on a sampling rate of 4 Hz. Data of arm acceleration were used at the given sampling rate and unit (mm/s^2) and data of the position sensor were not further analyzed as they were only used to define the point in time, the subjects lied down.

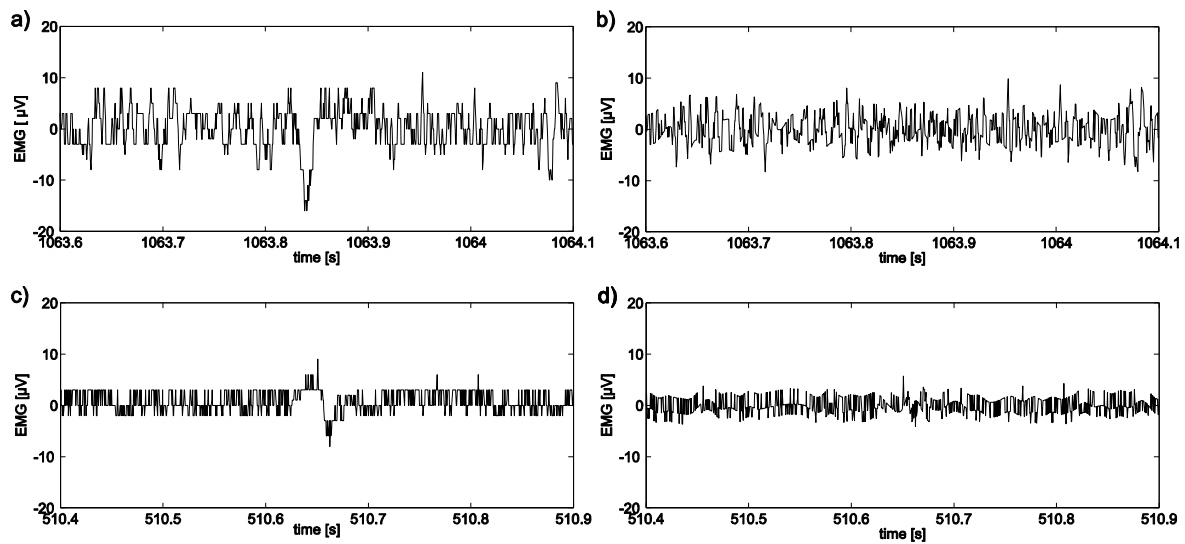


Figure 6.1: EMG data before and after artifacts filtering. Electrocardiogram (ECG) artifacts in the non-filtered electromyogram (EMG) in one subject during leisure (a) and during sleep (c). It is visible that the ECG artifact is monophasic in one diagram and diphasic in the other. After the filtering at 50 Hz the ECG artifacts are not visible anymore during leisure (c) as well as sleep (d).

From the measuring period of nearly 24 hours, the three sections work, leisure and sleep were detected and cut. The beginning and the end of the work and the beginning of the leisure was indicated by the subjects in the diary. The beginning of the sleep was indicated in the diary as well, but it was double-checked with the data. First, using the position sensor, it was detected if the subject was lying. The sleep onset was easily detected by a clear drop in the movement of the arm immediately followed by a drop of the heart rate. The same parameters were used to determine the wake up in the next morning. For the three sections work, leisure and sleep, based on the normalized EMG signal, the rest time, the 10th and the 90th percentile were calculated. Rest time was defined as the percentage of the duration with the EMG below 5%

RVE (based on the definition of Hansson et al. (2000)). From the heart rate, the 50th percentile was calculated and from the arm acceleration the rest time, the 10th and the 90th percentile. The rest time of arm acceleration was defined as the percentage of the time with a value below 90 mm/s². The value of 90 mm/s² was identified as motionless after visual inspection of the dataset. The neck pain score at the beginning and the end of the work, before sleep and at the second morning were used for analysis. The question was answered on a scale from 1 (“no pain”) to 5 (“very strong pain”).

Statistics

To compare the EMG parameters during work, leisure and sleep, a two-sided Wilcoxon rank test in IBM SPSS Statistics 22 was used. To analyze the influence of the subject on the EMG parameters a two-sided Spearman rank correlation in IBM SPSS Statistics 22 was used.

6.3 Results

Data of 20 female subjects were collected. One subject had to be excluded as the device stopped measuring after some hours. Seven additional subjects were excluded due to too small or too high RVE values. Some characteristics of the study sample and the excluded subjects are shown in Table 6.1. The mean measurement duration of the remaining 12 subjects was 22.0 h \pm 1.2 h. The EMG of one subject, divided in the three sections work, leisure and sleep is shown in Figure 6.2.

Table 6.1: Age and neck pain values of the study sample and the excluded subjects.

	Study Sample (n=12)	Excluded subjects (n=8)
Age [y]	38 \pm 13	38 \pm 13
Neck pain start of work ^a	1.1 \pm 0.3	1.2 \pm 0.4
Neck pain end of work ^a	1.2 \pm 0.4	1.0 \pm 0.0
Neck pain end of leisure ^a	1.0 \pm 0.0	1.0 \pm 0.0
Neck pain next morning ^a	1.1 \pm 0.3	1.0 \pm 0.0

^a Pain scale 1 (“no pain”) to 5 (“very strong pain”)

The trapezius muscle rest time was slightly higher during leisure than during work (s. Table 6.2). However, this difference did not reach statistical significance (s. Table 6.2). During sleep rest time was clearly higher than during work and leisure and reached nearly 100%. The 10th and the 90th percentile of trapezius muscle activity were significantly lower during sleep than

during work or leisure. No significant difference between work and leisure was found in the 10th and the 90th percentile, but the 10th percentile seemed to be slightly higher during work and the 90th percentile during leisure.

Table 6.2: Parameters of EMG, arm acceleration and heart rate. Rest time and percentiles (perc.) of the electromyography (EMG) of trapezius muscle, of arm acceleration and of heart rate (HR) during work, leisure and sleep (twelve subjects). Additionally the P value of the Wilcoxon rank test and R of the Spearman correlation for the comparison work versus leisure and work versus sleep are shown.

Parameters	Work	Leisure	Sleep	work vs. leisure		work vs. sleep	
				P	R (subject)	P	R (subject)
EMG							
rest time [% of time]	19 ± 14	24 ± 16	97 ± 1	0.75	0.40	<0.01	(0.01) ^a
10 th perc. [% RVE]	4 ± 2	3 ± 2	2 ± 1	0.12	0.65*	<0.01	0.65*
90 th perc. [% RVE]	61 ± 25	74 ± 28	3 ± 1	0.08	0.66*	<0.01	0.36
Arm acceleration							
rest time [% of time]	35 ± 10	28 ± 7	98 ± 1	0.91	-0.01	<0.01	-0.19
10 th perc. [mm/s ²]	72 ± 5	70 ± 3	64 ± 1	0.01	0.34	<0.01	-0.05
90 th perc. [mm/s ²]	793 ± 245	1314 ± 563	72 ± 3	<0.01	-0.27	<0.01	-0.07
HR							
50 th perc. [bpm]	80 ± 12	80 ± 10	61 ± 9	0.39	0.84**	<0.01	0.70*

^a not reasonable as the rest time is too high in all subjects

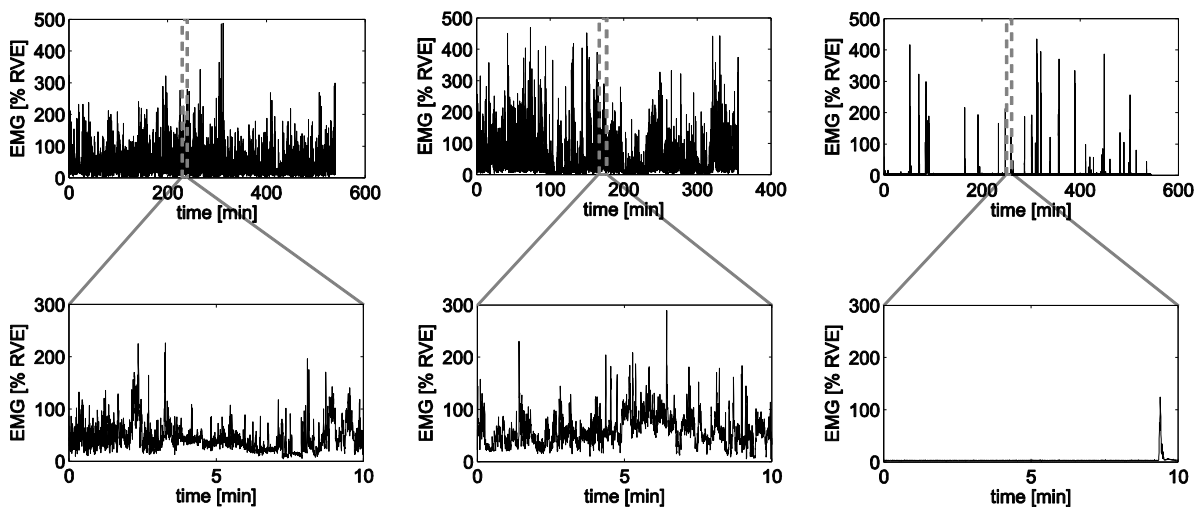


Figure 6.2: Dataset of one subject, divided in the three sections work, leisure and sleep. In every section, a 10 min period is showed in a magnified view.

