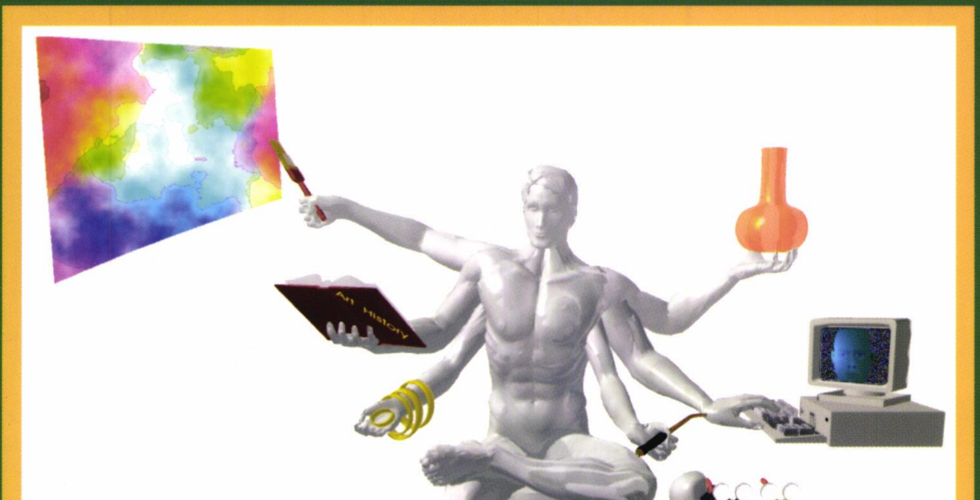
Upper extremity load in low-intensity tasks



Bart Visser

IFKB

Upper extremity load in low-intensity tasks

Bart Visser

The work presented in this thesis was carried out at the Institute for Fundamental and Clinical Human Movement Sciences, Faculty of Human Movement Sciences, Vrije Universiteit, Amsterdam, The Netherlands in collaboration with Body@Work, Research Center Physical Activity, Work and Health, TNO VUmc, Amsterdam, The Netherlands

ISBN: 90-9018422-8
NUGI: 744

Cover design: Liesbeth Groenesteijn
Cover image: "So Much To Do", © David Kim Lindaberry
Printer: PrintPartners Ipskamp B.V. Enschede

Printing of this thesis was financially supported by:
Stichting 'Anna fonds' Leiden

VRIJE UNIVERSITEIT

Upper extremity load in low-intensity tasks

ACADEMISCH PROEFSCHRIFT

ter verkrijging van de graad van doctor aan
de Vrije Universiteit Amsterdam,
op gezag van de rector magnificus
prof.dr. T. Sminia,
in het openbaar te verdedigen
ten overstaan van de promotiecommissie
van de faculteit der Bewegingswetenschappen
op donderdag 7 oktober 2004 om 15.45 uur
in het auditorium van de universiteit,
De Boelelaan 1105

door

Bart Visser

geboren te Amsterdam

promotor:	prof.dr. J.H. van Dieën
copromotoren:	dr. M.P. de Looze
	dr. H.E.J. Veeger

Contents

Chapter 1

Introduction

1.1 Introduction

Chronic pain and discomfort in muscles, tendons and joints constitute a health problem of great magnitude in the industrialized world. Musculoskeletal symptoms, although not life-threatening, can be very disabling and affect work participation, social activities, and financial income. The number of people affected is enormous and so is the negative impact on society. Mainly affected body regions are the low back and the upper extremity (neck, shoulder, arm and hand). None of the common musculoskeletal disorders is uniquely caused by work exposures; they are what the World Health Organization has defined as 'work related' diseases (WHO 1985). Work related diseases might be partially caused by adverse working conditions. They may be aggravated, accelerated, or exacerbated by workplace exposures, and they may impair working capacity. Personal characteristics and other environmental and socio-cultural factors usually play a role as risk factors in work-related diseases (WHO 1985).

Comprehensive reviews of the epidemiology on work related upper extremity disorders have shown strong and consistent associations between occupational exposures and upper extremity musculoskeletal symptoms (Armstrong et al. 1993; Sommerich et al. 1993; Hagberg et al. 1995; Bernard 1997; Buckle and Devereux 1999; Malchaire et al. 2001; National Research Council and the Institute of Medicine 2001; Sluiter et al. 2001; Bongers et al. 2002; Punnett and Gold 2003). These reviews also address the difficulties in case definition, interpretation of cross sectional data, and interaction of exposures. Although these reviews show a wide range of prevalence rates (20% - 45%) for work related upper extremity musculoskeletal disorders, it is clear that even the lower rates underline the gravity of the problem.

There is a range of terms used to indicate work related upper extremity musculoskeletal disorders (WRUEMD's), among them are Repetitive Strain Injuries (RSI), Cumulative Trauma Disorders (CTD), Occupational overuse syndrome and Cervico-brachial disorders. WRUEMD's include a heterogeneous group of specific and non-specific symptoms.

The awareness of work relatedness in the development of such complaints was already exemplified in the work of Bernardino Ramazzini, entitled: 'De morbis artificum diatriba (Diseases of Workers)', published in 1713 (Ramazzini 1964). It is striking to read how close his descriptions of 'maladies that afflict the clerks' (Box 1) match definitions of WRUEMD's proposed in the last decades.

The maladies that afflict the clerks arise from three causes: First, constant sitting, secondly the incessant movement of the hand and always in the same direction, thirdly the strain on the mind from the effort not to disfigure the books by errors or cause loss to their employers when they add, subtract, or do other sums in arithmetic. Incessant driving of the pen over paper causes intense fatigue of the hand and the whole arm because of the continuous and almost tonic strain on the muscles and tendons, which in course of time results in failure of power in the right hand. From the Latin text of 1713, translation by Wilmer Cave Wright, (Ramazzini 1964).

Box 1

Ramazzini did not only recognize the possible pathogenic consequences of low-intensity work, but he also realized that both physical and psychosocial factors are involved in the etiology. In spite of the impressive perspicacious contributions of Ramazzini to the understanding of upper extremity musculoskeletal disorders, a lot of questions are still to be answered. There are still huge gaps in our knowledge concerning exposure interactions, dose-response relationships, and especially the pathological processes determining onset and progression of these disorders. With the studies described in this thesis a modest attempt is made to contribute[1] to the filling of these gaps.

The general goal of the thesis is to increase insight in the role of work requirements during low intensity work, including computer work, in the pathogenesis of upper extremity musculoskeletal disorders.

Outline of the thesis (Figure 1.1)

A review of the literature on the pathophysiology of work related upper extremity ***muscle*** disorders is described in chapter two. The third chapter reviews the literature on the contribution of task-related constraints to the development of work-related myalgia. The review suggests that arm support, task precision, and mental pressure probably determine whether sustained muscle activity occurs during low intensity work. Chapter four addresses the effect of arm support during computer work on shoulder muscle activity. The subsequent

[1] 'Every little helps', said Chen Wei Li and watered in the Yellow Sea (*anonymous*)

chapters five and six focus on additional expected determinants of shoulder muscle activity: precision and mental pressure. Chapter five adresses the effects of force precision demands during a low intensity pinching task on muscle activation and load sharing between the fingers. In chapter six, the effect of positioning precision is studied. This chapter describes the effects of precision demands and mental pressure on muscle activation and hand forces in computer mouse tasks. Chapter seven focuses on the consequence of neck-shoulder muscle activity; it describes a study on the effect of static loading of the neck-shoulder region on the blood flow in the arm. In the epilogue of the thesis the results are discussed. Special attention is given to the relevance of the results for the practitioner.

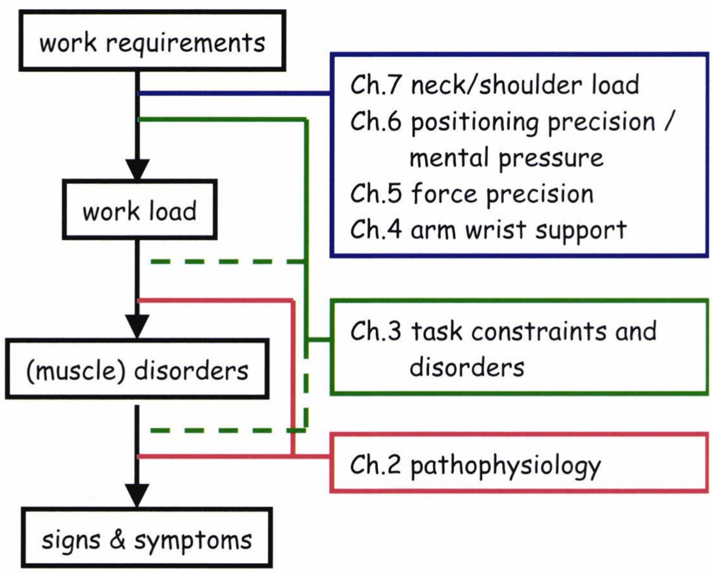


Figure 1.1 *The position of the chapters (Ch. 2-6) within a conceptual model describing the relationship between work requirements and symptoms.*

1.2 References

Armstrong TJ, Buckle P, Fine LJ, Hagberg M, Jonsson B, Kilbom A, Kuorinka IAA, Silverstein BA, Sjogaard G, Viikara-Juntura ERA (1993) A conceptual model for work-related neck and upper-limb musculoskeletal disorders. Scandinavian Journal of Work, Environment and Health 19: 73-84

Bernard BP (1997) Musculoskeletal disorders (MSDs) and workplace factors - a critical review of epidemiologic evidence for work-related musculoskeletal disorders of the neck, upper extremity, and low back. National Institute for Occupational Safety and Health, Cincinnati, OH

Bongers PM, Kremer AM, ter Laak J (2002) Are psychosocial factors, risk factors for symptoms and signs of the shoulder, elbow, or hand/wrist?: A review of the epidemiological literature. Am J Ind Med 41: 315-342

Buckle P, Devereux J (1999) Work-related neck and upper limb musculoskeletal disorders. Office for Official Publications of the European Communities, Luxembourg

Hagberg M, Silverstein B, Wells R, Smith MJ, Hendrick HW, Carayon P, Pérusse M (1995) Work related musculoskeletal disorders. A reference book for prevention. Taylor and Francis, London

Malchaire J, Cock N, Vergracht S (2001) Review of the factors associated with musculoskeletal problems in epidemiological studies. Int Arch Occup Environ Health 74: 79-90

National Research Council and the Institute of Medicine (2001) Musculoskeletal Disorders and the Workplace: Low Back and Upper Extremities. National Academy Press, Washington, DC

Punnett L, Gold JE (2003) Work-related upper extremity disorders: epidemiologic findings and unresolved questions. In: Johansson H, Windhorst U, Djupsjöbacka M, Passatore M (eds) Chronic Work-Related Myalgia - Neuromuscular Mechanisms behind Work-Related Chronic

Muscle Pain Syndromes. Gävle University Press, Gävle, Sweden, pp 47-56

Ramazzini B (1964) De morbis artificum diatriba (1713) (Diseases of Workers - Translated by Wilmer Cave Wright). Hafner, New York

Sluiter JK, Rest KM, Frings-Dresen MHW (2001) Criteria document for evaluation of the work-relatedness of upper extremity musculoskeletal disorders. Scandinavian Journal of Work, Environment and Health 27: 1-102

Sommerich CM, McGlothlin JD, Marras WS (1993) Occupational risk factors associated with soft tissue disorders of the shoulder: a review of recent investigations in the literature. Ergonomics 36: 697-717

WHO (1985) Identification and control of work-related diseases. In. World Health Organization., Geneva

Chapter 2

Pathophysiology of Work Related Upper Extremity Muscle Disorders

Bart Visser[a,b] and Jaap H. van Dieën[a]

[a]Institute for Fundamental and Clinical Human Movement Sciences, Faculty of Human Movement Sciences, Vrije Universiteit Amsterdam, The Netherlands

[b]Body@Work, Research Center Physical Activity, Work and Health, TNO VUmc, Amsterdam, The Netherlands

Abstract

A review of the literature on the pathophysiology of work related upper extremity muscle disorders (WRUEMD's) was performed. An overview is given of clinical findings and hypotheses on the pathogenesis of WRUEMD's. The following mechanisms have been proposed in the literature: 1) intra-cellular Ca^{2+} accumulation; 2) selective recruitment and overloading of type I (Cinderella) motor units; 3a) impaired blood flow; 3b) reperfusion injury; 3c) blood vessel-nociceptor interaction; 4a) myofascial force transmission; 4b) intramuscular shear forces; 5) trigger points; and 6) impaired heat shock response. The results of the review indicate that there are multiple possible mechanisms, but none of the hypotheses forms a complete explanation and is sufficiently supported by empirical data. Overall, the literature indicates that 1) sustained muscle activity, especially of type I motor units, may be a primary cause of WRUEMD's; 2) in WRUEMD's skeletal muscle may show changes in morphology, blood flow, and muscle activity; 3); accumulation of Ca^{2+} in the sarcoplasm may be the cause of muscle cell damage; 4) It seems plausible that suboptimal blood flow plays a role in pathogenesis of WRUEMD's; 5) altered metabolite concentrations in muscles may activate type III and IV afferents contributing to a self-maintaining 'vicious circle' in which pain and muscle activity amplify each other. With respect to prevention and treatment only tentative conclusions can be drawn. The literature suggests that sustained static activity should be prevented either by introduction of breaks or by introduction of variation in muscle activation and that reduction of muscle activity seems useful as a target in therapy.

2.1 Introduction

Insight in the physiological mechanisms involved in the development and perpetuation of work related disorders is of great importance with respect to prevention, diagnosis, treatment and rehabilitation of these disorders. Work related upper extremity disorders include a heterogeneous group of specific and non-specific symptoms. Specific indicates that (1) the symptom consists of a more or less fixed combination of signs, (2) testing results in a predictable reaction and (3) it is uniquely identified and described in the clinical scientific literature. Examples of such specific disorders are epycondilitis lateralis and carpal tunnel syndrome. If a certain symptom does not match the criteria mentioned above, the symptom is called non-specific (Sluiter et al. 2001). Work related upper extremity disorders comprise soft tissue disorders of the muscles, tendons, ligaments, joints, peripheral nerves, and supporting blood vessels (Keller et al. 1998; Sluiter et al. 2001). In view of the wide range of disorders, affected tissues and symptoms, it is unlikely that a single pathophysiological mechanism can be identified. In fact there are a number of hypotheses on the physiological mechanisms behind the development of work related upper extremity disorders. The proposed mechanisms are not necessarily conflicting, but might either play independent roles possibly leading to the same symptoms, or they might play complementary or interacting roles. This paper gives an overview of possible mechanisms; the scope is limited to the pathophysiology of work related upper extremity ***muscle disorders (WRUEMD's)***. Referring to pain as one of the main symptoms, these disorders are also indicated with the term 'work related myalgia'.

All hypotheses on pathophysiological mechanisms have in common that they describe an assumed causal relationship between work requirements and the symptoms of WRUEMD's. A simple model describing this relationship is presented in Figure 2.1.

Of course the model presents a strong simplification of the complex processes involved in the pathophysiology. This simplification was however, made on purpose , since added detail to a model like this, would quickly refer to, or be based on, a particular theory on the pathophysiology of WRUEMD's. Also the suggested linearity might be misleading, and in paragraphs 4 and 5 we will elaborate on possible circular relationships within the model. However, this simplification to a linear causal model provides a clear structure for grouping and interpreting the literature.

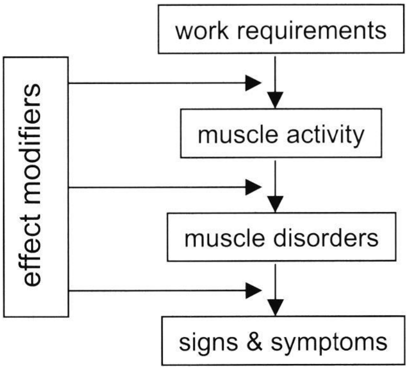


Figure 2.1 *Conceptual model of the pathophysiology of WRUEMD's.*

Comprehensive reviews of the epidemiology on WRUEMD's have shown strong and consistent associations between occupational exposures and WRUEMD's (Armstrong et al. 1993; Bongers et al. 1993; Sommerich et al. 1993; Hagberg et al. 1995; Bernard 1997; Buckle and Devereux 1999; Malchaire et al. 2001; National Research Council and the Institute of Medicine 2001; Bongers et al. 2002; Sluiter et al. 2001).

Although well-designed epidemiological studies provide important information on possible causality, no solid proof for inferences about causality can be gained from these studies. If one wants to have 'complete' insight in the pathogenesis, additional criteria need to be fulfilled. Criteria for inferences on causality address strength, temporality, consistency, and specificity of the association between presumed cause and the incidence of the disorder; dose-response association and biological plausibility. These criteria are known as the Bradford Hill criteria after the first author to clearly delineate these (Hill 1965). Biological plausibility refers to the likelihood that an association is compatible with existing knowledge on biological mechanisms. Although there are numerous examples of adequate interventions based on epidemiological observations prior to the discovery of the underlying biological mechanism, it is clear that insight in the biological mechanisms gives the best opportunities for optimizing prevention and treatment. Prevention will be most effective when pathogenetic occupational exposures can be precluded. Furthermore, understanding would provide a basis for explaining the signs and symptoms manifested by patients and a sound foundation for rational clinical care and therapy (Forde et al. 2002).

When we regard the model from a biological point of view we can see that *symptoms* are supposed to find their origin in disturbances of physiological processes in the body and *disorders of the muscle(s)*. Following the model backwards, the crucial question arise how the disorders are brought on by *muscle activity*.

Muscle activity depends on the human motor behavior, which comprises an extensive repertoire of postures, movements, and force exertion. In the model the human motor behavior is placed in the context of work and is seen as dependent on work requirements. The restriction to work does not imply that the described pathophysiology exists exclusively for work, it is obvious that non-work related muscle activity can be pathogenic as well.

Individual and contextual factors might, and are likely to, affect all described relationships. These factors are indicated in the model as *effect modifiers*. The multi-factorial nature of WRUEMD's is underlined by the influence of the effect modifiers.

2.2 clinical findings: signs and symptoms

WRUEMD's appear to mainly affect the neck and shoulder muscles, in particular the descending part of the trapezius muscle (Kuorinka and Koskinen 1979; Luopajärvi et al. 1979; Viikari-Juntura 1983). Nevertheless it is suggested that surrounding musculature like the paravertebral musculature (the splenius capitis muscle, the rectus capitis muscle, the semispinalis capitis muscle and the longissimus capitis muscle) (Sluiter et al. 2001) and the levator scapulae muscle (Kroemer 1989) can be affected as well. Also the forearm muscles, especially the extensor muscles, have been suggested to be affected quite frequently (Ranney et al. 1995).

Among the more subjective symptoms of muscle disorders are sensations of constant muscle fatigue and stiffness, accompanied by radiating pain. These symptoms, combined with objective observations of increased muscle tone during passive movements, painful locations, and/or palpable discrete, focal, hyperirritable spots (trigger points) contribute to the diagnosis of WRUEMD's (Waris 1979; Mense and Simons 2001).

To get more insight into the underlying pathology additional objective information has been gathered using a variety of techniques. Early studies focused on fatigability of the muscles. Using electromyographic fatigue indicators several authors have shown more rapid development of fatigue in the descending part of the trapezius muscle in patients with WRUEMD's compared to healthy subjects (Hagberg and Kvarnström 1984; Suurküla and Hägg 1987; Hägg and Suurküla 1991).

Bjelle et al. (1979; 1981) compared cases with acute, non-traumatic shoulder-neck pain to age- and sex-matched, paired controls. An increased blood concentration of creatine kinase (CK) was found in a substantial part of the cases.

Biopsy studies have been used to study muscle fiber abnormalities related to occupational load. Muscle fibers characterized by the presence of zones lacking activity in some mitochondrial enzymes are indicated with the term 'moth-eaten fibers'. Moth-eaten fibers have been regularly found in the trapezius muscle of myalgic patients (Henriksson et al. 1982; Lindman et al. 1991a; Lindman et al. 1991b) but also in control subjects (Lindman et al. 1991a; Larsson et al. 1992). The mitochondrial disorganization is disturbed in variable amounts of fibers in all trapezius muscles irrespective of whether they are from patients or control subjects. However, the level of disturbance is higher in symptomatic subjects (Kadi et al. 1998a; Kadi et al. 1998b).

Ten biopsy studies addressing structural and histochemical muscle fiber abnormalities related to occupational work and myalgia have been reviewed, by Hägg (2000). Hägg included studies comparing two or three groups of subjects: A) exposed with muscle complaints (myalgia), B) healthy and exposed, and C) healthy and non-exposed. Exposed refers to the fact that subjects perform work that presumably causes this type of disorders. However, descriptions of work exposure have been vague or missing in most studies. In general a higher percentage of type I fibers was found in group A compared to group C. Increased fiber cross-sectional area of both types I and II fibers were found in groups A and B compared to group C. In spite of an increased number of capillaries per fiber, capillarization per fiber cross-sectional area was decreased in group A. This effect was found to be more pronounced in the group with more severe complaints. Some studies analyzed the content of the energy substrate ATP and the activity of the enzyme Cytochrome-*c* oxidase (COX) in the biopsies. These measures, reflecting the quality of metabolic homeostasis, differed between the groups. ATP content was lower in group A compared to group C and the number of fibers with no COX activity (COX negative fibers) was higher in groups A and B compared to group C. The occurrence of Ragged red fibers (RRF's), indicating structural damage to the cell membrane and mitochondria, was similar in group A and B and markedly less frequent in group C. So RRF's reflect the exposure to work but do not differentiate between patients and healthy subjects. Within group A, a relationship between the number of RRF's and the severity of complaints was found. It was noticed the RRF's are often COX negative fibers of type I.

Studies of the normal trapezius indicate a relatively poor supply of capillaries as well as low mitochondrial volume density as compared with limb muscles (Lindman et al. 1995). Since the mitochondrial volume density is directly related to its oxidative capacity, the trapezius muscle has relatively low endurance capacity (Bengtsson 2002). The presence of moth eaten fibers and RRF's indicates uneven distribution and proliferation of mitochondria. (Accumulation of mitochondria is seen in Gomori trichrome staining, and this gives the ragged red appearance). The mitochondrial proliferation might be a compensatory phenomenon in pathophysiological states affecting oxidative metabolism. RRF's appear to be related to insufficient blood supply, and may be induced by ischemia (Heffner and Barron 1978).

Indications that micro-circulation is locally decreased around fibers in the trapezius muscle of subjects with myalgic pain have been reported (Larsson et al. 1990; Larsson et al. 1999). Furthermore, there are indications that arterial blood flow in subjects with a-specific WRUEMD's differs from that in control subjects. Pritchard et al. (1999) showed an impaired vasodilatation response of the brachial artery to forearm muscle activity in symptomatic subjects, resulting in a reduced blood flow. From the observation that a temperature reduction after typing occurs in symptomatic subjects and not in controls, Sharma et al. (1997) concluded that blood supply of the arm is diminished due to sympathetic disregulation.

One of the most puzzling aspects of the pathophysiology of WRUEMD's is the fact that complaints can occur in individuals who perform low intensity tasks, like computer work (Veiersted et al. 1990; Veiersted et al. 1993; Westgaard et al. 1996).

A commonly used indicator for muscle damage; the level of Creatine Kinase (CK) in blood is not found in these low intensity tasks (Mathiassen et al. 1993). Increasing concentrations of CK, over a period of days, have been found during work with a high WRUEMSD risk and a relatively high intensity (Hagberg et al. 1982; Malcolm et al. 1995).

Unaccustomed exercise involving stretch of active muscle at long length can cause extensive fiber damage, resulting in pain and tenderness (Edwards 1988; Faulkner and Brooks 1997; Fridén and Lieber 1997; Morgan and Allen 1999). Muscle damage has been shown to be greatest when large stretches at long sarcomere lengths occur (Talbot and Morgan 1998). Although, this type of eccentric contractions are rare in low intensity work and thus large effects are not expected, repeated eccentric contractions at short sarcomere lengths may be responsible for a part of the muscle damage (Westerblad et al. 2000). Westerblad et al. (2000) allude to repetitive, low force contractions over prolonged times with co-contracting agonist and antagonist muscles as can be seen in the forearm. But since WRUEMD's appears to mainly affect the neck and shoulder muscles where eccentric activations are less likely, this review will primarily focus on muscle damage due to concentric and isometric contractions.

Animal experimental research has clearly shown that low intensity loading can bring about muscle damage provided that the load imposed is static and of long duration. Lexell et al. (1993) performed a study to determine muscle fiber degeneration brought about by chronic low-frequency electrical stimulation. Rabbit fast-twitch muscles, tibialis anterior and extensor digitorum longus, were stimulated for 9 days with pulse trains ranging in frequency from 1.25 Hz to 10 Hz. At the higher stimulation frequencies there was a significantly higher incidence of degenerating muscle fibers. Moreover, muscles subjected to continuous stimulation showed significantly more degeneration than muscles stimulated intermittently (Figure 2.2). A recent paper (Barbe et al. 2003) described changes in motor skills and tissues of the upper extremity with regard to injury and inflammatory reactions resulting from performance of a voluntary forelimb repetitive reaching and grasping task in rats. Rats reached for food pallets at a rate of 4 reaches/min, 2 h/day, and 3 days/week for up to 8 weeks. The force level involved in the grasping task was estimated at 1% of maximal force. Besides the fact that rats were unable to maintain baseline reach rate over the weeks, significantly more macrophages were found in the reach limb and serum levels of pro-inflammatory cytokines were increased. These results demonstrate that performance of low intensity tasks can elicit responses associated with inflammation. However, in humans with WRUEMD's no acute inflammatory indicators have been found, but the presence of fibrotic tissue and anti-inflammatory mediators suggest a preceding inflammatory episode (Barr and Barbe 2004).

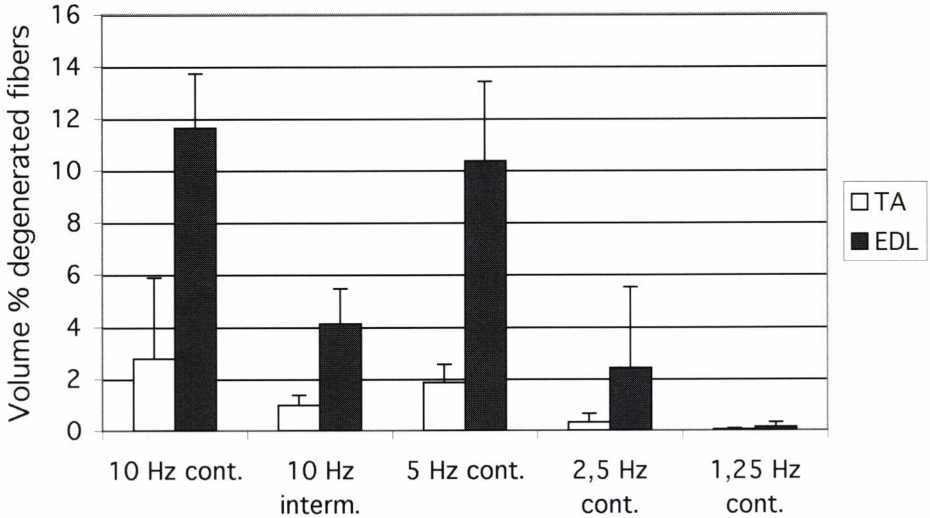


Figure 2.2 *Volume % degenerated fibers in rabbit muscles tibialis anterior (TA) and extensor digitorum longus (EDL) after several days of continuous and intermittent stimulation (data from Lexell et al. (1993)).*

2.3 Pathophysiological mechanisms

As stated in the introduction it is not likely that a single comprehensive pathophysiological mechanism exists that is responsible for the tissue damage and symptoms described. Several hypotheses on the pathogenesis have been put forward in the literature. We reviewed the literature on these hypotheses and give an overview of those mechanisms for which some experimental evidence has been provided either in the clinical literature or from animal experiments. The following mechanisms have been proposed in the literature: 1) Ca^{2+} accumulation; 2) Cinderella motor-unit loading; 3) Impaired blood flow; 3b) Reperfusion injury; 3.3c) Blood vessel-nociceptor interaction; 4a) Myofascial force transmission; 4b) Intramuscular shear forces; 5) Trigger points; 6) Impaired heat shock response.

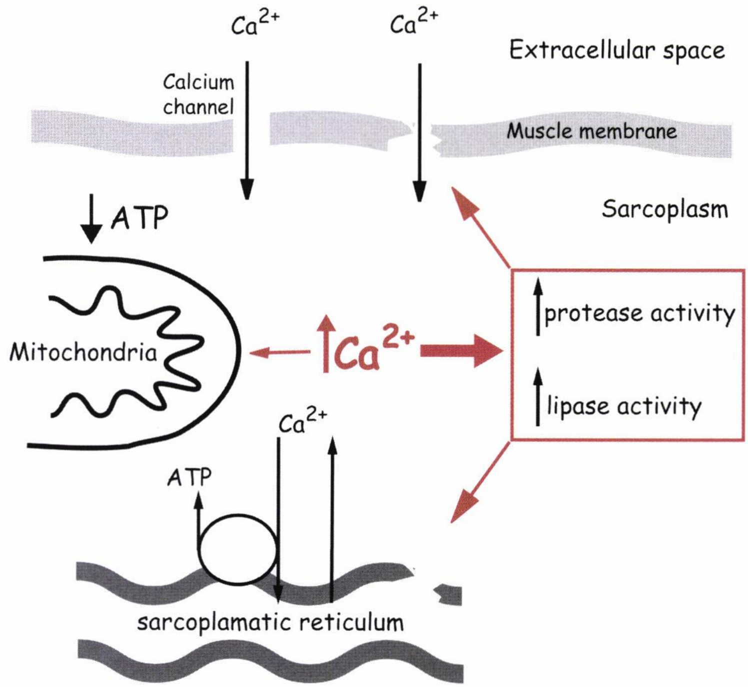


Figure 2.3 *Accumulation of Ca^{2+} might have noxious effects on the membranes of muscle fibres by stimulating protease and lipase activity. Mitochondrial damage might occur due to mitochondrial Ca^{2+} resorption. For further explanation see text.*

2.3.1 Ca^{2+} accumulation

Ca^{2+} accumulation due to sustained motor unit activity has been suggested to play a causative role in the development of muscle disorders in a recent review by Gissel (2000). Long-term low-frequency stimulation (1 Hz, 4 hours) caused an increased Ca^{2+} content in rat skeletal muscle cells. The accumulation of Ca^{2+} at this low frequency was much more pronounced in muscles mainly composed of type II fibers. However, a significant increase was also found in the soleus muscle, a muscle consisting of mainly type I fibers. Furthermore, long-term low-frequency stimulation induced leakage of the intracellular enzyme lactate dehydrogenase (LDH) from muscles containing substantial numbers of type II fibers, which indicates membrane damage. No LDH release from the soleus muscle was observed. However, at a higher stimulation frequency (10 Hz) LDH release was found also in the soleus muscle. LDH leakage may reflect degradation of membrane proteins by the Ca^{2+}-activated protease Calpain. This, in turn, leads to further influx of Ca^{2+} and further acceleration of protein breakdown (Figure 2.3). Membrane leakages are likely to result in sensations of pain in the damaged muscle. Ca^{2+} might play a central role in the development of muscle fiber injury during prolonged muscle activity (Fridén and Lieber 1997; McArdle and Jackson 1997; Gissel 2000). Furthermore Ca^{2+} accumulation may lead to mitochondrial Ca^{2+} resorption, which has been suggested to result in structural damage and energy depletion.

2.3.2 Cinderella hypothesis

The "Cinderella hypothesis" (Hägg 1991) can be seen as the most influential hypothesis for the development of muscle damage due to low intensity tasks. The considerations that led to the hypothesis did focus on the facts that the muscular force generated at sub-maximal levels engages only a fraction of the motor-units (MUs) available and that there may be a stereo-typed recruitment pattern causing an overload of specific MUs (Henneman et al. 1965; Yemm 1977).

Hennemans (1965) 'size principle' implies that small type I fibers are continuously activated during prolonged tasks. Recent experiments did confirm the presence of continuous activity of motor-units in the trapezius muscle over a wide range of occupational activities (Forsman et al. 1999; Kadefors et al. 1999; Westgaard and DeLuca 1999; Thorn et al. 2002; Zennaro et al. 2003). Similar results were found with respect to the extensor muscles in the forearm (Forsman et al. 2002). Reported firing rates of these MUs for trapezius muscle and extensor muscles are relatively high (10-20 Hz) (Westgaard and DeLuca 1999; Birch et al. 2000; Sogaard et al. 2001) and comparable with firing rates of previously mentioned animal studies. The finding in the study of Lexell et al. (1993) that especially muscles subjected to continuous stimulation are at risk for degeneration provides strong support for the "Cinderella hypothesis". The Cinderella hypothesis postulates the continuous activity of specific motor units (MUs) during low-level muscle contraction. The hypothesis requires MUs that are active for a time long enough to actually damage muscle fibers. Studies describing the recruitment of MUs show that in some subjects derecruitment of MUs occurs and that substitution of MUs takes place (Fallentin et al. 1985; Westgaard and DeLuca 1999; McLean and Goudy 2004). Also some epidemiological studies have shown that static muscle activity and a low rate of short unconscious interruptions in EMG activity (EMG gaps) are relevant for the development of complaints. Subjects in a group of manufacturing workers, who showed less EMG gaps in their trapezius muscle activity, were at higher risk to develop trapezius myalgia (Veiersted et al. 1990; Veiersted et al. 1993). Such EMG gaps were found to coincide with derecruitment and substitution of MUs (Westgaard and DeLuca 1999).

The relationship between the rate of EMG gaps and complaints could not be found in office work (Vasseljen and Westgaard 1995). A possible explanation could be that during office work periods of derecruitment occur anyway, which however, triggers the question why office workers would develop complaints at all. Recently, Westad (2003) showed that MU derecruitment is not only promoted by short depressions in contraction amplitude, but also by increased contraction levels. It appears that force variation in either direction promotes derecruitment of MUs. Although the Cinderella hypothesis gives a plausible explanation for the selective loading of type I muscle fibers, it does not explain the development of muscle fiber damage itself.

2.3.3a Impaired blood flow

Hampering of blood flow and reduction in muscle tissue oxygenation during sustained repetitive work has been suggested to contribute to the development of WRUEMD's (Carayon et al. 1999; Galen et al. 2002; Larsson 2003). The suggestion that local circulatory problems and the consequent disturbances of homeostasis play a role in the development of WRUEMD's, can also be found in several models proposed to describe the pathophysiology of WRUEMD's (Edwards 1988; Jonsson 1988; Sjøgaard and Jensen 1998; Kadefors et al. 1999; Sjøgaard et al. 2000). Keller et al. (1998) suggest that blood flow can be compromised due to compression of the brachial artery. Postural deviations, often seen in, for instance, keyboard work (forward displacement of the head and shoulder girdle in combination with scapular protraction), would reduce the cross-sectional area of the thoracic inlet. The resulting compression of the brachial artery, has effects distally, including edema, fibrosis, and temperature changes.

A more widely supported explanation for the lack of blood supply is an increased intramuscular pressure, which impedes microcirculation (Järvholm et al. 1988; Jensen et al. 1995). The intramuscular pressure is related to the produced force, the shape and location of the muscle with high pressure at high forces, in cylindrical, and deep muscles (Sejersted et al. 1984). With respect to the muscles involved in WRUEMD's, substantially higher pressures were demonstrated in, for example, the m. supraspinatus (round shaped/located deep under the surface) than in the m. trapezius (flatshaped/located at he surface) (Järvholm et al. 1991). Circulation becomes completely blocked when intramuscular pressure exceeds blood pressure. Low-intensity work tasks often involve fairly low levels of intramuscular pressure (Järvholm, 1991), which would suggest that blood flow is not severely restricted. However, local intra-muscular pressure might be much higher in parts of the muscle where MUs are active than would be expected on the basis of overall muscle activity (Sjøgaard et al. 1986). This could be the case when type I MUs or mechanically specialized subpopulations of MUs (Zuylen et al. 1988) are spatially clustered, such as in muscle compartments that have been identified in animal experiments (Windhorst et al. 1989). In several arm and shoulder muscles, among them the trapezius muscle, indications for compartmentalization have been found (Mathiassen and Winkel 1990; Brown et al. 1993; Paton and Brown 1994; Jensen et al. 1995; Hermans and Spaepen 1997; Jensen and Westgaard 1997). In addition, prolonged pressure at lower levels (8 hours, 30 mmHg) can cause muscle fiber damage at normal blood pressure (Hargens et al. 1981).