The rest time of the arm acceleration seemed to be higher during work than during leisure but this difference did not reach statistical significance. The 10th percentile of arm acceleration was higher during work than during leisure and the 90th percentile was higher during leisure than during work. The rest time of arm acceleration was significantly higher and the percentiles lower during sleep than during work. Heart rate showed no significant difference between work and leisure. A significant drop of heart rate was found during sleep.

Figure 6.3 shows the correlation of the trapezius muscle rest time, the 10th and the 90th percentile between work and leisure. For the 10th and the 90th percentile of trapezius muscle activity a significant correlation was found (Table 6.2). For the trapezius muscle rest time a weak correlation seems to be there, but it was statistically not significant. A highly significant correlation between work and leisure was also found for the heart rate. In none of the parameters of the arm acceleration a significant correlation between work and leisure was found. The only correlation found between work and sleep was in the 10th percentile of muscle activity and in the heart rate. As the deviation between the subjects was too small during sleep, no figures for the sleep were made.

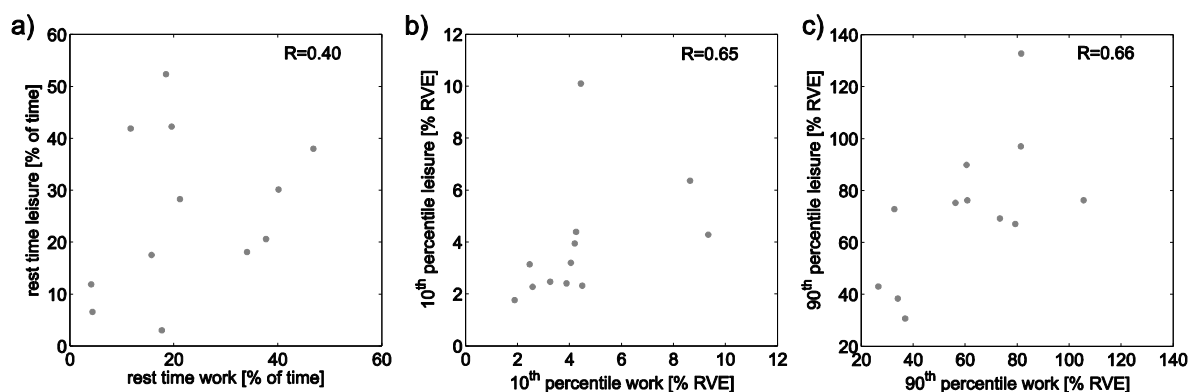


Figure 6.3: Correlation of the muscle activity between work and leisure. Trapezius muscle rest time and the 10th and the 90th percentile of trapezius muscle activity were correlated between work and leisure.

6.4 Discussion

None of the trapezius muscle parameters significantly differed between work and leisure, but trapezius muscle rest time was considerably and significantly lower and the percentiles significantly higher during work than sleep. In the 10th and the 90th percentile of the trapezius muscle activity, but not in the trapezius muscle rest time, a significant correlation between work and leisure was found. During work and leisure the strain on the trapezius muscle was

similar. This could be either due to similar loads or to the individual reaction to the loads. As shown by Zennaro et al. (2003) the trapezius muscle of different subjects may differently react to the same work task. In the present study subjects were selected from a specific occupational group but they were free to do whatever they liked during their leisure. During this leisure, the variability of the 90th percentile of arm acceleration was large. Although the arm acceleration parameters were not correlated between work and leisure the trapezius muscle activity was strongly correlated and reaching significance for the 10th and 90th percentile. Thus, our finding of similar activity during work and leisure could be due to a kind of a personal characteristic, how a subject reacts to loads. Similar findings were already reported (Nimbarte et al., 2012; Westgaard and Bjorklund, 1987). It also was expected that such a personal characteristic may also be visible when comparing work and sleep. However during sleep, all subjects were able to relax the trapezius muscle. The 3% \pm 1% of time the trapezius muscle was not relaxed represented short peaks that were mostly linked to body movements. So no signs for sustained trapezius muscle activity during sleep were found in this sample of healthy subjects. The only hint for a personal characteristic during sleep was the significant correlation of the 10th percentile of trapezius muscle activity during sleep and work. Our study sample included volunteers and the included subjects were free from neck pain. As a next step it should be investigated if during sleep subjects afflicted by trapezius myalgia have a reduced rest time and/or an increased activation level of the trapezius muscle and if after nights with a short rest time, neck pain is increased in the following morning. The amount of rest time during the night and the level of activity confirms the results of our recently published study (Muller et al., 2015), but contradicts the findings of the only existing study about trapezius muscle activity during sleep (Mork and Westgaard, 2004). Their study showed much lower values of trapezius muscle rest time during sleep. In the pain free subjects the median rest time was 73% of time or 52% of time (reached with two different analyzing methods). We think the differences between this study and ours could be due to the newer device and the more sophisticated data analysis (especially considering the ECG artifacts) in this paper.

The rest time and the 10th percentile of arm acceleration were slightly but not significantly higher during work than at leisure. As expected, all arm acceleration parameters were significantly lower during sleep than work. No significant correlations between work and leisure or work and sleep were found. In contrast to the trapezius muscle activity, no individual pattern of the arm acceleration seems to exist. This further confirms that parts of the trapezius muscle activity are not directly due to movements, but to other factors that have an effect on trapezius muscle activity during work as well as during leisure like psychosocial loads (Paksaichol et al., 2012) or as we propose are explained by individual characteristics such as

individual sensory-motor properties (Tomatis et al., 2012). Furthermore, the significantly lower 90th percentile during work could indicate that office work restricts fast movements but not the average activity level of the trapezius muscle.

No difference in heart rate was found between work and leisure, but the well-known highly significant difference between work and sleep. Heart rate showed highly significant correlations between work and leisure as well as between work and sleep probably indicating a personal characteristic that becomes evident at work, leisure and sleep. It is generally known that the resting level of heart rate and the reaction on loads differ between subjects and that the heart rate drops during night due to the circadian rhythm (Scheer et al., 2010) and sleep. It is noteworthy that the average level of heart rate was the same at work and at leisure and strongly correlated with each other. This might be interpreted that the average psycho-physiological load was similar during work compared to leisure even if arm acceleration was slightly but significantly smaller during work.

A limitation of this study was the small sample size. Twenty subjects participated in this study, but due to a shutdown of the measuring device and explained by too small or too high normalization values seven subjects had to be excluded. Furthermore, a rather high cut-off frequency of the high pass filter (50 Hz) was used. This was necessary because of ECG artifacts. However a comparison of values analyzed as described in the methods with values analyzed with the built-in filters of the measurement device showed a good correlation. This comparison was done during work, where the subjects were in an upright position and the built-in ECG filter of the measurement device functioned. In this study the sleep period was analyzed without defining sleep periods. As shown by Muller et al. (2015) this is not necessary in healthy subjects, as the trapezius muscle activity is not influenced by sleep stages. Finally it has to be mentioned, that this study was conducted with latest surface EMG technology. But even if no activity during night was found, it is not possible to say, if intra-muscular EMG would be able to find an active motor unit (Zennaro et al., 2003).

Conclusion

Healthy office employees showed a similar activation behavior of the trapezius muscle during work and leisure, while no such uniform pattern was evident for arm acceleration. It is assumed that during work as well as during leisure a personal characteristic could be relevant for the level of trapezius muscle activity. Such a personal factor for the trapezius muscle activity was not detectable during sleep, as all subjects were able to relax the trapezius muscle nearly during the full period of their sleep. After exploring healthy subjects, it should be

investigated if in cases with work-related trapezius myalgia, trapezius rest time is not only reduced during work but also during sleep and leisure.

Competing interests

The authors declare that they have no competing interests.

Author's contributions

CN conducted the study with the help of a master student and substantial help in conception and design from TL. CN drafted the manuscript and it was critically revised by TL. Both authors have given final approval of the version to be published and agree to be accountable for all aspects of the work.

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7. Trapezius muscle activity and body movement at the beginning and the end of a workday in female office employees (study 6)

Abstract

The aim of this study was to analyze the activity of the trapezius muscle and the arm acceleration during the progression of a workday in office employees. In addition, the influence of arm acceleration during lunch break on trapezius muscle was analyzed. The activity of trapezius muscle, the heart rate and the arm acceleration were measured in 19 female office employees. It was found that rest time and activity level of trapezius muscle and arm acceleration did not significantly change over the workday. Differences between the individual subjects were highly significant for all parameters of trapezius muscle activity and for heart rate, but not for the parameters of arm acceleration. A tendency was found that higher arm acceleration during lunch break augments the rest time and reduces the activity of the trapezius muscle in the late afternoon. A high inter-individual difference in the level of trapezius muscle rest time and activity in tasks with a low physical load such as computer work was found. Furthermore, in office work it seems to be sufficient to measure trapezius muscle activity over a one hour period in the morning and in the afternoon instead of continuously during the workday.

7.1 Introduction

Musculoskeletal disorders (MSDs) are a big health problem in the working population (Oh et al., 2011). MSDs can lead to a significant reduction of the quality of life (Scuffham et al., 2010). Due to the reduction in the quality of life, an often reduced productivity (Ng et al., 2014) and the high health costs (Bhattacharya and Leigh, 2011; Oh et al., 2011), MSDs do not only influence the affected person, but also related persons, the company where the affected person works and the whole economy. As an example, only the direct costs of low back pain in Switzerland in 2005, amounted to 6.1 % of the total healthcare expenses (Wieser et al., 2011).

Neck pain is one of the highly prevalent MSDs (Fejer et al., 2006b). One of the occupational groups highly affected by neck pain are office employees. The one-year prevalence rate of neck pain in office employees is between 51% and 58% (Baran et al., 2011; Harcombe et al., 2009; Wu et al., 2012). Thereby neck pain is more frequent in women than in men (Baran et al., 2011; Wu et al., 2012). Several studies reported that the activity of the trapezius muscle correlates with neck pain or predicts its development (Aaras, 1994; Hanvold et al., 2012). The commonly used method to detect the activity of the trapezius muscle is electromyography (EMG) (Mathiassen et al., 1995). Within the EMG signal, the most important parameter seems to be the rest time of the trapezius muscle (Hagg and Astrom, 1997; Veiersted et al., 1993). If rest time is missing, muscle activation of long duration will happen (Ostensvik et al., 2009).

Considering the Cinderella-Hypothesis of Hagg (1991a) a low-level activation of long duration in the trapezius muscle can keep the same muscle fiber active over the whole time. This can lead to overexertion of this fiber and therefore to pain (Hanvold et al., 2012). Especially during static muscle activation, it was shown that single muscle fibers were active over a long time (Farina et al., 2008).

Considering workload in general, physical (Falla and Farina, 2007), psychosocial (Birch et al., 2000) and mental loads (Nimbarte et al., 2012) can augment the activity of the trapezius muscle. In office work, the physical load is generally known to be small. However some specific risk factors are discussed. Zennaro et al. (2004) showed that while working at an improperly adjusted desk the number of active motor units of the trapezius muscle is augmented and that the length of activity is increased. Additionally Zennaro et al. (2003) found that during a 30 min task with a computer mouse a few motor units of the trapezius muscle were active over the whole period. Interestingly this behavior of motor units was only found in a part of the subjects. The authors also explained that it would have been possible to fulfill this task without activity in the trapezius muscle. However a review discussing the association of various loads to neck pain (Paksaichol et al., 2012) found for most of the analyzed factors no clear evidence. These uncertainties make it difficult to find optimal solutions for the prevention of neck pain in office work and demand further research. One approach that is often discussed is to interrupt the office work by active breaks (Hildebrandt et al., 2000; Samani et al., 2009; Sundelin and Hagberg, 1989). Sundelin and Hagberg (1989) found that active pauses induced a higher variation in trapezius muscle activity than passive pauses and were preferred by the subjects. Samani et al. (2009) found a higher variability in trapezius muscle activity during active pauses.

Several authors already analyzed the activity of the trapezius muscle in office employees (Blangsted et al., 2004; Holte and Westgaard, 2002; Zennaro et al., 2003). Based on the study of Zennaro that showed a high, sustained activity of the trapezius muscle in some subjects during 30 min, and a study showing that the hours spent with computer work per day is correlated with neck pain (Griffiths et al., 2012), it would be interesting to know, how the trapezius muscle behave in the course of a full day of computer work. The study by Luttmann et al. (2010) examined the rest time of the trapezius muscle during a workday and it was found that the trapezius muscle rest time decreased in the course of the workday in five of ten subjects, increased in one subject and in four subjects, no rest time was observed over the whole day. However, this study did not include all work tasks. The analysis was only made considering the parts of the workday classified as one of the “tasks with the lowest muscular

activity”. To the best of our knowledge, no study compared complete tasks of office work between the beginning and the end of the workday and none included the level of physical activity in the analysis.

Therefore, the aim of this study was to compare the activity of the trapezius muscle between the morning and the late afternoon of a workday in office employees. Furthermore we aimed to analyze movement parameters during the workday. It was hypothesized that the activity of the trapezius muscle is higher and the trapezius muscle rest time smaller in the late afternoon than in the morning. Additionally we hypothesized that the subjects showed less movements in the late afternoon than in the morning.

7.2 Subjects and methods

Subjects

19 female office employees (38 ± 12 years) participated in the study. They all worked as office employees with a regular working time of at least 80% (> 32 hours/week), and worked at least since one year on the job. Subjects fulfilling one of the following criteria were excluded: skin disease, clinical findings of a musculoskeletal disorder, drug abuse, intake of psychotropic drugs or intake of muscle relaxants. The study was approved by the ethical committee of the Federal Institute of Technology Zurich (Switzerland) and all subjects gave their written informed consent. Subjects were instructed according to the Helsinki declaration, participated voluntarily and were free to discontinue their participation at any time without explanation.

Procedure and apparatus

The data reported in this paper are part of a measurement from the beginning of the work on one day, until the waking up in the next morning (an analysis of the full data including leisure time activities and night is in preparation). The measuring devices were attached in the morning before the start of work. The activity of the descending part of trapezius muscle was measured. The EMG electrodes were placed on a line from the acromion to the cervical vertebra 7 (C7), based on the recommendations of SENIAM (2012). The midpoint of the two electrodes was 2 cm medial of the midpoint of this line and the electrode-electrode distance was 2 cm. The reference electrode was placed on C7. For the electrocardiogram (ECG) a two electrodes lead was used. One electrode was placed on the left side of the chest wall below the breast, the other one below the clavicle. On the top third of the dominant upper arm an accelerometer was placed. To reduce movement artifacts the cables were taped to the skin and

the recording device was worn around the waist. The recording device (PS11-UD, THUMEDI GmbH & Co. KG, Thum-Jahnsbach, Germany) used a sampling rate of 2048 Hz. Pre-gelled Ag/AgCl electrodes (35 x 26 mm, Kendall Arbo, Covidien, England) were used and the subjects' skin was prepared with abrasive paste (Nuprep, Weaver and Company, Aurora, CO, USA). EMG data was filtered with an analogue 3rd order high pass filter with a cut off frequency of 4 Hz (-3 dB) and a 10th order anti-aliasing filter adjusted to 650 Hz (-3 dB). Subsequently, a digital high pass filter at 12 Hz, a digital band replacement filter at 50 Hz, 100 Hz, 150 Hz, 200 Hz, 250 Hz, 300 Hz and 350 Hz, and two algorithms which used low and very low frequencies (7-13 Hz and 0.5-1.7 Hz) were applied. The flatness (ripple) of the transfer function from 20 Hz-500 Hz of the device is ± 0.1 dB and the intrinsic effective noise of the entire system was about 250 nV (12-650 Hz). Using the same measuring device, a two-electrode electrocardiogram (ECG) was acquired to remove ECG artifacts by a template-based algorithm (Clancy et al., 2002). The registered ECG was used to calculate the heart rate, too. A one-dimensional accelerometer was also part of the measurement device PS11-UD. The subjects wore the measurement device until the start of work in the next morning. Before the start of the measurement, a submaximal reference contraction, slightly modified from the description by Mathiassen et al. (1995) was performed. The subjects hold their arms in a horizontal position laterally extended in 90° abduction for 20 s. This procedure was repeated three times with a 40 s break in between. Before start of the work, before lunch break and after finishing the work the subjects answered a question about neck pain. The wording of the question was: "Do you feel pain in the neck or the shoulder area?". The scale used ranged from one to five, whereas one meant "no pain" and five meant "very strong pain".