The observation that partial obstruction of blood flow occurs at intramuscular pressure levels well below blood pressure is supported by studies that investigated tissue oxygenation (Murthy et al. 1997) and hyper-compensation in blood flow post-exercise (Byström and Kilbom 1990; Jensen et al. 1993; Jensen 1997; Byström et al. 1998; Røe and Knardahl 2002). For example, Jensen et al. (1993) found post-exercise hyperaemia values of two times the resting blood flow even after isometric handgrip exercise at an intensity as low as 2.5% MVC and Røe and Knardahl (2002) found such hyperaemia after computer work. Røe and Knardahl (2002) do, however, not share the opinion that this post exercise hyperaemia is related to local hypoxia, but suggest that it is centrally mediated. They even suggest that the vasodilation can be responsible for pain analogous to the pain phase in migraine (see paragraph 3.3c).

Central adjustment of blood pressure is one of the compensatory mechanisms to optimize blood flow. The increase in blood pressure is dependent on the relative muscle load. In addition, however, static contractions involving large muscle contractions trigger a greater blood pressure response than do those involving small muscle groups, like forearm muscles (Sjøgaard and Jensen 1997). The consequence might be that the blood pressure response will be insufficient in low intensity arm muscle activities. The inadequate blood flow regulation is possibly linked with the development of pain by a process known as 'granulocyte plugging', referring to granulocytes mechanically blocking flow through the capillaries. The combination of vasodilatation as a response to local accumulation of metabolites and a limited blood pressure response might give granulocytes the opportunity to enter the capillaries and block the micro-circulation. The phenomenon of granulocyte plugging is known from ischemic cardiac disease, but is no more than a hypothesis with respect to WRUEMD's (Sjøgaard and Jensen 1997).

Although it seems plausible that suboptimal blood flow (regulation) plays a role in the pathogenesis of WRUEMD's it still has to be investigated whether it is a causal factor itself or a reinforcing factor for other causal factors.

2.3.3b Reperfusion injury

Free radicals can cause damage by lipid peroxidation of saturated fatty acids in skeletal muscle membranes. Also, oxidation of some proteins including Na^+/K^+-ATP-ase and Ca^{2+}-ATPase can take place, resulting in a loss of enzyme activity. The consequences can be membrane damage and disfunctioning of the ion pump of the sarcoplasmatic reticulum (McArdle and Jackson 1997). Since variations in energy supply are especially large in intermittent concentric contractions, it is expected that also the oxygen flux through the tissue and the electron flux through the mitochondrial chain is large, predisposing to the formation of free radicals in this kind of activities (McArdle and Jackson 1997).

2.3.3c Blood vessel-nociceptor interaction

Knardahl (2002) proposed a hypothesis on the origin of muscle pain without muscle (cell) activation being the primary cause. He suggests a mechanism, similar to the supposed mechanisms in migraine, in which vessel-nerve interactions of the connective tissue of the muscle play a central role. Knardahl (2002) refers to evidence that nociceptive afferent nerves in connective tissue and free nerve endings are located close to the vessel wall of arteries and arterioles. He proposes three options for the interaction: 1) arterial vasodilatation stretches the blood vessel wall, producing mechanical activation; 2) vascular production and release of pain producing substances, like bradykinin and nitric oxide; and 3) inflammation, histamine and substance P leakage of cells and algogenic factors from the plasma space may activate or sensitize nociceptors.

Note that this hypothesis is partially conflicting with evidence of an impaired vasodilatation response of the brachial artery to forearm muscle activity in symptomatic subjects observed by Pritchard et al. (1999) and the indications that micro-circulation is locally decreased around fibers in the trapezius muscle of subjects with myalgic pain (Larsson et al. 1990; Larsson et al. 1999).

2.3.4a Myofascial force transmission

Recently, a hypothesis postulating that shear forces between and within muscles can be the cause of muscle damage has been presented. When contracting muscles apply forces to tendons attached to bony structures, they also apply forces to the surrounding (muscle) tissue (Figure 2.4). Especially when the relative position (Maas et al. 2004) or change of length of a single muscle (part) is large relative to its environment, substantial shear stresses and strains between muscles or muscle parts are expected to occur (Huijing and Baan 2001). This inter- and extramuscular myofascial force transmission has been predicted to cause a substantial distribution of the lengths of the sarcomeres arranged in series within muscle fibers (Yucesoy et al. 2003). Jaspers et al. (1999) postulated that local lengthening of sarcomeres could lead to damage, comparable to damage caused by eccentric contractions. In an experiment to verify this, prolonged (3 hours) stimulation of a multi-tendoned rat muscle was applied (Maas 2003). Intermittent (1 Hz) shortening of a single head of the extensor digitorum longus (EDL) muscle was combined with isometric contractions of the other heads of the EDL and adjacent muscles. Histological analysis revealed muscle damage in all muscles involved. Damaged muscle fibers were predominantly located near the interface with the EDL muscle. It has to be realized that the muscles were activated at a supra-maximal level making it difficult to generalize these results to humans in low intensity tasks.

Besides the short-term effects, myofascial force transmission might be responsible for adaptations of intramuscular connective tissue with respect to strength and stiffness (Jaspers et al. 2002). Interventions with the myotendinous force transmission of rat m. extensor digitorum longus (EDL) by tenotomy and aponeurotomy showed variations in strength of the intramuscular connective tissue at the interface between heads of the multi-tendoned EDL. Jaspers et al. (2002) suggested that local shear and stress deformations will initiate adaptations to the intramuscular connective tissue in such a way that independent finger movements become restricted. To prevent undesired digit movements, co-activation of antagonists and intrinsic muscles might be required. Leijnse (1997; 1998), who focused on the intertendinous connections between muscle bellies, similarly suggested that this anatomical limitation of independent finger movements ultimately leads to increased muscle activation in certain tasks were these movements are required and thus to an increased risk for 'overuse' of muscles.

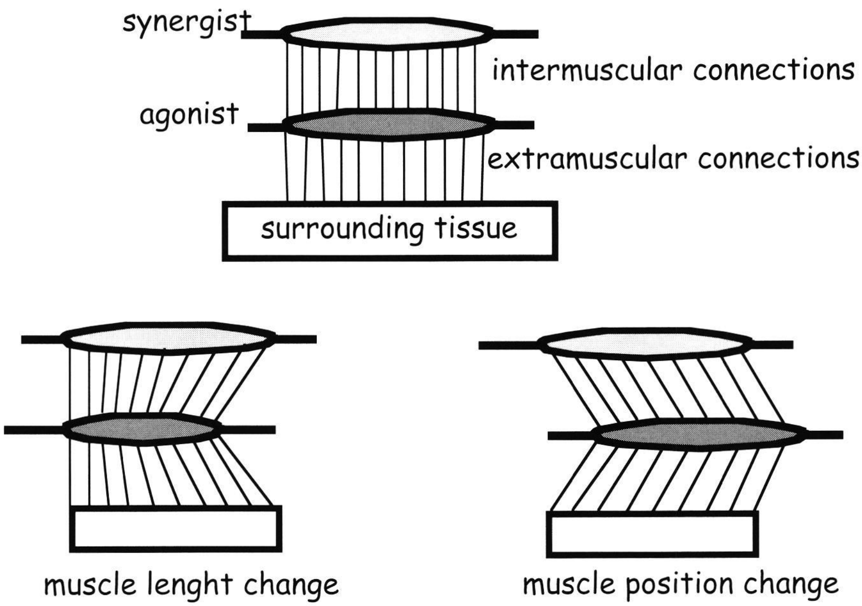


Figure 2.4 *Schematic presentation of configuration changes in inter- and extramuscular connections involved in myofascial force transmission. The effect of both muscle length change and muscle position change are illustrated.*

2.3.4b Intramuscular shear forces

With respect to the role of shear stresses in low intensity tasks, Vøllestad and Røe (2003) have suggested that low intensity static contractions lead to higher shear loading than high intensity dynamic contractions. Their argument is that only a small fraction of the muscle fibers within a muscle contracts during low-intensity contractions. Due to low firing rates in these situations MUs generate oscillating forces. Furthermore, MU shortening and lengthening is not synchronized, contributing to the movement of fibers with respect to each other. The nociceptors located between the muscle fibers are exposed to repetitive shear stresses under these conditions. Finally, the shear stresses may increase with duration of work as the amplitude of the oscillations increases during prolonged repetitive contractions.

To our knowledge, there are no experimental data to support the notion that this shear stress mechanism actually produces nociception and/or damage.

2.3.5 Trigger points

Mense and Simons (2001) argue that trigger points (TrPs) (Figure 2.5) are not just signs of myalgia, but that they play a causal role in the development of WRUMD's. TrPs are very common with prevalences of up to 50% in neck/shoulder muscles. The presence of TrPs is not always accompanied by sympoms. Mense en Simons distinguish between latent and active TrPs with the only difference the occurrence of spontaneous pain in the active TrPs. Both latent and active TrPs can be defined as hyperirritable nodules of spot tenderness in a palpable taut band of skeletal muscle (Simons 2004).

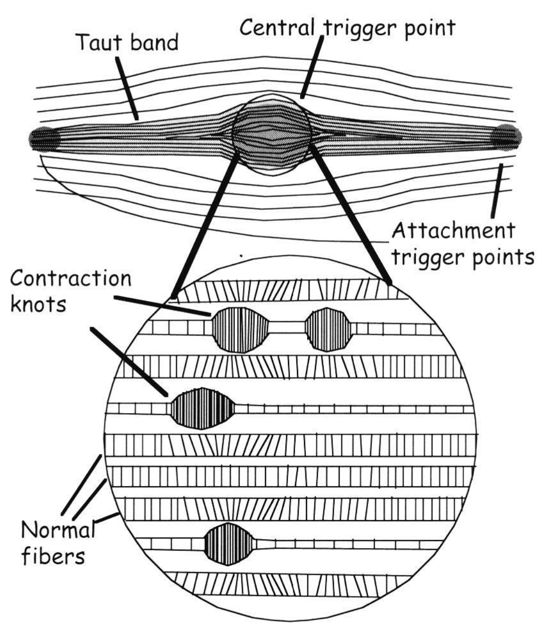


Figure 2.5 *Schematic presentation of trigger points in a palpable taut band of skeletal muscle. The magnification of the central trigger point, show contraction knots in some of the muscle fibers (based on Simons, 2004). For further explanation see text.*

TrPs are located near the insertion of the muscle or in the motor endplate area. The relevance of TrPs as causal factor is mainly based on the finding that muscle pain disappears when TrPs are removed by effective therapy. In a recent review, Simons (2004) describes a hypothesis on the development of TrPs. In short, the hypothesis postulates that a TrP has multiple muscle fibers with endplates releasing excessive Acetylcholine (Step 1), accompanied by regional sarcomere shortening (Step 2). The shortened sarcomeres have unusually high oxygen demands, while the increased tension likely compromises circulation producing local ischemia (Step 3). Ischemia and local hypoxia could lead to tissue distress: as appears from a reduction of ATP and release of sensitizing substances (Step 4). The sensitizing substances are responsible for the sensitization of nociceptors (Step 5), leading to pain. Some of the steps in the trigger point hypothesis overlap with the previously mentioned theories. Dysfunctioning of the endplates is exclusive for this hypothesis and especially this part of the hypothesis has some uncertainties with respect to a possible causal role of work requirements. Mense and Simons (2001) and Simons (2004) mention that the step from latent TrPs to active TrPs is under the influence of an autonomic central process, but at the same time they argue that it can be triggered by a rather broad range of muscle activities leading to muscle overload.

2.3.6 Impaired heat shock response.

Forde et al. (2002) formulated the hypothesis that disruption of the heat shock response could lead to pathogenic levels of chaperone proteins causing cell death. The hypothesis is based on the observation that exposing cells to stress - either heat stress, oxygen stress as occurs in inflammatory responses, or ischemic conditions – leads to an increased production of chaperone proteins. Under normal conditions a self-limiting feedback loop exists in which chaperones shut down there own production. However, as cells age, either naturally or prematurely due to adverse external exposures, the heat shock response does not function properly leading to harmful levels of chaperones. Forde et al. (2002) themselves indicate a lack of information on the relationship between occupational muscle activity and the level of cellular stress as a weak point in this theory.

2.4 From disorder to symptom

The understanding of the pathophysiological process from muscle activity to disturbances of physiological processes in the body and disorders of the muscle(s) is crucial, but does not necessarily clarify the occurrence of the symptoms. Additional hypotheses with respect to the symptoms, pain, stiffness and loss of coordination, are reviewed in this paragraph.

Pain is defined as an unpleasant sensory experience associated with actual or potential tissue damage. Pain is one of the somatic sensibilities with its own specialized set of neural pathways. Nociceptors are specialized receptors that serve as injury (or noxious stimuli) receptors. Nociceptors are sensitive to chemical substances, released from damaged or overloaded cells, and excessive tissue deformation that may occur as a consequence of high mechanical loads or as a consequence of (connective) tissue damage (Mense 1993).

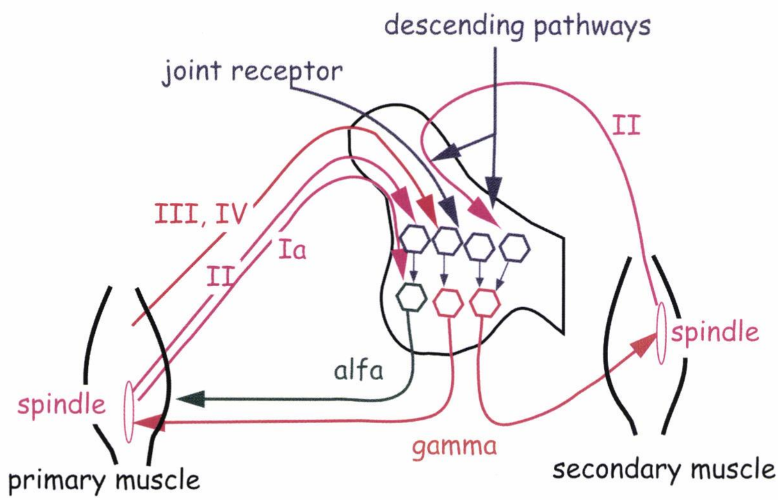


Figure 2.6 *The possible role of the γ-muscle spindle system in a self-maintaining 'vicious circle': muscle contraction produces metabolites and reduces pH, which can activate nociceptive type III and IV muscle afferents, which in turn activate the γ-motor neurons. Elevated γ-motor neuron activity would cause elevated muscle spindle activity, which in turn would increase muscle fiber activity and stiffness. The positive feedback loop might also reinforce the activity of surrounding muscles.*

Recurrent stimulation may induce sensitization, which means that the nociceptor threshold is lowered and the firing frequency in response to the same stimulus is increased (which is likely to be accompanied by an increased pain intensity). Sensitization is often accompanied by an increase of the sensitive area, leading to radiating pain (Mense 1993; Blair et al. 2003). A similar sensitization process occurs at the central nervous system (CNS), with substance P playing an important role. The concentration of this neurotransmitter, measured in the spinal marrow, was increased in rats that had performed repeated activities (Barbe et al. 2000). The central and peripheral sensitization might play an important role in the chronicity of pain. Animal studies have shown that cytokine release occurs after low intensity repetitive activities (Archambault et al. 2001; Barbe et al. 2003). Besides their role in the inflammation process, cytokines have a large impact elsewhere in the body through circulatory distribution and on the CNS, leading to widespread physiological effects and even behavioral changes. Cytokines have, for example, been shown to influence illness related behavior, like inactivity (Watkins and Maier 1999; Watkins and Maier 2001) and may cause increased pain sensitivity (Ek et al. 2001; Samad et al. 2001).

Pain may be the consequence of muscle activity but can in turn play a role in muscle activation. Johansson (1991) proposed that the γ-muscle spindle system plays a central role in a self-maintaining 'vicious circle' in which pain and muscle activity amplify each other. Muscle contraction produces metabolites and low pH, which activates nociceptive type III and IV muscle afferents, which in turn activate the γ-motor neurons. Elevated γ-motor neuron activity would cause elevated muscle spindle activity, which in turn would increase muscle fiber activity and stiffness. The positive feedback loop might also reinforce the activity of surrounding muscles, explaining the spreading of complaints to neighboring muscles (Figure 2.6). Recent studies have not provided unambiguous support for this theory. An increased output of muscle spindles in cat hind leg and neck muscles, as a consequence of nociceptive stimuli, was found in a range of experiments (Ljubisavljevic et al. 1992; Djupsjöbacka et al. 1994; Pedersen et al. 1997; Pedersen et al. 1998). However, an experiment in which myositis was induced in the hind leg of the cat showed a decreased activity of γ-motor neurons (Mense and Skeppar 1991). Also in cat back muscles no increased γ-motor neuron activity was found after injection of bradykinin and capsaicin (Kang et al. 2001). In human calf and masticatory muscles, the stretch reflex, which is mediated by muscle spindle afferents, was found to be enhanced after injection of hypertonic saline (Matre et al. 1998; Svensson et al. 2001). However, in back muscles no enhancement of stretch reflexes was found after hypertonic saline injection (Zedka et al. 1999). In addition, during walking the stretch reflex in the calf muscles was unaffected by induced pain (Matre et al. 1999). Evidence of hyper-excitability of the α-motor neuron pool after noxious stimulation of muscle was found in cats (Pedersen et al. 1956). In rat, the flexion reflex was increased following induction of muscle pain (Wall and Woolf 1984). Likewise resting EMG levels in rat masticatory muscles were found to be increased after induction of pain. This effect did however last only up to 10 minutes (Svensson et al. 1998). Experimental results in humans are sparse. The amplitude of the Hofmann's reflex, which is an indicator of α-motor neuron excitability, was not increased after injection of hypertonic saline in the calf muscles (Matre et al. 1998). However, resting EMG levels were increased in human masticatory muscles (Svensson et al. 1998), although the effect was only short-lived. Besides the direct sensation of pain and discomfort type III and IV afferents may have an impact on the movement and position sense (proprioception). In animal studies, increased type III and IV afferent activation did diminish the information content of muscle spindle afference (Pedersen et al. 1998; Thunberg et al. 2002). Also in humans, muscle fatigue has been shown to negatively affect propriocepsis (Pedersen et al. 1999; Björklund et al. 2000; Forestier et al. 2002). Furthermore, patients with pain in the cervical region were shown to display an impaired ability in a head-repositioning task (Revel et al. 1991). A recent reformulation of the hypothesis of Johanssen and Sojka focuses on this aspect, where it is assumed that the reduced proprioception requires increased effort to maintain task performance, which might lead to a vicious circle (Johansson et al. 2003). Results from animal studies indicate that, in addition to the peripheral effects on sensorial quality, changes in the cerebral cortex as a response to sustained repetitive muscle activity can occur (Byl et al. 1996; Byl and Melnick 1997; Byl et al. 1997). In monkeys that performed repetitive movements with one hand, changes in the cerebral cortex suggest a reduction in the differentiation of sensory information from the hand and arm (Byl et al. 1996). It is therefore possible that the impaired proprioception will lead to less precise motor control and as a compensatory reaction, to an increased effort mainly in the form of increased co-activation of muscles. Increased muscle activation and especially a lack of relaxation as shown in patients with WRUEMD's (Elert et al. 1992; Larsson et al. 2000) and whiplash associated disorders (Nederhand et al.

2000), and increased pen pressure during a graphical aiming task in patients with a-specific forearm pain (Bloemsaat et al. 2004) support this assumption.

2.5 Discussion

This review focused on the injury mechanisms that could underlie work related muscle disorders. The following mechanisms were discussed: 1) Ca^{2+} accumulation; 2) Cinderella motor-units loading; 3a) Impaired blood flow; 3b) Reperfusion injury; 3c) Blood vessel-nociceptor interaction; 4a) Myofascial force transmission; 4b) Intramuscular shear forces; 5) Trigger points; 6) Impaired heat shock response. The literature shows no complete proof for any of these mechanisms. Some mechanisms have been studied quite extensively and have received partial support. Other mechanisms have hardly been studied yet.

As expected, none of the hypotheses included in this review is able to explain the pathogenesis to its full extent. Nevertheless, in our opinion increased insight can be gained by taking into account that some the mechanisms interact and are complementary to each other. It appears that selective and sustained MU recruitment as proposed in the Cinderella hypothesis in combination with homeostatic disturbances possibly due to limitations in blood supply and metabolite removal offers a plausible basis for the pathogenesis of muscle disorders in low-intensity tasks. The bulk of the findings from the biopsy studies reviewed, which indicate mitochondrial dysfunction of type I fibers in myalgic muscles, could also be accounted for by such a mechanism. Johansson et al. (2003) came to the conclusion that the multiple individual mechanisms interact in (series of) circular processes, with the implication that it is unlikely to pinpoint a unique causal starting point. In our simple model we arbitrarily chose the muscle activity as a starting point leading to a disturbance of the physiological homeostasis. As a response to the release of metabolites in the muscle the circulation increases. Sympathetic activation (stress) might lead to a reduction of circulation and an increase of muscle activation. Sustained exposure can result in an accumulation of metabolites, stimulating nociceptors. This process can be enhanced in subjects with relatively large type I fibers and low capillarization, which paradoxically may have developed as an adaptation to the exposure. Nociceptor activation can disturb the proprioception and thereby the motor control most likely leading to increased further disturbance of muscle homeostasis. In addition, in the long run a reduction of the pain threshold and an increase of pain sensitivity can develop. It is worth noting that initial nociceptor stimulation may be a response to metabolite accumulation and not to tissue damage.

As indicated in Figure 2.1, the pathophysiological process is under the influence of effect modifiers, varying form individual to psychosocial factors. Task stress has an influence on all levels of the model. It has an effect on the relationship between task requirements and muscle activity (Visser et al. 2004), with task stress having an increasing effect on muscle activation. Stress can also have a negative effect on circulation and oxygen supply to the muscles by sympathetic influence and hyperventilation (Schleifer et al. 2002). In addition, hormonal effects of stress may lead to a decreased anabolic capacity, which would negatively affect tissue quality and the capacity to regenerate tissue after injury (Theorell 2000). Finally stress has an influence on the relation between disorders and symptoms, the sensation of pain and illness related behavior. Pain itself is a powerful stressor, so a reciprocal reinforcement is likely to occur. Obviously, a multitude of individual factors may have substantial influence on the relations in the model in Figure 2.1. Muscle activation levels differ widely between subjects performing the same tasks (Mathiassen et al. 2002). With respect to WRUEMD's the individual pain tolerance seems to be a relevant source of inter individual variation (Madeleine et al. 2003). This individual pain tolerance seems however less determined by genetic than by situational, psycho-social factors (Blair et al. 2003).

This review is not the proper place to go into detail with respect to preventive measures, but some general and generic preventive approaches can be inferred from the proposed pathophysiological mechanisms. There are several indications that sustained static activity should be prevented either by introduction of (micro-)breaks or by introduction of variation in muscle activation. Positive effects are to be expected for both MU activation (MU substitution) and blood circulation. Although the Cinderella hypothesis underlines that lowering the activation level does not necessarily provide relief for the small MUs, a reduction of muscle activation levels can be regarded as positive. Lowering of muscle activation levels might be achieved by optimizing working postures, adding effective support (arm supports, back rest) and by bringing about a working technique with limited co-contraction.

With respect to treatment, similarly only tentative conclusions can be drawn. The complex interactions between processes suggest that a multi-disciplinary approach with respect to diagnostics and possibly in treatment of WRUEMD's is indicated. It has to be realized that in the diagnostic process other tissues than muscle are involved, making a multi-disciplinary approach even more important. A tentative inference with respect to treatment of WRUEMD's could be that rest is indicated as a therapeutical intervention. The proposed mechanisms in the pathogenesis of WRUEMD's, especially the circular interactions leading to reinforcement of complaints, suggest that an interruption of exposure could be a necessary intervention. The observations of hypertrophia (Larsson et al. 1990; Larsson et al. 1992) of muscles in subjects with WRUEMD's also point in the direction of reduction of muscle activity as a target in therapy. Opposing results are reported on the effectiveness of exercise as therapy. Kadi et al. (Kadi et al. 2000) reported positive results, while Waling et al. (2002) showed that on the long-term training programs did not have a positive effect . Rest as treatment is also not as obvious as it seems when we look at the extensive knowledge of treatment of back complaints. In the literature on back complaints, rest is often rejected because of the negative effects on chronicity and deconditioning. Caution is required both with respect to generalizing this observation on back pain treatment to treatment of WRUEMD's as well as in drawing conclusion based on the presumed pathophysiology of WRUEMD's.

The literature reviewed here indicated that objectifiable peripheral disorders could underlie WRUEMD's, although a one to one relationship between disorders and symptoms has not been shown. Perhaps the latter is hardly to be expected given the important role of a range of effect modifiers of both situational and individual nature. Furthermore, the literature provides some tentative but plausible mechanisms that could cause these disorders. Preventive and therapeutic efforts could be designed on the basis of these mechanisms. Effectiveness of this approach of course remains to be shown.

Acknowledgements

This study was partially supported by a grant from the ministry of Social Affairs and Employment of the Netherlands. I. Kingma and H.E.J. Veeger are acknowledged for reviewing an early version of the manuscript.

2.6 References

Archambault JM, Hart DA, Herzog W (2001) Response of rabbit Achilles tendon to chronic repetitive loading. Connect Tissue Res 42: 13-23

Armstrong TJ, Buckle P, Fine LJ, Hagberg M, Jonsson B, Kilbom A, Kuorinka IAA, Silverstein BA, Sjogaard G, Viikara-Juntura ERA (1993) A conceptual model for work-related neck and upper-limb musculoskeletal disorders. Scandinavian Journal of Work, Environment and Health 19: 73-84

Barbe MF, Barr AE, Gorzelany I, Amin M, Gaughan JP, Safadi FF (2003) Chronic repetitive reaching and grasping results in decreased motor performance and widespread tissue responses in a rat model of MSD. J Orthop Res 21: 167-176

Barbe MF, McDonough BM, Erthal DM, Inman HT, Rice TL, Barr AE (2000) Substance P increases in spinal cord in response to peripheral inflammation induced by repetitive tasks. In: Society of Neuroscience abstracts, vol 26, p 1835

Barr AE, Barbe MF (2004) Inflammation reduces physiological tissue tolerance in the development of work-related musculoskeletal disorders. J Electromyogr Kinesiol 14: 77-85

Bengtsson A (2002) The muscle in fibromyalgia. Rheumatology 41: 721-724

Bernard BP (1997) Musculoskeletal disorders (MSDs) and workplace factors - a critical review of epidemiologic evidence for work-related musculoskeletal disorders of the neck, upper extremity, and low back. National Institute for Occupational Safety and Health, Cincinnati, OH

Birch L, Christensen H, Arendt-Nielsen L, Graven-Nielsen T, Sogaard K (2000) The influence of experimental muscle pain on motor unit activity during low-level contraction. European Journal of Applied Phywiology 83: 200-206

Bjelle A (1981) Occupational and individual factors in acute shoulder-neck disorders among industrial workers. British Journal of Industrial Medicine 38: 356-363

Bjelle A, et a (1979) Clinical and ergonomic factors in prolonged shoulderpain among industrial workers. Scandinavian Journal of Work, Environment and Health 5: 205-210

Björklund M, Crenshaw AG, Djupsjöbacka M, Johansson H (2000) Position Sense acuity is diminished following repetitive low-intensity work to fatigue in a simulated occupational setting. European Journal of Applied Physiology 81: 361-367

Blair S, Djupsjöbacka M, Johansson H, Ljubisavljevic M, Passatore M, Windhorst U (2003) Neuromuscular mechanisms behind chronic work-related myalgias. Overview. In: Johansson H, Windhorst U, Djupsjöbacka M, Passatore M (eds) Chronic work-related myalgia. Neuromuscular mechanisms behind work-related chronic muscle syndromes. Gävle University Press, Gävle, Sweden, pp 5-46

Bloemsaat JG, Ruijgrok JM, Van Galen GP (2004) Patients suffering from nonspecific work-related upper extremity disorders exhibit insufficient movement strategies. Acta Psychol (Amst) 115: 17-33

Bongers PM, Kremer AM, ter Laak J (2002) Are psychosocial factors, risk factors for symptoms and signs of the shoulder, elbow, or hand/wrist?: A review of the epidemiological literature. Am J Ind Med 41: 315-342

Brown JMM, Solomon C, Paton ME (1993) Further evidence of functional differentiation within biceps brachii. Electromyography and clinical Neurophysiology 33: 301-309

Buckle P, Devereux J (1999) Work-related neck and upper limb musculoskeletal disorders. Office for Official Publications of the European Communities, Luxembourg

Byl NN, Melnick M (1997) The Neural Consequences of Repetition: clinical implications of a learning hypothesis. Journal of Hand Therapy april-june: 160-174

Byl NN, Merzenich MM, Cheung S, Bedenbaugh P, Nagarajan SS, Jenkins WM (1997) A primate model for studying focal dystonia and repetitive strain injury: Effects on the primary somatosensory cortex. Physical Therapy 77: 269-284

Byl NN, Wilson F, Merzenich MM, Melnick M, Scott P, Oakes A, McKenzie A (1996) Sensory dysfunction associated with repetitive strain injuries of tendinitis and focal hand dystonia: A comparative study. Journal of Orthopaedic & Sports Physical Therapy 23: 234-244

Byström S, Jensen B, Jensen-Urstad M, Lindblad LE, Kilbom A (1998) Ultrasound-Doppler technique for monitoring blood flow in the brachial artery compared with occlusion plethysmography of the forearm. Scand J Clin Lab Invest 58: 569-576

Byström SE, Kilbom A (1990) Physiological response in the forearm during and after isometric intermittent handgrip. Eur J Appl Physiol Occup Physiol 60: 457-466

Carayon P, Smith MJ, Haims MC (1999) Work Organization, Job Stress, and Work-Related Musculoskeletal Disorders. Human Factors 41: 644-663

Djupsjöbacka M, Johansson H, Bergenheim M (1994) Influences on the gamma-muscle-spindel system from muscle afferents stimulated by increased intramuscular concentrations of arachidonic acid. Brain Research 663: 293-302

Edwards RHT (1988) Hypotheses of peripheral and central mechanisms underlying occupational muscle pain and injury. European Journal of Applied Physiology 57: 275-281

Ek M, Engblom D, Saha S, Blomqvist A, Jakobsson PJ, Ericsson DA (2001) Inflammatory response: pathway across the blood-brain barrier. Nature 410: 430-431

Elert J, Rantapää -D, S., Henriksson-Larsén K, Lorentzon R, Gerdle B (1992) Muscle performance, electromyography and fibre type composition in fibromyalgia and work-related myalgia. Scandinavian Journal of Rheumatology 21: 28-34

Fallentin N, Sidenius B, Jorgensen K (1985) Blood pressure, heart rate and EMG in low-level static contractions. Acta Physiologica Scandinavica 125: 265-275

Faulkner JA, Brooks SV (1997) Muscle damage induced by contraction: an in situ single skeletal muscle model. In: Salmons S (ed) Muscle damage. Oxford University Press, Oxford, pp 28-40

Forde MS, Punnett L, Wegman DH (2002) Pathomechanisms of work-related musculoskeletal disorders: conceptual issues. Ergonomics 45: 619-630

Forestier N, Teasdale N, Nougier V (2002) Alteration of the position sense at the ankle induced by muscular fatigue in humans. Med Sci Sports Exerc 34: 117-122

Forsman M, Kadefors R, Zhang Q, Birch L, Palmerud G (1999) Motor-unit recruitment in the trapezius muscle during arm movements and in VDU precision work. International Journal of Industrial Ergonomics 24: 619-630

Forsman M, Taoda K, Thorn S, Zhang Q (2002) Motor-unit recruitment during long-term isometric and wrist motion contractions: a study concerning muscular pain development in computer operators. International Journal of Industrial Ergonomics 30: 237-250

Fridén J, Lieber RL (1997) Muscle damage induced by cyclic eccentric contraction: biomechanical and structural studies. In: Salmons S (ed) Muscle damage. Oxford University Press, Oxford, pp 41-63

Galen GPV, Müller MLTM, Meulenbroek RGJ, Gemmert AWAV (2002) Forearm EMG response activity during motor performance in individuals prone to increased stress reactivity. American Journal of Industrial Medicine 41: 406-419

Gissel H (2000) Ca2+ accumulation and cell damage in skeletal muscle during low frequency stimulation. European Journal of Applied Physiology 83: 175-180

Hagberg M, Kvarnström S (1984) Muscular endurance and electromyographic fatigue in myofascial shoulder pain. Archives of Physical Medicine and Rehabilitation 65: 522-525

Hagberg M, Michaelson. G, Ortelius A (1982) Serum creatine Kinase as an indicator of local muscular strain in experimental and occupational work. International Archives of Occupational Environment and Health 50: 377-386

Hagberg M, Silverstein B, Wells R, Smith MJ, Hendrick HW, Carayon P, Pérusse M (1995) Work related musculoskeletal disorders. A reference book for prevention. Taylor and Francis, London

Hägg GM (1991) Lack of relation between maximal force capacity and muscle disorders caused by low level static loads. A new explanation model. In: Queinnec Y, Daniellou F (eds) IEA, vol 1. Taylor & Francis, Paris, pp 9-11

Hägg GM (2000) Human muscle fibre abnormalities related to occupational load. European Journal of Applied Physiology 83: 159-165

Hägg GM, Suurküla J (1991) Zero crossing rate of electromyograms during occupational work and endurance tests as predictors for work related myalgia in the shoulder/neck region. European Journal of Applied Physiology 62: 436-444

Hargens AR, Schmidt DA, Evans KL, Gonsalves MR, Cologne JB, Garfin SR, Mubarak SJ, Hagan PL, Akeson WH (1981) Quantitation of skeletal-muscle necrosis in a model compartment syndrome. J Bone Joint Surg Am 63: 631-636

Heffner RR, Barron SA (1978) The early effects of ischemia upon skeletal muscle mitochondria. J Neurol Sci 38: 295-315

Henneman E, Somjen G, Carpenter DO (1965) Excitability and inhibitability of motorneurons of different sizes. Journal of Neurophysiology 28: 599-620

Henriksson KG, Bengtsson A, Larsson J, Lindstrom F, Thornell LE (1982) Muscle biopsy findings of possible diagnostic importance in primary fibromyalgia (fibrositis, myofascial syndrome). Lancet 2: 1395

Hermans V, Spaepen AJ (1997) Influence of electrode position on changes in electromyograph parameters of the upper trapezius muscle during submaximal sustained contractions. European Journal of Applied Physiology 75: 319-325

Hill AB (1965) The environment and disease: Association or causation? Proceedings of the Royal Society of Medicine 58: 295-300

Huijing PA, Baan GC (2001) Extramuscular myofascial force transmission within the rat anterior tibial compartment: proximo-distal differences in muscle force. Acta Physiol Scand 173: 297-311

Järvholm U, Palmerud G, Karlsson D, Herberts P, Kadefors R (1991) Intramuscular pressure and electromyography in four shoulder muscles. Journal of Orthopaedic Research 9: 609-619

Järvholm U, Styf J, Suurkula M, Herberts P (1988) Intramuscular pressure and muscle blood flow in supraspinatus. European Journal of Applied Physiology 58: 219-224

Jaspers RT, Brunner R, Baan GC, Huijing PA (2002) Acute effects of intramuscular aponeurotomy and tenotomy on multitendoned rat EDL: indications for local adaptation of intramuscular connective tissue. Anat Rec 266: 123-135

Jaspers RT, Brunner R, Pel JJ, Huijing PA (1999) Acute effects of intramuscular aponeurotomy on rat gastrocnemius medialis: force transmission, muscle force and sarcomere length. J Biomech 32: 71-79

Jensen BR (1997) Doppler blood flow and peripheral resistance in the forearm during and following low-level isometric hand-grip contractions. Advances in occupational medicine and rehabilitation 3: 21-35

Jensen BR, Fallentin N, Byström S, Sjøgaard G (1993) Plasma potassium concentration and Doppler blood flow during and following submaximal handgrip contractions. Acta Physiol. Scand. 147: 203-211

Jensen BR, Jørgensen K, Huijing PA, Sjøgaard G (1995) Soft tissue architecture and intramuscular pressure in the shouder region. European Journal of Morphology 33: 205-220

Jensen C, Westgaard RH (1997) Functional subdivision of the upper trapezius muscle during low-level activation. European Journal of Applied Physiology 76: 335-339

Johansson H, Arendt-Nielsen L, Bergenheim M, Djupsjöbacka M, Gold JE, Johansson H, Ljubisavljevic M, Mano T, Matre DA, Passatore M, Punnett L, Roatta S, Dieën JHv, Windhorst U (2003) Epilogue: an integrative model. In: Johansson H, Windhorst U, Djupsjöbacka M, Passatore M (eds) Chronic work-related myalgia. Neuromuscular mechanisms behind work-related chronic muscle syndromes. Gävle University Press, Gävle, Sweden, pp 291-300

Johansson H, Sojka P (1991) Pathophysiological mechanisms involved in genesis and spread of muscular tension in occupational muscle pain and in chronic musculoskeletal pain syndromes. A hypothesis. Medical Hypotheses 35: 196-203

Jonsson B (1988) The static load component in muscle work. European Journal of Applied Physiology 57: 305-310

Kadefors R, Forsman M, Zoega B, Herberts P (1999) Recruitment of low threshold motor-units in the trapezius muscle in different static arm positions. Ergonomics 42: 359-375

Kadi F, Ahlgren C, Waling K, Sundelin G, Thornell LE (2000) The effects of different training programs on the trapezius muscle of women with work-related neck and shoulder myalgia. Acta Neuropathol (Berl) 100: 253-258

Kadi F, Hagg G, Hakansson R, Holmner S, Butler-Browne GS, Thornell LE (1998a) Structural changes in male trapezius muscle with work-related myalgia. Acta Neuropathol (Berl) 4: 352-360

Kadi F, Waling K, Ahlgren C, Sundelin G, Holmner S, Butler-Browne GS, Thornell L-E (1998b) Pathological mechanisms implicated in localized female trapezius myalgia. Pain 78: 191-196

Kang YM, Wheeler JD, Pickar JG (2001) Stimulation of chemosensitive afferents from multifidus muscle does not sensitize multifidus muscle spindles to vertebral loads in the lumbar spine of the cat. Spine 26: 1528-1536

Keller K, Corbett J, Nichols D (1998) Repetitive strain injury in computer keyboard users: pathomechanics and treatment principles in individual and group intervention. J Hand Ther 11: 9-26

Knardahl S (2002) Psychophysiological mechanisms of pain in computer work: the blood vessel-nociceptor interaction hypothesis. Work & Stress 16: 179 - 189

Kroemer KHE (1989) Cumulative trauma disorders: their recognition and ergonomics measures to avoid them. Ergonomics 20: 274-280

Kuorinka I, Koskinen P (1979) Occupational rheumatic disease and upper limb strain in manual jobs in a light mechanical industry. Scandinavian Journal of Work, Environment and Health 6: 39-47

Larsson B, Bjork J, Elert J, Gerdle B (2000) Mechanical performance and electromyography during repeated maximal isokinetic shoulder forward flexions in female cleaners with and without myalgia of the trapezius muscle and in healthy controls. Eur J Appl Physiol 83: 257-267.