Analysis

All data were processed with Matlab R2012b. The root mean square (RMS) signal (window length 500 ms, 50% overlap) of the EMG was normalized with the reference voluntary electrical activation (RVE) of submaximal reference contractions and the RVE value was calculated as the mean of the most constant 10 s of every of the three reference contractions. As a result, the EMG was expressed in % RVE. Subjects with too small or too high RVE values (Nicoletti and Läubli, 2013) were excluded. Data of the arm acceleration and the heart rate were processed by the device and reduced on a sampling rate of 4 Hz.

To answer the hypotheses, three parts out of the workday were analyzed. We analyzed one hour in the morning, as the beginning of the workday and one hour in the late afternoon as the end of the workday. To avoid phenomena of arriving at work, getting a coffee or tidying up in the evening, we excluded the first 30 min and the last 30 min of the workday (s. Figure 7.1).

As we did not report the exact lunchtime of the subjects, we analyzed the period from 11:30 until 13:30 as lunchtime. Thus we were sure that this period includes the lunchtime of every subject. The subjects did not receive any instructions on their behavior during lunch break.

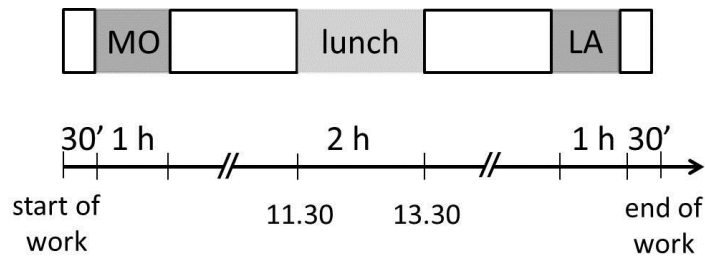


Figure 7.1: Location of the measurement periods morning (MO) and late afternoon (LA) during the workday of the subjects.

Based on the normalized EMG signal, the heart rate, and the arm acceleration the 10th, the 50th and the 90th percentile were calculated for the morning, the lunchtime, and the late afternoon. For the EMG and the arm acceleration, we additionally calculated the rest time. The rest time of the EMG was defined as the percentage of the duration with the EMG below 5% RVE (based on the definition of Hansson et al. (2000)). For the arm acceleration, the rest time was defined as the percentage of time with a value below 90 mm/s². This limit was set as motionless after visual inspection of the dataset.

Statistics

Statistical analysis was done using IBM SPSS Statistics 22. The following dependent variables were examined: trapezius muscle rest time, percentiles of trapezius muscle activity, arm acceleration rest time and percentiles of arm acceleration and the heart rate. To test for significant differences between the morning and the late afternoon values of the various parameters two-sided Wilcoxon rank tests were used. To describe the correlations of the morning and afternoon values within the subjects two-sided Spearman rank correlations were calculated. The strength of correlations between the parameters of the trapezius muscle and the arm acceleration were tested by a two-sided Spearman rank correlation. The magnitude of the variances explained by the time of the day (morning or late afternoon) and by differences between the individuals was determined calculating an analysis of variance with a two factorial design.

7.3 Results

Nineteen female subjects participated in the study. Because of an error of the measurement device, one subject had to be excluded. Seven additional subjects had to be excluded because of too small or too high RVE values (see Nicoletti and Läubli (2013)). The remaining 12 subjects were included in the analysis. Age and level of neck pain of the study sample and the excluded subjects are shown in Table 7.1.

Table 7.1: Age and neck pain levels for the study sample and the excluded subjects.

	Study Sample	Excluded subjects
Age [yr]	38 ± 13	38 ± 13
Neck pain at the start of work ^a	1.1 ± 0.3	1.2 ± 0.4
Neck pain at the end of work ^a	1.2 ± 0.4	1.0 ± 0.0

^a Pain scale 1 (“no pain”) to 5 (“very strong pain”)

Comparison between morning and late afternoon

EMG, heart rate, and arm acceleration were compared between the morning and the late afternoon. Figure 7.2 shows the progression of the parameters from the morning to the late afternoon for all subjects. In Figure 7.2a the trapezius muscle rest time is shown. Trapezius muscle rest time in the morning varied between 1% of time and 49% of time and in the late afternoon between 2% of time and 34% of time. We observed a significant difference of the trapezius muscle rest time between the subjects (s. Table 7.2 and Figure 7.2a). The progression of the trapezius muscle rest time from the morning to the late afternoon differed between the subjects. In some subjects trapezius muscle rest time in the morning was higher than in the late afternoon, in other subjects it was higher in the late afternoon than in the morning and in some subjects, nearly no change was visible. Over all subjects, no systematic change from the morning to the late afternoon was found (s. Table 7.2). The 10th, the 50th and the 90th percentile of trapezius muscle activity showed similar results (s. Figures 7.2b-7.2d). All the parameters showed significant differences between the subjects, but no significant difference between the morning and the late afternoon.

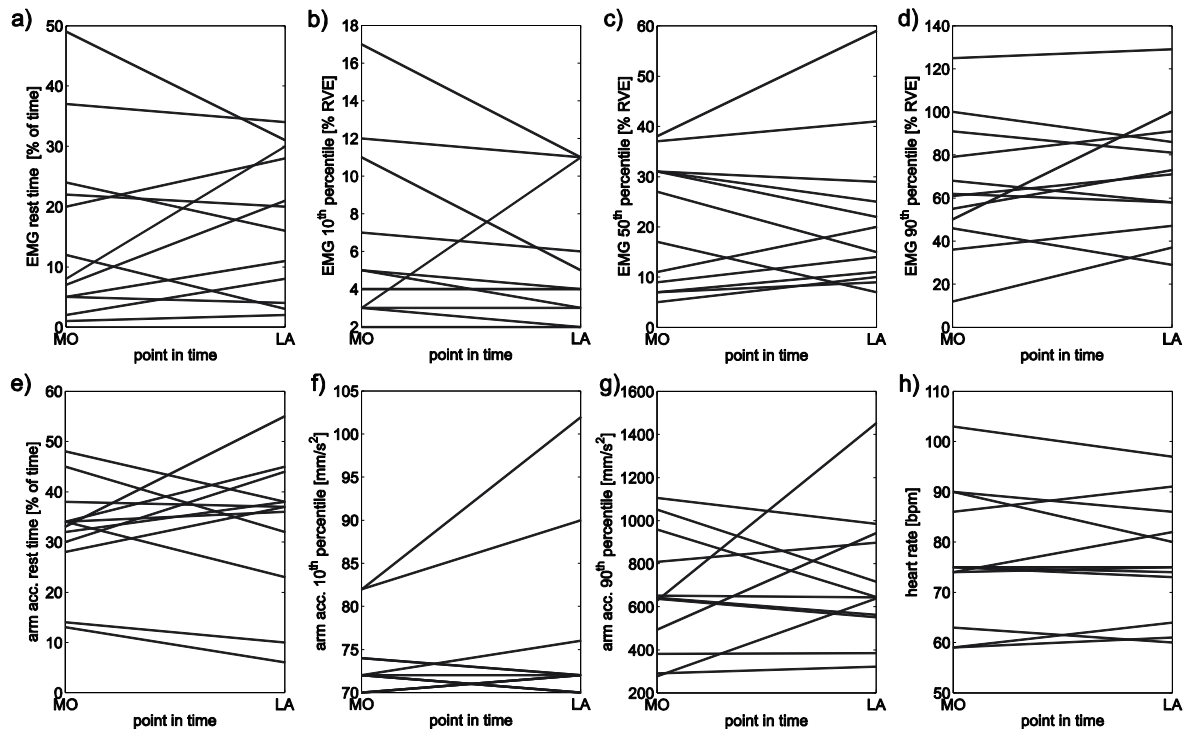


Figure 7.2: Values and progression from the morning to the late afternoon for the single subjects for a) the rest time of trapezius muscle, b) the 10th, c) the 50th and d) the 90th percentile of trapezius muscle activity, for e) the rest time, f) the 10th and g) the 90th percentile of arm acceleration and for h) the 50th percentile of the heart rate.