Larsson B, Libelius R, Ohlsson K (1992) Trapezius muscle changes unrelated to static work load. Chemical and morphologic controlled studies of 22 women with and without neck pain. Acta Orthopaedica Scandinavica 63: 203-206

Larsson R, Oberg PA, Larsson SE (1999) Changes of trapezius muscle blood flow and electromyography in chronic neck pain due to trapezius myalgia. Pain 79: 45-50

Larsson SE (2003) Neck-shoulder pain in relation to blood microcirculation and EMG, psychophysiological stress. In: Johansson H, Windhorst U, Djupsjöbacka M, Passatore M (eds) Chronic Work-Related Myalgia - Neuromuscular Mechanisms behind Work-Related Chronic

Muscle Pain Syndromes. Gävle University Press, pp 111-115

Larsson SE, Bodegard L, Henriksson KG, Oberg PA (1990) Chronic trapezius myalgia. Morphology and blood flow studied in 17 patients. Acta Orthopaedica Scandinavica 61: 394-398

Leijnse JN (1997) Anatomical factors predisposing to focal dystonia in the musician's hand--principles, theoretical examples, clinical significance. J Biomech 30: 659-669

Leijnse JN (1998) A method and device for measuring force transfers between the deep flexors in the musician's hand. J Biomech 31: 773-779

Lexell J, Jarvis J, Downham D, Salmons S (1993) Stimulation-induced damage in rabbit fast-twitch skeletal muscles: a quantitative morphological study of the influence of pattern and frequency. Cell Tissue Res 273: 357-362

Lindman R, Eriksson A, Thornell LE (1991a) Fiber type composition of the human female trapezius muscle: enzyme-histochemical characteristics. Am J Anat 190: 385-392

Lindman R, Hagberg M, Änquist KA, Söderlund K, Hultman E, Thornell LE (1991b) Changes in muscle morphology in chronic trapezius myalgia. Scandinavian Journal of Work, Environment and Health 17: 347-355

Lindman R, Hagberg M, Bengtsson A, Henriksson KG, Thornell LE (1995) Capillary Structure and Mitochondrial Volume Density in the Trapezius Muscle of Chronic Trapezius Myalgia, Fibromyalgia and Healthy Subjects. Journal of Musculoskeletal Pain 3: 5-22

Ljubisavljevic M, Jovanovic K, Anastasivic R (1992) Changes in discharge rate of fusimotor neurons provoked by fatiguing contractions of cat triceps surae muscles. Journal of Physiology (London) 445: 499-513

Luopajärvi T, Kuorinka I, Virolainen M, Holmberg M (1979) Prevalence of tenosynovitis and other injuries of the upper extremities in repetitive work. Scandinavian Journal of Work, Environment and Health 6: 48-55

Maas H (2003) Myofascial Force Transmission - Intra-, inter and extramuscular pathways. In: Institute for Fundamental and Clinical Human Movement Sciences. Vrije Univesiteit, Amsterdam

Maas H, Baan GC, Huijing PA (2004) Muscle force is determined also by muscle relative position: isolated effects. J Biomech 37: 99-110

Madeleine P, Lundager B, Voigt M, Arendt-Nielsen L (2003) The effects of neck-shoulder pain development on sensory-motor interactions among female workers in the poultry and fish industries. A prospective study. International Archives of Occupational Environment and Health 76: 39-49

Malchaire J, Cock N, Vergracht S (2001) Review of the factors associated with musculoskeletal problems in epidemiological studies. Int Arch Occup Environ Health 74: 79-90

Malcolm SA, Anstee A, Halloran M (1995) Time course changes in plasma creatine kinase over four days of repetitive manual work. Ergonomics 38: 1019-1024

Mathiassen SE, Burdorf A, Beek AJvd (2002) Statistical power and measurement allocation in ergonomic intervention studies assessing upper trapzius EMG amplitude. A case study of assembly work. Journal of Electromyography and Kinesiology 12: 45-57

Mathiassen SE, Winkel J (1990) Electromyographic activity in the shoulder-neck region according to arm position and glenohumeral torque. European Journal of Applied Physiology 61: 370-379

Mathiassen SE, Winkel J, Sahlin K, Melin E (1993) Biochemical indicators of hazardous shoulder-neck loads in light industry. Journal of Occupational Medicine 35: 404-407

Matre DA, Sinkjaer T, Knardahl S, Andersen JB, Arendt-Nielsen L (1999) The influence of experimental muscle pain on the human soleus stretch reflex during sitting and walking. Clin Neurophysiol 110: 2033-2043.

Matre DA, Sinkjaer T, Svensson P, Arendt-Nielsen L (1998) Experimental muscle pain increases the human stretch reflex. Pain 75: 331-339

McArdle A, Jackson MJ (1997) Intracellular mechanisms involved in skeletal muscle damage. In: Salmons S (ed) Muscle damage. Oxford University Press, Oxford, pp 90-106

McLean L, Goudy N (2004) Neuromuscular response to sustained low-level muscle activation: within- and between-synergist substitution in the triceps surae muscles. Eur J Appl Physiol 91: 204-216

Mense S (1993) Nociception from skeletal muscle in relation to clinical muscle pain. Pain 54: 241-289

Mense S, Simons DG (2001) Muscle pain. Understanding its nature, diagnosis, and treatment. Lippincott Willimas & Wilkins, Philadelphia

Mense S, Skeppar P (1991) Discharge behaviour of feline gamma-motoneurons following induction of an artifical myositis. Pain 46: 201-210

Morgan DL, Allen DG (1999) Early events in stretch-induced muscle damage. J Appl Physiol 87: 2007-2015

Murthy G, Kahan NJ, Hargens AR, Rempel DM (1997) Forearm muscle oxygenation decreases with low levels of voluntary contraction. J Orthop Res 15: 507-511

National Research Council and the Institute of Medicine (2001) Musculoskeletal Disorders and the Workplace: Low Back and Upper Extremities. National Academy Press, Washington, DC

Nederhand MJ, MJ IJ, Hermens HJ, Baten CT, Zilvold G (2000) Cervical muscle dysfunction in the chronic whiplash associated disorder grade II (WAD-II). Spine 25: 1938-1943

Paton ME, Brown JMM (1994) An electromyographic analysis of functional differentiation in human pectroalis major muscle. Journal of Electromyography and Kinesiology 4: 161-169

Pedersen HE, Blunck CFJ, Gardner E (1956) The anatomy of lumbosacral posterior rami and meningeal branches of spinal nerves (sinu-vertebral nerves). With an experimental study of their functions. Journal of Bone & Joint Surgery 38A: 377-391

Pedersen J, Ljubisavljevic M, Bergenheim M, Johansson H (1998) Alterations in information transmission in ensembles of primary muscle spindle afferents after muscle fatigue in heteronymous muscle. Neuroscience 84: 953-959

Pedersen J, Lönn J, Hellström F, Djupsjöbacka M, Johansson H (1999) Localized muscle fatigue decreases the acuity of the movement sense in the human shoulder. Med. & Sci. Sport Exerc. 31: 1047-1052

Pedersen J, Sjolander P, Wenngren BI, Johansson H (1997) Increased Intramuscular Concentration of Bradykinin Increases the Static Fusimotor Drive to Muscle Spindles in Neck Muscles of the Cat. Pain 70: 83-91

Pritchard MH, Pugh N, Wright I, Brownlee M (1999) A vascular basis for repetitive strain injury. Rheumatology (Oxford) 38: 636-639

Ranney D, Wells R, Moore A (1995) The anatomical location of work-related chronic musculoskeletal disorders in selected industries characterized by repetitive upper limb activity. Ergonomics 38: 1408-1423

Revel M, Andre Deshays C, Minguet M (1991) Cervicocephalic kinesthetic sensibility in patients with cervical pain. Archives of Physical Medicine & Rehabilitation 72: 288-291

Røe C, Knardahl S (2002) Muscle activity and blood flux during standardised data-terminal work. International Journal of Industrial Ergonomics 30: 251-264

Samad TA, More KA, Sapirstein A, Billet S, Allchrone A, Poole S, Bonventre JV, Woolf CJ (2001) Interleukin-1beta-mediated induction of Cox-2 in the CNS contributes to inflammatory pain hypersensitivity. Nature 410: 471-475

Schleifer LM, Ley R, Spalding TW (2002) A hyperventilation theory of job stress and musculoskeletal disorders. American Journal of Industrial Medicine 41: 420-432

Sejersted OM, Hargens AR, Kardel KR, Blom P, Jensen O, Hermansen L (1984) Intramuscular fluid pressure during isometric contraction of human skeletal muscle. J Appl Physiol 56: 287-295

Sharma SD, Smith EM, Hazleman BL, Jenner JR (1997) Thermographic changes in keyboard operators with chronic forearm pain. British Medical Journal 314: 118

Simons DG (2004) Review of enigmatic MTrPs as a common cause of enigmatic musculoskeletal pain and dysfunction. J Electromyogr Kinesiol 14: 95-107

Sjøgaard G, Jensen BR (1997) Muscle pathology with overuse. In: Ranney A (ed) Clinical Orthopaedics and Related Research. W.B. Saunders Company, Philadelphia, pp 17-40

Sjøgaard G, Jensen BR (1998) Muscle injury in repetitive motion disorders. Clinical Orthopaedics and Related Research 351: 21-31

Sjøgaard G, Kiens B, Jorgensen K, Saltin B (1986) Intramuscular pressure, EMG and blood flow during low-level prolonged static contraction in man. Acta Physiologica Scandinavica 128: 475-484

Sjøgaard G, Lundberg U, Kadefors R (2000) The role of muscle activity and mental load in the development of pain and degenerative processes at the muscle cell level during computer work. European Journal of Applied Physiology 83: 99-105

Sluiter JK, Rest KM, Frings-Dresen MHW (2001) Criteria document for evaluation of the work-relatedness of upper extremity musculoskeletal disorders. Scandinavian Journal of Work, Environment and Health 27: 1-102

Sogaard K, Sjogaard G, Finsen L, Olsen HB, Christensen H (2001) Motor unit activity during stereotyped finger tasks and computer mouse work. J Electromyogr Kinesiol 11: 197-206.

Sommerich CM, McGlothlin JD, Marras WS (1993) Occupational risk factors associated with soft tissue disorders of the shoulder: a review of recent investigations in the literature. Ergonomics 36: 697-717

Suurküla AJ, Hägg GM (1987) Relations between shoulder/neck disorders and EMG zero crossing shifts in female assembly workers using the test contraction method. Ergonomics 30: 1553-1564

Svensson P, Graven-Nielsen T, Matre D, Arendt-Nielsen L (1998) Experimental muscle pain does not cause long-lasting increases in resting electromyographic activity. Muscle & Nerve 21: 1382-1389

Svensson P, Macaluso GM, De Laat A, Wang K (2001) Effects of local and remote muscle pain on human jaw reflexes evoked by fast stretches at different clenching levels. Exp Brain Res 139: 495-502.

Talbot JA, Morgan DL (1998) The effects of stretch parameters on eccentric exercise-induced damage to toad skeletal muscle. J Muscle Res Cell Motil 19: 237-245

Theorell T (2000) Psychosocial factors at work in relation to musculoskeletal conditions. Implications for job design and rehabilitation. In: Violante F, Armstrong T, Kilbom Å (eds) Occupational ergonomics. Work related musculoskeletal disorders of the upper limb and back. Talyor and Francis, London, pp 29-50

Thorn S, Forsman M, Zhang Q, Taoda K (2002) Low-threshold motor unit activity during a 1-h static contraction in the trapezius muscles. International Journal of Industrial Ergonomics 30: 225-236

Thunberg J, Ljubisavljevic M, Djupsjöbacka M, Johansson H (2002) Effects on the fusimotor-muscle spindle system induced by intramuscular injections of hypertonic saline. Experimental Brain Research 142: 319-326

Vasseljen O, Westgaard RH (1995) A case-control study of trapezius muscle activity in office and manual workers with shoulder and neck pain and symptom-free controls. Int Arch Occup Environ Health 67: 11-18

Veiersted KB, Westgaard RH, Andersen P (1990) Pattern of muscle activity during stereotyped work and its relation to muscle pain. Int. Arch. Occup. Environ. Health 62: 31-41

Veiersted KB, Westgaard RH, Andersen P (1993) Electromyographic evaluation of muscular work pattern as a predictor of trapezius myalgia. Scand J Work Environ Health 19: 284-290

Viikari-Juntura E (1983) Neck and upper limb disorders among slaughterhouse workers, an epidemiologic and clinical study. Scandinavian Journal of Work, Environment and Health 9: 283-290

Visser B, De Looze M, De Graaff M, Van Dieen J (2004) Effects of precision demands and mental pressure on muscle activation and hand forces in computer mouse tasks. Ergonomics 47: 202-217

Vøllestad NK, Røe C (2003) Metabolic and Mechanical Changes during Low-Intensity Work and their Relation to Work-Related Pain. In: Johansson H, Windhorst U, Djupsjöbacka M, Passatore M (eds) Chronic work-related myalgia. Neuromuscular mechanisms behind work-related chronic muscle syndromes. Gävle University Press, Gävle

Waling K, Jarvholm B, Sundelin G (2002) Effects of training on female trapezius Myalgia: An intervention study with a 3-year follow-up period. Spine 27: 789-796

Wall PD, Woolf CJ (1984) Muscle but not cutaneus C-afferent input produces prolonged increases in the excitability of the flexion reflex in the rat. Journal of Physiology 356: 443-458

Waris P (1979) Occupational cervico-brachial syndromes. A review. Scandinavian Journal of Work, Environment and Health 5, suppl. 3: 3-14

Watkins LR, Maier SF (1999) Implications of immune-to-brain communication for sickness and pain. Proceedings of the National Academy of Sciences of the USA 96: 7710-7713

Watkins LR, Maier SF (2001) Beyond neurons: evidence that immune and glial cells contribute to pathological pain states. Physiological Reviews 82: 981-1011

Westad C, Westgaard RH, De Luca CJ (2003) Motor unit recruitment and derecruitment induced by brief increase in contraction amplitude of the human trapezius muscle. J Physiol 552: 645-656

Westerblad H, Bruton JD, Allen DG, Lannergren J (2000) Functional significance of Ca2+ in long-lasting fatigue of skeletal muscle. European Journal of Applied Physiology 83: 166-174

Westgaard RH, DeLuca CJ (1999) Motor unit substitution in long-duration contractions of the human trapezius muscle. Journal of Neurophysiology 82: 501-504

Westgaard RH, Jansen T, Jensen C (1996) EMG of neck and shoulder muscles: the relationship between muscle activity and muscle pain in occupational settings. In: Kumar S, Mital A (eds) Electromyography in ergonomics. Taylor and Francis, London, pp 227-258

Windhorst U, Hamm TM, Stuart DG (1989) On the function of muscle and reflex partitioning. Behavioral and Brain Sciences 12: 629-681

Yemm R (1977) The orderly recruitment of motor units of the masseter and temporal muscles during voluntary isometric contraction in man. J Physiol 265: 163-174

Yucesoy CA, Koopman BH, Baan GC, Grootenboer HJ, Huijing PA (2003) Effects of inter- and extramuscular myofascial force transmission on adjacent synergistic muscles: assessment by experiments and finite-element modeling. J Biomech 36: 1797-1811

Zedka M, Prochazka A, Knight B, Gillard D, Gauthier M (1999) Voluntary and reflex control of human back muscles during induced pain. Journal of Physiology 520: 591-604

Zennaro D, Laubli T, Krebs D, Klipstein A, Krueger H (2003) Continuous, intermitted and sporadic motor unit activity in the trapezius muscle during prolonged computer work. J Electromyogr Kinesiol 13: 113-124

Zuylen EJv, Gielen CCAM, Denier van der Gon JJ (1988) Coordination of inhomogeneous activation of human arm muscles during isometric torques. Journal of Neurophysiology 60: 1523-1548

Chapter 3

The contribution of task-related biomechanical constraints to the development of work-related myalgia

Jaap H. van Dieën[a], Bart Visser[a,b] and Veerle Hermans[a,c]

[a]Institute for Fundamental and Clinical Human Movement Sciences, Faculty of Human Movement Sciences, Vrije Universiteit Amsterdam, The Netherlands

[b]Body@Work, Research Center Physical Activity, Work and Health, TNO VUmc, Amsterdam, The Netherlands

[c]Currently: PREVENT vzw, Institute for Occupational Safety and Health, Brussels Belgium, and Faculty of Psychology and Education, Vrije Universiteit Brussel, Belgium

Abstract

The literature on the contribution of task-related constraints to the development of work-related myalgia (WRM) was reviewed. The literature on the pathophysiology of WRM, shows that the intensity of contractions and the lack of periods of complete relaxation play a major role in the development of WRM. The muscular activity might not only, be determined by task constraints, like the magnitude and direction of forces and moments, but also by constraints with respect to stability and position control. Sustained muscle activity in low intensity tasks might be the result of the necessity to preserve moment equilibrium in combination with the use of co-activation of muscles in order to suppress neuro-motornoise (i.e. noise resulting from imprecision of motor control). The literature shows that stability of the upper extremity might be influenced by the use of arm supports and that the level of co-contraction used to counteract the neuro-motor noise might be affected by task precision, and mental pressure.

3.1 Introduction

Work-related myalgia appears to mainly affect the neck and shoulder muscles, most notably the descending part of the trapezius muscle (Waris 1979; Kroemer 1989), although it has been suggested that myalgia is often overlooked as a cause of pain in the forearm (Ranney et al. 1995). The development of myalgia appears to be related to frequent execution of manual exertions, not necessarily of high intensity (Hagberg et al. 1995). A substantial body of epidemiological (Hagberg et al. 1995), physiological (Sjøgaard et al. 1986; Sjøgaard 1988; Jensen 1997; Lexell et al. 1997), and clinical (Larsson et al. 1990; Hägg 2000) evidence suggests that sustained contractions associated with hand-arm tasks may be a causative factor in the development of these complaints. Fatigue-related changes of intra-muscular electrolyte and metabolite concentrations have been assumed to underlie the patho-physiological process (Edwards 1988; Vøllestad and Sejersted 1988; Johansson and Sojka 1991; Gissel 2000).

Two aspects of muscular activity appear to constitute risk factors for work-related myalgia. The first aspect is the intensity of the contraction, with higher contraction levels increasing the probability of developing complaints (Westgaard et al. 1996). Evidently, disturbance of the muscular homeostasis will be more pronounced at higher contraction levels (assuming equal duration). This risk factor is therefore coherent with the above assumption on physiological mechanisms. The second risk factor is a lack of periods of complete relaxation of the muscle over the working day as is evidenced by an association of myalgia with the absence of brief interruptions of muscle activity (EMG-gaps) during work and the continuation of muscular activity during rest breaks (Westgaard et al. 1996). Again this appears to be coherent with the physiological literature, which suggests that fatigue development is more rapid as the contractions are more isotonic (Byström and Sjogaard 1991; Byström et al. 1991; Hermans and Spaepen 1997b). Variability of contraction level appears to reduce fatigue development even when the average contraction level is not changed (Mathiassen, personal communication). Animal experiments on the effects of prolonged muscle activity on fiber damage support the assumption that both intensity of contraction and lack of relaxation are important factors in the development of myalgia. Lexell et al. (1997) applied electrical stimulation to the peroneal nerve of rabbits at varying fairly low stimulation frequencies (10 Hz, 5 Hz, 2.5 Hz, and 1.25 Hz). In addition, 10 Hz stimulation was performed for 9 days either continuously or interrupted (1 hour on - 1 hour off). The animals were sacrificed after 9 days and the tibialis anterior and extensor digitorum longus muscles were investigated for evidence of degenerated muscle fibers. Largest percentages of degenerated fibers were found after 10 Hz continuous stimulation, followed by 5 Hz continuous stimulation. 10 Hz intermittent stimulation resulted in less fiber degeneration than 5 Hz continuous. Lower stimulation rates (2.5 and 1.25 Hz) caused only very little degeneration.

The above suggests that preventive actions towards myalgia might be based on reducing the activity level of the muscles involved and by avoiding sustained isotonic contractions of these muscles. The aim of the present contribution is therefore to review to what extent task-related biomechanical constraints affect the level of muscular activity in the arm and neck and shoulder muscles and the occurrence of sustained contractions. Though myalgia appears to involve in particular neck and shoulder muscles, only limited experimental data is available on this muscle-joint system. Therefore, it is necessary to draw upon data collected from other muscle-joint systems. Where possible, we will attempt to relate the concepts considered to the function of neck and shoulder muscles in manual exertions typically associated with myalgia. To this end we will use computer input work as an example. This is probably one of the most common occupational tasks at present and it has been shown to be related to myalgia (Punnett and Bergqvist 1997).

3.2 Biomechanical Constraints and Muscle Activity

In producing a sub-maximal moment about a joint a large number of degrees of freedom exists with respect to which muscles, parts of muscles, or ultimately motor units are recruited. In the motor control literature, this has been typically addressed as a 'problem of choice' for the central nervous system (Bernstein 1967). It has been well established that the preferential recruitment of fatigue-resistant, type I motor units, known as the size principle, acts as a neurophysiological constraint limiting the available degrees of freedom (Henneman et al. 1965). Both patterns of intra-muscular co-ordination (i.e. the recruitment order of motor units) (Milner-Brown et al. 1973) and patterns of inter-muscular co-ordination (Kuo and Clamann 1981) can in part be explained on this basis. The size principle has even been suggested to be a key factor in the pathophysiology of myalgia, since it might lead to selective overloading of type I motor units in sustained activity (Hägg 1991). As Bernstein (1967) pointed out, task-related mechanical constraints might further reduce the degrees of freedom available. A wide range of studies has attempted to explain inter-muscular coordination of specific motor tasks on the basis of these mechanical constraints. The present paper will follow this approach.

In general two types of mechanical constraint can be discerned. The first type of constraint is based on the requirement that the sum of the moments about the joints produced by all external forces including gravity and inertial forces is balanced by equal and opposite moments produced by the muscles. Thus the level of activity of the muscles is in part determined by the magnitude and direction of the moments acting on the upper arm. Note that these external moments do also comprise the moment effect of reaction forces due to forces exerted by the subject on the environment. The second type of constraint is related to stability, i.e. the requirement that the hand-arm system returns to its original posture or movement trajectory after a perturbation. In practice moment equilibrium is not a sufficient condition for a stable posture or movement. Since passive stiffness of the joints involved is low, especially in the shoulder girdle, muscle (co-)activation is required to provide adequate joint stiffness. In the following we will consider the consequences with respect to muscle activity of the necessity to balance external moments. We will separately address equilibration of moments in magnitude and direction. Subsequently we will consider the effect of stability constraints on muscle activity. In the final paragraph the implications of the findings with respect to the pathogenesis and the prevention of myalgia will be discussed.

3.2.1 The Magnitude of the External Moment

In a computer input task, the external moments about the joints involved are mainly caused by gravitational forces acting on the arm segments. The effect of the moment-equilibrium constraint in such tasks is quite straightforward and has been addressed in various studies (for a review see Jensen et al. 1999). It will therefore be outlined only briefly to clarify some biomechanical principles and for the sake of completeness. The moment arms of the gravitational forces and consequently the arm posture are the main determinants of the required muscle moment. Consider a subject typing with the upper arms slightly abducted and the elbow 90 degrees flexed. Gravity acts on the arm producing an adducting moment about the glenohumeral joint, which needs to be counteracted by abductor muscles (medial deltoid and supraspinous muscles). The sum of the moments produced by these muscles has to equilibrate the net moment, i.e. the product of the moment arm and magnitude of the gravitational force acting on the arm. In turn these muscles exert a force on the scapula which needs to be counteracted by for instance the trapezius and levator scapulae muscles. Obviously larger moments require larger muscle forces and consequently higher activation. As an additional effect the number of degrees of freedom in terms of the choice of which motor units will be recruited is reduced. Consequently, less temporal variation of motor unit activity will be possible (Fallentin et al. 1985).

Changes in arm posture (e.g. less abduction of the upper arm) obtainable through workplace modifications (e.g. keyboard redesign, work height correction), reduce the moment arm of the gravitational forces and consequently the muscle activity required. Arm support could in theory completely abolish the net moment by equilibrating the gravitational forces. Although arm support has been shown to reduce the activity of the descending part of trapezius, its effect is rather limited (Aarås and Ro 1998; Hermans et al. 1998; Visser et al. 2000). Apparently, even though the net moment may be completely negated, muscle activity is not. As we will see below, the remaining activity can be explained on the basis of additional constraints (paragraph 2.3).

3.2.2 The Direction of the Joint Moment or External Force

As mentioned in the introduction, a given sub-maximal net moment about a joint can be produced by activating different combinations of motor units. This 'problem of choice' can just as well be considered as an 'opportunity of choice'. Several studies have shown that, when subjects are instructed to sustain a sub-maximal moment about a joint, the activity of individual muscles (Sirin and Patla 1987; Dieën et al. 1994; Hermans and Spaepen 1997b), muscle parts (Sjøgaard et al. 1986; Zijdewind et al. 1995), and even motor units (Fallentin et al. 1985; Westgaard and DeLuca 1999) will vary over time, in some cases including complete derecruitment. Some studies have confirmed the presence of time varying recruitment for parts of the descending part of the trapezius muscles (Mathiassen and Winkel 1990; Sundelin and Hagberg 1992; Hermans and Spaepen 1997a; Jensen and Westgaard 1997; Westgaard and DeLuca 1999). Given the fact that the moment is sustained, reduced activity in one muscle (part) needs to be compensated by another muscle (part) (Palmerud et al. 1998). We have been able to show that this alternating of muscle activity reduces fatigue development substantially in trunk extensor muscles (Dieën et al. 1993).

Model simulations suggest that this also holds for neck and shoulder muscles (Nieminen et al. 1995; Niemi et al. 1996). Given the 'opportunity of choice' provided by the "redundant" number of motor units crossing each joint and the beneficial effects of temporally varying activation, one might wonder why prolonged (isotonic) contractions occur at all.

Obviously muscles, but even subpopulations of motor units with overlapping muscle territory, are functionally (mechanically) differentiated, i.e. they contribute to moments in a specific direction resulting in a specific direction of the force applied on the environment or, in other words, to a specific task (Zuylen et al. 1988; Turkawski et al. 1998). In an experiment on the first dorsal interosseus (FDI) muscle during sub-maximal index abduction, switches in recruitment of muscle parts were shown to coincide with changes in the direction of the moment exerted (Zijdewind et al. 1995). While the abduction moment was kept constant as instructed, in several cases it could be shown that moments about the flexion/extension axis changed sign at the instants recruitment strategy changed. The temporal variation in recruitment was therefore referred to as "task switching". Reversing the line of thought it can be argued that in a very constrained task, this phenomenon will not be observed, or in other words that tasks, which require an external force to be applied in a specific direction continuously, pose such constraints that sustained recruitment of a population of motor units will result. The effect of such task constraints on temporal variation of muscle activation has to our knowledge not been explicitly investigated. Investigating the effects of constraints on force magnitude in a two-finger pinching task, we did find more selective loading of one finger when force level was more precisely controlled (Visser et al. 2003). This suggests that more strict constraints on the level of the external force produced cause more selective loading of parts of a synergistic group. However temporal variability of the force contribution of the fingers was unaffected and constraints on the direction of the external force were not given. A comparison of different experiments provides some indirect evidence for an effect of joint moment direction constraints on alternating of activity between synergists. For example, in contrast with Zijdewind et al. (see above), consistent steady increases in EMG activity of the FDI muscle were found in a study in which the moment direction was strictly controlled (Fuglevand et al. 1993).

The results obtained by Zijdewind et al. (1995) imply a topographical clustering of functionally related motor units in FDI. Therefore, it is possible that the mechanically specialized subpopulations of motor units identified in experiments on human subjects (Zuylen et al. 1988) are equivalent to muscle compartments that have been identified in animal experiments (Windhorst et al. 1989). In several arm and shoulder muscles, among them the trapezius muscle, indications for compartmentalization have been found (Mathiassen and Winkel 1990; Brown et al. 1993; Paton and Brown 1994; Jensen et al. 1995; Hermans and Spaepen 1997a; Jensen and Westgaard 1997). If compartmentalization is indeed present in human muscles, constrained tasks would involve activity of motor units in the same compartment and local intra-muscular pressure might be much higher then expected on the basis of overall muscle activity (Sjøgaard et al. 1986). Consequently, local homeostatic disturbances might also be larger than expected.

3.2.3 Stability and Position Control

3.2.3.1 Reaction forces and interaction torques

Equilibration of moments about all the upper extremity joints caused by external forces is not a sufficient condition for a stable position or movement trajectory of the hand. To be able to perform tasks such as computer input work the hand needs to return to its original position or trajectory after a transient perturbation. Passive stiffness of the joints especially in the normal operating range of motion is too low to achieve this and therefore muscle activity is required (Rozendaal 1997). In theory this could be achieved by feedback control. However, given the delays in neuromuscular control this will cause disturbances of task performance (Bennett 1993; Milner 1993).

In computer input tasks the proximal joints of the arm have to be maintained in position, whereas the distal joints perform a fast repetitive dynamic task. Reaction forces and torques caused by these distal motions will perturb the position of the proximal joints. Muscles flexing the finger joints directly perturb the wrist joint angle, consequently sustained wrist extensor muscle activity is required (Hägg and Milerad 1997; Visser et al. 2003). However also indirect perturbations do occur. For instance the reaction force caused by hitting a key on the keyboard with the index finger will create a perturbing moment about the elbow joint in supination and flexion direction. Reaction forces in keying on a computer keyboard are in general between 2.5 and 7 N (Martin et al. 1996) and occur at a frequency of 2-3 Hz. This will result in a flexion perturbation at the elbow joint of about 1 to 3 Nm at the same frequency.

In a study by Milner (1993), similar magnitude (5 Nm) transient (50 ms) perturbations caused positional disturbances of as much as 0.7 rad (40 degrees) of relaxed static elbow postures. During movements, elbow stiffness was somewhat higher, resulting in perturbations of up to 0.25 rad (14 degrees) during fast movements and up to 0.4 rad (23 degrees) during slow movements. Even lower stiffness values (2-4 Nm/rad) for the elbow joint in a relaxed posture were reported by Bennett (1993). After a transient 5 Nm perturbation the elbow returned to the unperturbed movement trajectory only after more than 400 ms in slow movements and 200 ms in the faster movements (Milner 1993). Relating these data to the perturbing moment caused by keying forces suggests that the reaction forces in keying could cause substantial perturbations of arm position.

To hit the next key correctly perturbations of substantial magnitude as described above need to be corrected quickly (before the next key is hit, i.e. within 300-500 ms). In view of the delays in feedback control, it may be problematic to achieve such corrections fast enough. However, muscle stiffness provides instantaneous corrections, suppressing the perturbation effects on kinematics. It is strongly determined by short-range stiffness (stretching of attached cross-bridges) (Rack and Westbury 1974; Cholewicki and McGill 1995), the force-length-velocity relation of muscle (Soest and Bobbert 1993; Burg et al. submitted), and history dependence of muscle contractile force (Ettema 2002). All of these become more effective with higher numbers of cross-bridges attached in the stretched muscle. Thus increased activation, which in static postures requires co-activation of agonist and antagonist muscles, will increase stiffness and as such can prevent large positional disturbances (Akazawa et al. 1983; Cholewicki et al. 2000; Stokes and Gardner-Morse 2000; Stokes et al. 2000). Given the fact that the corrective reflex actions take effect with relatively high delay as mentioned above this may be a necessary strategy in fast repetitive tasks.

Returning to computer input work, the stability constraint identified might explain the proximal muscle activity found even when using arm supports. However, it can be argued that the perturbations in this task are caused by actions performed by the subject and consequently can be anticipated. By adequate coordination of distal and proximal muscle activity only phasic stabilizing activity would be required. It is at present unclear whether in tasks as fast as keying this is indeed feasible.

3.2.3.2 Suppression of neuromotor noise

Stability constraints become more problematic when tasks require high precision, due to the fact that motor control is to some extent imprecise as a consequence of bandwidth limited noise arising in the neural control and motor systems (Galen and Jong 1995; Galen et al. 1996; Gemmert and Galen 1997; Harris 1998; Harris and Wolpert 1998). This noise consists of inaccuracies either in motor planning or execution (Wing and Kristofferson 1973). Noise levels in the neural system are expected to depend on factors such as force level (Harris and Wolpert 1998) and movement velocity (Wing and Kristofferson 1973), and the presence of additional stressors (Gemmert and Galen 1997; Gemmert and Galen 1998; Noteboom et al. 2001a; Noteboom et al. 2001b). Levels of noise in the motor system may depend on task conditions such as the number of degrees of freedom involved (Heuvel et al. 1998).

The neuromotor noise theory states that in order to obtain a desired level of positional accuracy of the end-effector (e.g., hand, finger, mouse), noise is filtered out by increasing joint stiffness through co-activation (Galen and Jong 1995; Galen et al. 1996; Gemmert and Galen 1997). Perturbation experiments (Bennett 1993; Milner 1993; Cholewicki et al. 2000; Mirbagheri et al. 2000; Stokes and Gardner-Morse 2000; Stokes et al. 2000) show that joint stiffness is indeed closely related to the level of muscle activity. In addition, when subjects are exposed to higher levels of environmental mechanical noise, trunk muscle co-activation in lifting is elevated (Dieën et al. 2003) and arm stiffness in aiming is increased (Burdet et al. 2001).

The assumption that increasing limb stiffness is used to counteract effects of noise of neural origin is non-trivial, for several reasons. Neural noise is usually assumed to be signal-dependent (Galen and Jong 1995; Harris and Wolpert 1998; Christou et al. 2002). This would imply that with increased co-activation, neural noise would increase, possibly negating the beneficial effect of the increased stiffness. In addition, the increased resonant frequency of the limb, accompanying increased stiffness, might amplify the effects of noise. However, a simulation study suggests that increased co-activation may indeed filter out neural noise resulting in higher movement accuracy (Seidler-Dobrin et al. 1998).

Empirical support for the use of co-activation to filter out neuromotor noise is based on indirect evidence, such as increased pen tip pressure in writing characters with increasing task demands or under stressful task conditions (Gemmert and Galen 1998; Heuvel et al. 1998) and on experimental data on EMG increases with increasing precision demands (Milerad and Ericson 1994; Laursen et al. 1998; Sporrong et al. 1998; Birch et al. 2000). Unfortunately, in the latter studies movement velocity and precision realized were not but carefully controlled. More recent studies did control for these factors and showed a limited increase of muscle activity in the upper extremity in response to increased precision demands (Laursen and Jensen 2000; Visser et al. 2004). Furthermore, some studies have shown evidence of increased muscle activity when tasks are performed under stressful conditions (Larsson et al. 1995; Westgaard et al. 1996; Lundberg et al. 1999; Galen et al. 2002; Visser et al. 2004).