Table 7.2: P values of the Wilcoxon test of the comparison between morning (MO) and late afternoon (LA), R values of the Spearman correlation to analyze the influence of the subject and the amount of variance explained through differences between subjects.

Parameter	P (MO-LA)	R (subject)	Variance explained by differences between subjects [%]
EMG, rest time	0.81	0.72**	84
EMG, 10 th percentile	0.16	0.67*	81
EMG, 50 th percentile	0.94	0.86***	89
EMG, 90 th percentile	0.33	0.70*	88
Arm acc., rest time	0.72	0.25	80
Arm acc., 10 th percentile	0.33	0.43	80
Arm acc., 90 th percentile	0.75	0.50	67
HR, 50 th percentile	0.79	0.81**	96

None of the parameters of the arm acceleration showed a significant difference between the morning and the late afternoon (s. Figure 7.2e-2g). The progression of the rest time of the arm acceleration differed between the subjects, as in some subjects it got higher towards the late afternoon, in some it got lower and in one subjects it was stable. Similar developments were found for the 10th and the 90th percentile of the arm acceleration. For the parameters of the arm acceleration, no significant difference between the subjects was found. The heart rate (s. Figure 7.2h) showed no difference between the morning and the late afternoon. Also the progression seemed not to differ between the subjects, as the heart rate seemed to be stable over the workday in all subjects.

Influence of the arm acceleration during lunch time

In Figure 7.3a and Figure 7.3c the three subjects with the highest arm acceleration during lunch time are plotted as dashed-dotted lines. A tendency was found that these three subjects had a higher trapezius muscle rest time and a lower 50th percentile of trapezius muscle activity in the late afternoon than in the morning. No visible pattern was found for the three subjects with the lowest arm acceleration during the lunch time. Figure 7.3b and d showed that the six subjects with a higher arm acceleration during lunch time did visually not differ from the six subjects with a lower arm acceleration during lunch time.

Explained variation by the subject

In all analyzed parameters, a considerable amount of the variance could be explained through differences between subjects (s. Table 7.2). In the parameters of the trapezius muscle activity the variance explained through differences between the subjects was between 81% and 89%. For the rest time and the 10th percentile of arm acceleration, it was 80%. With an explained variation of 67% through differences between the subjects, the 90th percentile of the arm acceleration showed the lowest amount. The highest value showed the heart rate, with an amount of 96%. The high between subjects variation is mainly caused by the big differences observed among the twelve subjects as is depicted by the figures 7.2a-7.2d. E.g. for trapezius muscle rest time the percentages with rest time ranged from 1% until 49%.

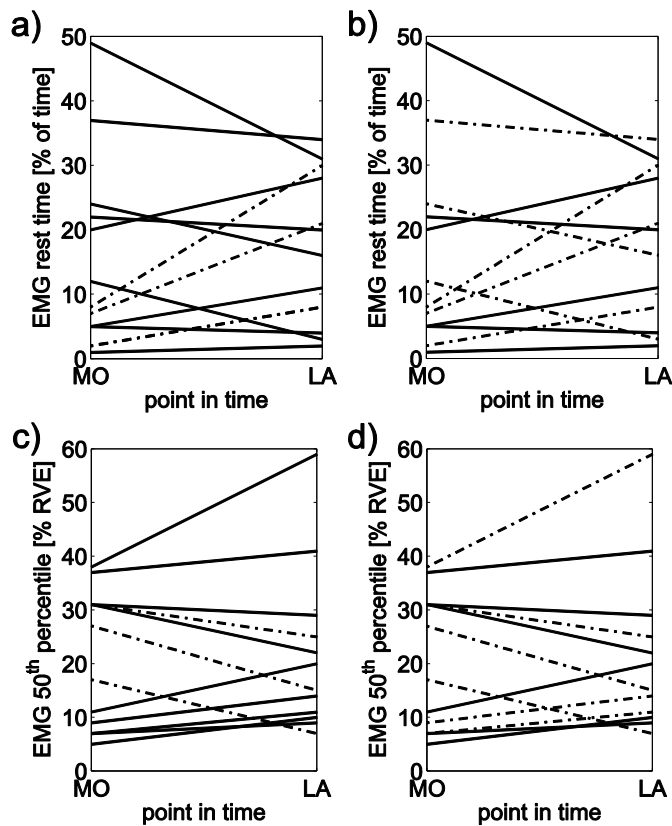


Figure 7.3: Values and progression from the morning to the late afternoon for the single subjects for the trapezius muscle rest time and the 50th percentile of trapezius muscle activity. The three subjects with the most active lunch break are shown as dashed-dotted lines for the trapezius muscle rest time in a) and for the 50th percentile of trapezius muscle activity in c). The six subjects with the most active lunch break are shown dashed-dotted lines for the trapezius muscle rest time in b) and for the 50th percentile of trapezius muscle activity in d).

Correlations between trapezius muscle activity and arm acceleration

Correlations between all parameters of the trapezius muscle activity and the arm acceleration were calculated in the morning and in the late afternoon. No correlations were found in the late afternoon. In the morning, two single significant correlations were found between the 50th percentile of trapezius muscle activity and the rest time of the arm acceleration ($R=-0.69$) and between the 90th percentile of trapezius muscle activity and the rest time of the arm acceleration ($R=-0.68$).

7.4 Discussion

The activity of the trapezius muscle, the heart rate and the arm acceleration of office employees at the beginning and the end of a workday were analyzed. In none of the parameters a significant difference between the morning and the late afternoon was found. Significant

differences between the subjects were found for trapezius muscle rest time, the parameters of trapezius muscle activity and the heart rate. They were not significant for the parameters of the arm acceleration. It seemed that higher arm acceleration at lunch time can have a positive influence on trapezius muscle activity.

To compare the beginning and the end of the workday, we chose one hour in the morning and one hour in the late afternoon (s. Figure 7.1). To double-check the robustness of this analysis, the same procedure was done with the data from two hours in the morning and two hours in the afternoon. As we got similar results, we decided to only use the data of one hour.

In the rest time of the trapezius muscle, no significant progression from the morning to the late afternoon was found. The lack of an overall progression could be due to different progressions in the different subjects (s. Figure 7.2a). Similar results were obtained for the 10th, the 50th and the 90th percentile of trapezius muscle activity. The progression from the morning to the late afternoon was not significant, but varied between the subjects. As shown by Kimura et al. (2007) during predefined tasks of office work, muscle fatigue can happen and can lead to some change in the EMG like an increase of the amplitude. This was not found in our dataset. However a review showed that fatigue often could only be detected if the activity level was at least 15 % of the maximal voluntary contraction (MVC) (de Looze et al., 2009). As shown by an own study (Läubli, 2013), 100% RVE approximately corresponds to 17% MVC. The median of the trapezius muscle activity in this study over all subjects and both points in time was 21% RVE \pm 14% RVE. This shows that the activity levels were far below the 15% MVC so that eventual muscular fatigue may not be depicted by conventional surface EMG methods.

In trapezius muscle rest time and all parameters of the trapezius muscle activity, the differences between the subjects were significant. Also high amounts of explained variability through differences between subjects were found. Even though we are aware that the used statistical method could lead to an overestimation of the between-subject effect, substantial differences between the subjects seems to exist. Other authors already found substantial differences between subjects during computer work in controlled laboratory tasks. Westgaard and Bjorklund (1987) showed that subjects reacted with strongly differing levels of activity of the trapezius muscle on standardized laboratory experiments with identical movements. Similarly, Zennaro et al. (2003) found big differences in the trapezius muscle activity between the subjects in a 30 min task on the computer. With this study, we were able to show the same effect in a field experiment. Considering the findings of Hagg and Astrom (1997), who showed that secretaries with more trapezius muscle rest time had less neck pain, this variability

between the subjects could be of high relevance. We hypothesize that the differences between the subjects could be due to a kind of a personal factor, which eventually may be linked to a specific trait of character. So we hypothesize that a kind of “tense persons” exist. This effect seemed to be the biggest in the median activity of the trapezius muscle. It is generally known that the strain is different in different occupational tasks. If the strain is more equal in the different subjects, the more likely it is that the person has an influence on the muscle activity. This is the case in our study, where all the subjects were employed as office workers. As confirmed by literature (Richter et al., 2009), different tasks of an office employee did not show relevant differences in the trapezius muscle activity and therefore, the differences found should be due to something inside the subjects. The result that the rest time and the activity of the trapezius muscle are influenced by some personal factors is additionally confirmed by the findings of twin studies. Two different twin studies (Fejer et al., 2006a; Stahl et al., 2013) concluded that especially in younger ages, the prevalence of neck pain is strongly influenced by genetic factors. Nevertheless, the differences between the subjects in the EMG parameters, especially in the rest time were higher than expected. The mechanisms that may explain the observed personal differences were not further studied. Therefore, besides the explanation through personal traits that are associated with specific muscular activation patterns also other mechanisms have to be considered. Such risk factors could lie in the fact that the habitual head position is different, or that the ergonomic situation was not optimal in some subjects. Another possibility is the visual strain, a parameter that was discussed by Aaras et al. (2005). Therefore, future studies should include such measures.