At present, it is unclear how co-activation level is modulated with required precision or neuromotor noise level. Hence little can be said about the physiological cost of the assumed strategy. Nevertheless, if high precision demands solicit more co-activation, and consequently higher and more sustained muscle activity, fatigue-related accumulation of electrolytes and metabolites will be more pronounced. This will affect the gamma-system through type III and IV afference from the muscle. In cats, this has been shown to cause an increased static firing rate of the muscle-spindle afferents and a reduced information content of muscle-spindle and Golgi tendon organ feedback from both agonist and antagonist muscles (Djupsjöbacka et al. 1994; Bergenheim 1995; Pedersen et al. 1997; Pedersen et al. 1998). In line with this expectation, fatigue in humans was shown to reduce proprioceptive acuity (Pedersen et al. 1999; Björklund et al. 2000). Fatigue can thus be expected to increase neural noise. In addition, fatigue can be expected to increase synchronization of motor unit firing (Maton 1981; Krogh-Lund and Jorgensen 1992), which will likely cause increased motor noise (Lippold 1981; Yao et al. 2000).

Given the expected increase of neural and motor noise with fatigue, it can be assumed that the implications of the precision demands are amplified by fatigue. Higher precision demands presumably entail more co-activation (see above). The increased co-activation would accelerate fatigue development, which in turn would require more co-activation to maintain precision. Due to the fact that fatigue development affects the EMG force relationship, only tentative support for an effect of fatigue on co-activation can be found (Gagnon et al. 1992; Psek and Cafarelli 1993).

3.3 Relevance for Pathogenesis and Prevention of Myalgia

From the above it appears that high frequency movements of the distal joints require sustained contractions of the stabilizing musculature to suppress the negative effects of reactive forces and interaction torques on performance. Furthermore, the noise in the neural control signals constrains the solution space available in the type of tasks typically associated with myalgia. The unfavorable signal-to-noise ratio of neural control (Galen and Jong 1995; Christou et al. 2002; Visser et al. 2003) in low-intensity contractions probably causes precision demands to be more constraining in the type of task typically associated with myalgia than in high-intensity tasks.

Several chapters in this volume describe the effects of sustained activity on muscle spindle information and proprioception. If as discussed proprioception deteriorates during sustained activity, it is highly likely that this will affect the precision with which movement tasks can be performed (Sainburg et al. 1993; Cordo et al. 1995). Less precise control will cause more frequent and/or larger perturbations of the required joint positions or trajectories. To deal with these, a further increase in co-activation of stabilizing musculature would be required. This in turn will entail sustained contractions and a vicious circle may develop. This vicious circle may be strengthened through the influence of mental stress. Once pain has developed its effect as a potent mental stressor may further increase the gain of this feedback loop.

In prevention of myalgia one of the aspects traditionally addressed has been the moment-equilibrium constraint in upper extremity tasks. Examples of approaches addressing this aspect are for instance optimization of working-postures and providing arm support. The above suggests that, in addition, constraints related to task precision (force direction and end-effector position) and mental stressors need to be considered. Certainly in combination with stress, precision demands may initiate or strengthen a vicious circle, which might lead to myalgia. Given precision demands and the presence of neuromotor noise, sustained activity of some stabilizing muscles is inevitable in computer work. Therefore, work-place optimization can only partially decrease the risk factors for myalgia. Work organization will be crucial. The theory indicates that rest breaks and reducing the total task duration, need to be considered in prevention.

This is supported by epidemiological and intervention studies showing the effects of such measures (Blatter and Bongers 2002; Jensen et al. 2002; Heuvel et al. 2003). Furthermore variability in muscle activation can be promoted by variability in task content, which thus suggests that job-enlargement provides opportunities to prevent work-related myalgia.

3.4 References

Aarås A, Ro O (1998) Supporting the forearms at the table top doing VDU work. A laboratory and field study. In: Kumar S (ed) Advances in Occupational Ergonomics and safety. IOS, Amsterdam, pp 549-552

Akazawa K, Milner TE, Stein RB (1983) Modulation of reflex EMG and stiffness in reponse to stretch of human finger muscle. Journal of Neurophysiology 49: 16-27

Bennett DJ (1993) Torques generated at the human elbow joint in response to constant position errors imposed during voluntary elbow joint movements. Experimental Brain Research 95: 488-498

Bergenheim M (1995) Encoding of stimulus discrimination in ensembles of muscle afferents. In: Department of Physiology. University of Umea, Umea

Bernstein N (1967) The coordination and regulation of movements. Pergamon Press, Oxford, UK

Birch L, Juul-Kristensen B, Jensen C, Finsen L, Christensen H (2000) Acute repsonses to precision, time pressure and mental demand during simulated computer work. Scandinavian Journal of Work, Environment and Health 26: 299-305

Björklund M, Crenshaw AG, Djupsjöbacka M, Johansson H (2000) Position sense acuity is diminished following repetitive low-intensity work to fatigue in a simulated occupational setting. European Journal of Applied Physiology 81: 361-367

Blatter BM, Bongers PM (2002) Duration of computer use and mouse use in relation to musculoskeletal disorders of neck and upper limb. International Journal of Industrial Ergonomics 30: 295-306

Brown JMM, Solomon C, Paton ME (1993) Further evidence of functional differentiation within biceps brachii. Electromyography and clinical Neurophysiology 33: 301-309

Burdet E, Osu R, Franklin DW, Milner TE, Kawato M (2001) The central nervous system stabilizes unstable dynamics by learning optimal impedance. Nature 414: 446-449.

Burg JCEvd, Casius LJR, Kingma I, Dieën JHv, Soest AJv (submitted) The contribution of muscle properties in controlling perturbations during lifting. Journal of Biomechanics

Byström SE, Sjogaard G (1991) Potassium homeostasis during and following exhaustive submaximal static handgrip contractions. Acta Physiologica Scandinavica 142: 59-66

Byström SEG, Mathiassen SE, Fransson-Hall C (1991) Physiological effects of micropauses in isometric handgrip exercise. European Journal of Applied Physiology 63: 405-411

Cholewicki J, McGill SM (1995) Relationship between muscle force and stiffness in the whole mammalian muscle: A simulation study. Journal of Biomechanical Engineering 117: 339-342

Cholewicki J, Simons APD, Radebold A (2000) Effects of external trunk loads on lumbar spine stability. Journal of Biomechanics 33: 1377-1385

Christou EA, Grossman M, Carlton LG (2002) Modeling variability of force during isometric contractions of the quadriceps femoris. J Mot Behav 34: 67-81

Cordo P, Bevan L, Gurfinkel V, Carlton L, M. C, Kerr G (1995) Proprioceptive coordination of discrete movement sequences: mechanism and generality. Canadian Journal of Physiology and Pharmacology 73: 305-315

Dieën JHv, Heijblom P, Helmes MHB, Oude Vrielink HHE (1994) Fatigue during low-intensity contractions of the triceps surae. In: Wolf S (ed) Tenth congress of the International Society of Electrophysiology and Kinesiology. ISEK, Charleston, pp 58-59

Dieën JHv, Kingma I, van der Bug JC (2003) Evidence for a role of antagonistic cocontraction in controlling trunk stiffness during lifting. J Biomech 36: 1829-1836

Dieën JHv, Oude Vrielink HHE, Toussaint HM (1993) An investigation into the relevance of the pattern of temporal activation with respect to erector spinae muscle endurance. European Journal of Applied Physiology 66: 70-75

Djupsjöbacka M, Johansson H, Bergenheim M (1994) Influences on the gamma-muscle-spindle system from muscle afferents stimulated by increased intramuscular concentrations of arachidonic acid. Brain Research 663: 293-302

Edwards RHT (1988) Hypotheses of peripheral and central mechanisms underlying occupational muscle pain and injury. European Journal of Applied Physiology 57: 275-281

Ettema GJ (2002) Effects of contraction history on control and stability in explosive actions. Journal of Electromyography and Kinesiology 12: 455-461

Fallentin N, Sidenius B, Jorgensen K (1985) Blood pressure, heart rate and EMG in low-level static contractions. Acta Physiologica Scandinavica 125: 265-275

Fuglevand AJ, Winter DA, Patla AE (1993) Models of recruitment and rate coding organization in motor-unit pools. Journal of Neurophysiology 70: 2470-2488

Gagnon D, Arsenault AB, Smyth G, Kemp F (1992) Cocontraction changes in muscular fatigue at different levels of isometric contraction. International Journal of Industrial Ergonomics 9: 343-348

Galen GPv, Hendriks AW, Jong WPd (1996) What Behavioral Benefit Does Stiffness Control Have - an Elaboration of Smiths Proposal. Behavioral & Brain Sciences 19: 478-479

Galen GPv, Jong WPd (1995) Fitts Law As the Outcome of a Dynamic Noise Filtering Model of Motor Control. Human Movement Science 14: 539-571

Galen GPv, Müller MLTM, Meulenbroek RGJ, Gemmert AWAv (2002) Forearm EMG response activity during motor performance in individuals prone to increased stress reactivity. American Journal of Industrial Medicine 41: 406-419

Gemmert AWAv, Galen GPv (1997) Stress, Neuromotor Noise, and Human Performance - a Theoretical Perspective. Journal of Experimental Psychology: Human Perception & Performance 23: 1299-1313

Gemmert AWAv, Galen GPv (1998) Auditory Stress Effects On Preparation and Execution of Graphical Aiming - a Test of the Neuromotor Noise Concept. Acta Psychologica 98: 81-101

Gissel H (2000) Ca2+ accumulation and cell damage in skeletal muscle during low frequency stimulation. European Journal of Applied Physiology 83: 175-180

Hagberg M, Silverstein B, Wells R, Smith MJ, Hendrick HW, Carayon P, Pérusse M (1995) Work related musculoskeletal disorders. A reference book for prevention. Taylor and Francis, London

Hägg G (1991) Static work loads and occupational myalgia - a new explanation model. In: Danoff JV (ed) Electromyographical kinesiology. Elsevier science, Amsterdam, pp 141-143

Hägg GM (2000) Human muscle fibre abnormalities related to occupational load. European Journal of Applied Physiology 83: 159-165

Hägg GM, Milerad E (1997) Forearm extensor and flexor muscle exertion during simulated gripping work – an electromyographic study. Clinical Biomechanics 12: 39-43

Harris CM (1998) On the optimal control of behaviour: a stochastic perspective. J Neurosci Methods 83: 73-88

Harris CM, Wolpert DM (1998) Signal-dependent noise determines motor planning. Nature 394: 780-784

Henneman E, Somjen G, Carpenter DO (1965) Excitability and inhibitability of motorneurons of different sizes. Journal of Neurophysiology 28: 599-620

Hermans V, Hautekiet M, Spaepen AJ (1998) Relation between posture and neck-shoulder muscular effort. In: Kumar S (ed) Advances in Occupational Ergonomics and safety. IOS, Amsterdam, pp 202-205

Hermans V, Spaepen AJ (1997a) Influence of electrode position on changes in electromyograph parameters of the upper trapezius muscle during submaximal sustained contractions. European Journal of Applied Physiology 75: 319-325

Hermans V, Spaepen AJ (1997b) Muscular activity of the shouler and neck region during sustained and intermittent exercise. Clinical Physiology 17: 95-104

Heuvel CEvd, Galen GPv, Teulings H-L, Gemmert AWAv (1998) Axial pen force increases with processing demands in handwriting. 100: 145-159

Heuvel SGvd, Looze MPd, Hildebrandt VH, The KH (2003) Effects of software programs stimulating regular breaks and exercises on work-related neck and upper-limb disorders. Scandinavian Journal of Work Environment & Health 29: 106-116

Jensen BR (1997) Doppler blood flow and peripheral resistance in the forearm during and following low-level isometric hand-grip contractions. Advances in occupational medicine and rehabilitation 3: 21-35

Jensen BR, Jørgensen K, Huijing PA, Sjøgaard G (1995) Soft tissue architecture and intramuscular pressure in the shouder region. European Journal of Morphology 33: 205-220

Jensen C, Finsen L, Søgaard K, Christensen H (2002) Musculoskeletal symptoms and duration of computer and mouse use. International Journal of Industrial Ergonomics 30: 265-275

Jensen C, Laursen B, Sjøgaard G (1999) Shoulder and Neck. In: Kumar S (ed) Biomechanics in ergonomics. Taylor and Francis, London, pp 201-220

Jensen C, Westgaard RH (1997) Functional subdivision of the upper trapezius muscle during low-level activation. European Journal of Applied Physiology 76: 335-339

Johansson H, Sojka P (1991) Pathophysiological mechanisms involved in genesis and spread of muscular tension in occupational muscle pain and in chronic musculoskeletal pain syndromes. A hypothesis. Medical Hypotheses 35: 196-203

Kroemer K (1989) Cumulative trauma disorders: Their recognition and ergonmics measures to avoid them. Applied Ergonomics 20: 274-280

Krogh-Lund C, Jorgensen K (1992) Modification of myo-electric power spectrum in fatigue from 15% maximal voluntary contraction of human elbow flexor muscles, to limit of endurance: reflection of conduction velocity variation and/or centrally mediated mechanisms. European Journal of Applied Physiology and Occupational Physiology 64: 359-370

Kuo KHM, Clamann HP (1981) Coactivation of synergistic muscles of different fiber types in fast and slow contractions. American Journal of Physical Medicine & Rehabilitation 60: 219-238

Larsson SE, Bodegard L, Henriksson KG, Oberg PA (1990) Chronic trapezius myalgia. Morphology and blood flow studied in 17 patients. Acta Orthopaedica Scandinavica 61: 394-398

Larsson SE, R. L, Zhang Q, Cai H, Oberg PA (1995) Effect of psychophysical stress on trapezius muscle blood flow and electromyography during static load. European Journal of Applied Physiology 71: 493-498

Laursen B, Jensen BR (2000) Shoulder muscle activity in young and older people during a computer mouse task. Clinical Biomechanics 15: S30-33

Laursen B, Jensen BR, Sjøgaard G (1998) Effect of speed and precision demands on human shoulder muscle electromyography during a repetitive task. European Journal of Applied Physiology 78: 544-548

Lexell J, Jarvis JC, Downham DY, Salmons S (1997) Muscle damage induced by neuromuscular stimulation. In: Salmons S (ed) Muscle damage. Oxford University Press, Oxford, pp 76-89

Lippold OC (1981) The tremor in fatigue. In: Whelan J (ed) Human muscle fatigue: physiological mechanisms. Pitman medical, London, pp 234-248

Lundberg U, Dohns IE, Melin L, Sondsjo L, Palmerud G, Kadefors R, Enkstrom M, Parr D (1999) Psychophysiological stress responses, muscle tension and neck and shoulder pain among supermarket cahsiers. Journal of Occupational Health Psychology 4: 245-255

Martin BJ, Armstrong TJ, Natarjan S, Rempel D, Linenberg E, Serina E (1996) Keyboard reaction force and finger flexor electromyograms during computer keyboard work. Human Factors 38: 654-664

Mathiassen SE, Winkel J (1990) Electromyographic activity in the shoulder-neck region according to arm position and glenohumeral torque. European Journal of Applied Physiology 61: 370-379

Maton B (1981) Human motor unit activity during the onset of muscle fatigue in submaximal isometric isotonic contraction. European Journal of Applied Physiology 46: 271-281

Milerad E, Ericson MO (1994) Effects of precision and force demands, grip diameter, and arm support during manual work: an electromyographic study. Ergonomics 37: 255-264

Milner TE (1993) Dependence of elbow viscoelastic behavior on speed and loading in voluntary movements. Experimental Brain Research 93: 177-180

Milner-Brown HS, Stein RB, Yemn R (1973) The orderly recruitment of human motor units during voluntary isometric contractions. Journal of Physiology (London) 230: 359-370

Mirbagheri MM, Barbeau H, Kearney RE (2000) Intrinsic and reflex contribution to human ankle stiffness: variation with activation level and position. Experimental Brain Research 135: 423-436

Niemi J, Nieminen H, Takala EP, Viikari-Juntura E (1996) A static shoulder model based on a time-dependent criterion for load sharing between synergistic muscles. Journal of Biomechanics 29: 451-460

Nieminen H, Takala EP, Niemi J, Viikarijuntura E (1995) Muscular Synergy in the Shoulder During a Fatiguing Static Contraction. Clinical Biomechanics 10: 309-317

Noteboom JT, Barnholt KR, Enoka RM (2001a) Activation of the arousal response and impairment of performance increase with anxiety and stressor intensity. J Appl Physiol 91: 2093-2101.

Noteboom JT, Fleshner M, Enoka RM (2001b) Activation of the arousal response can impair performance on a simple motor task. Journal of Applied Physiology 91: 821-831.

Palmerud G, Sporrong H, Herberts P, Kadefors R (1998) Consequences of trapezius relaxation on the distribution of shoulder muscle forces: an electromyographic study. Journal of Electromyography & Kinesiology 8: 185-193

Paton ME, Brown JMM (1994) An electromyographic analysis of functional differentiation in human pectroalis major muscle. Journal of Electromyography and Kinesiology 4: 161-169

Pedersen J, Ljubisavljevic M, Bergenheim M, Johansson H (1998) Alterations in Information Transmission in Ensembles of Primary Muscle Spindle Afferents After Muscle Fatigue in Heteronymous Muscle. Neuroscience 84: 953-959

Pedersen J, Lönn J, Hellström F, Djupsjöbacka M, Johannsson H (1999) Localized muscle fatigue decreases the acuity of the movement sense in the human shoulder. Medicine and Science in Sports and Exercise 31: 1047-1052

Pedersen J, Sjolander P, Wenngren BI, Johansson H (1997) Increased Intramuscular Concentration of Bradykinin Increases the Static Fusimotor Drive to Muscle Spindles in Neck Muscles of the Cat. Pain 70: 83-91

Psek JA, Cafarelli E (1993) Behavior of coactive muscles during fatigue. Journal of Applied Physiology 74: 170-175

Punnett L, Bergqvist U (1997) Visual display unit work and upper extremity disorders. A review of epidemiological findings. In: Kjellberg K (ed) National Institute for working Life - Ergonomic expert committee document no. 1. National Institute for Working Life, Solna, pp 1-161

Rack PMH, Westbury DR (1974) The short range stiffness of active mammalian muscle and its effect on mechanical properties. Journal of Physiology 240: 331-350

Ranney D, Wells R, Moore A (1995) The anatomical location of work-related chronic musculoskeletal disorders in selected industries characterized by repetitive upper limb activity. Ergonomics 38: 1408-1423

Rozendaal L (1997) Stability of the shoulder. Intrinsic muscle properties and reflexive control. In. Delft University of Technology, Delft, p 291

Sainburg RL, Poizner H, Ghez C (1993) Loss of proprioception produces deficits in interjoint coordination. J Neurophysiol 70: 2136-2147

Seidler-Dobrin RD, He J, Stelmach GE (1998) Coactivation to reduce variability in the elderly. Motor Control 2: 314-330

Sirin AV, Patla AE (1987) Myoelectric changes in the triceps surae muscles under sustained contractions. Evidence for synergism. European Journal of Applied Physiology 56: 238-244

Sjøgaard G (1988) Muscle energy metabolism and electrolyte shifts during low-level prolonged static contraction in man. Acta Physiologica Scandinavica 134: 181-187

Sjøgaard G, Kiens B, Jorgensen K, Saltin B (1986) Intramuscular pressure, EMG and blood flow during low-level prolonged static contraction in man. Acta Physiologica Scandinavica 128: 475-484

Soest AJv, Bobbert MF (1993) The contribution of muscle properties in the control of explosive movements. Biological Cybernetics 69: 195-204

Sporrong H, Palmerud G, Kadefors R, Herberts P (1998) The effect of light manual precision work on shoulder muscles--an EMG analysis. Journal of Electromyography & Kinesiology 8: 177-184

Stokes IAF, Gardner-Morse MG (2000) Strategies used to stabilize the elbow joint challenged by inverted pendulum loading. Journal of Biomechanics 33: 737-743

Stokes IAF, Gardner-Mrsoe M, Henry SM, Badger GJ (2000) Decrease in trunk muscular response to perturbation with preactivation of lumbar spinal musculature. Spine 25: 1957-1964

Sundelin G, Hagberg M (1992) Electromyographic signs of shoulder muscle fatigue in repetitive arm work paced by the time-methods measurement system. Scandinavian Journal of Work, Environment and Health 18: 262-268

Turkawski SJJ, Van Eijden TMGJ, Weijs WA (1998) Force vectors of single motor units in a multipennate muscle. Journal of Dental Research 77: 1823-1831

Visser B, de Korte E, van der Kraan I, Kuijer P (2000) The effect of arm and wrist supports on the load of the upper extremity during VDU work. Clinical Biomechanics 15: S34-38

Visser B, De Looze M, De Graaff M, Van Dieen J (2004) Effects of precision demands and mental pressure on muscle activation and hand forces in computer mouse tasks. Ergonomics 47: 202-217

Visser B, Looze MPd, Veeger HEJ, Douwes M, Groenesteijn L, Korte Ed, Dieën JHv (2003) The effects of precision demands during a low intensity pinching task on muscle activation and load sharing of the fingers. Journal of Electromyography and Kinesiology 13: 149-157

Vøllestad NK, Sejersted OM (1988) Biochemical correlates of fatigue A brief review. European Journal of Applied Physiology 57: 336-347

Waris P (1979) Occupational cervico-brachial syndromes. A review. Scandinavian Journal of Work, Environment and Health 5, suppl. 3: 3-14

Westgaard RH, DeLuca CJ (1999) Motor unit substitution in long-duration contractions of the human trapezius muscle. Journal of Neurophysiology 82: 501-504

Westgaard RH, Jansen T, Jensen C (1996) EMG of neck and shoulder muscles: the relationship between muscle activity and muscle pain in occupational settings. In: Mital A (ed) Electromyography in ergonomics. Taylor and Francis, London, pp 227-258

Windhorst U, Hamm TM, Stuart DG (1989) On the function of muscle and reflex partitioning. Behavioral and Brain Sciences 12: 629-681

Wing AM, Kristofferson AB (1973) Response delays and the timing of discrete motor responses. Perception & Psychophysics 14: 5-12

Yao W, Fuglevand RJ, Enoka RM (2000) Motor-unit synchronization increases EMG amplitude and decreases force steadiness of simulated contractions. Journal of Neurophysiology 83: 441-452.

Zijdewind I, Kernell D, Kukulka CG (1995) Spatial differences in fatigue-associated electromyographic behaviour of the human first dorsal interosseus muscle. J Physiol (Lond) 483: 499-509

Zuylen EJv, Gielen CCAM, Denier van der Gon JJ (1988) Coordination of inhomogeneous activation of human arm muscles during isometric torques. Journal of Neurophysiology 60: 1523-1548

Chapter 4

The effect of arm and wrist supports on the load of the upper extremity during VDU-work

Bart Visser[a,b], Elsbeth de Korte [a,b], Ingrid van der Kraan [a] and Paul Kuijer [a]

[a]Institute for Fundamental and Clinical Human Movement Sciences, Faculty of Human Movement Sciences, Vrije Universiteit Amsterdam, The Netherlands

[b]Body@Work, Research Center Physical Activity, Work and Health, TNO VUmc, Amsterdam, The Netherlands

Abstract

Objective. The objective of the study was to evaluate the effectiveness of arm and wrist supports in reducing the workload during computer work.

Design. Female subjects (n=10) performed computer work in conditions with arm or wrist supports and in a condition without supports.

Background. Sustained muscle tension in the trapezius muscle is a risk factor for trapezius myalgia. Arm and wrist supports are used at the workplace with the intention to reduce the muscle tension. The effectiveness of these aids in reducing the load is not clear.

Methods. In laboratory a typing task and a mouse task were performed, each with four types of supports and without support. Electromyography and subjective ratings were used to quantify the workload.

Results. Lower levels of trapezius muscle activation were recorded with the use of arm supports. Wrist supports did not reduce the trapezius muscle activation. The rated perceived workload did not discriminate.

Conclusions. Reduction of muscle activation in the neck shoulder region during standard VDU work can be achieved with arm supports. Wrist supports do not reduce the strain on the neck-shoulder region. Subjective ratings seems not of use in selecting ergonomic aids in low intensity tasks.

Relevance. Visual display unit workers are at risk of developing complaints of the neck and upper extremity. Arm and wrist supports are introduced at the workplace to reduce the workload. If arm and wrist supports are effective in reducing the workload they might be of use as preventive measures to reduce the risk of neck-shoulder complaints.

4.1 Introduction

Visual display unit (VDU) workers are at risk of developing complaints of the neck and upper extremity (Bergqvist et al. 1995; Fogleman and Brogmus 1995). During VDU work there is often a prolonged static load on the neck-shoulder region (Hermans and Spaepen 1995). Sustained muscle tension in the trapezius muscle, as a result of prolonged abduction of the upper arm and elevation of the shoulder, is a risk factor for trapezius myalgia (Veiersted 1994). Several preventive measures to reduce the risk of neck-shoulder complaints are proposed, like adjustments of the work height to reduce the need for shoulder elevation, keyboard redesign to reduce the need for upper arm abduction, (relaxation) training of the workers and the use of ergonomic aids. These last measures intend to reduce negative effects of the postures instead of changing the postures themselves.

Arm and wrist supports are recommended to reduce the workload of VDU work by reducing the force required to keep the arm in position. This study investigated whether a reduction of workload is effectively achieved by using arm and wrist supports. Workload is quantified as the perceived workload and the myo-electric activity of the m. trapezius pars descendens.

4.2 Methods

Ten healthy experienced female VDU workers participated in the study (Table 4.1). All subjects were right hand dominant with respect to computer mouse tasks. They had no experience in using ergonomic aids.

Table 4.1 *Subject description. Mean and standard deviation (SD) of age, length, weight, weekly VDU work, VDU work experience, and VDU skills.*

Subject characteristics	Mean	SD
Age (years)	22	1
Length (cm)	172	7
Weight (kg)	64	8
VDU work/week (hours)	11	9
VDU work experience (years)	7	2
Skill (number of fingers used)	7	4

Four types of supports were used (Table 4.2). There were two arm supports (ERGOarm and ERGOrest) and two wrist supports (TOPtec and TC100/210).

Subjects performed two VDU tasks (a typing task and a mouse task) each with the four types of arm supports and without arm support (WS). The duration of each task was 11 minutes. The five conditions (4 supports and WS) are presented in a randomized order and within the conditions variation in the order of performing the type task and mouse task was varied.

The typing task consisted of reproducing a text placed on a document holder. The document holder was positioned in front of the subjects between the keyboard and the computer screen. A computer version of a jigsaw puzzle was used as the mouse task. By clicking and dragging the pieces of the puzzle a continuous mouse task was performed.

Table 4.2 *Support description*

Support	Description
Ergoarm (EA)	The arms are resting on two shells. Movement in the horizontal plane is made possible by using two arms with three rotation points. The shells have a length of 204 mm The EA's are connected to the table with a distance of 900 mm. The EA is adjustable in height up to 85 mm above the desk height Length of arms is 280 mm Range of motion of each EA is described by a circle.
Ergorest (ER)	The arms are resting on two shells. Movement in the horizontal plane is made possible by using two arms with three rotation points. The shells have a length of 131 mm The Er's are connected to the table with a distance of 600 mm. The ER is adjustable in height up to 75 mm above the desk height Length of arms is 235 mm Range of motion of each ER is described by a circle.
Toptec (TT)	The Toptec is a wrist support connected to the table in front of the keyboard. The size of the TT is 570 x 130 mm. The height can be adjusted up to 50 mm above the desk height. The slope of the support can be adjusted (in this study the TT was placed horizontal)
TC 100/210 (TC)	The TC 210 and the TC 100 are wrist supports placed in front of the keyboard and the mouse respectively. The size of the TC 210 is 480 x 75 mm The size of the TC 100 is 130 x 75 mm The TC consist of a soft foam with an unloaded height of 20 mm

Electromyography and subjective ratings were used to quantify the workload.

The myoelectric activity of the descending part of the right trapezius muscle was recorded by means of bipolar Ag/AgCl surface electrodes with a recording distance of 20 mm. The EMG signals were band-pass filtered (10-200 Hz) and A/D converted at a sample frequency of 600 Hz. The myoelectric activity during a standard isometric contraction (SIC), holding a 2 kg load, is used as a reference value for each subject. By using the Amplitude Probability Distribution Function (Jonsson 1978), the static level (10th percentile, P10), the median level (P50) and peak level (P90) of the normalized EMG of the trapezius activity were computed (Jonsson 1978).

The subjects were asked to rate the perceived workload with three different scales:

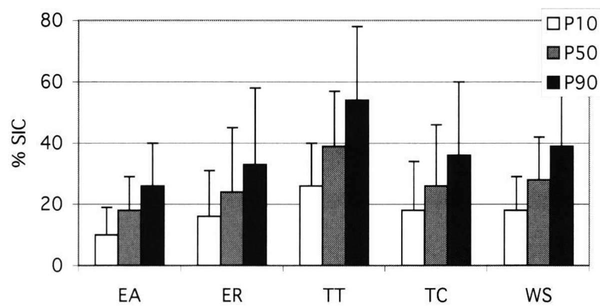
1. Perceived (dis)comfort of the neck-shoulder region, the lower arm and the wrist-hand region were rated by means of visual analogue scales (VAS). Extreme discomfort (0 cm) - extreme comfort (10 cm).
2. An overall mark (1 - 10) was given for each support with respect to the neck-shoulder region, the lower arm and the wrist-hand region.
3. Ranking with respect to comfort (1 least comfortable - 5 most comfortable)

The scores for the mouse task and the type task are averaged for scale 1 and for scale 2. Scale 3 was filled out at the end of the experiment with respect to the combination of the type task and the mouse task.

Variance analysis (ANOVA) is used to test whether supports influence the level of workload. The EMG-data and the subjective data 1 & 2 are post-hoc tested with a parametric test for repeated measures. The subjective data 3 are post-hoc tested with a non-parametrical test for repeated measures.

4.3 Results

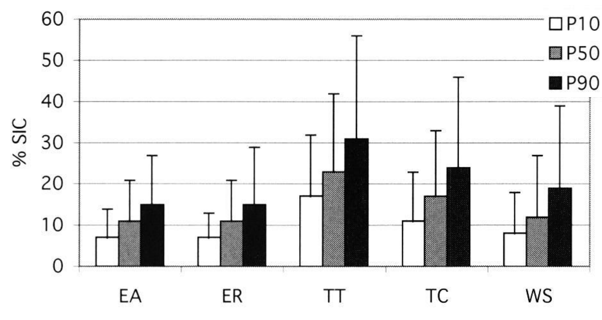
The EMG results for the typing tasks (Figure 4.1) show that the P10, P50 and P90 level of the activation of the descending part of the trapezius muscle is significantly lower with the use of the arm support EA compared to the use of the other supports (ER, TT, TC) and the no-support (WS) condition. The use of the arm support ER lead to a lower P90 level compared to the wrist supports TT and TC and to the WS condition. The P50 level with the EA is lower than with the TT and WS. The P10 level is lower with ER than with the TT. Higher P10, P50 and P90 levels are obtained with the TT compared to the other supports or the no support condition. The P90 with the use of TC is lower than the no-support condition.



P10 ea < er, tt, tc, ws
er < tt
tc < tt
ws < tt
P50 ea < er, tt, tc, ws
er < tt, ws
tc < tt
ws < tt
P90 ea < er, tt, tc, ws
er < tt, tc, ws
tc < tt, ws
ws < tt

Figure 4.1 *Mean and standard deviation of P10, P50 and P90 levels of the activation of the m. trapezius pars descendens during the type task. Significant differences are indicated (lower activation level: <).*

The results for the mouse tasks (Figure 4.2) show that the use of the TT lead to higher P10, P50 and P90 levels of the activation of the descending part of the trapezius muscle compared to all other conditions. The P10, P50 and P90 levels with the use of the arm supports EA and EC are lower than with the use of the wrist support TT and TC. The P90 level in the no support condition is lower than with the use of TC.



P10 ea < tt, tc
er < tt, tc
tc < tt
ws < tt, tc
P50 ea < tt, tc
er < tt, tc
tc < tt
ws < tt, tc
P90 ea < tt, tc, ws
er < tt, tc, ws
tc < tt
ws < tt, tc

Figure 4.2 *Mean and standard deviation of P10, P50 and P90 levels of the activation of the m. trapezius pars descendens during the mouse task. Significant differences are indicated (lower activation level: <)*

The results of the subjective ratings are summarized in Figure 4.3a-c. The (Dis)comfort ratings with respect to the body regions are not affected by the supports. There is one significant difference in the overall mark of the supports, the TC is preferred above the EA with respect to hand-wrist region. There is no difference between the ranking of the five conditions.

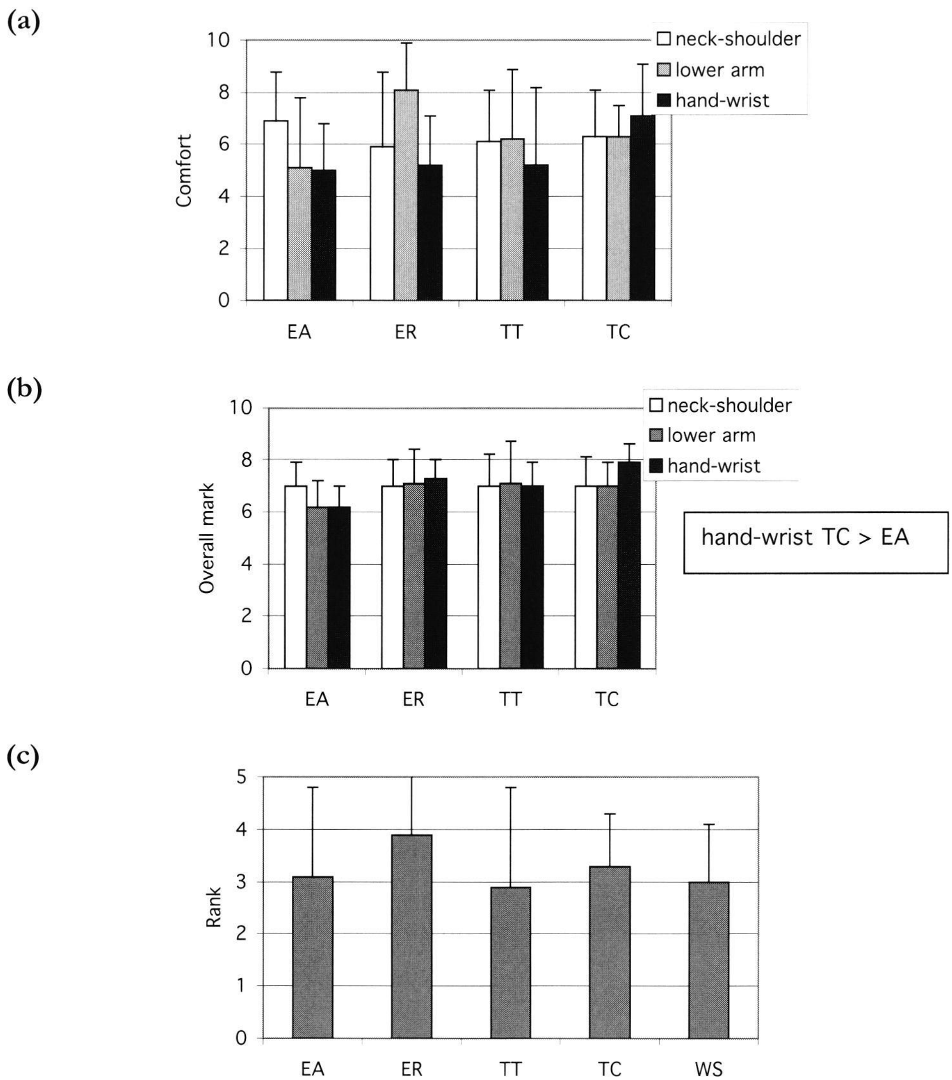


Figure 4.3 (a) *mean and standard deviation of (dis)comfort scores for the supports with respect to the body regions neck-shoulder, lower arm and hand-wrist.* **(b)** *mean and standard deviation of Overall marks for the supports with respect to the body regions neck-shoulder, lower arm and hand-wrist.* **(c)** *mean and standard deviation of the ranking of the conditions. Significant differences are indicated (> = higher score)*

4.4 Discussion

In the experiment the typing task and the mouse task are distinguished as two tasks, while in VDU work a mixture of both task is seen. The mixture of the type task and the mouse task will add repositioning of the arm. The movements of the arm during repositioning are comparable to the movements during typing but they have a wider range. Because of the similarity in the results of the typing task and the mouse task we assume that the results are representative for VDU work.

There is a clear disparity in the EMG results and the results of the subjective ratings. A possible explanation for the lack of discriminating power of the subjective ratings can be the short task duration. An other explanation can be the low level of physical activity during the task. Results of other studies show that the sensitivity of subjective ratings for differences in low intensity task is low (Smutok et al. 1980; Chaffin et al. 1999; Kumar and Lechtelt 1999).

The implications of the results for evaluation of ergonomic aids in occupational settings seems that subjective ratings are not useful when low intensities are involved.

Based on the EMG measures a positive effect of arm support can be seen. The arm supports seem to be able to bear a part of the weight of the arm. In recent review of the Office Ergonomics Research Committee (Office ergonomics research committee 1998) similar results are presented. Any reduction of load might be effective in reducing the risk of shoulder myalgia because in the shoulder it is suggested that there is no tolerable lower limit for long term static contractions of muscle without chronic consequences (Aarås and Westgaard 1987; Wells et al. 1994).

During the typing task EA seems to be superior to the ER in reducing the trapezius load. This difference is not seen during the mouse task. It seems most likely that the differences are due to differences in dynamic features of the supports. We suggest that the larger shells, larger arms and possible better hinges of the EA compared to the ER are responsible for a better dynamic performance in the horizontal plane.

The wrist supports show a negative effect on the trapezius activation. It is possible that the subjects were not able to rest their wrist effectively on the supports during the tasks. This alone does not explain why the trapezius activity is higher with the wrist supports than in the no support condition. The combination of lifting of the arm and the larger distance between the subject and the input devices, might cause an increased biomechanical load on the shoulder, reflected in higher muscle activity.

The wrist supports seem to have a negative influence on the posture of the arm resulting in a higher activation level of the trapezius muscle. This might also be the explanation for the larger (negative) effect of the broad TT compared to the slimmer TC.

Before drawing the conclusion that wrist supports should be banned from the workplace it should be realized that we did not do a movement analysis. The wrist supports might have a positive influence on known risk factors for upper extremity disorders, movements and awkward postures of forearm and wrist (Duncan and Ferguson 1974; Serina et al. 1999). The higher overall mark with respect to the hand-wrist region of the wrist supports (TC) compared to the arm support (EA) is an indication that the hand wrist support has a local effect on the perceived workload.

In conclusion, reduction of muscle activation in the neck shoulder region during standard VDU work can be achieved with arm supports. Wrist supports do not reduce the strain on the neck-shoulder region. Subjective ratings seems not of use in selecting ergonomic aids in low intensity tasks.

4.5 References

Aarås A, Westgaard RH (1987) Further studies of postural load and musculo-skeletal injuries of workers at an electro-mechanical assembly plant. Applied Ergonomics 18: 211-219

Bergqvist U, Wolgast E, Nilsson B, Voss M (1995) Musculoskeletal disorders among visual display terminal workers: individual, ergonomic, and work organizational factors. Ergonomics 38: 763-776

Chaffin DB, Andersson GBJ, Martin JM (1999) Occupational Biomechanics. Wiley, New York

Duncan J, Ferguson D (1974) Keyboard operating posture and symptoms in operating. Ergonomics 17: 651-662

Fogleman M, Brogmus G (1995) Computer mouse use and cumulative trauma disorders of the upper extremities. Ergonomics 38: 2465-2475

Hermans V, Spaepen AJ (1995) Perceived discomfort and electromyographic activity of the upper trapezius while working at a VDT-station. Journal of Occupational Safety and Ergonomics 1: 208-214

Jonsson B (1978) Kinesiology with special reference to electromyographic kinesiology. Contemporary Clininical Neurophysiology 34: 417-428

Kumar S, Lechtelt EC (1999) Comparative resolution of metabolic and psychophysical variables in discriminating between smal-difference low-demand lifting tasks. International Journal of Industrial Ergonomics 24: 61-71

Office ergonomics research committee i (1998) Upper extremity musculoskeletal disorders in the office workplace. In. The office ergonomics research committee, inc., Yarmouth Port, p 17

Serina ER, Tal R, Rempel D (1999) Wrist and forearm postures and motions during typing. Ergonomics 42: 938-951

Smutok MA, Skrinar GS, Pandolf KB (1980) Exercise intensity: subjective regulation by perceived exertion. Arch Phys Med Rehabil 61: 569-574

Veiersted KB (1994) Sustained muscle tension as a risk factor for trapezius myalgia. International Journal of Industrial Ergonomics 14: 333-339

Wells R, Moore A, Potvin J, Norman R (1994) Assessment of risk factors for development of work-related musculoskeletal disorders (RSI). Applied Ergonomics 25: 157-164

Chapter 5

The effects of precision demands during a low-intensity pinching task on muscle activation and load sharing of the fingers

Bart Visser[a,b,*], Michiel P. de Looze[b], DirkJan (H.E.J.) Veeger[a,c], Marjolein Douwes[b], Liesbeth Groenesteijn[b], Elsbeth de Korte[b], Jaap H. van Dieën[a]

[a]Institute for Fundamental and Clinical Human Movement Sciences, Faculty of Human Movement Sciences, Vrije Universiteit Amsterdam, The Netherlands

[b]Body@Work, Research Center Physical Activity, Work and Health, TNO VUmc, Amsterdam, The Netherlands

[c]Laboratory for Measurement and Control, Delft University of Technology, Delft , The Netherlands

Abstract

High precision demands in manual tasks can be expected to cause more selective use of a part of the muscular synergy involved. To test this expectation, load sharing of the index finger and middle finger was investigated during a pinching task. Myoelectric activation of lower arm and neck-shoulder muscles was measured to see if overall level of effort was affected by precision demands. Ten healthy female subjects performed pinching tasks with 3 levels of force and 3 levels of precision demands. The force level did not significantly affect the relative contribution of the index and middle finger to the force. Higher precision demands, however, led to higher contribution of the index finger to the pinch force. Consequently, a more selective load of the fore-arm and hand occurs during tasks with high precision demands. The variability of the force contribution of the fingers increased during the task. No effects of precision demand on the activation of fore-arm and neck-shoulder muscles were found. Force level did affect the EMG parameters of several muscles. The effects were most apparent in the muscles responsible for the pinch force, the fore-arm muscles. Activation of these muscles was higher at higher force levels. In the trapezius muscle at the dominant side EMG amplitudes were lower at the high pinch force compared to the low force and median force conditions.

5.1 Introduction

During a normal (working) day we are almost continuously using our hands, manipulating our environment by pushing, pulling, gripping, steering, using a computer mouse, joystick, a knife or a multitude of other tools and objects. Many of these manipulations require precise positioning and / or force application. The current study focuses on precision demands in force production and their consequences for motor control. Precise force application is important for instance in gripping and lifting a fragile object (Savelsbergh et al. 1996) and in occupational tasks such as, control tasks with some types of joysticks, applying silicone with a sealant gun, dental hygiene tasks and cutting meat.

Several studies have shown that, when subjects are instructed to sustain a sub-maximal moment about a joint, the activity of individual muscles (Sirin and Patla 1987; Dieën et al. 1993; Hermans and Spaepen 1997), muscle parts (Sjøgaard et al. 1986; Zijdewind et al. 1995), and even motor units (Fallentin et al. 1985; Westgaard and DeLuca 1999) will vary over time, in some cases including complete derecruitment. In view of the mechanical specialization of pools of motor units (Zuylen et al. 1988), it can be expected that in a very constrained task, this phenomenon will not be observed. Or in other words, that high precision demands pose such constraints that sustained recruitment of a population of motor units will occur. The constraint posed by the task is expected to depend not only on precision demands, but also on force demands, since force level has been shown to affect accuracy of force production (Slifkin and Newell 1999). Therefore, force level can be expected to interact with required precision.

We suggest that precision demands might lead to a reduction of the degrees of freedom in performing the task. This constrained task performance will then result in a selective use of certain elements in a synergistic group. This selective use might occur at the different levels: selective use of the dominant arm compared to the non dominant arm, or within the arm selective use of the fingers instead of the palm of the hand, or within the hand selective use of one finger compared to the other fingers, at the level of muscles or parts of muscles selective use of a part of the many synergistic motorunits. This line of reasoning is based on electromyographical evidence of variable load sharing between motorunit pools. In view of the inherent variability in the EMG signal, an experimental paradigm developed by Latash et al. (1998) and Li et al. (1998) to study load sharing may provide more unambiguous support. These authors proposed to study load sharing by looking at the contribution of the fingers to the total force in gripping or pinching.

The aim of the present study was to investigate the effects of precision demands and force demands on load sharing of the fingers. In addition, the effects of precision demands and force demands on the level of myo-electric activity of the fore-arm and neck-shoulder muscles were analyzed.

5.2 Methods

Ten healthy female subjects participated in the study. Prior to the experiment, the subjects filled out an informed consent. In Table 5.1 the mean and standard deviation of the subjects age, length and weight are shown. Nine of the subjects were right hand dominant, one was left hand dominant.

Table 5.1 *Subject description. Mean and standard deviation (SD) of age, length and weight*

Subject characteristics	Mean	SD
Age (year)	24	1.56
Length (cm)	174	6.45
Weight (kg)	68.3	7.66

The subjects performed isometric pinching tasks with the thumb opposing the index and middle finger of the dominant hand. The subjects sat in a standardized posture with the upper arm vertically, the lower arm horizontally and neutral with respect to pro - and supination, and the wrist in a neutral position (Figure 5.1).

The maximal pinch force (F_{max}) was determined as the maximal value during three attempts of 3 seconds maximal pinching with at least 30 seconds rest between the attempts. Force levels in the experimental conditions were presented as percentages of F_{max}.

The experiment comprised of nine trials of intermittent isometric pinching with the thumb opposing the index finger and middle finger. The duty cycle consisted of 2 s pinching and 2 s rest and task duration per experimental condition was 10 minutes. On a computer screen a target force was marked and feedback of the produced force was presented. The nine trials consisted of combinations of three target force (F_{target}) levels (5%, 10% and 20% F_{max}) and three levels of precision demand. The levels of precision demand were imposed by varying the sensitivity of the feedback presented on a computer screen. In the least precise condition a pinch force within a range of 5 % of target force was presented on the screen as correctly on target. In the more precise conditions the ranges were smaller, for median precision 2.5 % and for high precision 1.7 % of target. Trials were presented to the subjects in variable order with 15 minutes rest between the trials.

Maximal voluntary contractions (MVC) of each muscle were obtained using manual resistance as described by Kendall et al. (1983). MVCs with a duration of three seconds were performed three times with at least 30 seconds rest between two contractions. The trial with the highest 1-second average of the EMG was used as MVC.

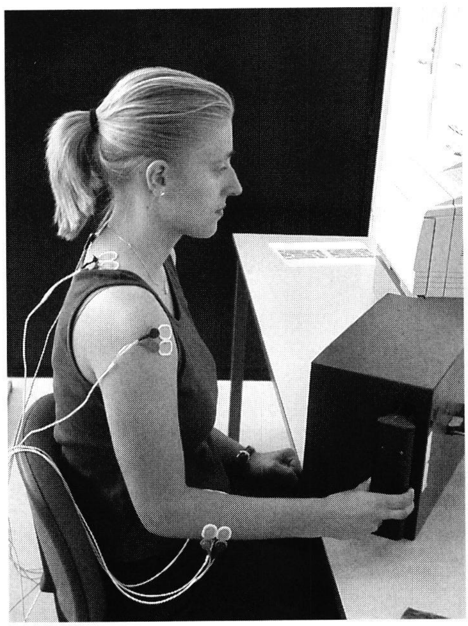


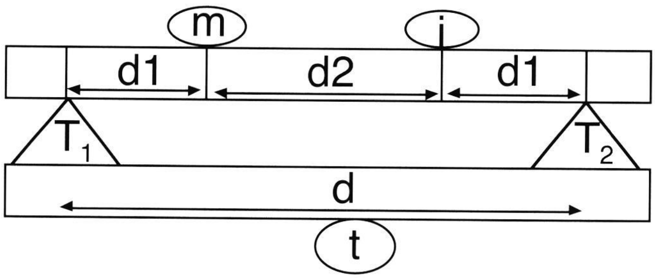
Figure 5.1 *Standardized posture with the upper arm vertically, the lower arm horizontally and neutral with respect to pro - and supination, and the wrist in a neutral position.*

Measurements of the pinch force were performed with force transducers (sample frequency 50 Hz) built into a handle (Figure 5.2). On the handle the position to place the thumb and fingers was indicated. Visual feedback about the force level, the target force and the target frequency were presented on a computer screen.

As a measure of the (in)accuracy in performing the task, an error value (F_{error}) was calculated during minute 2, 6 and 10. The error was calculated as the RMS difference between the force produced and F_{target} over a one-minute window.

The relative contribution of the index finger force and middle finger force to the pinch force was calculated from the forces measured by the two transducers build into the handle (Figure 5.2).

As a measure of the variability in the force contribution of the fingers, the standard deviation of the relative contribution of the index finger to the force was used.



$$-d \cdot F_{T_1} = (d1) \cdot F_i + (d1+d2) \cdot F_m$$

$$-d \cdot F_{T_2} = (d1+d2) \cdot F_i + (d1) \cdot F_m$$

Figure 5.2 *Schematic of the instrumented handle. The contributions of the two fingers to the summed force were calculated from the forces measured at the two transducers (T1 and T2), which were at equal distances (d1) to the midpoints of the two fingers (i=index, m = middle finger, t = thumb). The two equation given in the figure can be solved to calculate the force produced by the index finger (Fi) and middle finger (Fm)*

EMG signals were recorded from selected neck-shoulder muscles (anterior part of the deltoid muscle at the dominant side and the descending part of the trapezius muscle and infraspinatus muscle at both sides) and fore-arm muscles (extensor carpi radialis muscle, flexor carpi radialis muscle and flexor digitorum superficialis muscle, all measured at the dominant side), during the second, 6th and 10th minute of each task. Bipolar Ag/AgCl (Meditrace Pellet) surface electrodes with a recording distance of 15 mm were used. A reference electrode was placed on C7 spinous process. Signals were amplified 20 times (Porti-17™, TMS, Enschede, The Netherlands; input impedance > $10^{12}\Omega$, CMRR > 90 dB), band-pass filtered (10-400 Hz) and A-D converted (22bits) at 1000 Hz. EMG data of the descending part of the trapezius muscle and the infraspinatus muscle were digitally high pass filtered (30 Hz cut-off, FIR, order 100, (Redfern et al. 1993)) to reduce ECG contamination. Subsequently, all EMG signals were rectified, filtered (4^{th} order Butterworth lowpass 5 Hz) and normalized to the EMG level obtained during maximal voluntary contractions (MVC). Data reduction was obtained by extracting the median level from the Amplitude Probability Distribution Functions of the normalized EMG signals (Jonsson 1978).

A repeated-measures analysis of variance (ANOVA) was used to determine effects of precision demand, force and task duration on F_{error}. Since this analysis indicated that the difficulty of the task was determined by an interaction of force and precision demands, effects on the contribution of the index finger to total pinch force, and the variability of the index contribution were tested by means of generalized estimating equations (GEE; (Liang and Zeger 1993)). This technique allows for modeling effects of independent variables and their interactions on the dependent variable, comparable to a regression analysis, but taking into account the within-subject dependence of data. A MANOVA was used to test for effects of precision demand, force and task duration on median EMG amplitudes for all muscles. Univariate ANOVAs and paired t-tests with Bonferroni correction were used for post-hoc testing. Significance was accepted when $p < 0.05$.

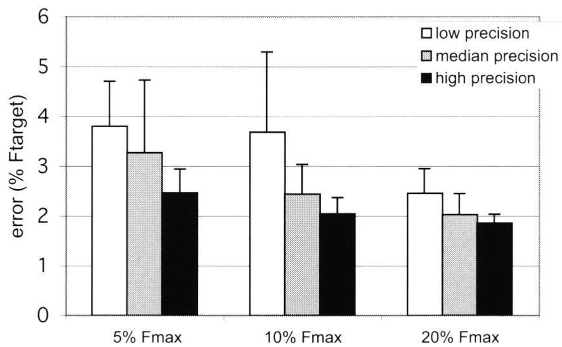
5.3 Results

The maximal pinch force (F_{max}) varied between 76 N and 154 N with an average of 112 N and a standard deviation of 23.6 N.

F_{error} was constant over time. Therefore, the data were averaged over the three periods. With higher precision demands F_{error} expressed as a percentage of F_{target} decreased ($p < 0.001$; Figure 5.3a). This shows that overall subjects indeed performed the task with different levels of accuracy. However, closer inspection of the data reveals that not all subjects increased performance when the precision demand was increased. (Figure 5.3b). In addition, the accuracy achieved by the subjects increased with increasing force ($p < 0.001$) and the effect of precision demand appeared most marked at the lowest force level. This was supported by a significant interaction of force and precision demand on

F_{error} ($p = 0.036$). The interaction of force and precision indicates that the difficulty of the task is determined by the combination of the two. Since low forces clearly resulted in larger errors, the same precision demand at a lower force level poses a more demanding task. As a consequence at the lowest force level the effects of precision demand on F_{error} were less consistent than at the highest force level (Figure 5.3b).

(a)



(b)

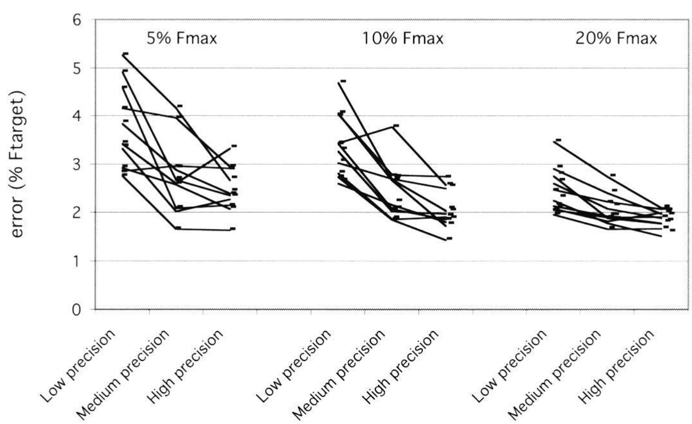


Figure 5.3 (a) *Mean and standard deviation (error bars) of Ferror expressed as a percentage of Ftarget at 3 levels of precision demand and 3 force levels.* **(b)** *Ferror expressed as a percentage of Ftarget at 3 levels of precision demand and 3 force levels for the individual subjects.*

The precision demand had a consistent effect on the index contribution, with higher contributions in the more precise conditions (Figure 5.4). The index contribution to the pinch force was constant over time and therefore the data were averaged over the three periods. The analysis of F_{error} indicated that task difficulty was determined by force, precision demand and their interaction. To account for this in the analysis GEE was used to test for effects on the contribution of the index finger to the total pinch force. The effect of precision demand was highly significant (p = 0.001). Also force level appeared to affect the index contribution, with the higher contribution at lowest force level. However this effect appeared not significant (p = 0.140). Although the effect of force was not significant, Figure 5.4 strongly suggests an increased contribution of the index finger to the total force with increasing task difficulty. The effects of precision demands and force demands appear to be additive rather than multiplicative, since no interaction was found (p = 0.550).

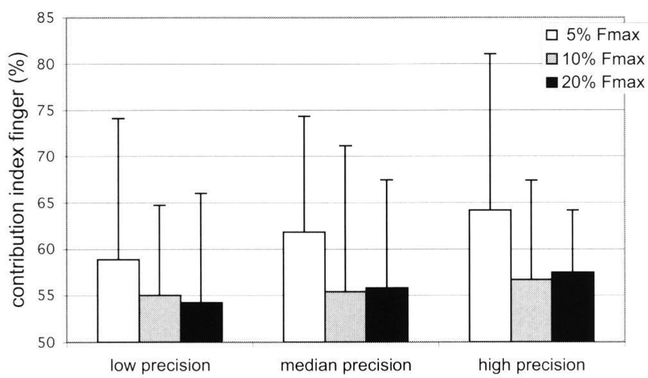


Figure 5.4: *Mean and standard deviation (error bars) of the contribution of index force to the pinch force at 3 levels of precision demand and 3 force levels.*

The variability of the force contribution of the fingers was not affected by precision demand or force level, or by interactions of these factors. The variability of the force contribution of the fingers was higher when the duration of the task was longer (p = 0.000). Post hoc testing shows that the standard deviation of the relative index finger contribution was lower in the second minute compared to the sixth minute (p = 0.001) and the tenth minute (p = 0.000). (Figure 5.5).

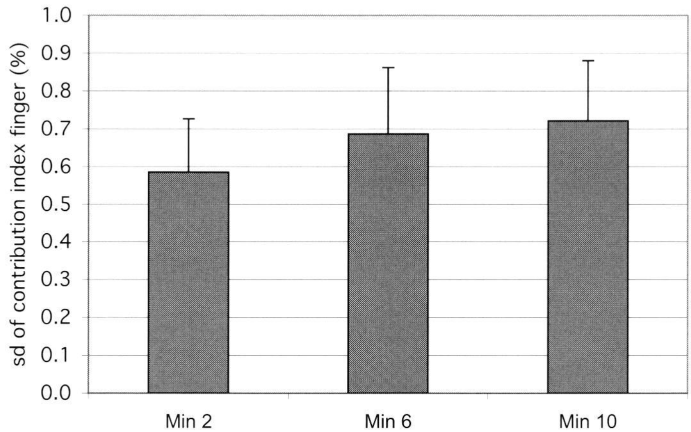


Figure 5.5 *Mean values and standard deviation (error bars) over subjects of the temporal variability (expressed as the standard deviation) of the relative contribution of the index finger to the pinch force at the second, sixth and tenth minute of the task.*

No significant effects of precision demand and task duration on median EMG levels were found, nor any significant interactions with these factors. Force level had a significant overall effect on the median EMG level ($p < 0.001$). There were no significant interaction effects. Univariate analyses revealed increasing median EMG in the muscles responsible for the pinch force, the fore-arm muscles (Figure 5.6; Table 5.2). In the descending part of the trapezius muscle at the dominant side the median EMG values were significantly lower at the high pinch force compared to the low force and median force conditions (Figure 5.6; Table 5.2).

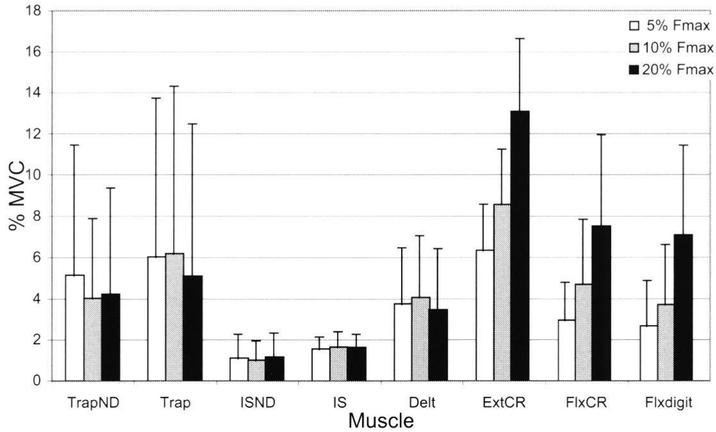


Figure 5.6 *Mean and standard deviation (error bars) of the median muscle activation level expressed as percentage MVC at 3 force levels, averaged over the levels of precision demand and sampling periods. TrapND-Descending part of the trapezius muscle-non dominant side; Trap-Descending part of the trapezius muscle; ISND-Infraspinatus muscle-non dominant side; IS-Infraspinatus muscle; Delt-Anterior part of the deltoid muscle; ExtCR-Extensor carpi radialis muscle; FlxCR-Flexor carpi radialis muscle; Flxdigit-Flexor digitorum superficialis muscle*

Table 5.2 *Main effects of force on the median EMG levels of all muscles obtained in univariate analyses and post-hoc comparisons of the force levels: H = high force condition, M= medium force, L = low force condition. In the column with post-hoc results significant differences only are marked. Empty cells were not tested in view of the absence of a main effect.*

Muscle	Main effect Force	Post hoc
Trapezius muscle	0.007	H<L, H<M
Trapezius muscle - non dominant side	ns	
Infraspinatus muscle	ns	
Infraspinatus muscle - non dominant side	ns	
Anterior part of the deltoid muscle	ns	
Extensor carpi radialis muscle	< 0.001	L<M<H
Flexor carpi radialis muscle	0.008	L<M<H
Flexor digitorum superficialis muscle	0.005	L<M<H

5.4 Discussion

We found an increase in accuracy of force production, with increasing force levels. Bergowitz and Woldstad (1991) presented the results of isometric elbow flexion and extension forces. They found a U-shaped relationship between force errors and target force with the minimum error at 65 $\%F_{max}$. Slifkin and Newell (Slifkin and Newell 1999) found similar curves for finger flexion with the lowest point at 40-45 % F_{max}. Since all force levels tested in the present study were well below these minima, our results can be considered in agreement with these earlier findings. The lower relative accuracy at lower force levels could be explained by the unfavorable signal to noise ratio related to recruitment being the primary force regulation mechanism instead of rate coding of motor units, which dominates at higher forces (Bergowitz and Woldstad 1991; Rockwell et al. 1992; Galen and Jong 1995). In addition, it can be expected that, with more motor units being active, variations in firing rate of individual motor unit will be averaged out. These findings support the suggestion that an optimal force level might exist for tasks with high precision demands (Hewson et al. 2001). However, high force demands in manual tasks are considered a risk factor for upper extremity musculoskeletal disorders (UEMSDs) (Bernard 1997). It would therefore be necessary to find a balance between demands with respect to precision and force level in designing manual tasks.

With increased precision demands the relative force error decreased. However, in some subjects especially at the low force level this decrease was not found. This may have reduced the power of this study in showing effects of the precision constraint. In addition, it is evident that at the lowest level of precision demand (range around target = 5%) subjects on average remained within the required range of force precision. Since the cursor only moved from the target position when this range was exceeded, subjects in this case did not receive feedback. In the high precision condition, (range around target = 1.7%) errors did exceed this range. Thus the precision demand can be seen as a clear constraint in the high precision condition, while this was not the case in the low precision condition. The precision constraint did affect the relative contribution of the index and middle finger to the force production, with a higher index finger contribution in the more precise conditions. In the literature, no information was found with respect to the effect of precision demands on the contribution of the fingers to force production.

Since force level clearly influenced F_{error}, it was expected that force would together with precision demand determine the contribution of the index finger. Although there appeared to be a consistent trend toward an increasing contribution of the index finger to the pinch force with decreasing force, the effect of force and the interaction of force and precision demand were not significant. Kinoshita et al. (1995) also found no effect of force on the relative contribution of the fingers in pinching studied at three force levels (2, 4 and 8 N). Our results were obtained at substantially higher force levels (5, 10 en 20% F_{max}, corresponding to on average 5.6, 11.2 and 22.4 N). These findings would suggest that whereas F_{error} is determined by the difficulty of the task, which is based on precision demand and force, the index finger contribution is determined by the precision demand only.

The higher index finger contributions in the more precision demanding task implies that load sharing is more constrained at higher precision demands. Consequently, more selective loading of the fore-arm and hand occurs during tasks with high precision demands. The overall intensity of the load acting on the muscle was low in the tasks investigated. However, under high precision demands the load will be born by a smaller part of the muscular synergy involved. It has been suggested that the fact that the load is concentrated on only a small part of the muscular synergy may form the basis of the association between UEMSDs and manual work of relatively low intensities (Hägg 1991). Accordingly, the fact that high precision demands in manual tasks lead to more selective loading of parts of the muscular synergy may have implications with respect to the development of such disorders.

A main effect of task duration on the variability in the force contribution of the fingers was found, with variability increasing over time. At the same time accuracy in the force produced by the two fingers together was not affected. Latash and co-workers (1998) emphasized that variability in force production by elements of a synergy is not independent. If a negative covariance exists between the force produced by these elements, total force produced will vary less than expected on the basis of the variances of the elements. In other words reductions in forces in one element will be compensated by increases in forces in the other elements, thereby not affecting performance. Apparently this was the case in the present experiments. The increase of variability over time can either be interpreted as a strategy to prevent fatigue or a reflection of fatigue. Dieën et al. (1993) suggested that variability could be effective in reducing the rate of fatigue development. They reported that subjects who used their back muscles with more variation during intermittent isometric force production showed longer endurance times. The other explanation, variability as a result of fatigue, is supported by the results of Enoka et al. (1989). They described that after exhaustion recruitment patterns of motor units in the intrinsic hand muscles show more variability than in non-fatigued conditions. A third explanation can be that the variability is lowered at the beginning of the condition. Tuller et al. (1982) have shown that at the beginning of a learning process freezing of the kinematic degrees of freedom can be seen. It is possible that in our task the first minutes are a learning phase with little variation and that after a few minutes this effect disappears. This might explain that there are no differences between the 6^{th} and 10^{th} minute. Further study of the effects of precision and duration on variability and fatigue appears warranted.

The EMG results did not support our expectation that with increased precision demands activation levels of neck/shoulder and fore-arm muscles would increase. Several studies have shown effects of precision demands on EMG activity of both proximal and distal arm muscles (Milerad and Ericson 1994; Laursen et al. 1998; Laursen and Jensen 2000), (1998). Several possible explanations for these discrepancies can be given.

First, methodological limitations might explain the lack of an effect in our study. The differences between the levels of precision demand (1.7%, 2.5% and 5% range around the target force) may have been too small to be reflected in the amplitude of the EMG. In contradiction with this explanation is our finding that inaccuracy did differ between the levels of precision demand, which suggests that the experiment succeeded in imposing substantially different demands. Lack of statistical power appears not to explain the lack of effect. The cited studies used similar numbers of subjects. In a repeated measures design, measuring in one without electrode replacement and in a highly constrained task, within subject variance is expected to be low, which is supported by the very low p-vales of force effects on EMG amplitudes. Cross-talk is likely to occur between EMG signals of the muscles in the fore-arm, but differential precision effects on activation of different muscles were not sought for.

Secondly, an explanation might be that the precision effects in previous studies were confounded by effects of movement speed and acceleration. In a study by Sporrong et al. (1998), subjects performed a positioning task with their arms (holding a stick) in combination with a tracking task with their hand/wrist (tracking with the point of the stick). Simply holding the stick in position coincided with less trapezius muscle activity as compared to performing a precise tracking task. This was interpreted as an effect of the high precision demand in the tracking task. However, it is conceivable that reaction moments acting on the shoulder, which would be caused by the accelerations of the hand, were the true cause of the effect. In other experiments on positional precision demands, aiming tasks were used. Mottet and Bootsma (Mottet and Bootsma 1999) showed that with increased precision demands systematic changes in kinematics occur, most notably movement speed increases in the middle part of the movement and decreases near the target. Therefore higher precision demands lead to higher accelerations in the first part of the movement and higher decelerations in the second part were the actual precision is required. The higher EMG amplitudes may be related to these accelerations and decelerations.

The third explanation for the discrepancy with other studies and for the lack of effects of precision demands might be the type of precision required. Previous studies cited above deal with positional precision, whereas the present study considered force precision. Buchanan and Lloyd (1995) have shown that motor control differs between tasks where the goal is controlling isometric force compared to controlling position. The authors suggested that these differences are due to difference in the central control mechanism and not to movement dynamics, contraction velocity or afferent feedback. Support for this theory can be found in a study of Bard et al. (1995) were the role of propriocepsis in movement control was investigated. Deafferentiated subjects were able to perform an isometric pinching task with equal precision as a control group, while they performed less when movement was involved. The authors concluded that force control is a feed-forward process under the control of the CNS and that position control relies on feed-back processes. The delays inherent in such a feedback control strategy might enhance noise levels and therefore require stiffening of the arm through cocontraction. Our experiment was a typical force control task, it might be that no additional stiffness was needed to perform at a higher level of precision. Furthermore, Jeka and Lackner (1994) have shown that contact with a stable object enhances whole body stabilization. When subjects were standing in the Romberg position (feet placed behind each other) touched a stable pole with their fingertip their postural sway was less than without contact. Slijper and Latash (2000) have shown that this so-called informational support decreases levels of cocontraction. In our experiment, pinching the handle with the force transducer might have given the subjects a stable endpoint and thus making it less urgent to stabilize the upper extremity through increased muscle cocontraction. In the set-up of the experiment we have tried to prevent this stabilizing effect by placing the handle on a chart with wheels with little resistance, but this was effective in just one direction.

A final explanation for the lack of increased muscle activation can be found in the contribution of intrinsic hand muscles to the pinch forces. Maier and Hepp-Reymond (1995) performed a comparable pinching experiment and concluded that intrinsic hand muscles were responsible for the fine-tuning of the force. We did not measure EMG of intrinsic hand muscles and are thus not able to draw conclusions on this part.

Force had a significant but paradoxical effect on the median EMG amplitude of the descending part of the trapezius muscle at the dominant side. The EMG amplitude was lower in the high force conditions compared to the median and low force conditions. The stabilizing function of the trapezius muscle appears less important at higher pinch forces. This observation is in accordance to the role of a fixed contact in providing stability through informational support as suggested above. But it may also be due to the mechanical support in the vertical direction provided by pinching. Especially forceful pinching might be expected to be effective in this respect. It is important to realize that at the lower task intensities the load on the neck-shoulder is higher. This suggests that lowering force demands in manual tasks may actually lead to an increase in activity in the trapezius muscle. This finding may be practically relevant, since sustained activity of this muscle is seen as a risk factor for neck-shoulder complaints.(Kroemer 1989)

On the other hand, the force level in (pinching-) tasks is related to the prevalence of wrist complaints (Silverstein et al. 1987; Malchaire et al. 1996) and elbow complaints (Snijders et al. 1987). As expected, the median EMG amplitudes of the fore-arm muscles clearly reflect the different pinch force levels. A remarkable finding was the higher level of activation of the extensor muscles (expressed as a percentage MVC) as compared to the flexor muscles. Snijders et al. (1987) have found similar results in a pinching experiment (25 and 50N). The extensor muscles are probably active to prevent wrist flexion. Since the force transducer could move freely in the horizontal plane, flexion movement was not otherwise restricted. Hägg and Milerad (1997) have found that in pinching at 25% MVC at different frequencies, more pronounced fatigue effects occur in the extensor muscles compared to flexor muscles.

5.5 Conclusion

The present study showed that in a pinching task, force precision demands function as a constraint with respect to the distribution of the force over the fingers. Generalizing this finding suggests that precision demands may lead to more selective loading of parts of the musculoskeletal system. Increased pinch forces did require higher activation levels of the fore-arm muscles, but paradoxically this coincided with lower activation of the descending part of the trapezius muscle.

Acknowledgements

We would like to acknowledge the technical support of Jos D. van den Berg and the contribution to the statistics of Marco J.M. Hoozemans.