The rest time, the 10th, and the 90th percentile of arm acceleration showed no difference between the morning and the late afternoon. No significant differences between the subjects were found. An interpretation could be that the amount of arm acceleration during office work is due to the tasks and not influenced by the subject. Nevertheless, in the rest time and the 10th percentile of arm acceleration a rather high amount of the variance could be explained through differences between the subjects and as shown in Figure 7.1, the absolute values and the progression from the morning to the late afternoon clearly varied between the subjects. As the acceleration did not change in the progression of the day, neither the work tasks nor the behavior of the subjects seemed to change. The missing difference between the subjects again supports the similarity of the work tasks. As nearly no correlations between parameters of trapezius muscle activity and parameters of arm acceleration were found, it seems that the arm acceleration did hardly influence the activity of the trapezius muscle. Yet a tendency was found that a complete motionless arm could help to reduce the trapezius muscle activity. Stronger dependencies between the amount of arm acceleration and the activity of the trapezius

muscle were found in literature. Mork and Westgaard (2007) reported that 20% of the intra-individual variation of the trapezius muscle activity was explained by the arm movements, but no correlations were found to the arm elevation.

The 50th percentile of the heart rate showed no change between morning and late afternoon. Also for the single subjects (see Figure 7.2h) nearly no progression was visible. The heart rate seemed to be stable over the workday but significantly different between the subjects. As the heart rate can be altered by physical (Grandjean, 1991) as well as psychological loads (Fisher and Newman, 2013), it seems that the physical and the psychological loads were rather stable over the workday.

Due to the small sample size, it was not feasible to run an analysis of variance for the influence of the arm acceleration during the lunch break on the progression of the EMG parameters. Considering Figure 7.3a and 7.3c, it is visually striking that the three subjects with the highest arm acceleration during lunch break showed in the late afternoon a clearly reduced trapezius muscle activity and a higher trapezius muscle rest time. If the arm acceleration is interpreted as a measure of the physical activity, a tendency to an augmented trapezius muscle rest time and a lower trapezius muscle activity after a lunch break with a higher level of physical activity can be assumed. We think this is an interesting phenomenon and should be further examined. Especially as we conclude from the literature that active pauses could augment the variability of the muscle activation (Samani et al., 2009; Westgaard and Bjorklund, 1987) and therefore they could be able to interrupt the activity over a long duration of single motor units that was shown by Kitahara et al. (2000) during computer entry tasks and by Zennaro et al. (2003) during work and even during passive breaks.

Furthermore, in office work it seems to be sufficient to measure trapezius muscle activity over a one hour period in the morning and in the afternoon instead of continuously during the workday.

Limitations

A clear limitation of this study is the small number of subjects. Nineteen subjects were measured. This number of subjects would have allowed a more refined analysis of the results, including an analysis of variance. Due to a high variation in the values of the reference contractions and the resulting normalization values (RVE), it was necessary to exclude six subjects. Another subject had to be excluded because of an error of the measuring device. With the remaining twelve subjects, a bias because of a deviation of the normal distribution was

probable. Therefore we only used simple, non-parametric procedures. Especially for the analysis of the influence of the arm acceleration during the lunch break, the sample size was too small to obtain clear results. Furthermore, it has to be mentioned, that the analysis relies on the measurement of one workday. As shown by Delisle et al. (2009) the best reliability is reached when two days are measured and averaged. Therefore it is possible, that the influence of the subject could be overestimated in this study. As in all studies using surface EMG, some caution in the interpretation of the results is needed. Using this technique it is not possible to show results for single motor units (Farina et al., 2006).

Conclusions

It was found that in working environments with similar loads for all subjects, as office work in the case of this study, the rest time and the activity of the trapezius muscle can show considerable differences between subjects. A possible explanation for this variation could be a personal factor of the subjects.

Acknowledgement

We thank Gabriela Helfenberger for the conduction of all the measurements during her master thesis.

8. General discussion and conclusion

8.1 General Discussion

The high prevalence of neck pain (Picavet and Schouten, 2003), the burden for the affected persons (Scuffham et al., 2010), and the resulting costs (Borghouts et al., 1999) are reasons to elucidate the only partly known mechanism of the development of neck pain. This dissertation makes an important contribution as it highlights the importance of the work organization and the characteristics of the subject for the rest time and activity of trapezius muscle. Furthermore, a model explaining the mechanism of the development of work-related neck pain, starting with the temporal and spatial distribution of trapezius muscle activity is proposed. Explaining the mechanism of the development of neck pain, this model connects trapezius muscle rest time and activity to neck pain.

This discussion shows first the main achievements of the six presented manuscripts, shows afterwards the methodological achievements of this dissertation and focus on the implications of these findings for the occupational groups of the nurses and the office employees. Then the new model that could be developed based on the achievements of the conducted studies is discussed and finally the impact of the presented findings for the prevention of neck pain is elucidated.

Work organization

The two conducted studies in nurses (Chapter 4 und 5) focused on the work organization and its impact on trapezius muscle rest time and activity. It was found that Japanese nurses showed less trapezius muscle rest time than Swiss nurses. Furthermore, in Swiss nurses trapezius muscle activity was higher during day shift than night shift and in Japanese nurses higher during night shift than day shift. The most possible explanation for this is that the organization of the work is critical for trapezius muscle rest time and activity. So this dissertation highlights the importance of the work organization for trapezius muscle rest time and activity and through the mechanisms proposed in the developed model also for the development of neck pain. This is one of the main findings, as it can be implemented in prevention. An organizational aspect could for example be the amount of staff working in a shift. As only shift workers (working day shifts and night shifts) were tested, it is not possible to say that less trapezius muscle rest time happened because of the shift work. The Japanese nurses showed slightly less trapezius muscle rest time and more trapezius muscle activity during night shift than during day shift. However, it is difficult to say if this is caused by the night shift itself or by a high work load during night shift. Additionally, Nicoletti et al. (2014b) showed in Swiss nurses the same subjective burden during day and night shift, even when the night shift was objectively less

burdening as result of a smaller workload, more trapezius muscle rest time and less trapezius muscle activity. It is assumed that other factors of work organization could influence the rest time and the activity of trapezius muscle, too, such as long working hours or overtime. The review of Caruso and Waters (2008) analyzed different factors of the work organization in the healthcare sector. The results were inconsistent for the effect of mandatory overtime and extended work shifts. The review reported one study analyzing the time interval between two shifts (Trinkoff et al., 2006). This study found that less than 10 hours off between two shifts increased the risk for neck pain. This may have been the case in the investigated Japanese nurses, too. The time off before the measured night shift was indeed shorter than 10 hours. In my opinion, the different parameters of work organization should be further investigated to clarify the inconsistent findings. First evidence that the work organization could be critical for trapezius muscle rest time and activity was found in own studies and evidence for a correlation of work organization to neck pain was reported by other authors (Caruso and Waters, 2008). Considering prevention, the work organization is a parameter that can easily be changed. However, it may be difficult to convince the superiors and those responsible to redesign the work organization and/or eventually to employ more staff. Therefore, data showing the importance and also the benefits of organizational changes have to be obtained.