5.6 References

Bard C, Fleury M, Teasdale N, Paillard J, Nougier V (1995) Contribution of proprioception for calibrating and updating the motor space. Canadian Journal of Physiology and Pharmacology 73: 246-254

Bergowitz JP, Woldstad JC (1991) Movement tracking performance as a function of required force level. Proceedings of the Human Factors Society 35th annual meeting: : 772-775

Bernard BP (1997) Musculoskeletal disorders (MSDs) and workplace factors - a critical review of epidemiologic evidence for work-related musculoskeletal disorders of the neck, upper extremity, and low back. National Institute for Occupational Safety and Health, Cincinnati, OH

Buchanan TS, Lloyd DG (1995) Muscle activity is different for humans performing static tasks which require force control and position control. Neuroscience Letters 194: 61-64

Dieën JHv, Oude Vrielink HHE, Toussaint HM (1993) An investigation into the relevance of the pattern of temporal activation with respect to erector spinae muscle endurance. European Journal of Applied Physiology 66: 70-75

Enoka RM, Robinson GA, Kossev AR (1989) Task and fatigue effects on low-threshold motor units in human hand muscle. J. of Neurophysiology 62: 1344-1359

Fallentin N, Sidenius B, Jorgensen K (1985) Blood pressure, heart rate and EMG in low-level static contractions. Acta Physiologica Scandinavica 125: 265-275

Galen GPv, Jong WPd (1995) Fitts Law As the Outcome of a Dynamic Noise Filtering Model of Motor Control. Human Movement Science 14: 539-571

Hägg G (1991) Static work loads and occupational myalgia - a new explanation model. In: Anderson PA, Hobart DJ, Danoff JV (eds) Electromyographical kinesiology. Elsevier science, Amsterdam, pp 141-143

Hägg GM, Milerad E (1997) Forearm extensor and flexor muscle exertion during simulated gripping work – an electromyographic study. Clinical Biomechanics 12: 39-43

Hermans V, Spaepen AJ (1997) Muscular activity of the shouler an neck region during sustained and intermittent exercise. Clinical Physiology 17: 95-104

Hewson DJ, McNair PJ, Marshall RN (2001) The effect of aircraft control forces on pilot performance during instrument landings in a flight simulator. Aviat Space Environ Med 72: 617-623

Jeka JJ, Lackner JR (1994) Fingertip contact influences human postural control. Exp. Brain Res. 100: 495-504

Jonsson B (1978) Kinesiology with special reference to electromyographic kinesiology. Contemporary Clininical Neurophysiology 34: 417-428

Kendall FP, Kendall McCreary E, Kendall HO, Wadsworth GE (1983) Muscles testing and function. Williams & Wilkins, Baltimore

Kinoshita H, Kawai S, Ikuta K (1995) Contributions and co-ordination of individual fingers in multiple finger prehension. Ergonomics 38: 1212-1230

Kroemer KHE (1989) Cumulative trauma disorders: their recognition and ergonomics measures to avoid them. Ergonomics 20: 274-280

Latash ML, Li ZM, Zatsiorsky VM (1998) A principle of error compensation studied within a task of force production by a redundant set of fingers. Experimental Brain Research 122: 131-138

Laursen B, Jensen BR (2000) Shoulder muscle activity in young and older people during a computer mouse task. Clinical Biomechanics 15: S30-33

Laursen B, Jensen BR, Sjøgaard G (1998) Effect of speed and precision demands on human shoulder muscle electromyography during a repetitive task. European Journal of Applied Physiology 78: 544-548

Li ZM, Latash ML, Zatsiorsky VM (1998) Force sharing among fingers as a model of the redundancy problem. Experimental Brain Research 119: 276-286

Liang KY, Zeger SL (1993) Regression analysis for correlated data. Annu Rev Public Health 14: 43-68

Maier MA, Hepp-Reymond M (1995) EMG activation patterns during force production in precision grip. I. Contribution of 15 finger muscles to isometric force. Exp. Brain Res 103: 108-122

Malchaire JB, Cock NA, Robert AR (1996) Prevalence of musculoskeletal disorders at the wrist as a function of angles, forces, repetitiveness and movement velocities. Scandinavian Journal of Work, Environment and Health 22: 176-181

Milerad E, Ericson MO (1994) Effects of precision and force demands, grip diameter, and arm support during manual work: an electromyographic study. Ergonomics 37: 255-264

Mottet D, Bootsma RJ (1999) The dynamics of goal-directed rhythmical aiming. Biological Cybernetics 80: 235-245

Redfern MS, Hughes RE, Chaffin DB (1993) High-pass filtering to remove electrocardiographic interference from torso EMG recordings. Clinical Biomechanics 8: 44-48

Rockwell CJ, Woldstad JC, Berkowitz JP (1992) Optimal force level and antagonistic muscle exertion strategies for an isometric tracking task. In: Advances in Industrial Ergonomics and Safety IV,. Taylor & Francis, pp 1235-1242

Savelsbergh GJP, Steenbergen B, van der Kamp J (1996) The role of fragility information in the guidance of the precision grip. Human Movement Science 15: 115-127

Silverstein BA, Fine LJ, Armstrong TJ (1987) Occupational factors and carpal tunnel syndrome. American Journal of Industrial Medicine 11: 342-358

Sirin AV, Patla AE (1987) Myoelectric changes in the triceps surae muscles under sustained contractions Evidence for synergism. European Journal of Applied Physiology 56: 238-244

Sjøgaard G, Kiens B, Jorgensen K, Saltin B (1986) Intramuscular pressure, EMG and blood flow during low-level prolonged static contraction in man. Acta Physiologica Scandinavica 128: 475-484

Slifkin AB, Newell KM (1999) Noise, Information Transmission, and Force Variability. Journal of Experimental Psychology 25: 837-851

Slijper H, Latash M (2000) The effects of instability and additional hand support on anticipatory postural adjustments in leg, trunk, and arm muscles during standing. Exp Brain Res 135: 81-93.

Snijders CJ, Volkers ACW, Mechelse K, Vleeming A (1987) Provocation of epicondylalgia lateralis (tennis elbow) by power grip or pinching. Medicine and Science in Sports and Exercise 19: 518-523

Sporrong H, Palmerud G, Kadefors R, Herberts P (1998) The effect of light manual precision work on shoulder muscles--an EMG analysis. Journal of Electromyography & Kinesiology 8: 177-184

Tuller B, Turvey MT, Fitch H (1982) The Bernstein perspective II: The concept of muscle linkage or coordinative structures. In: Kelso JAS (ed) Human motor behaviour: An introduction. Lawrence Erlbaum, Hillsdale, NJ, pp 253-270

Westgaard RH, DeLuca CJ (1999) Motor unit substitution in long-duration contractions of the human trapezius muscle. Journal of Neurophysiology 82: 501-504

Zijdewind I, Kernell D, Kukulka CG (1995) Spatial differences in fatigue-associated electromyographic behaviour of the human first dorsal interosseus muscle. J Physiol (Lond) 483: 499-509

Zuylen EJv, Gielen CCAM, Denier van der Gon JJ (1988) Coordination of inhomogeneous activation of human arm muscles during isometric torques. Journal of Neurophysiology 60: 1523-1548

Chapter 6

Effects of precision demands and mental pressure on muscle activation and hand forces in computer mouse tasks

Bart Visser[a,b], Michiel P. de Looze[b], Matthijs. P. De Graaff[c] & Jaap H. van Dieën[a]

[a]Institute for Fundamental and Clinical Human Movement Sciences,
Faculty of Human Movement Sciences, Vrije Universiteit Amsterdam, The Netherlands

[b]Body@Work, Research Center Physical Activity, Work and Health, TNO VUmc, Amsterdam, The Netherlands

[c]TNO TPD, Delft, The Netherlands

Abstract

The objective of the present study was to gain insight into the effects of precision demands and mental pressure on the load of the upper extremity. We used two computer mouse tasks: an aiming and a tracking task. Upper extremity loading was operationalized as the myo-electric activity of the wrist flexor and extensor and trapezius descendens muscles and the applied grip- and click-forces on the computer mouse. Performance measures, reflecting the accuracy in both tasks and the clicking rate in the aiming task, indicated that the levels of the independent variables resulted in distinguishable levels of accuracy and work pace. Precision demands had a small effect on upper extremity loading with a significant increase in the EMG-amplitudes (21%) of the wrist flexors during the aiming tasks. Precision had large effects on performance. Mental pressure had substantial effects on EMG-amplitudes with an increase in tracking of 22% in the Trapezius and increases in aiming ranging from 41% in the Trapezius and 45% and 140% in the wrist extensors and flexors, respectively. During aiming, grip- and click-forces increased by 51% and 40% respectively. Mental pressure had small effects on accuracy but large effects on tempo during aiming.

Precision demands and mental pressure in aiming and tracking tasks with a computer mouse were found to coincide with increased muscle activity in some upper extremity muscles and increased force exertion on the computer mouse. Mental pressure caused significant effects on these parameters more often than precision demands. Precision and mental pressure were found to have effects on performance, with precision effects being significant for all performance measures studied and mental pressure effects for some of them. The results of this study suggest that precision demands and mental pressure increase upper extremity load, with mental pressure effects being larger than precision effects. The possible role of precision demands as an indirect mental stressor in working conditions is discussed.

6.1 Introduction

Epidemiological studies and reviews clearly show that work related upper extremity musculoskeletal disorders (UEMSDs) have become a major problem over the last decades, with high and apparently increasing incidence and prevalence rates (Bernard 1997, Buckle and Devereux 1999, Sluiter et al. 2000). Although the pathophysiology of these disorders is still largely unknown, several risk factors such as force, precision and task stress have been identified (Ekberg et al. 1994, Milerad and Ericson 1994, Ariëns et al. 2001, Buckle and Devereux 2002).

There are indications that UEMSDs are related to computer work (Fogleman and Brogmus 1995, Karlqvist et al. 1996, Punnett and Bergqvist 1997, Jensen et al. 2002). In a few studies mouse use is indicated as a risk factor in computer work (Karlqvist et al. 1996, Jensen et al. 1998, Jensen et al. 2002).

During computer work, static contractions of the shoulder and neck muscles occur to maintain the position of the arm in the gravitational field (Visser et al. 2000). Although the muscle activity can be reduced, by adding a horizontal support to the forearm, it cannot be entirely obviated (Visser et al. 2000). Static contractions of proximal musculature often combined with dynamic contractions of the distal musculature are known to form a high risk with respect to UEMSDs (Bernard 1997, Sluiter et al. 2000). Physiological lines of evidence suggest that sustained contractions of arm and neck muscles even at relatively low intensities may explain this association (Gissel 2000, Hägg 2000, Sjøgaard et al. 2000).

On the basis of theoretical considerations it has been suggested that the duration and intensity of sustained muscle contractions are influenced by the precision demands of a task. To obtain sufficient positional accuracy of the end-effectors (hands, fingers, or tools) the arm and shoulder girdle need to be stabilised by means of muscular activity. Stability in the proximal upper extremity joints can be achieved by co-contraction of muscles spanning these joints (Akazawa et al. 1983). In addition, in the distal joints increased precision demands may coincide with increased cocontraction. The neuro-motor noise theory suggests that in high precision movements, the noise effects in neuro-motor control are counteracted by means of increased cocontraction. The stiffness provided by cocontraction is expected to filter out noise effects (Galen et al. 1996, Gemmert and Galen 1997, Gemmert and Galen 1998, Seidler-Dobrin et al. 1998, Galen et al. 2002). At low intensities the unfavourable signal to noise ratio of neural control (Galen and Jong 1995) may increase the necessity of cocontractions. The level of cocontraction will be even higher under stressful tasks conditions because of the increased neural noise under these conditions (Galen et al. 2002).

Computer work often comprises high precision and concentration demands and high time pressure. In epidemiological studies it is extremely difficult to disentangle the effects of precision demands and mental pressure due to concentration and time pressure. Earlier experimental studies mostly involved one exposure in isolation while keeping others constant.

The aim of the present study was to gain insight into the effects of precision demands and mental pressure (to perform accurately and to perform at highest speed) on the load of the upper extremity. Several combinations of precision demands and mental pressure were imposed in two computer mouse tasks: an aiming and a tracking task. We used tracking and aiming tasks to disentangle the different underlying aspects of precision and mental pressure (like accuracy and speed) while still allowing the results to be generalized to computer work. Aiming is very common in computer work but has a disadvantage as an experimental task due to the interaction between speed and accuracy (Laursen et al. 1998). The tracking task is less common in computer work but has a distinct advantage in that movement velocity can be controlled.

The upper extremity load was operationalized as 1) the myo-electric activity of the forearm and neck-shoulder muscles and 2) the grip- and click-forces applied on the computer mouse.

For the mouse tracking and aiming task, it was hypothesized that a higher precision demand or a higher level of mental pressure would contribute to higher grip- and click-forces and higher EMG levels.

The effects of precision demands and mental pressure on task performance were studied, to verify that the experimental conditions were chosen such that the subjects' effort was affected as intended.

6.2 Methods

Subjects

Ten healthy right-handed subjects (4 males, 6 females) participated in the study. Prior to the experiment, the subjects filled out an informed consent. They had experience in computer work, but were not professional computer workers. Their ages varied between 23 and 58 year.

Procedure

The subjects performed two computer mouse tasks: a tracking task and an aiming task. Each task was performed at two levels of precision and two levels of mental pressure.

In the tracking task subjects made the cursor follow a dot moving anti-clockwise on the computer screen in a circle at a fixed speed. The level of precision was set by the diameter of the dot, respectively 50 and 15 pixels for low and high precision. Mental pressure was increased in the high pressure condition by a verbal instruction to perform as good as possible in combination with performance feedback. This feedback was presented on the screen as a bar, which decreased in height when the cursor was not on the dot, with the magnitude of the decrease depending on the distance between cursor and dot. The task comprised of eight rounds with a duration of 15 seconds each, resulting in a total task duration of 120 seconds.

In the aiming task subjects were asked to click on a dot, which appeared at random locations on the computer screen. The level of precision was defined by the diameter of the dot (50 and 15 pixels for low and high precision, respectively). In the low mental pressure condition, 60 dots were presented on the screen with an interval of two seconds between the dots, resulting in a total task duration of 120 seconds. In the high mental pressure condition the subjects had to make 60 correct clicks as quickly as possible. A penalty of two extra dots was given for each miss (clicking with the cursor outside the border of the dot).

To exclude order effects, the precision and mental pressure conditions were presented to the subjects in an as varied as possible order.

The workplace in which the tasks were performed was a common computer-workplace with a keyboard, a standard computer mouse and a 17 inch monitor. Prior to the experiments the workplace was adjusted to the anthropometry of the individual subject according to common ergonomic guidelines. Subjects were seated on a wheeled chair, with height adjustable arm rests. The table was adjusted to elbow-height.

Measurements and data analysis

Muscular activity was measured by means of Electromyography (EMG). EMG signals were recorded from three muscles at the subject's dominant side:

- a neck-shoulder muscle (musculus trapezius pars descendes), abbreviated as 'Trapezius' in the results;
- and two forearm muscles (musculus extensor digitorum, musculus flexor digitorum superficiales), abbreviated as 'Extensor' and 'Flexor' respectively.

Prior to the experimental trials maximal voluntary contractions (MVC) of each muscle were obtained using manual resistance as described by Kendall (1983). MVCs with a duration of three seconds were performed three times with at least 30 seconds rest between two contractions. The trial with the highest 1-second average of the EMG was used as MVC.

Standard procedures were followed for the use of surface EMG (Hermens et al. 1999).

Bipolar Ag/AgCl (Medicotest, Rugmarken, Denmark) surface electrodes were used with an inter-electrode distance of 20 mm. Signals were amplified 20 times (Porti-17™, TMS, Enschede, The Netherlands, input impedance > $10^{12}\Omega$, CMRR > 90 dB), band-pass filtered (10-300 Hz) and A-D converted (22bits) at 1000 Hz. EMG data were digitally rectified, filtered (4^{th} order Butterworth lowpass 5 Hz) and normalized to maximal voluntary contractions (MVC). Data reduction was obtained by extracting the median level (P50) (from the Amplitude Probability Distribution (Jonsson 1978)).

The mouse used in the experiments is shown in Figure 6.1. The mouse was equipped with two force transducers, a click-force and a grip-force transducer. The click-force transducer (type FSL05N2C, Honeywell, Morris Township, N.J., USA) was placed internally in the mouse under the left mouse button. This transducer measures the contact force of the index finger on the left mouse button.

The mouse further includes a force transducer (Force Sensing Resistor model 402, Interlink Electronics, Eternach, Luxembourg) on the left-hand side to measure the grip- force of the user's thumb on the device. This transducer was placed at the outside and is visible as a black circle in Figure 6.1. The subjects were instructed to place their thumb on the transducer whenever they used their thumb in manipulating the mouse. The transducer was very thin but a different surface of the transducer compared to the mouse gave tactile feedback about where to position the thumb. The sample frequency of click- and grip-force was 20 (Hz).

Calculations were done on the force data for the periods that force was applied to the transducers: zero values were eliminated from the recordings. The mean grip-force was calculated for both tasks, and the mean click-force was calculated for the aiming task.

Figure 6.1 *The instrumented computer mouse*

The position (XY-coördinates) of the centre of the target dot and the position of the cursor were recorded. During the tracking tasks a sample frequency of 50 (Hz) was used, during the aiming tasks the positions were recorded at each mouse click.

Two performance measures were calculated for each tracking task:

- Distance - The mean distance (pixels) between the cursor and the middle of the target dot.
- %Missing - The percentage of the time the cursor was not positioned on the target dot.

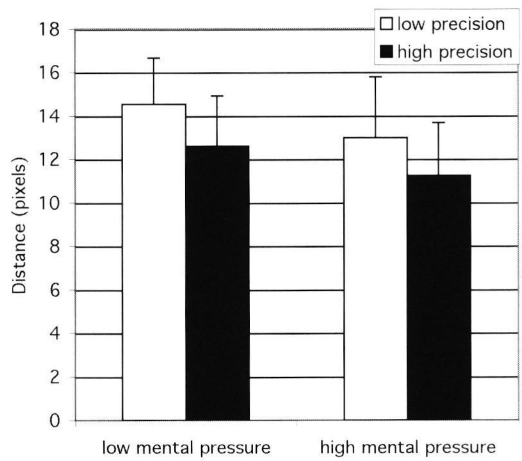
Three performance measures were calculated for each aiming task:

- Distance - The mean distance (pixels) between the cursor and the middle of the target dot at the moment of clicking.
- Missed - The number of missed dots till 60 correct clicks are made.
- Time/click - The time per click, calculated over the first 60 clicks.

Statistical analysis

The effects of mental pressure and precision demands on the mouse forces, EMG amplitudes and performance measures during the mouse aiming and tracking tasks were evaluated using analysis of variance (ANOVA) for repeated measures. Prior to the application of the ANOVA, the performance measures were transformed, using a log-transformation. A paired t-test was used for post hoc testing. A p-value less than 0.05 was considered statistically significant.

(a)



(b)

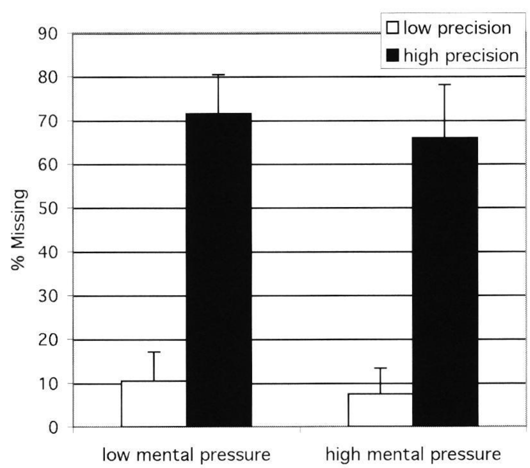


Figure 6.2 *Mean and standard deviation (error bars) of the performance measures for the tracking tasks at 2 levels of precision demand and 2 levels of mental pressure.* **(a)** *Distance, the mean distance (pixels) between the cursor and the middle of the target dot.* **(b)** *%Missing, the percentage of the time the cursor was not positioned on the target dot.*

6.3 Results

The performance results for the tracking tasks are presented in Figures 6.2a-b and the corresponding statistics in Table 1. Precision demands and mental pressure both had a significant effect on the mean distance between the cursor and the middle of the target dot (see Figure 6.2a). High precision demands and high mental pressure led to smaller distances between cursor and the middle of the target dot.

Precision demands and mental pressure also had a significant effect on the percentage of the time the cursor was not positioned on the target dot (see Figure 6.2b). The high precision level led to high percentages of the time the cursor was not on the dot. The effect of mental pressure was much smaller and opposite in direction, under high pressure the cursor was on the dot a higher percentage of time.

Table 6.1 *Effects of precision demands and mental pressure during tracking on the performance measures Distance and %Missing. Significant effects are indicated with an asterisk *.*

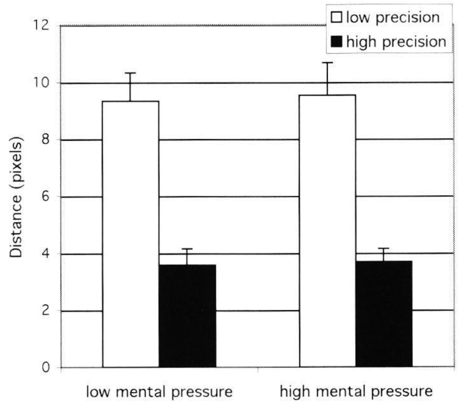
Tracking	Distance			% Missing		
	F	*p*		F	*p*	
Precision demands	22.39	0.001	*	107.10	<0.001	*
Mental pressure	18.61	0.002	*	6.45	0.029	*
Mental pressure X precision demands	0.03	0.865		4.95	0.050	

Table 6.2 *Effects of precision demands and mental pressure during aiming on the performance measures Distance, Missed and Time/click. Significant effects are indicated with an asterisk *.*

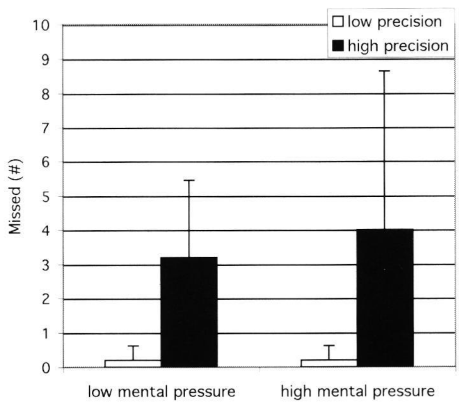
Aiming	Distance		Missed		Time/ Click		
	F	*p*	F	*p*	F	*p*	
Precision demands	2001.27	<0.001*	47.18	<0.001*	525.17	<0.001	*
Mental pressure	0.88	0.373	0.04	0.854	340.71	<0.001	*
Mental pressure X precision demands	0.05	0.829	0.10	0.755	465.22	<0.001	*

There was no significant interaction effect of precision demands and mental pressure on the mean distance between the cursor and the middle of the target dot. An almost significant interaction effect of precision demands and mental pressure was found for the percentage of the time the cursor was not positioned on the target dot.

(a)



(b)



(c)

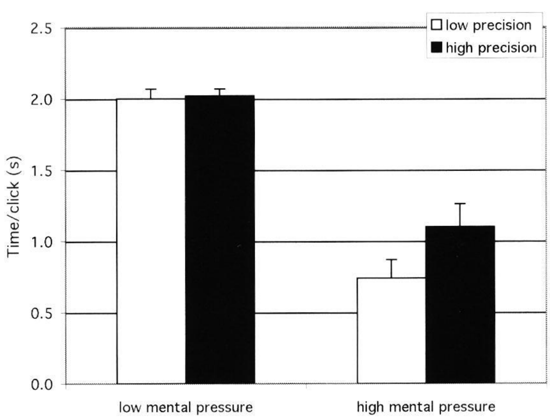


Figure 6.3 *Mean and standard deviation (error bars) of the performance measures for the aiming tasks at 2 levels of precision demand and 2 levels of mental pressure.* **(a)** *Distance, the mean distance (pixels) between the cursor and the middle of the target dot at the moment of clicking* **(b)** *Missed, the number of missed dots till 60 correct clicks were made.* **(c)** *Time/click, the time per click (s), calculated over the first 60 clicks.*

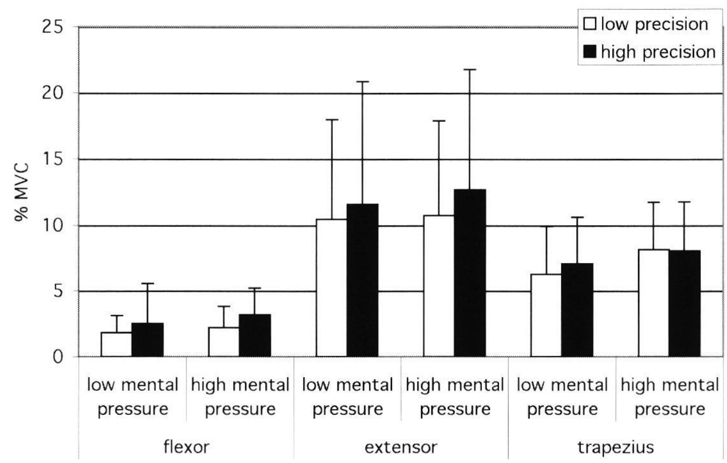
The performance measures for the aiming tasks are presented in Figures 3a-c and the corresponding statistics in Table 2. Precision demands had a marked effect on the three performance measures. High precision demands led to a) smaller distances between the cursor and the middle of the target dot at the moment of clicking, b) more missed dots till 60 correct clicks were given and c) an increase in time per click, calculated over the first 60 clicks.

Mental pressure only had a significant effect on 'time/click'. High mental pressure led to a decreased 'time/click'. A significant interaction effect was present of precision demand and mental pressure on the 'time/click', with 'time/click' being dependent on precision in the high mental pressure condition but as expected not in the low mental pressure condition, where it was the intention to click at a constant rate. Post hoc testing showed that under the high mental pressure condition high precision demands led to an increased 'time/click' ($p<0.001$).

Results on upper extremity loading during the tracking tasks are presented in Figures 4a-b. The P50 values of the EMG-amplitudes are shown in panel a and the grip- force applied to the mouse in panel b. The results of the statistical tests for these variables are summarized in Table 3. There was an almost significant effect of precision on the flexor activation. No significant effects of precision were found for the trapezius and extensor activation, nor for the grip-force applied to the mouse. Mental pressure had a significant effect on trapezius EMG-amplitude during the tracking tasks, with high mental pressure leading to 22% higher EMG-amplitude. No significant effects were found on the EMG-amplitude of the flexor and extensor. The influence of mental pressure on grip-force was almost significant. No significant interaction effects of mental pressure and precision were found.

Results of upper extremity loading during the aiming tasks are presented in Figures 5a-b. The P50 values of the muscle activation are shown in panel a and the results of the grip-force and click-force applied to the mouse in panel b. The results of the statistical tests for these variables are summarized in Table 4. Precision had a significant effect on the flexor EMG-amplitude and an almost significant effect on the extensor activation, with higher precision leading to higher muscle activation. An increase of 21% in flexor EMG-amplitude was found. No significant effects of precision were found for the trapezius EMG-amplitude and the forces applied to the mouse. Mental pressure had a significant effect on the EMG-amplitude of all muscles during the aiming tasks, with higher mental pressure leading to higher EMG-amplitudes. Increases in EMG-amplitudes for Flexor, Extensor and Trapezius were 142%, 45% and 41% respectively. There also was a significant effect of mental pressure on the grip- and click-force, with higher mental pressure resulting in higher forces applied to the mouse. Increases in grip-force and click- force were 51% and 40% respectively.

(a)



(b)

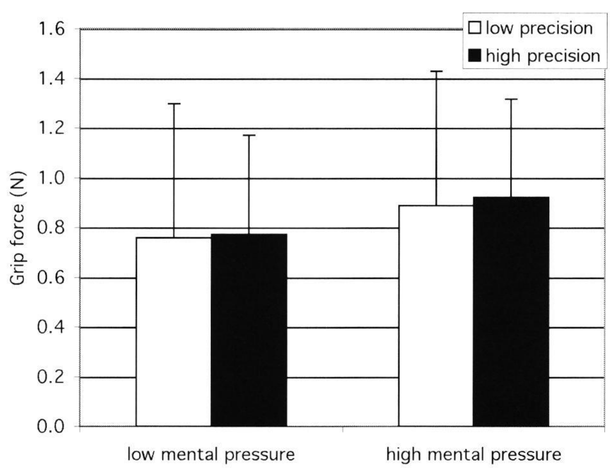


Figure 6.4 (a) *Mean and standard deviation (error bars) of the median muscle activation level during tracking expressed as percentage MVC of the Flexor, Extensor and Trapezius at 2 levels of precision demand and 2 levels of mental pressure.* **(b)** *Mean and standard deviation (error bars) of the grip-force (N) during tracking at 2 levels of precision demand and 2 levels of mental pressure.*

A significant interaction effect of mental pressure and precision was found only in the extensor EMG-amplitude. The interaction shows that effects of precision are more pronounced at low mental pressure.

6.4 Discussion

The goal of this study was to simulate work situations with different levels of mental pressure and precision demand. Both factors of interest were defined in terms of demands to perform at a certain level with respect to accuracy and/or speed. Thus, performance measures could be used to check whether the manipulations were effective in this regard. There were clear effects of precision demands in both mouse tasks on all performance measures. Mental pressure effects were present in both tasks, clearly so in tracking and somewhat less consistent in aiming, where only the 'time/click' was affected. We may therefore conclude that the levels of the independent variables imposed differed sufficiently to simulate work situations with distinguishable levels of precision and mental pressure. The absence of significant interaction effects of precision and mental pressure for four of the five performance measures indicates that their effects were additive and not multiplicative. The interaction effect found on the 'time/click' in the aiming task was due to the fact that the dots were presented at fixed intervals during the low mental pressure condition, whereas in the high mental pressure condition subjects performed as fast as possible.

Effects of precision on parameters of upper extremity loading were limited and significant only in the aiming task in spite of the clear effects on performance in both tasks. In other words, the increased effort, necessary to achieve the precision demands is reflected in only small changes in muscle activation, which moreover were limited to the forearm region. An explanation for the small increases in muscle activation might be the contribution of intrinsic hand muscles to mouse manipulation. Maier and Hepp-Reymond (1995) performed an experiment on precision grip and concluded that intrinsic hand muscles were responsible for the fine-tuning of the force. We did not measure EMG of intrinsic hand muscles and are thus unable to draw conclusions in this regard.

Table 6.3 *Effects of precision demands and mental pressure during tracking on the upper extremity loading measures, EMG-amplitudes of Flexor, Extensor and Trapezius and grip-force on the mouse. Significant effects are indicated with an asterisk *.*

Tracking	Flexor EMG		Extensor EMG		Trapezius EMG		Grip force	
	F	*p*	F	*p*	F	*p*	F	*p*
Precision demands	4.86	0.052	2.05	0.183	0.29	0.601	0.06	0.811
Mental pressure	2.67	0.133	1.79	0.211	7.65	0.020*	4.86	0.055
Mental pressure X precision demands	0.20	0.667	1.71	0.219	1.06	0.327	0.01	0.931

Table 6.4 *Effects of precision demands and mental pressure during aiming on the upper extremity loading measures, EMG-amplitudes of Flexor, Extensor and Trapezius and grip-force and click-force on the mouse. Significant effects are indicated with an asterisk *.*

Aiming	Flexor EMG		Extensor EMG		Trapezius EMG		Grip force		Click force	
	F	*p*	F	*p*	F	*p*	F	*p*	F	*p*
Precision demands	8.27	0.017*	4.67	0.056	0.39	0.546	0.19	0.675	0.13	0.725
Mental pressure	22.59	0.001*	11.95	0.006*	6.57	0.028*	7.39	0.024*	30.01	<0.001*
Mental pressure X precision demands	1.12	0.315	7.30	0.022*	0.85	0.377	0.06	0.809	0.62	0.452

Effects of precision may also in part have been counterbalanced by a lower productivity. This was illustrated by Birch et al. (2000), who investigated simulated computer work with different levels of precision, time pressure, and mental demand. They found that high precision demands and high mental demands did not influence the EMG of upper extremity musculature. However, productivity appeared reduced. It should be noted that in the present study productivity under high precision demand was at least equal to the low precision condition, except in the aiming task under high mental pressure. In the latter condition, the productivity increased, indicated by the decreased 'time/click'. In working life similar effects may occur and this may reduce effects of precision demands on physical loading.

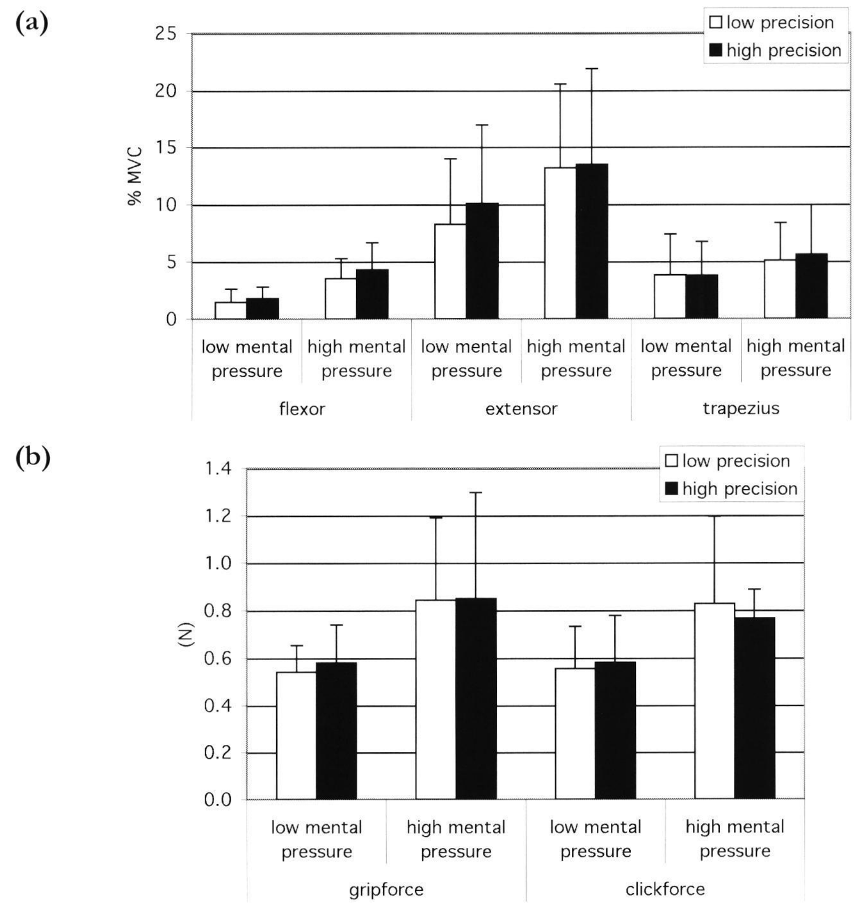


Figure 6.5 **(a)** *Mean and standard deviation (error bars) of the median muscle activation level during aiming expressed as percentage MVC of the Flexor, Extensor and Trapezius at 2 levels of precision demand and 2 levels of mental pressure.* **(b)** *Mean and standard deviation (error bars) of the grip-force (N) and click-force (N) during aiming at 2 levels of precision demand and 2 levels of mental pressure.*

Two explanations for an increase in muscle activation with increased precision demands can be identified. First, cocontraction may be increased to filter out noise to meet the increased demand. Second, the trajectory choice may differ between precision conditions. Mottet and Bootsma (1999) showed that with increased precision demands systematic changes in kinematics occur, most notably movement speed increases in the middle part of the movement and decreases near the target. In other words, higher precision demands lead to higher accelerations in the first part of the movement and higher decelerations in the second part where the actual precision is required. The effect of precision on the flexor muscle in the aiming tasks may therefore be partly explained by effects of movement speed and acceleration (Laursen et al. 1998, Wahlstrom et al. 2002).

Previous studies have also found effects of precision demands on EMG activity of both proximal and distal arm muscles (Laursen et al. 1998, Sporrong et al. 1998, Laursen and Jensen 2000). In the study by Sporrong et al. (Sporrong et al. 1998), subjects performed either a positioning task with their arms (holding a stick) or combined this with a tracking task with their hand/wrist (tracking with the point of the stick). Simply holding the stick in position coincided with less trapezius muscle activity as compared to performing a precise tracking task. This was interpreted as an effect of the high precision demand in the tracking task. However, it is conceivable that reaction moments acting on the shoulder, which would be caused by the accelerations of the hand, were the true cause of the effect. In the study by Laursen et al. (Laursen et al. 1998, Sporrong et al. 1998, Laursen and Jensen 2000) the precision effects may be explained on the basis of differences in movement speed, as in the present aiming task. The study by Laursen and Jensen (Laursen et al. 1998, Sporrong et al. 1998, Laursen and Jensen 2000), did show significant effects in a tracking task, suggesting that the almost significant effect in the present study was not a chance finding.

Mental pressure had an effect on trapezius activation during the tracking tasks, with higher mental pressure leading to higher muscle activation and the influence of mental pressure on grip-force was at the border of significance. Mental pressure had an effect on the activation of all muscles during the aiming tasks, with higher mental pressure leading to higher muscle activation. There was also an effect of mental pressure on the grip- and click-force, with higher mental pressure resulting in higher forces applied to the mouse. Again the stronger effect in the aiming task may be explained on the basis of differences in movement speed, which was intentionally influenced. The higher EMG amplitudes and higher grip-forces in aiming in the high mental pressure condition may be related to the associated accelerations and decelerations. The increased trapezius muscle activation in tracking can not be due to the effects of movement speed and acceleration, suggesting that another mechanism must be operative. The neuro-motor noise theory predicts such a direct effect of mental pressure. In addition, an overall increase in arousal (Westgaard 1996, Lundberg 2002) due to the mental effort to perform as good as possible might be operative. .This is supported by the increased click-force during aiming, which would not contribute to counteracting neuromotor noise effects.

Previous studies have also shown effects of work pressure (Waersted 2000, Bansevicius et al. 2001, Lundberg 2002). It should be noted that a wide range of stressors, some related to the actual task and other additional to the task were used in these studies.

The level of muscle activity in the forearm extensor muscles during these intensive mouse tasks was surprisingly high. In addition, trapezius activity appeared high especially in the tracking task. This suggests that mouse tasks pose a health risk, in line with epidemiological findings. The magnitude of this risk would be modified by precision demands and mental pressure, which explains their association with the prevalence of UEMSDs . When comparing the effects of precision and mental pressure it can be concluded that precision had a much larger effect than mental pressure on performance and mental pressure had a larger effect than precision on upper extremity loading.

The strong effect of precision on the performance measures might have some implications for real computer work, in such a way that making errors might have serious consequences and thereby pose high mental pressure on the worker. Feedback of the performance in the tracking task in the present study with no other consequence than getting a low end score was already enough to add mental pressure. It can be argued that in working conditions where performance is important or even crucial, precision has an indirect effect on upper extremity loading by its strong effect on performance en thereby on mental pressure. In other words, precision demands in real work can be implicit mental stressors.

6.5 Conclusion

Precision demands and mental pressure in aiming and tracking tasks with a computer mouse were found to coincide with increased muscle activity in some upper extremity muscles and increased force exertion on the computer mouse. Mental pressure caused significant effects on these parameters more often than precision demands. Precision and mental pressure were found to have effects on performance, with precision effects being significant for all performance measures studied and mental pressure effects for some of them. The results of this study suggest that precision demands and mental pressure increase upper extremity load, with mental pressure effects being larger than precision effects.