Personal characteristics

The two studies in office employees (Chapter 6 and 7) showed a correlation of trapezius muscle activity between office work and leisure time and a tendency to a correlation in trapezius muscle rest time. No correlation in arm acceleration between work and leisure time was found. Furthermore, significant differences of trapezius muscle rest time and activity between the subjects during computer work were found, while no difference in arm acceleration was found. These findings were interpreted to be due to something inside the subject that we called personal characteristics and that is hypothesized to be an issue of the sensory-motor system of the subject. It should be a factor that “decides” whether the trapezius muscle reacts with activity on a certain situation or not. Thus it could define a “tense person”, a person that reacts with muscle tension on stress situations. Thus it may be seen as a character trait or in some persons during extremely burdening stages of life also as a state or a temporal pattern of reaction. This personal characteristic is one of the main findings of this dissertation. In combination with the proposed model of neck pain development, it could be one of the missing links in the explanation of the high prevalence of neck pain in occupations with rather low burdens. Additionally, it may explain the findings of the study of Zennaro et al. (2003) that found a large difference in the trapezius muscle rest time between the subjects in a tapping task. As trapezius muscle was almost completely relaxed in some subjects, a tapping task on an

adjusted computer workstation seems not to require an activity of the trapezius muscle. Nevertheless, some subjects showed an activity of trapezius muscle and some even a nearly continuous activity of single motor units. However, the conducted studies did not aim at identifying these subject-related factors and besides arm acceleration further information on subjects' characteristics were not collected. Nevertheless, in office work, even in field studies, a rather high standardization of the work is expected, justifying this interpretation. The influence of these personal characteristics has to be further analyzed and confirmed in other studies. It is certainly important enough to be included in future studies about neck pain. Regarding prevention of neck pain, the personal characteristics seems extremely hard to change and therefore not the best mean for prevention. However, if its exact nature and how it could be bypassed can be identified, it may be a good approach for secondary or tertiary prevention.

Circadian rhythm of heart rate

The heart rate was measured in all studies as a measure for physical (Grandjean, 1991) and psychosocial (Fisher and Newman, 2013) loads and for artifact removal from the EMG. During shift work including night shifts, heart rate is particularly important. Heart rate follows a circadian rhythm and it is known that by disrupting this circadian rhythm, shift work is associated with different diseases such as breast cancer (Bonde et al., 2012). Especially the exposure to light during night is known to be disruptive for the circadian rhythm (Bonde et al., 2012). As it is known that a high level of physical activity during the biological night can force a change of the circadian rhythm (e.g. during travelling over time zones) (Atkinson et al., 2007), a high level of workload during night shifts may lead to an additional disruption of the circadian rhythm and therefore to higher risks of diseases. In Chapter 5, these effects were analyzed in the dataset of Swiss and Japanese nurses during day and night shift. The circadian rhythm of heart rate was found to be largely preserved during shift work. Interestingly even if the average physical activity during night shift was high, the level of heart rate remained lower compared to the day shift. This phenomenon was observed in Japanese nurses as in this sample the workload during night shift was as high as during day shift. It indicates that the human body seems not to be able to react with the usual physiological reaction to a high workload during night. This raises the question if a high workload during night will lead to negative health effects. To the best of our knowledge, the effect of a high workload in combination with a low heart rate during night was shown for the first time in this dissertation. Considering the negative health effects related to a disruption of the circadian rhythm, this finding seems to be of high importance and a lower workload during night shifts is proposed. However, the study

was not designed to analyze the circadian rhythm of heart rate. Therefore, further research in this field is strongly needed.

Trapezius muscle activity during sleep

In the fifth study (Chapter 6) trapezius muscle activity during sleep was analyzed. It was found that all examined subjects were able to relax trapezius muscle during nearly the full sleeping period. So trapezius muscle activity during sleep appeared to be uncritical in subjects without chronic neck pain. The hypothesis formulated during the progression of my doctoral studies, that some subjects could show prolonged trapezius muscle activity during sleep could not be confirmed. However, as no follow up examination was done, we do not know if the evaluated subjects will develop neck pain. If, per chance, all the evaluated subjects will not develop neck pain, then it is still possible that prolonged trapezius muscle activity during night can be a precursor for neck pain. Furthermore, trapezius muscle activity during sleep in subjects suffering from chronic neck pain still has to be explored. The one study existing (Mork and Westgaard, 2004) showed a rather high amount of time with trapezius muscle activity during sleep in pain-afflicted subjects. However, this study should be repeated because some methodological concerns could be raised.

This study was only the second study measuring trapezius muscle rest time and activity over nearly 24 hours. As discussed in the introduction, studies with long measurement duration are rare. In our opinion they are very important to gain an overall picture of the trapezius muscle rest time and activity. This dissertation made a step in this direction.

Progression of trapezius muscle rest time and activity during an office workday

In the sixth study (Chapter 7) the progression of trapezius muscle rest time and activity during a full workday in office employees was evaluated. None of the evaluated parameters did change in the progression of the workday. Changes in the EMG signal due to fatigue, as an increase in the amplitude that was described by Kimura et al. (2007), were not found. This can be due to the fact that no fatigue happened or that the used methods were not able to detect the fatigue. In the model of the development of neck pain, we propose that low-frequency fatigue could be a missing link in the development of neck pain. Further research is strongly needed and already planned (see the intervention study in the outlook chapter).

Level of physical activity during lunch break

In the sixth study (Chapter 7) the influence of a higher level of arm acceleration during lunch break on trapezius muscle rest time and activity in the afternoon was evaluated. Arm acceleration was interpreted to be a measure of general physical activity. A tendency of more trapezius muscle rest time and less trapezius muscle activity in the late afternoon after a higher level of physical activity during lunch break was found. Further investigations are strongly needed. If this tendency could be confirmed and if trapezius muscle rest time and activity could be linked to neck pain as proposed in the developed model, physical activity could be a good mean for prevention of neck pain. It has to be mentioned that physical activity was only assessed by the acceleration of the dominant upper arm, limiting the interpretation. Further studies of physical activity may use more sensors.

Methodological aspects

The first manuscript of this dissertation (Chapter 2) showed a limitation of the method generally used in this field of research. It was found that through the normalization a slight falsification of data is possible as the normalization value (RVE) was found to be correlated with the measured values. This dissertation provides a good solution to avoid this limitation before the start of the measurements as well as an acceptable solution with some limitations to apply after the measurements are conducted. So the normalization procedure ought to be improved and the possible hazards are pointed out. To the best of my knowledge it was never tested before if the normalized EMG values and the normalization value (RVE) correlate. However, we identified a method that enables the researcher to scrutinize already recorded data, but it could result in a high amount of subjects that have to be excluded. For future studies it would be desirable if the researchers place the electrodes in a way that RVE values in the proposed range will be reached. After the publication of this manuscript studies with concentration on workloads in nurses and office employees were conducted. These studies showed that in some subjects, especially in female subjects, it can be difficult to reach normalization values that are equal to 55 μ V or higher. In some subjects the electrode position was changed several times, but the lower limit of 55 μ V was not achieved. Further research in this area is strongly needed, as the higher prevalence of neck pain in women than in men (Baran et al., 2011; de Zwart et al., 2001) shows that such studies seem to be especially important in women. Furthermore, Steinhilber and Rieger (2013) reported that the conduction of the RVE and MVE measurement procedures also strongly varied between the authors, which may again result in an undesired variability. The second methodological study ensured that no error arises if the EMG of trapezius muscle is measured during sleep without recording

the sleep stages. It was found that in healthy subjects the sleep stages did nearly not influence the activity of trapezius muscle measured during a full night and that the expensive and maybe for the subject disturbing equipment of the polysomnography is not needed.

Implications for the nursing profession

Considering the studies in Chapter 4 and 5, the nursing profession was generally found to be extremely burdening. A high workload and accordingly a high heart rate were found. Additionally, in Japanese nurses the temporal distribution of the workload was unfavorable as it was as higher in night shifts as in day shifts. Furthermore, the shift system seems to be better in the evaluated Swiss hospitals than in the Japanese one. So Japanese nurses only had seven hours off before the start of the night shift. If trapezius muscle rest time is compared with the existing studies (Holte and Westgaard, 2002; Westgaard et al., 2001), it is slightly smaller in our study. This is especially the case in the measured Japanese nurses. Based on this dissertation, the conclusion can be drawn that it is necessary to rethink the work organization in this profession and to reduce the burdens. This may be achieved by using more staff and reallocating the working hours and the shift rotation.

Implications for office employees

Considering the studies about office work in Chapter 6 and 7, also in this occupational group some changes would be appreciated. The 90th percentile of arm acceleration was found to be clearly higher during leisure time than during work. This raises the question, if office work limits the possible movements and maybe prevents some naturally performed movements. As static muscle load is proposed to be an important factor in the development of neck pain (Farina et al., 2008), movements seems to be important and should not be constrained during office work. Therefore, after conducting this dissertation, it can be recommended that a higher level of movements should be possible. This could be reached by regular short breaks or by a change of the organization of some work tasks so that the employees regularly have to get up and move. An example could be placing the printer, books, or folders far from reaching distance. Another benefit of additional movements would be a reduction of the health risks triggered by the uninterrupted sitting such as cardiovascular diseases (Gardiner et al., 2011; Saidj et al., 2013) or an increase of mortality (Dunstan et al., 2011; Katzmarzyk et al., 2009). If the recorded trapezius muscle rest time is compared with the two existing studies (Holte and Westgaard, 2002; Nordander et al., 2000), the values of our study are between the ones of the two other studies.

A proposed model of the development of neck pain

After reviewing the literature, conducting these studies, and analyzing the described parameters it became clear that further research is needed and that introducing a model of the development of neck pain was required. To determine a continuous activity of certain parts of the trapezius muscle two parameters of the EMG are taken into account: 1) the trapezius muscle rest time (temporal aspect); and 2) the spatial distribution of muscle activity (spatial aspect). The model allows describing which factors acting together can result in overload and finally can promote the development of neck pain. For some of the proposed parameters it is still unknown if they are connected to the spatial distribution of muscle activity and the list of parameters may not be complete as well. However, if the proposed model can be confirmed, it will show for the first time a clear pathway describing the connection of EMG measurements, trapezius muscle rest time and activity, and neck pain. Furthermore, it explains the influence of (work-related) parameters on this process. Based on this model, intervention studies evaluating the influence of known risk factors on physiological parameters can be conducted. The first intervention study, evaluating low-frequency fatigue of trapezius muscle and the influence of additional, short rest breaks during the workday, is already granted. This model will allow us to predict if in a given situation a constraint activity of the motor unit pool will happen. A limitation that has to be mentioned is that it is not on the first sight visible if the parameter personal state and/or trait anxiety is present in a person or not. The two parameters work organization and personal characteristics that are proposed to be able to explain the development of neck pain, so to decide if a constraint spatio-temporal activity of the motor unit pool will be preserved over a longer time, could have been shown to be related to trapezius muscle rest time in this dissertation. If the work organization or the personal state and/or trait anxiety prevents an interruption of the constraint spatio-temporal activity of trapezius muscle, discomfort or acute neck pain will occur. The development of this acute pain is proposed to be the consequence of low-frequency fatigue of trapezius muscle. This part of the model still has to be proven (s. Chapter 9). After the onset of discomfort or acute pain, some parameters were suggested to be responsible to decide if the muscle can adapt to the workload or if chronic neck pain will develop. Such parameters are leisure time behavior, sleep muscle relaxation, genetics and personal state and/or trait anxiety, whereby the first three are proposed to interact. The influence of genetics on the development of neck pain was already proven by literature (Fejer et al., 2006a; Stahl et al., 2013). It even may be necessary to mention genetics as one of the factors that can cause a constraint spatio-temporal activity of the motor unit pool, so to mention it as one of the factors at the beginning of the model. The influence of a personal characteristic could be shown to be highly relevant. Sleep time behavior was shown as not relevant, because the studied subjects were all able to relax trapezius muscle during the largest

part of the night. For the parameter of the leisure time behavior, until now, only the level of physical activity was observed. As only tendencies were found, further research is needed. A limitation that has to be mentioned is that the subjects of the conducted studies were not in the state of acute pain. We excluded subjects with chronic neck pain, but all subjects without chronic neck pain were included. Therefore, it may be that all the subjects in our sample will not develop neck pain. Furthermore, the results are only valid for subjects without chronic neck pain. It may for example be that subjects with chronic neck pain show trapezius muscle activity during sleep. After an adaptation/recovery or a maladaptation (chronic neck pain) happened, the model stops. It would be possible to continue the model with rehabilitation after the development of chronic neck pain, where the mechanisms as well as the relevant parameters are mostly unknown, too.

Impact of the dissertation on neck pain prevention

In the introduction it was mentioned that only a clear model explaining the development of neck pain and knowledge of the parameters that could lead to neck pain will allow for a purposeful prevention. Even though the main focus of this dissertation lays on trapezius muscle rest time and activity, based on the proposed model, some conclusions about the prevention of neck pain can be drawn. This dissertation showed some parameters that are related to trapezius muscle rest time and activity and through the proposed model also to neck pain. Regarding the prevention of neck pain, the main achievement of this dissertation is that a first model explaining the development of neck pain and the related parameters was developed. At the moment, however, the model is not ready to be used in prevention, because important factors still have to be proven (first of all the development of long lasting fatigue). But based on the conducted studies, first recommendations for prevention can be given. The most important one is the significance of the work organization. Especially in jobs with high organizational loads (e.g. nursing), but also in other jobs, following the basic rules of work organization seems to have a bigger impact than assumed until now. The personal characteristic of a subject seems to have a bigger impact than assumed, too. However we are not yet clear about the best way to implement this result in prevention. The only thing we can conclude right now is that prevention of neck pain does not seem to be as important for every employee. Rather it seems that some employees are predisposed to develop neck pain. These employees should be involved in secondary prevention.

8.2. General Conclusion

In conclusion, trapezius muscle rest time and activity is not only related to physical and psychosocial parameters, but more than expected additionally to parameters of work organization and personal characteristics. Combining this information with the proposed model, prevention of work-related neck pain should not only focus on physical and psychosocial factors, but increasingly on organizational factors, too. Especially a high workload during night shifts seemed to be more harmful than expected and we strongly encourage rethinking the organization of shift work. It is not yet clear how the knowledge about the influence of personal characteristics could be implemented in the prevention of neck pain.

9. Outlook

First of all, the proposed model of the development of neck pain has to be fully verified. Especially the part including the low-frequency fatigue has to be verified. It is proposed to be the crucial mechanism on muscular level in the development of acute neck pain. After the first version of this model was developed, a lab study was granted by the Swiss National Science Foundation (SNF). This intervention study is already in planning and includes two measurement days whereby the second measurement day includes additional short breaks. As it is proposed for all following studies, beside the temporal activity, the spatial distribution of trapezius muscle activity will be analyzed, too. After the model is fully verified, it could also be extended to rehabilitation of chronic neck pain. To be able to extend the model to rehabilitation, studies with patients suffering from chronic neck pain are strongly needed. The influence of different parameters during work as well as the influence of trapezius muscle rest time and activity during leisure time and sleep on neck pain should be reanalyzed in patients. After these factors are clarified and a first understanding of the mechanism for developing neck pain is given, cost-intensive long-term studies will be justified.

Furthermore, it is crucial that the high social and financial impact of neck pain will be recognized by companies and the government and that the elaborated strategies for preventing neck pain can be applied.

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11. Curriculum Vitae

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Education

2012-2015	Doctoral studies at ETH Zurich, Department of Health Science and Technology, Sensory-Motor Systems Lab
2012-2014	Master of Advanced Studies (MAS) in Work and Health with the focus on Ergonomics, ETH Zurich and IST Lausanne
2010-2012	Master in Human Movement Science at ETH Zurich with the focus Sports Physiology
2007-2010	Bachelor in Human Movement Science at ETH Zurich
2003-2007	Matura degree at Kantonsschule Solothurn

Work experience

2010-2011	ETH Zurich, internship in the group Ergonomics and Environment, Department of Management, Technology and Economics (MTEC)
2009	ETH Zurich and city of Zurich, collaboration in the project „Wir bewegen Zürich“
2008-2011	Adidas, brand coach and member of the specialist group Running
2003-2012	City of Grenchen, lifesaver in the indoor swimming pool

Awards and Scholarships

2011,2012,2014	Best presentation award (3 rd place) at the Symposium „Arbeitsmedizin und Arbeitswissenschaft für Nachwuchswissenschaftler“
2010-2012	Member of the „Excellence Scholarship & Opportunity Programme“ of ETH Zurich

Publications

Nicoletti, C., Läubli, T., 2013. Normalization of trapezius muscle EMG with submaximal reference contractions: Difficulties and solution approaches Zbl Arbeitsmed 63, 250–253. (main part of the article in German: Normalisierung der EMG-Aktivität des m. Trapezius mithilfe submaximaler Referenzkontraktionen: Schwierigkeiten und Lösungsansätze.)

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