Acknowledgements

The data of the present study was collected in the GEMINI-project funded by Dräger, Business Unit HomeCare. We would like to acknowledge the contributions of the GEMINI-project group: H.A. Cramer, K.M. van der Hel, M.G.H. Meijerink and B.D. Netten. P.J. Beek and M. Douwes are acknowledged for reviewing an early version of the manuscript.

6.6 References

Akazawa, K., Milner, T. E. and Stein, R. B., 1983. Modulation of reflex EMG and stiffness in reponse to stretch of human finger muscle. Journal of Neurophysiology 49, 16-27.

Ariëns, G. A. M., Mechelen, W. v., Bonger, P. M., Bouter, L. M. and Wal, G. v. d., 2001. Psychosocial risk factors for neck pain: A systematic review. American Journal of Industrial Medicine 39, 180-193.

Bansevicius, D., Westgaard, R. H. and Stiles, T., 2001. EMG activity and pain development in fibromyalgia patients exposed to mental stress of long duration. Scand J Rheumatol 30, 92-8.

Bernard, B. P., 1997. Musculoskeletal Disorders (MSDs) and Workplace Factors - A Critical Review of Epidemiologic Evidence for Work-Related Musculoskeletal Disorders of the Neck, Upper Extremity, and Low Back, National Institute for Occupational Safety and Health, Cincinnati, OH).

Birch, L., Juul-Kristensen, B., Jensen, C., Finsen, L. and Christensen, H., 2000. Acute repsonses to precision, time pressure and mental demand during simulated computer work. Scandinavian Journal of Work, Environment and Health 26, 299-305.

Buckle, P. and Devereux, J., 1999. Work-related neck and upper limb musculoskeletal disorders, (Luxembourg, Office for Official Publications of the European Communities).

Buckle, P. W. and Devereux, J. J., 2002. The nature of work-related neck and upper limb musculoskeletal disorders. Appl Ergon 33, 207-17.

Ekberg, K., Bjorkqvist, B., Malm, P., Bjerre-Kiely, B., Karlsson, M. and Axelson, O., 1994. Case-control study of risk factors for disease in the neck and shoulder area. Occup Environ Med 51, 262-6.

Fogleman, M. and Brogmus, G., 1995. Computer mouse use and cumulative trauma disorders of the upper extremities. Ergonomics 38, 2465-75.

Galen, G. P. v., Hendriks, A. W. and Jong, W. P. d., 1996. What Behavioral Benefit Does Stiffness Control Have - an Elaboration of Smiths Proposal. Behavioral & Brain Sciences 19, 478-479.

Galen, G. P. v. and Jong, W. P. d., 1995. Fitts Law As the Outcome of a Dynamic Noise Filtering Model of Motor Control. Human Movement Science 14, 539-571.

Galen, G. P. V., Müller, M. L. T. M., Meulenbroek, R. G. J. and Gemmert, A. W. A. V., 2002. Forearm EMG response activity during motor performance in individuals prone to increased stress reactivity. American Journal of Industrial Medicine 41, 406-419.

Gemmert, A. W. A. and Galen, G. P. v., 1998. Auditory stress effects on preparation and execution of graphical aiming: a test of the neuromotor noise concept. Acta Psychologica 98 81-101.

Gemmert, A. W. A. v. and Galen, G. P. v., 1997. Stress, Neuromotor Noise, and Human Performance - a Theoretical Perspective. Journal of Experimental Psychology: Human Perception & Performance 23, 1299-1313.

Gissel, H., 2000. Ca2+ accumulation and cell damage in skeletal muscle during low frequency stimulation. European Journal of Applied Physiology 83, 175-80.

Hägg, G. M., 2000. Human muscle fibre abnormalities related to occupational load. European Journal of Applied Physiology 83, 159-65.

Hermens, H. J., Freriks, B., Merletti, R., Stegeman, D., Blok, J., Rau, G., Disselhorst-Klug, C. and Hägg, G., 1999. European recommendations for surface electromyography, (Enschede, Roessingh Research and Development).

Jensen, C., Borg, V., Finsen, L., Hansen, K., Juul-Kristensen, B. and Christensen, H., 1998. Job demands, muscle activity and musculoskeletal symptoms in relation to work with the computer mouse. Scand J Work Environ Health 24, 418-424.

Jensen, C., Finsen, L., Sogaard, K. and Christensen, H., 2002. Musculoskeletal symptoms and duration of computer and mouse use. International Journal of Industrial Ergonomics 30, 265-275.

Jonsson, B., 1978. Kinesiology with special reference to electromyographic kinesiology. Contemporary Clininical Neurophysiology 34, 417-428.

Karlqvist, L. K., Hagberg, M., Koster, M., Wenemark, M. and nell, R., 1996. Musculoskeletal Symptoms among Computer-assisted Design (CAD) Operators and Evaluation of a Self-assessment Questionnaire. Int J Occup Environ Health 2, 185-194.

Kendall, F. P., Kendall McCreary, E., Kendall, H. O. and Wadsworth, G. E., 1983. Muscles testing and function, (Baltimore, Williams & Wilkins).

Laursen, B. and Jensen, B. R., 2000. Shoulder muscle activity in young and older people during a computer mouse task. Clinical Biomechanics 15, S30-3.

Laursen, B., Jensen, B. R. and Sjøgaard, G., 1998. Effect of speed and precision demands on human shoulder muscle electromyography during a repetitive task. European Journal of Applied Physiology 78, 544-548.

Lundberg, U., 2002. Psychophysiology of work: Stress, gender, endocrine response, and work-related upper extremity disorders. American Journal of Industrial Medicine 41, 383-392.

Maier, M. A. and Hepp-Reymond, M., 1995. EMG activation patterns during force production in precision grip. I. Contribution of 15 finger muscles to isometric force. Exp. Brain Res 103, 108-122.

Milerad, E. and Ericson, M. O., 1994. Effects of precision and force demands, grip diameter, and arm support during manual work: an electromyographic study. Ergonomics 37, 255-264.

Mottet, D. and Bootsma, R. J., 1999. The dynamics of goal-directed rhythmical aiming. Biological Cybernetics 80, 235-245.

Punnett, L. and Bergqvist, U., 1997. Visual display unit work and upper extremity disorders. A review of epidemiological findings. In: Kjellberg, K. (eds.), National Institute for working Life - Ergonomic expert committee document no. 1. (Solna: National Institute for Working Life), 1-161.

Seidler-Dobrin, R. D., He, J. and Stelmach, G. E., 1998. Coactivation to reduce variability in the elderly. Motor Control 2, 314-330.

Sjøgaard, G., Lundberg, U. and Kadefors, R., 2000. The role of muscle activity and mental load in the development of pain and degenerative processes at the muscle cell level during computer work. European Journal of Applied Physiology 83, 99-105.

Sluiter, J. K., Rest, K. M. and Frings-dresen, M. H. W., 2000. Criteria document for evaluation of the work-relatedness of upper extremity musculoskeletal disorders, (Amsterdam, The Netherlands,

Sporrong, H., Palmerud, G., Kadefors, R. and Herberts, P., 1998. The effect of light manual precision work on shoulder muscles--an EMG analysis. Journal of Electromyography & Kinesiology 8, 177-84.

Visser, B., de Korte, E., van der Kraan, I. and Kuijer, P., 2000. The effect of arm and wrist supports on the load of the upper extremity during VDU work. Clinical Biomechanics 15, S34-8.

Waersted, M., 2000. Humen muscle activity related to non-biomechanical factors in the workplace. European Journal of Applied Physiology 83, 151-8.

Wahlstrom, J., Hagberg, M., Johnson, P. W., Svensson, J. and Rempel, D., 2002. Influence of time pressure and verbal provocation on physiological and psychological reactions during work with a computer mouse. Eur J Appl Physiol 87, 257-63.

Westgaard, R. H., 1996. Effects of psychological demand and stress on neuromuscular function. In: Moon, S. D. and Sauter, S. L. (eds.), Beyond biomechanics. Psychosocial aspects of musculoskeletal disorders in office work (London: Taylor & Francis), 75-89.

Chapter 7

The effects of shoulder load and pinch force on electromyographic activity and blood flow in the forearm during a pinch task

Bart Visser[a,b], Pernille Kofoed Nielsen[c], Heleen de Kraker[a,b], Miriam Smits[a], Bente Rona Jensen[e], DirkJan (H.E.J.) Veeger[a,d], Jaap H. van Dieën[a]

[a]Institute for Fundamental and Clinical Human Movement Sciences, Faculty of Human Movement Sciences, Vrije Universiteit Amsterdam, The Netherlands

[b]Body@Work, Research Center Physical Activity, Work and Health, TNO VUmc, Amsterdam, The Netherlands

[c]Department of Physiology, National Institute of Occupational Health, Copenhagen, Denmark

[d]Laboratory for Measurement and Control, Delft University of Technology, Delft , The Netherlands

[e]Department of Human Physiology, Institute of Exercise and Sport Sciences, University of Copenhagen, Denmark

Abstract

The object of the current study was to determine whether static contraction of proximal musculature has an effect on the blood flow more distally in the upper extremity. Static contractions of muscles in the neck shoulder region at three levels (relaxed, shoulders elevated, and shoulders elevated loaded with of 4.95 kg each) were combined with intermittent pinch forces at 0, 10 and 25% of the voluntary maximum (MVC). Blood flow to the forearm was measured with Doppler ultrasound. Myoelectric activity of the forearm and neck-shoulder muscles were recorded to check for the workload levels. Across all levels of shoulder load blood flow increased significantly with increasing pinch force (21 % at 10% MVC and by 44% at 25% MVC). Blood flow was significantly affected by shoulder load, with the lowest blood flow at the highest shoulder load. Interactions of pinch force and shoulder load were not significant. The myo-electric activity of forearm muscles increased with increasing pinch force. The activation of the trapezius muscle decreased with increasing pinch force and increased with increasing shoulder load. The precise mechanisms accounting for the influence of shoulder load remains unclear. The results of this study indicate that shoulder load might influence blood flow to the forearm.

7.1 Introduction

Work related upper extremity musculoskeletal disorders (UEMSDs) are indicated with a variety of terms like Repetitive Strain Injury (RSI), Cumulative Trauma Disorders (CTD) and Occupational Cervico-brachial Disorders (OCD). Both specific and a-specific disorders of muscles, tendons and nerves of the neck, shoulder and upper extremity are classified under these terms (Kroemer 1989; Muggleton et al. 1999; Sluiter et al. 2000). Epidemiological studies and reviews clearly show that these disorders have become a major problem over the last decades, with high and apparently increasing incidence and prevalence rates (Bernard 1997; Buckle and Devereux 1999; Sluiter et al. 2000).

Hampering of blood flow and reduction in muscle tissue oxygenation during sustained repetitive work has been suggested to contribute to the development of UEMSDs (Carayon et al. 1999; Galen et al. 2002; Larsson 2003). The suggestion that local circulatory problems and thus disturbances of homeostasis play a role in the development of UEMSDs, can also be found in several models proposed to describe the patho-physiology of UEMSDs (Edwards 1988; Jonsson 1988; Sjøgaard and Jensen 1998; Kadefors et al. 1999; Sjøgaard et al. 2000).

A possible and often mentioned explanation for the lack of blood supply is an increased intramuscular pressure, which impedes microcirculation (Järvholm et al. 1988; Jensen et al. 1995). This is supported by studies that investigated tissue oxygenation (Murthy et al. 1997) and hyper-compensation in blood flow post-exercise (Byström and Kilbom 1990; Jensen et al. 1993; Jensen 1997; Byström et al. 1998; Røe and Knardahl 2002). In this context, Jensen et al. (1993) found post-exercise hyperaemia values of two times the resting blood flow even after isometric handgrip exercise at an intensity as low as 2.5% MVC and Røe and Knardahl (2002) found such hyperaemia after computer work.

An alternative mechanism was proposed by Keller et al. (1998), who suggested that blood flow can be compromised due to compression of the brachial plexus. The thoracic inlet would be reduced in size by forward displacement of the head and shoulder girdle in combination with scapular protraction. This may result in compression of the brachial plexus, which can have effects distally, including edema, fibrosis, and temperature changes.

Repetitive hand or finger motions involving static contractions of proximal musculature have been shown to characterize tasks, which pose a high risk with respect to UEMSDs (Bernard 1997; Sluiter et al. 2000). These risks are most pronounced in high intensity work in industry but can also be found in low intensity jobs (Bernard 1997). An example of this type of work is computer work (Visser et al. 2000), where static contractions of the shoulder and neck muscles occur to maintain the position of the arm in the gravitational field, while forearm muscles contract intermittently to move the fingers. Although the static activity of the neck shoulder muscles can be reduced by providing a horizontal support to the forearm, it can not be totally prevented (Visser et al. 2000). In addition, postural deviations as described by Keller et al. (1998) often occur during these tasks.

The object of the current study, therefore, was to determine whether static contraction of proximal musculature has an effect on the blood flow, more distally in the upper extremity. It was expected that interaction effects occur between the energy demand in the forearm and possible proximal obstructions of blood flow.

7.2 Methods

Subjects

Thirteen healthy, right-handed, male subjects, without a history of musculoskeletal complaints in neck, shoulders and hands/wrists, participated in the study. The measurements were performed on the dominant side. Prior to the experiment, subjects filled in an informed consent and the Nordic questionnaire (Kuorinka et al. 1987). The average age of the subjects was 33 years (standard deviation (SD) =8), their average body height 180 cm (SD=3) and their average body mass 75 kg (SD=10).

Protocol

After standard preparation, surface EMG electrodes were placed on the location of the descending part of the trapezius muscle, the extensor carpi radialis brevis muscle and the extensor digitorum muscle. Initially subjects attempted to perform three static maximum voluntary contractions (MVC) for each muscle, to determine the maximum voluntary excitation (EMGmax). There was at least 60 seconds of rest in between the trials.

For the extensor muscles in the forearm, three maximal handgrips and three maximal wrist and finger extensions against a flat, vertical resistance, were performed. For the trapezius muscle, resistance to the combination of maximal elevation and maximal abduction of the upper arm against manual resistance was used.

Then, the subjects performed isometric pinching with the thumb opposing the index and middle finger of the dominant hand. The subjects sat in a standardised posture with the upper arm elevated 40° in a plane of elevation approximately 10° outward, relative to the sagittal plane. The forearm was held horizontally in the sagittal plane and neutral with respect to pro - and supination. The wrist was held in a neutral position. A small force transducer (Futek, model Q07309, Irvine, CA, USA) hung on a cord exactly between the thumb and the index and middle finger (Figure 7.1). Two maximal voluntary pinch forces were measured to determine the pinch force for the trials.

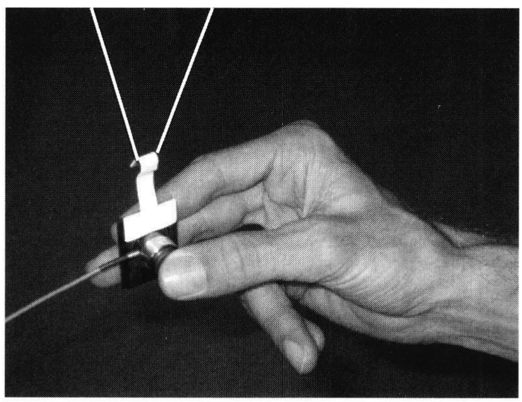


Figure 7.1 *Detail of pinch force measurements*

A balanced design of three pinch forces with three static load levels at the shoulders was used. Pinch forces were set at 0, 10 and 25% of maximal pinch force. The first load level was with the shoulders relaxed (this condition is abbreviated as 'hang'). Second load level was with the shoulders raised bilaterally to an indicated level ('lift') with no external load. The third load level was with raised shoulders and a load (4.95 kg) added to the each shoulder ('load'). The loads were attached to belts over the acromion. The combination of these pinch forces and shoulder loads were chosen to simulate work with low intensity. The contraction-relaxation ratio for the pinch force in all the exercise periods was 10:2 seconds (10 seconds contraction followed by 2 seconds relaxation) and each trial lasted for 3 minutes.

The exerted force and the target force level were presented on a computer screen. In addition to the visual feedback, verbal feedback was given about the contraction and relaxation periods. There was at least five minutes rest in between trials.

Data acquisition and analysis

The blood velocity waveforms were measured beat-by-beat using Doppler ultrasound (Diasonics VST Masters Series System, GE-Medical, Denmark). A 5 MHz probe (Curved Linear Array, GE-Medical, Denmark) was placed over the brachial artery, just proximal to the elbow. Gain settings were the same for all the subjects and were kept constant in all measurements. All recordings were stored on videotape for later analysis. At the end of the experiment, three brachial artery diameter measurements were performed.

EMG was measured from the muscle bellies of the descending part of the trapezius muscle, the extensor carpi radialis brevis muscle and the extensor digitorum muscle using an EMG-system (Porti-17^{TM}, TMS, Enschede, The Netherlands; input impedance > $10^{12}\Omega$, CMRR > 90 dB, software Poly5) and bipolar surface electrodes (Ag-AgCl, type N-10-A, Medicotest, Denmark). Signals were amplified 20 times and A-D converted (22bits) at 1000 Hz.

Blood flow data were analyzed from the videotapes using the software on the ultrasound scanner. Mean peak blood velocity (MPBV) was determined from the maximum outline trace of the blood velocity wave form during one cardiac cycle. MPBV values were obtained 3 times per minute during the second and third minute of the exercise period. Assuming a parabolic velocity profile in the vessel, the mean blood velocity (MBV) is half as high as the MPBV. For each subject, the radius of the vessel was obtained from the average of the three brachial artery diameter measurements. Ten out of 13 Doppler data sets were complete and thus judged suitable for analysis.

Because the data of the exercise periods contained data points from the 10 second contractions ('on' points) as well as from the 2 second relaxations ('off' points, see Figure 7.2), the 'off' points were identified, where appropriate. To prevent the influence of the 'off' data points to be over- or underestimated, a weighted average, based on the duration of the contraction and relaxation periods (10 and 2 seconds), was calculated.

For each subject, the weighted average of the MBV per trial was calculated.

Finally the absolute values of forearm volume blood flow were calculated according to the formula: $F = MBV^* \pi r^2$, where F is the absolute volume blood flow in ml/min, *MBV* the mean blood velocity and *r* the radius of the brachial artery in cm (Hughson et al., 1996).

EMGmax values for each muscle were derived from the MVC and reference contractions by selecting the highest 1 second average. From the EMG data the absolute value was taken, the data were filtered (4^{th} order Butterworth lowpass 5 Hz) and normalized to the EMGmax . The 50^{th} percentile (P50), the median activity over the exercise period was subsequently calculated.

Statistics

SPSS software (version 7.5) was used for the statistical analysis of the data. In case of missing data, a missing values analysis was done with an EM-estimation (estimated means, maximum number of iterations: 100). ANOVA-repeated measures was used for analysing the main and interaction effects of pinch level and shoulder load. Post-hoc measurements were also done with ANOVA-repeated measures. The level of significance was set at $p < 0.05$.

7.3 Results

To show the time course of blood flow and the influence of the 2-seconds interruption of the pinching task on the blood flow, a typical example is shown in Figure 7.2. The peaks at times 26, 60 and 125 seconds are measurements during the interruptions in this trial.

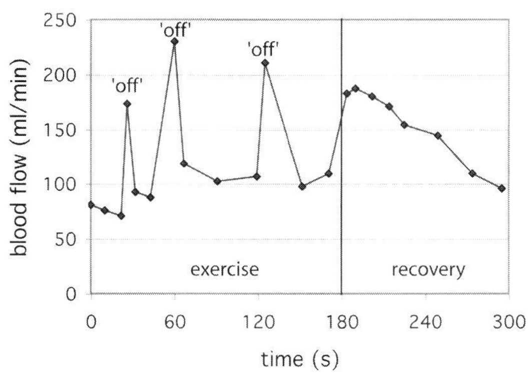


Figure 7.2 *Example of the time course of blood flow during three minutes exercise and two minutes recovery. Note the rapid response of the blood flow during relaxation.*

Table 7.1 *Summary table of statistical results of the blood flow data. Values marked with a (*) are significant at p<0.05. Post-hoc tests are only shown when a significant effect was found.*

		Blood Flow	
		p	
Shoulder		**.024**	*
	hang- no load < lift - no load	.274	
	hang- no load > lift load	.073	
	lift - no load > lift load	.005	*
Pinch		**<.001**	*
	0<10%	<.001	*
	0<25%	<.001	*
	10<25%	<.001	*
Shoulder X Pinch		**.311**	

Average blood flow values of 10 subjects at three pinch and three shoulder levels are shown in Figure 7.3. In the exercise period, blood flow increased with increasing pinch force ($p<.001$) and was affected by shoulder load ($p=.024$). Post-hoc, the effect of shoulder load was only explained by a significantly lower blood flow during the 'lift – load' condition compared to the 'lift – no load' condition ($p=.005$). For the pinch force all post-hoc tests showed significantly increased blood flow with increasing pinch force. No interaction effects were found. A summary of the main and post-hoc effects is given in table 7.1.

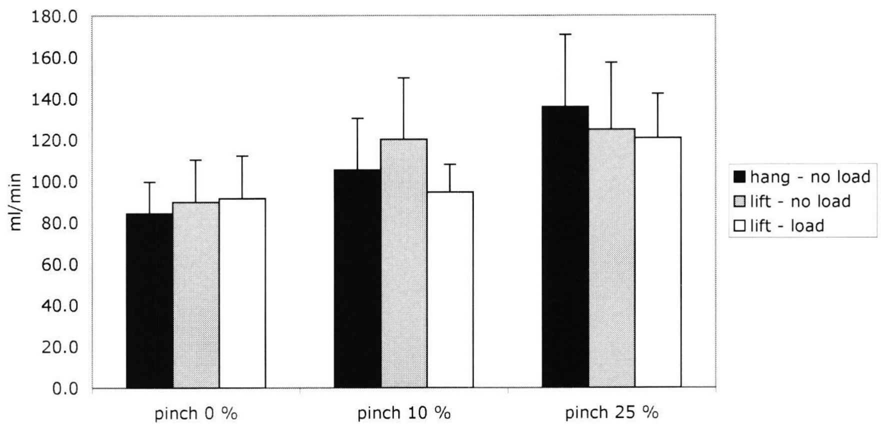


Figure 7.3 *Mean and standard deviation of blood flow at the shoulder levels hang, lift and load combined with three levels of pinch force 0%, 10% and 25% of maximal pinch force.*

No influence of time on EMG-measurements during the exercise periods was found. Therefore the average values of the exercise periods were used for analysis. For the forearm muscles the EMG-activity increased significantly with increasing pinch force. Figure 7.4 shows the effect of pinch force at three shoulder loads. All post-hoc tests showed increasing EMG signals with increasing pinch force. Shoulder load had a minor but significant effect on the EMG amplitude of one of the forearm muscles, the carpi radialis brevis muscle (p=.048). Post-hoc testing showed a higher activation in the 'lift – no load' than in the 'hang – no load' condition (p=.048).

The EMG amplitude of the trapezius muscle significantly decreased with increasing pinch force and significantly increased with increasing shoulder load (Figure 7.5). All post-hoc tests showed significantly higher EMG signals with higher shoulder load. The effect of pinch force appeared to be caused by a significant drop between the 0 and 10% conditions (p=.003) and 0 and 25% conditions (p=.011). No interaction effects were found. A summary of significant main and post-hoc effects of the muscles is given in table 7.2.

Table 7.2 *Summary table of statistical results of the EMG data (the 50th percentile (P50) was tested). Values marked with a (*) are significant at p<0.05. Post-hoc tests are only shown when significant effect was found. Note that the direction of the post-hoc effect of pinch on m. trapezius (marked with **) is opposite to the forearm muscles i.e. 0>10%.*

	extensor carpi rad. br. (P50)		extensor digitorum (P50)		Trapezius (P50)	
	p		*p*		*p*	
Shoulder	**.048**	*****	**.223**		**<.001**	*****
hang- no load < lift - no load	.042		-		<.001	*
hang- no load > lift load	.067		-		<.001	*
lift - no load > lift load	.441		-		.036	*
Pinch	**<.001**	*****	**<.001**	*****	**.005**	*****
0<10%	<.001	*	.028	*	.003	**
0<25%	.001	*	.001	*	.011	**
10<25%	.003	*	.002	*	.788	
Shoulder X Pinch	**.074**		**.333**		**.632**	

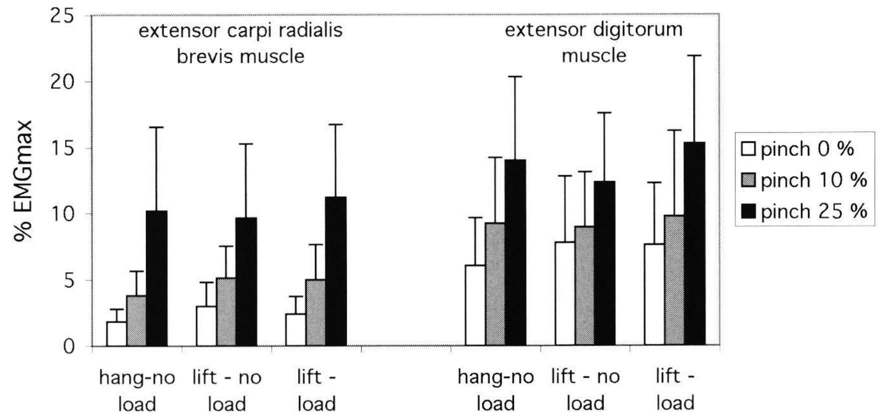


Figure 7.4 *Mean and standard deviation of EMG activity (% EMGmax) of the extensor carpi radialis brevis muscle and the extensor digitorum muscle at the shoulder levels hang, lift and load combined with three levels of pinch force 0%, 10% and 25% of maximal pinch force.*

7.4 Discussion

We demonstrated a positive association between intermittent pinch grip exercise and blood flow to the forearm muscles. In addition a significant effect of shoulder load on blood flow to the forearm was found.

An increase in blood flow to the forearm caused by an increase in force exerted by forearm muscles was found in several studies (Byström and Kilbom 1990; Jensen et al. 1993; Jensen 1997; Byström et al. 1998). Despite differences in protocol, such as performing pinch grip instead of handgrip exercise and performing the task intermittently instead of continuously, similar results were obtained. Active hyperaemia, a phenomenon of local regulation, is most likely responsible for this increase in flow. As a result of increased metabolic activity of the exercising muscle, various factors (e.g.: decreased oxygen concentration, increased concentrations of carbon dioxide and hydrogen ions) act upon the arteriolar smooth muscle and cause it to dilate (Radegran and Saltin 1998). In addition, central vascular control mechanisms and increased cardiac output occur in response to exercise leading to increased blood flow. Simultaneously muscle contraction resulting in compression of the vessels may counteract these mechanisms (Jensen et al. 1993). Since the results of the present study show an increase in flow during the trials, the former mechanisms apparently outweigh the latter mechanism. This is possibly due to the fact that exercise during this study was performed intermittently (each contraction (10 s) is followed by a relaxation (2 s, see Figure 7.2)) through which the intramuscular pressure frequently drops and hyperaemia was elicited, even though it is only briefly.

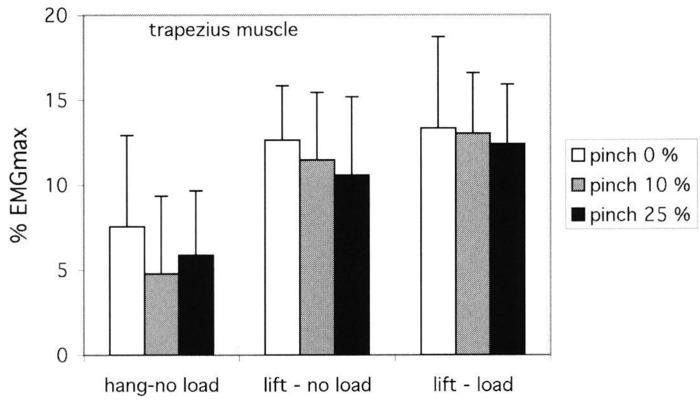


Figure 7.5 *Mean and standard deviation of EMG activity (% EMGmax) of the trapezius muscle at the shoulder levels hang, lift and load combined with three levels of pinch force 0%, 10% and 25% of maximal pinch force.*

Beside the influence of pinch force on blood flow, a significant effect of shoulder load on blood flow in the arm was found. No previous reports on such a relationship were found. There are two possible mechanisms that might explain this effect: 1) compression of the vessels in the shoulder region by contraction of the shoulder muscles and 2) competition for the available volume of blood. Shoulder elevation and the associated muscle tension and movement of anatomical structures relative to each other, might compress the vessels and restrict flow as suggested by Keller et al. (1998). Similarly, in patients with the Thoracic Outlet Syndrome (TOS), vascular compression causes upper extremity pain, numbness, weakness and fatigability (Rayan 1998; Coletta et al. 2001). However, the blood pressure in the great arteries in the shoulder is probably higher than the pressure that is generated in the shoulder muscles during the shoulder load conditions. We estimated the latter to be approximately 42 mmHg based on data of Järvholm (1988) and the pressure in the arteries to be approximately 110 mmHg. Consequently, this mechanism is not expected to result in a major obstruction of blood flow.

Alternatively, competition between shoulder and forearm muscles for the available volume of blood might explain our results. No literature about blood flow distribution within the upper extremity during exercise was found. Kilbom and Brundin (1976) investigated the distribution of blood flow when isometric handgrip exercise (20% MVC) was added to light dynamic leg exercise. Leg blood flow was unaffected when the handgrip exercise was added. However, other experiments showed that circulatory responses during combined exercise are lower than the sum of those developed during the corresponding single exercises (Grucza et al. 1989; Kagaya and Ogita 1992; Saito et al. 1992; Kagaya et al. 1994). In one experiment, when subjects were cycling (50-60 % $VO_{2,max}$) and arm exercise was added a decrease in leg blood flow was found (Harms 2000). Ogita (1996) compared the cardio-respiratory responses to various combinations of upper and lower limb exercise with the sum of the responses to the component exercises. A decrease in the exercise duration and forearm blood flow was found when comparing rhythmic handgrip exercise (50% MVC till exhaustion) added to rhythmic plantar flexion (10% MVC) to handgrip exercise alone at the same intensity. This decrease in blood flow was only found when handgrip exercise was added to plantar flexion, not when plantar flexion (50% MVC) was added to handgrip exercise (10% MVC). At present it remains unclear which of the two mechanisms accounts for the reduced blood flow in the high shoulder load condition.

The fact that no clear monotonous effect of shoulder load on arm blood flow was found may be due to effects of an opposing mechanism. First, the increase in forearm muscle activity with shoulder loading might promote blood flow and hence partially offset the mechanisms discussed above. Second, with increasing shoulder load the total active muscle mass increases, which may also promotes blood flow, through effects on cardiac output. However, changes in cardiac output appeared to be responsible for only a minor part of the blood flow increase in comparable exertions (Jensen et al. 1993). In additon, the actual shoulder load imposed by the experimental manipulations may have varied between subjects reducing the power of the experimental design.

The EMG-results indicate that the tasks can be qualified as low intensity tasks. The average P50 is lower than 15 %MVE for all muscles. Although the loading of the shoulder seems to be rather artificial in the 'load' condition, the levels of activation are not rare for low intensity tasks. Westgaard et al. (1996) showed similar activation levels for the m. trapezius in office work.

From the EMG-results, it can be concluded that the different intensities of pinch force and shoulder load lead, as intended, to increasing levels of distal and proximal muscle activity, respectively. Trapezius activity however, also decreased significantly with increasing pinch force. Post-hoc tests revealed that the difference between 0% pinch and 10% pinch (i.e. between no pinch and pinch) was responsible for this decrease. A reduction in activity is expected when the subjects use the transducer as a support. But, since the force transducer hung in such way that only little weight could be borne, it is not likely that this explains the reduction in trapezius activity. Just holding the arm in position apparently is a greater challenge for the trapezius then pinching at low intensities. A similar result was found in a previous study, at higher pinch force a decreased trapezius activity was found (Visser et al. 2003). It seems plausible that this reduction in trapezius activation is related to a change in the demands for keeping the arm stable. Jeka and Lackner (1994) found in their study on postural control that just touching a stable point (with the fingertip), lead to a similar improvement in whole body stability as holding a stable endpoint with the whole hand. The fact that the subjects were holding the force transducer while pinching, might similarly facilitate stabilizing of the arm. During the no pinch trials this extra stability was lacking, which apparently increased trapezius activity.

In conclusion, increased pinch force increased blood flow to forearm. Shoulder load had an effect on blood flow to the forearm with a decreased blood flow at the high load condition. The precise mechanisms accounting for the influence of shoulder load remains unclear. Trapezius activity decreased from keeping the arm still in the desired position (0% maximal pinch force) to pinching tasks (10% and 25% maximal pinch force). This decrease is probably due to facilitation of stabilizing the arm as a consequence of the information provided by holding the sensor.

The results of this study indicate that shoulder load might influence blood flow to the forearm. It seems to be valuable to find out whether this influence might lead to a cumulative deficiency of blood flow over time and thus be a risk factor for UEMSDs on the long term. Postural effects on blood flow such as demonstrated here might aggravate symptoms of UEMSDs related to reduced vasodilation during exercise such as demonstrated by Pritchard et al. (1999).

7.5 References

Bernard BP (1997) Musculoskeletal Disorders (MSDs) and Workplace Factors - A Critical Review of Epidemiologic Evidence for Work-Related Musculoskeletal Disorders of the Neck, Upper Extremity, and Low Back. National Institute for Occupational Safety and Health, Cincinnati, OH

Buckle P, Devereux J (1999) Work-related neck and upper limb musculoskeletal disorders. Office for Official Publications of the European Communities, Luxembourg

Byström S, Jensen B, Jensen-Urstad M, Lindblad LE, Kilbom A (1998) Ultrasound-Doppler technique for monitoring blood flow in the brachial artery compared with occlusion plethysmography of the forearm. Scand J Clin Lab Invest 58: 569-576

Byström SE, Kilbom A (1990) Physiological response in the forearm during and after isometric intermittent handgrip. Eur J Appl Physiol Occup Physiol 60: 457-466

Carayon P, Smith MJ, Haims MC (1999) Work Organization, Job Stress, and Work-Related Musculoskeletal Disorders. Human Factors 41: 644-663

Coletta JM, Murray JD, Reeves TR, Velling TE, Brennan FJ, Hemp JR, Hall LD (2001) Vascular thoracic outlet syndrome: successful outcomes with multimodal therapy. Cardiovasc Surg 9: 11-15

Edwards RHT (1988) Hypotheses of peripheral and central mechanisms underlying occupational muscle pain and injury. European Journal of Applied Physiology 57: 275-281

Galen GPV, Müller MLTM, Meulenbroek RGJ, Gemmert AWAV (2002) Forearm EMG response activity during motor performance in individuals prone to increased stress reactivity. American Journal of Industrial Medicine 41: 406-419

Grucza R, Kahn JF, Cybulski G, Niewiadomski W, Stupnicka E, Nazar K (1989) Cardiovascular and sympatho-adrenal responses to static handgrip performed with one and two hands. Eur J Appl Physiol Occup Physiol 59: 184-188

Harms CA (2000) Effect of skeletal muscle demand on cardiovascular function. Med Sci Sports Exerc 32: 94-99

Järvholm U, Styf J, Suurkula M, Herberts P (1988) Intramuscular pressure and muscle blood flow in supraspinatus. European Journal of Applied Physiology 58: 219-224

Jeka JJ, Lackner JR (1994) Fingertip contact influences human postural control. Exp. Brain Res. 100: 495-504

Jensen BR (1997) Doppler blood flow and peripheral resistance in the forearm during and following low-level isometric hand-grip contractions. Advances in occupational medicine and rehabilitation 3: 21-35

Jensen BR, Fallentin N, Byström S, Sjøgaard G (1993) Plasma potassium concentration and Doppler blood flow during and following submaximal handgrip contractions. Acta Physiol. Scand. 147: 203-211

Jensen BR, Jørgensen K, Huijing PA, Sjøgaard G (1995) Soft tissue architecture and intramuscular pressure in the shouder region. European Journal of Morphology 33: 205-220

Jonsson B (1988) The static load component in muscle work. European Journal of Applied Physiology 57: 305-310

Kadefors R, Forsman M, Zoéga B, Herberts P (1999) Recruitment of low threshold motor-units in the trapezius muscle in different static arm positions. Ergonomics 42: 359-375

Kagaya A, Ogita F (1992) Peripheral circulatory readjustment to superimposition of rhythmic handgrip exercise to plantar flexion of different duration. Journal of Exercise Science 2: 5-12

Kagaya A, Saito M, Ogita F, Shinohara M (1994) Exhausting handgrip exercise reduces the blood flow in the active calf muscle exercising at low intensity. European Journal of Applied Physiology 68: 252-257

Keller K, Corbett J, Nichols D (1998) Repetitive strain injury in computer keyboard users: pathomechanics and treatment principles in individual and group intervention. J Hand Ther 11: 9-26

Kilbom (1976) Circulatory adaptation during static muscular contractions. Scandinavian Journal of Work, Environment and Health 2: 1-13

Kroemer KHE (1989) Cumulative trauma disorders: their recognition and ergonomics measures to avoid them. Ergonomics 20: 274-280

Kuorinka I, Jonsson B, Kilbom Å, Vinterberg H, Biering-Sorensen F, Andersson G, Jorgensen K (1987) Standardized nordic questionnaires for the analysis of musculoskeletal symptoms. Ergonomics 18: 233-237

Larsson SE (2003) Neck-shoulder pain in relation to blood microcirculation and EMG, psychophysiological stress. In: Johansson H, Windhorst U, Djupsjöbacka M, Passatore M (eds) Chronic Work-Related Myalgia - Neuromuscular Mechanisms behind Work-Related Chronic

Muscle Pain Syndromes. Gävle University Press, pp 111-115

Muggleton JM, Allen R, Chappell PT (1999) Hand and arm injuries associated with repetitive manual work in industry: a review of disorders, risk factors and preventive measures. Ergonomics. 42: 714-739

Murthy G, Kahan NJ, Hargens AR, Rempel DM (1997) Forearm muscle oxygenation decreases with low levels of voluntary contraction. J Orthop Res 15: 507-511

Ogita F, Kagaya A (1996) Differential cardiorespiratory response to combined exercise with different combinations of forearm and calf exercise. European Journal of Applied Physiology and Occupational Physiology 73: 511-515

Pritchard MH, Pugh N, Wright I, Brownlee M (1999) A vascular basis for repetitive strain injury. Rheumatology (Oxford) 38: 636-639

Radegran G, Saltin B (1998) Muscle blood flow at onset of dynamic exercise in humans. Am J Physiol 274: H314-322

Rayan GM (1998) Thoracic outlet syndrome. J Shoulder Elbow Surg 7: 440-451

Røe C, Knardahl S (2002) Muscle activity and blood flux during standardised data-terminal work. International Journal of Industrial Ergonomics 30: 251-264

Saito M, Kagaya A, Ogita F, Shinohara M (1992) Changes in muscle sympathetic nerve activity and calf blood flow during combined leg and forearm exercise. Acta Physiol Scand 146: 449-456

Sjøgaard G, Jensen BR (1998) Muscle injury in repetitive motion disorders. Clinical Orthopaedics and Related Research 351: 21-31

Sjøgaard G, Lundberg U, Kadefors R (2000) The role of muscle activity and mental load in the development of pain and degenerative processes at the muscle cell level during computer work. European Journal of Applied Physiology 83: 99-105

Sluiter JK, Rest KM, Frings-dresen MHW (2000) Criteria document for evaluation of the work-relatedness of upper extremity musculoskeletal disorders. Amsterdam, The Netherlands

Visser B, de Korte E, van der Kraan I, Kuijer P (2000) The effect of arm and wrist supports on the load of the upper extremity during VDU work. Clinical Biomechanics 15: S34-38

Visser B, de Looze MP, Veeger DE, Douwes M, Groenesteijn L, de Korte E, van Dieen JH (2003) The effects of precision demands during a low intensity pinching task on muscle activation and load sharing of the fingers. J Electromyogr Kinesiol 13: 149-157

Westgaard RH, Jansen T, Jensen C (1996) EMG of neck and shoulder muscles: the relationship between muscle activity and muscle pain in occupational settings. In: Kumar S, Mital A (eds) Electromyography in ergonomics. Taylor and Francis, London, pp 227-258

Chapter 8

Epilogue

8.1 Epilogue

The studies in this thesis were meant to increase our insight in the role of work requirements during low-intensity work, including computer work, in the pathogenesis of upper extremity musculoskeletal disorders. After a short overview of the most relevant results, reflections on what we have learned from the studies are presented from two different perspectives. The first perspective is a researcher's point of view, addressing methodological topics and future research issues. The second is a practitioner's point of view, focusing primary on the practical implications for prevention of WRUEMD's.

8.2 Overview

The review of the literature on the pathophysiology of muscle disorders show that 1) sustained muscle activity, especially of type I motor units, may be a primary cause of WRUEMD's; 2) In WRUEMD's skeletal muscle may show changes in morphology, blood flow, and muscle activity; 3) There are multiple possible mechanisms; 4) Accumulation of Ca^{2+} in the sarcoplasm may be the cause of membrane damage of the muscle cells; 5) It seems plausible that impaired blood flow plays a role in pathogenesis of WRUEMD's; 6) Increased metabolite concentrations in muscles may activate type III and IV afferents contributing to a self-maintaining 'vicious circle' in which pain and muscle activity amplify each other.

The review in chapter three on the contribution of task-related constraints to the development of work-related myalgia suggests that task constraints determine sustained muscle activity. The combination of the moment equilibrium constraint and the co-activation of muscles in order to counteract neuro-motor noise might lead to sustained muscle activity. This implicates that arm support, task precision, and mental pressure probably determine whether and at what level sustained muscle activity occurs during low-intensity work.

Chapter four addressed the effect of arm support during computer work. Results showed that the activity of the neck-shoulder muscles was reduced by arm supports but not completely negated. The use of wrist supports had a negative effect on neck-shoulder muscle activation. This suggests that wrist supports are contra-indicated although these supports may have beneficial effects on wrist posture.

Chapters five and six focus on precision and mental pressure as other potential determinants of muscle activity. The main result of the study on force precision demands during a low-intensity pinching task was that the relative contribution in force production of the index finger did increase with increasing precision. It was concluded that increased precision led to a decreased freedom of choice in task performance, with as possible effect that a small part of the involved musculature bears a relative high load. Chapter six describes the effects of positioning precision demands and mental pressure on muscle activation and hand forces in computer mouse tasks. Precision demands and mental pressure were found to coincide with increased muscle activity in some muscles and increased force exertion on the computer mouse. Precision demands had large effects on performance measures indicating that precision might be an indirect mental stressor by affecting the fear to make mistakes/faults or the necessity to avoid errors.

Chapter seven focused on the consequence of neck-shoulder muscle activity. The study described the effect of static loading of the neck-shoulder region on the blood flow in the arm. The study showed that arm blood flow was affected by neck-shoulder muscle activity and, consequently the effects of sustained neck-shoulder muscle activity, might not be limited to the muscle itself but may also precipitate more distal disorders and complaints.

8.3 Research

It was expected in advance that only a modest contribution to the body of knowledge and an even smaller contribution to solving problems in WRUEMD's would be realistic. This was a logical consequence of the multifactorial nature of the pathogenesis and the diverse tissues involved in the disorders (see chapter 2). It was clear that, in order to obtain results within reasonable time, it would be necessary to restrict the focus of our studies, with the implication that we brushed aside a lot of other probably relevant aspects. In this paragraph we will review some of these choices in retrospective.

Focus on low intensity

Our choice to focus on low-intensity tasks was based more on curiosity than on epidemiological data on risk factors. The prevalences and severity of complaints in high-intensity upper extremity tasks, like plastering (stucco-work) or deboning (slaugtherhouse workers), are at least as high as in low-intensity tasks (Bernard 1997). In high-intensity tasks the mechanism by which task loads lead to complaints is easily conceived, in contrast to the intriguing situation in low-intensity work where it is far from clear how these tasks could possibly lead to complaints. It is quite likely that the pathophysiological mechanisms involved differ between low- and high-intensity tasks, which mean that generalization of from the one to the other might be difficult. On the other hand, some of the findings on low-intensity work point in the direction of localized high tissue loading and energy depletion indicating that similar processes might be responsible for tissue damage as in high-intensity tasks.

Focus on muscles

The focus on muscles that was opted for in this study, was motivated by the idea that muscle activity plays a major role in task performance. The impact of this restriction might be that the results of this thesis are exclusive for muscle complaints and symptoms. On the other hand, it can be expected that muscle activation at least partly reflects tendon loading as well. The mechanisms underlying tendon and nerve disorders do certainly differ from each other and from muscle disorders. Perhaps that the more generic effects on circulation and sustained loading patterns play a role in the pathogenesis in each of these tissues.

The focus on muscles also had consequences for the choice of dependent variables: surface EMG was used in all experiments. We have tried to differentiate between different amplitude levels (static, median an peak levels), but the results revealed similar results for all amplitude levels, and in the later experiments only median values were presented. Although the literature does suggests that short interruption of EMG activity which have been labeled EMG gaps, may be relevant in the development of WRUEMD's, we did not consider these in the analyses. A lack of sensitivity and high variability in combination with the relative short duration of the experimental tasks let to the rejection of this measure. We calculated the static level in the EMG amplitude, the 10^{th} percentile, which is known to be strongly related to the occurrence of EMGgaps (Røe and Vøllestad 2001). But as said before differentiation between different amplitude measures appeared not very helpful in our studies.

The pathophysiological literature reviewed in chapter 2 gives no clear indications of a role of muscle fatigue, which may be understandable given the fact that muscle load is in general too low in the sort of tasks studied to detect fatigue with commonly used parameters such as changes of the frequency content of the electromyogram (Jørgensen et al. 1988). Other fatigue indicators based on force measurements do interfere with task performance. We therefore did not focus on fatigue in the experiments. Note however, that the measurement of low-frequency fatigue may hold some promise in relation to the development of WRUEMD's (Westerblad et al. 2000; Dennerlein et al. 2003).

In addition to EMG, in all experiments except the arm support study, force was measured, either as (control of) an independent variable (pinch forces in the pinching experiments) or as a dependent variable (mouse forces in the clicking and aiming experiment). The force measures appeared useful because they reflect absolute load levels.

Choice of task related factors

The amount of possible task related factors is large and becomes unmanageable when discrete levels of these factors are considered. With respect to possible levels we often chose two or three levels with the intention to cover the range of exposure found in low-intensity work.

Task related factors that we intentionally manipulated were force, the use of arm / wrist supports, force precision, positioning precision and mental pressure. Other task related factors were kept constant at levels within the ranges of common low-intensity work: f.i. normal typing speed, non-extreme postures, sub-maximal pinch-relaxation rates, etc. The implication of these choices is that generalization of the results should be restricted to work situations with similar characteristics.

Future research issues

A suggestion for future research, most closely related to this thesis is to continue research on precision. The results (chapters 5 & 6) did show that precision is a relevant factor contributing to the occurrence and level of muscle load. More specifically it is suggested to focus on prevention by setting up research to optimize the design of tasks which pose high precision demands.

The lack of knowledge on several temporal aspects in the development of WRUEMD's advocates to focus on optimizing work-rest patterns, getting insight in effects of exposure time on dose-response relationships. Essential for this kind of studies is to add measures for temporal effects; measures sensitive enough to reveal subtle effects of workload occurring over time. Other topics that require further investigation are the potential vicious circles and their role in chronicity of WRUEMD's, the role of affected motor control, possibly in relation to changes in proprioception, individual susceptibility, and the interrelation of physical and psyho-sociological risk factors in work.

More general suggestions for all topics mentioned above are to consider the upper extremity as a functional unit in research. In several places mutual influences of neck-shoulder and forearm load can be found. Applying stability to the forearm, whether by supports or by increasing pinch force led to reduced muscle activation in the neck shoulder region. Neck shoulder load in return had effects on blood circulation in the forearm, and led to a slight increase in forearm muscle activity. It seems important in future research to have an open eye for these these interactions and also look for more proximal causes for distal effects.

8.4 Practical implications

The existence of (occupational) risk factors for WRUEMD's implicates that they are to some degree preventable. Addressing the proper risk factors in the proper way is important.

Reducing the intensity of exposure to risk factors like force, repetition and non-neutral postures is likely to be useful in prevention. For example, reducing the force levels and thus lowering of muscle activation levels might be achieved by optimizing working postures, adding effective support (arm supports, back rest) and by bringing about a working technique with limited co-contraction. However it should be realized that reducing the intensity will not necessarily eliminate the risk of developing complaints because as the Cinderella hypothesis underlines, lowering the activation level does not necessarily provide relief for the small motorunits. Even very low intensities over prolonged time can have harmful effects. Therefore, the main implication of this thesis is that ***breaking the pattern of sustained activity*** is of eminent importance for effective prevention. Interruption of the sustained activity does not necessarily mean that reductions of load levels are required; shifting to more dynamic activation patterns might be effective as well (Westad et al. 2003). The task requirements leading to sustained activity are related to task precision, task stress, work-rest schedules and psychosocial factors. Reducing the precision demands might be an independent factor reducing the risk, but might have a positive influence on the reduction of the task stress as well. Reducing the precision demand in operating machines like cranes, saws, and drills might reduce activation levels of muscles involved and reduce the risk of accidents at the same time. The latter will probably reduce task stress, enhancing the effect of lowering muscle activation.

Reduction of precision demands in computer work can be influenced by user settings in most applications; increasing screen font sizes and icon sizes can be helpful. But maybe more important, designers of software and input devices should add low-precision demands to their design-criteria for the user-interface.

Task stress was shown to be a relevant factor, so preventive measures with respect to task stress might have positive effects. This thesis does not provide indications for healthy levels of task stress, but it is almost certain that for most stressors (individual) optimal levels exist. In general, it will be useful to increase the workers participation in decision-making and by doing this increasing their control over their job (Karasek and Theorell 1990).

As stated above with regard to optimal work-rest schedules no clear evidence based recommendations can be given. Nevertheless, it is likely that providing breaks and limitations of exposure duration are profitable. In computer work, software reminding to take pauses and micro breaks can be helpful (Heuvel et al. 2003).

Finally, the effectiveness of any intervention is also dependent on the intervention strategy. When it comes to prevention of a disorder of a multi-factorial nature like WRUEMD's, it is recommended to come up with interventions that mediate both physical and psychosocial stressors (Gezondheidsraad 2000). Preferably, the interventions are embedded in an ergonomic approach, whereby, employee involvement and employer commitment are essential for success (Looze et al. 2001).

8.5 References

Bernard BP (1997) Musculoskeletal disorders (MSDs) and workplace factors - a critical review of epidemiologic evidence for work-related musculoskeletal disorders of the neck, upper extremity, and low back. National Institute for Occupational Safety and Health, Cincinnati, OH

Dennerlein JT, Ciriello VM, Kerin KJ, Johnson PW (2003) Fatigue in the forearm resulting from low-level repetitive ulnar deviation. AIHA J (Fairfax, Va) 64: 799-805

Gezondheidsraad (2000) RSI. In. Gezondheidsraad, Den Haag, p 80

Heuvel SGvd, Looze MPd, Hildebrandt VH, The KH (2003) Effects of software programs stimulating regular breaks and exercises on work-related neck and upper-limb disorders. Scand J Work Environ Health 29: 106-116

Jørgensen K, Fallentin N, Krogh-Lund C, Jensen B (1988) Electromyography and fatigue during prolonged, low-level static contractions. European Journal of Applied Physiology 57: 316-321

Karasek RA, Theorell T (1990) Healthy work stress, productivity, and the reconstruction of working life. Basic Books, New York

Looze MPd, Urlings IJ, Vink P, van Rhijn JW, Miedema MC, Bronkhorst RE, van der Grinten MP (2001) Towards successful physical stress reducing products: an evaluation of seven cases. Appl Ergon 32: 525-534

Røe C, Vøllestad NK (2001) Relation between muscle activation level and gap frequency during dataterminal work. In: Premus - Fourth International Scienific Conference on Prevention of Work-Related Musculoskeletal Disorders, Amsterdam, The neteherlands, p 142

Westad C, Westgaard RH, De Luca CJ (2003) Motor unit recruitment and derecruitment induced by brief increase in contraction amplitude of the human trapezius muscle. J Physiol 552: 645-656

Westerblad H, Bruton JD, Allen DG, Lannergren J (2000) Functional significance of Ca2+ in long-lasting fatigue of skeletal muscle. European Journal of Applied Physiology 83: 166-174

Summary

Summary

Chronic pain and discomfort in muscles, tendons and joints constitute a health problem of great magnitude in the industrialized world. Mainly affected body regions are the low back and the upper extremity (neck, shoulder, arm and hand). Although, the musculoskeletal disorders are not uniquely caused by work exposures, they can be seen as 'work related' diseases. Reviews of the epidemiology on work related upper extremity disorders have shown strong and consistent associations between occupational exposures and upper extremity musculoskeletal symptoms. Nevertheless, there is still a lot unknown concerning exposure interactions, dose-response relationships, and especially the pathological processes determining onset and progression of these disorders. This observation led to the following general goal of the thesis: to increase insight in the role of work requirements during low-intensity work, including computer work, in the pathogenesis of upper extremity musculoskeletal disorders.

In Chapter 2, a review of the literature on the pathophysiology of work related upper extremity muscle disorders (WRUEMD's) is described. An overview is given of clinical findings and hypotheses on the pathogenesis of WRUEMD's. The following mechanisms have been proposed in the literature: 1) intra-cellular Ca^{2+} accumulation; 2) selective recruitment and overloading of type I (Cinderella) motor units; 3) impaired blood flow; 3b) reperfusion injury; 3.3c) blood vessel-nociceptor interaction; 4a) myofascial force transmission; 4b) intramuscular shear forces; 5) trigger points; and 6) impaired heat shock response. The results of the review indicate that there are several possible mechanisms, but none of the hypotheses forms a complete explanation and is sufficiently supported by empirical data. Overall, the literature indicates that 1) sustained muscle activity, especially of type I motor units, may be a primary cause of WRUEMD's; 2) in WRUEMD's skeletal muscle may show changes in morphology, blood flow, and muscle activity; 3); accumulation of Ca^{2+} in the sarcoplasm may be the cause of muscle cell damage; 4) It seems plausible that suboptimal blood flow plays a role in pathogenesis of WRUEMD's; 5) altered metabolite concentrations in muscles may activate type III and IV afferents contributing to a self-maintaining 'vicious circle' in which pain and muscle activity amplify each other. With respect to prevention and treatment only tentative conclusions can be drawn. The literature suggests that sustained static activity should be prevented either by introduction of breaks or by introduction

of variation in muscle activation and that reduction of muscle activity seems useful as a target in therapy.

Another review is described in chapter 3; the literature on the contribution of task-related constraints to the development of work-related myalgia was reviewed. The literature on the pathophysiology, shows that the intensity of contractions and the lack of periods of complete relaxation play a major role in the development of work-related myalgia. The muscular activity might not only, be determined by the magnitude and direction of forces and moments, but also by constraints with respect to stability and position control. Sustained muscle activity in low intensity tasks might be the result of the necessity to preserve moment equilibrium in combination with the use of co-activation of muscles in order to suppress neuro-motornoise (i.e. noise resulting from imprecision of motor control). The literature shows that stability of the upper extremity might be influenced by the use of arm supports and that the level of co-contraction used to counteract neuro-motor noise might be affected by task precision, and mental pressure.

Chapter 4 describes an experiment on the use of arm and wrist supports. The objective of the study was to evaluate the effectiveness of arm and wrist supports in reducing the workload during computer work. Sustained muscle tension in the trapezius muscle is a risk factor for trapezius myalgia. Arm and wrist supports are used at the workplace with the intention to reduce muscle tension. The effectiveness of these aids in reducing the load is not clear. Female subjects (n=10) performed computer work in conditions with arm or wrist supports and in a condition without supports. In the laboratory, a typing task and a mouse task were performed, each with four types of supports and without support. Electromyography and subjective ratings were used to quantify the workload.

Lower levels of trapezius muscle activation were recorded with the use of arm supports. Wrist supports did not reduce the trapezius muscle activation. The rated perceived workload did not discriminate. It was concluded that reduction of muscle activation in the neck shoulder region during standard VDU work can be achieved with arm supports. Wrist supports do not reduce the strain on the neck-shoulder region.

Chapter 5 describes the first of two experiments on task precision. High precision demands in manual tasks can be expected to cause more selective use of a part of the muscular synergy involved. To test this expectation, load sharing of the index finger and middle finger was investigated during a pinching task. Myoelectric activation of lower arm and neck-shoulder muscles was measured to see if overall level of effort was affected by precision demands. Ten healthy female subjects performed pinching tasks with 3 levels of force and 3 levels of precision demands. The force level did not significantly affect the relative contribution of the index and middle finger to the force. Higher precision demands, however, led to a higher contribution of the index finger to the pinch force. Consequently, a more selective load of the fore-arm and hand occurs during tasks with high precision demands. The variability of the force contribution of the fingers increased during the task. No effects of precision demand on the activation of fore-arm and neck-shoulder muscles were found. Force level did affect the EMG parameters of several muscles. The effects were most apparent in the muscles responsible for the pinch force, the fore-arm muscles. Activation of these muscles was higher at higher force levels. In the trapezius muscle at the dominant side EMG amplitudes were lower at the high pinch force compared to the low force and median force conditions.

The objective of the study in chapter 6 was to gain insight into the effects of positioning precision demands and mental pressure on the load of the upper extremity. We used two computer mouse tasks: an aiming and a tracking task. Upper extremity loading was operationalized as the myo-electric activity of the wrist flexor and extensor and trapezius descendens muscles and the applied grip- and click-forces on the computer mouse. Performance measures, reflecting the accuracy in both tasks and the clicking rate in the aiming task, indicated that the levels of the independent variables resulted in distinguishable levels of accuracy and work pace. Precision demands had a small effect on upper extremity loading with a significant increase in the EMG-amplitudes (21%) of the wrist flexors during the aiming tasks. Precision had large effects on performance. Mental pressure had substantial effects on EMG-amplitudes with an increase in tracking of 22% in the Trapezius and increases in aiming ranging from 41% in the Trapezius and 45% and 140% in the wrist extensors and flexors, respectively. During aiming, grip- and click-forces increased by 51% and 40% respectively. Mental pressure had small effects on accuracy but large effects on work rate during aiming.

Precision demands and mental pressure in aiming and tracking tasks with a computer mouse were found to coincide with increased muscle activity in some upper extremity muscles and increased force exertion on the computer mouse.

Mental pressure caused significant effects on these parameters more often than precision demands. Precision and mental pressure were found to have effects on performance, with precision effects being significant for all performance measures studied and mental pressure effects for some of them. The results of this study suggest that precision demands and mental pressure increase upper extremity load, with mental pressure effects being larger than precision effects. The possible role of precision demands as an indirect mental stressor in working conditions is discussed.

An experiment on blood flow effects during low intensity work is described in chapter 7. The object of the study was to determine whether static contraction of proximal musculature has an effect on the blood flow more distally in the upper extremity. Static contractions of muscles in the neck shoulder region at three levels (relaxed, shoulders elevated, and shoulders elevated loaded with of 4.95 kg each) were combined with intermittent pinch forces at 0, 10 and 25% of the voluntary maximum (MVC). Blood flow to the forearm was measured with Doppler ultrasound. Myoelectric activity of the forearm and neck-shoulder muscles were recorded to check for the workload levels. Across all levels of shoulder load blood flow increased significantly with increasing pinch force (21 % at 10% MVC and by 44% at 25% MVC). Blood flow was significantly affected by shoulder load, with the lowest blood flow at the highest shoulder load. Interactions of pinch force and shoulder load were not significant. The myo-electric activity of forearm muscles increased with increasing pinch force. The activation of the trapezius muscle decreased with increasing pinch force and increased with increasing shoulder load. The precise mechanisms accounting for the influence of shoulder load remains unclear. The results of this study indicate that shoulder load might influence blood flow to the forearm.

The epilogue of the thesis contains an overview of the previous chapters and reflects on them from a researcher's and a practitioner's perspective. The choice for low-intensity work as main topic was based more on curiosity than on epidemiological data on risk factors. The prevalences and severity of complaints in high intensity upper extremity tasks are at least as high as in low-intensity tasks, but the puzzling question is really how low-intensity tasks could possibly lead to complaints. The focus on muscles was motivated by the idea that muscle activity plays a major role in task performance, and that in most situations the level of muscle activation also reflects tendon loading. The focus on muscles had as consequence that surface EMG was used as a dependent variable in all experiments. Task related factors that we intentionally manipulated were force, the use of arm / wrist supports, force precision, positioning precision and mental pressure. Among the topics suggested for future research are continuation of research on precision, optimizing work-rest patterns, the potential vicious circles and their role in chronicity of WRUEMD's, the role of affected motor control and individual susceptibility. A general suggestion for al topics mentioned above is to consider the upper extremity as a functional unit in research because of the mutual influences of proximal and distal parts.

The existence of (occupational) risk factors for WRUEMD's implicates that they are to some degree preventable. Although it seems feasible to reduce force levels (f.i. by using arm supports), repetition and exposure to non-neutral postures, this thesis suggests that breaking the pattern of sustained activity is of eminent importance for effective prevention. Risk factors like precision and mental pressure deserve attention as well. Task stress was shown to be a relevant factor, so preventive measures with respect to task stress might have positive effects. Reducing the precision demand in operating machines might reduce activation levels of muscles involved and reduce the risk of accidents at the same time. The latter will probably reduce task stress, enhancing the effect of lowering muscle activation. Reduction of precision demands in computer work can be influenced by user settings in most applications; increasing screen font sizes and icon sizes can be helpful. But maybe more important, designers of software and input devices should add low precision demands to their design-criteria for the user-interface.

Samenvatting

Belasting van de bovenste extremiteit bij laag intensieve taken

Samenvatting

Chronische pijn en discomfort van spieren, pezen en gewrichten vormen een groot gezondheidsprobleem in de geïndustrialiseerde wereld. De meeste problemen doen zich voor in de lage rug en de bovenste extremiteit (nek, schouder, arm en hand). Hoewel de aandoeningen niet uitsluitend door het werk veroorzaakt worden, kunnen ze beschouwd worden als werkgerelateerde aandoeningen. Epidemiologische studies laten zien dat er sterke en consistente verbanden zijn tussen blootstelling aan factoren in het werk en aandoeningen van de bovenste extremiteit. Toch is er nog veel onduidelijk over bijvoorbeeld de blootstelling aan combinaties van factoren (zoals krachtleverantie in combinatie met extreme gewrichtsstanden), dosis-respons relaties en in het bijzonder over de pathologische processen die een rol spelen bij het ontstaan en verergeren van aandoeningen. Deze constatering leidde tot het volgende algemene doel van dit onderzoek: het vergroten van het inzicht in de rol van taakvereisten bij laag intensieve arbeid, waaronder computerwerk, in het ontstaan van aandoeningen van het spierskeletstelsel van de bovenste extremiteit.

In dit proefschrift worden de aandoeningen aangeduid met de afkortingen WRUEMD's – Work Related Upper Extremity Musculoskeletal Disorders.

Een overzicht van de literatuur (Hoofdstuk 2) over ontstaansmechanismen van WRUEMD's en in het bijzonder spieraandoeningen laat zien dat er veel verschillende hypothesen worden beschreven. Schade aan het spierweefsel wordt bijvoorbeeld verklaard door ophoping van Calcium-ionen (Ca^{2+}) in het intra-cellulaire milieu, eventueel in combinatie met selectieve rekrutering en overbelasting van of type I (Assepoester) spiervezels in de spier. In een aantal hypothesen wordt aan (beperkingen in) de doorbloeding van de spieren groot belang toegedicht. Een tweetal mogelijke mechanismen richt zich op de krachten die werken op en worden overgedragen door bindweefselstructuren in de spieren (myofasciale krachtsoverdracht en intramusculaire krachtsoverdracht). Tot slot worden zogenaamde 'trigger points' en een inadequate 'heat shock respons' genoemd. De afzonderlijke hypothesen overziend wordt geconcludeerd dat 1) ononderbroken spieractiviteit van type I spiervezels een primaire oorzaak kan zijn van WRUEMD's; 2) de skeletspieren in het geval van WRUEMD's veranderingen laten zien in morfologie, doorbloeding en activiteit; 3) Ca^{2+} ophoping kan leiden tot schade aan de spiercellen; 4) het plausibel is dat

verminderde doorbloeding een rol speelt; 5) ophoping van metabolieten in spierweefsel bij kan dragen aan een vicieuze cirkel waarin pijn en spieractiviteit elkaar versterken.

Een belangrijke implicatie van het bovenstaande is dat preventie zich zal moeten richten op het reduceren van de intensiteit van belasting en bovenal op het voorkomen van ononderbroken activiteit van type I spiervezels door het introduceren van onderbrekingen of variatie van activiteit.

In een tweede literatuuronderzoek (Hoofdstuk 3) werd de bijdrage van werkfactoren aan de ontwikkeling van WRUEMD's bestudeerd. Uit het vorige onderzoek bleek dat de intensiteit van spieractiviteit en het ontbreken van onderbrekingen in de activiteit van belang zijn bij het ontstaan van WRUEMD's. De benodigde spieractiviteit voor de uitvoering van een taak hangt behalve van de grootte en richting van de (extern) te leveren krachten en momenten ook af van vereisten met betrekking tot stabiliteit en positie-controle. Bij laag intensieve taken is de spieractiviteit mogelijk een gevolg van het handhaven van een momenten evenwicht in combinatie met co-activatie van spieren ten behoeve van het onderdrukken van neuro-motorische ruis. Door verhoging van het activatieniveau van de spieren wordt het effect van ruis, onnauwkeurigheid in bewegen, tegengegaan. Uit de literatuur blijkt dat stabiliteit van de bovenste extremiteit behalve door spieractiviteit ook beïnvloed kan worden door armondersteuning en dat niveau's van co-activatie om neuro-motorisch ruis te onderdrukken, mogelijk afhangen van taakprecisie en mentale druk.

Er is een experiment uitgevoerd om de effectiviteit van arm- en polsondersteuning in het verlagen van de belasting bij beeldschermwerk te onderzoeken (Hoofdstuk 4). In een laboratoriumexperiment hebben 10 vrouwelijke proefpersonen typ- en muistaken uitgevoerd zonder ondersteuning en met vier verschillende modellen arm- en polsondersteuning. Er is gebruik gemaakt van oppervlakte EMG (electromyografie) van een nek/schouderspier (m. Trapezius) en van schalen voor subjectief ervaren belasting. De activatie van de m. Trapezius bij het gebruik van de armondersteuning was lager dan in de situatie zonder ondersteuning. Pols ondersteuning leidde niet tot een verlaging van de belasting van de m. Trapezius. De subjectief ervaren belasting verschilde niet tussen de condities.

Vervolgens zijn er twee experimenten verricht die betrekking hebben op de invloed van taakprecisie op de belasting van de bovenste extremiteit. In het eerste experiment (Hoofdstuk 5) is onderzocht of de verwachting dat hoge precisie vereisten leiden tot een beperking van de uitvoeringsvrijheid met als gevolg een relatief hoge locale van belasting, juist is. De bijdrage van de wijsvinger en middelvinger aan de benodigde kracht bij het uitvoeren van een knijptaak is onderzocht bij 3 niveaus van precisievereisten gecombineerd met 3 krachtniveaus. Tevens is oppervlakte EMG gebruikt om spieractivatie van onderarm- en nek/schouderspieren te bepalen. Het krachtniveau had geen invloed op de relatieve bijdrage van wijsvinger en middelvinger. Hogere precisie vereisten resulteerden in een grotere bijdrage van de wijsvinger aan de te leveren kracht. Met andere woorden, hoge precisievereisten leiden tot een selectieve belasting van delen van onderarm en hand. De activatie van nek/schouderspieren en onderarmspieren werd niet beïnvloed door de precisievereisten. Krachtniveaus waren van invloed op de activatie van zowel de onderarm als nek/schouderspieren, waarbij een hogere knijpkracht resulteerde in een hogere spieractivatie in de onderarm en in een lagere activatie van de m. Trapezius. Dit laatste resultaat kan mogelijk verklaard worden door een toegenomen stabiliteit in de arm bij hogere krachtleverantie.

In het tweede experiment met betrekking tot precisievereisten (Hoofdstuk 6) stond positioneringsprecisie, in combinatie met mentale druk, tijdens een computertaak centraal. In dit experiment werden een volgtaak en een aanwijstaak met een computermuis uitgevoerd. In beide taken werden met de grootte van het doelobject de precisievereisten gemanipuleerd. De mentale druk werd in de aanwijstaak gevarieerd van een rustig tot een zeer hoog werktempo. In de volgtaak werd dit gedaan door de taakuitvoering zonder feedback uit te voeren of met feedback in combinatie met instructie om 'zeer goed' te presteren. De belasting van de bovenste extremiteit werd wederom met oppervlakte EMG bepaald, in combinatie met metingen van de knijp- en klikkracht uitgeoefend op de muis. Daarnaast werden verschillende maten om de kwaliteit van taakuitvoering te kwantificeren bepaald, zoals het aantal missers bij de aanwijstaak of het percentage van de tijd dat het te volgen doel werd geraakt met de cursor.

De precisievereisten hadden een gering effect op de belasting van de bovenste extremiteit maar hadden grote effecten op de maten voor taakuitvoering. De mentale druk had grote effecten op de EMG–amplituden bij zowel de aanwijs- als volgtaak. Er werden ook grotere krachten op de muis uitgeoefend onder de hoge mentaal druk. Mentale druk had geringe effecten op de nauwkeurigheid van taakuitvoering maar een groot effect op het werktempo.

De resultaten van deze studie wijzen erop dat zowel precisievereisten als mentale druk de belasting verhogen. In de discussie van deze studie wordt geopperd dat precisie vereisten ook kunnen bijdrage aan mentale druk, bijvoorbeeld in situaties waar het maken van fouten grote consequenties heeft.

Het laatste experiment dat wordt beschreven (Hoofdstuk 7) richt zich op het effect van statische belasting van de nek/schouderregio op de doorbloeding van de onderarm. Drie niveaus van statische belasting van de nek/schouderregio (ontspannen, opgetrokken schouders, en opgetrokken schouders met op ieder schouder een last van circa 5 kg) werden gecombineerd met drie niveaus van intermitterend knijpen (0, 10 en 25 % van de maximale knijpkracht). De doorbloeding in de arm werd bepaald met behulp van Doppler ultrageluid. De belasting niveaus in zowel onderarm als nek/schouderregio werden met behulp van oppervlakte EMG bepaald. De doorbloeding van de arm nam toe met de knijpkracht. Er was een effect van de schouderbelasting op de doorbloeding zodanig dat de hoogste belasting leidde tot de laagste doorbloeding. Evenals in het eerder beschreven knijpexperiment trad een afname van de EMG amplitude van de m, Trapezius op bij toenemende knijpkracht.

Vanuit het perspectief van de onderzoeker en de adviseur in de praktijk wordt teruggeblikt op de voorgaande hoofdstukken (Hoofdstuk 8). De keuze voor laag intensieve taken als het onderwerp van de studies was vooral ingegeven door nieuwsgierigheid en veel minder door gegevens over risicofactoren in relatie tot aandoeningen aan de bovenste extremiteit. Immers bij hoog intensieve taken komen klachten minstens zo veel voor, doch hier ontbreekt de intrigerende vraag hoe de niveaus van belasting te rijmen zijn met de optredende klachten. Het toespitsen van de studie op de spieren impliceert dat andere weefsels die betrokken zijn bij WRUEMD's relatief onderbelicht zijn. Duidelijk is dat spieren en centrale rol spelen bij de belasting van de bovenste extremiteit met daarbij de toevoeging dat spierbelasting tot op zeker hoogte ook de belasting op andere structuren (met name de pezen) reflecteert. Een belangrijke consequentie van de focus op spieren was het gebruik van oppervlakte EMG om de belasting te kwantificeren. Met de keuze voor EMG werd goed aangesloten bij in het onderzoeksveld gehanteerde methoden, zodat vergelijken van onderzoeksresultaten mogelijk werd.

Voor toekomstig onderzoek wordt voorgesteld om, door te gaan met het onderzoeken van precisie als risicofactor, werk-rust schema's te optimaliseren, meer zicht te krijgen op de chroniciteit van de aandoeningen en de rol van vicieuze cirkels tussen belasting en belastingsgevolgen, aandacht te besteden aan individuele verschillen van personen ten aanzien van het risico om klachten te krijgen. Voor al deze onderwerpen geldt dat wordt geadviseerd om de bovenste extremiteit als functionele eenheid te onderzoeken, omdat gebleken is dat wederzijdse beïnvloeding van distale (hand/arm) en proximale (nek/schouder) delen optreedt.

Uit het feit dat er 'risicofactoren' voor het optreden van WRUEMD's te benoemen zijn, kan de optimist concluderen dat ze dus in enige mate te voorkomen zijn. Hoewel in het algemeen het verlagen van de intensiteit van risicofactoren, zoals het verlagen van kracht of het realiseren van meer neutrale gewrichtshoudingen, zinvol lijkt, is misschien de belangrijkste aanbeveling van dit proefschrift om het patroon van langdurige (eenzijdige) belasting te doorbreken. Daarnaast lijkt het zinvol om ook in de praktijk aandacht te besteden aan het reduceren van precisie vereisten en mentale druk tijdens werk. Het verminderen van precisievereisten bij het bedienen van machines leidt mogelijk niet alleen tot het verlagen van de belasting maar tevens tot het verminderen van de kans op ongelukken. Dit laatste zal de mentale druk mogelijk verlagen wat eveneens positief werkt op het verlagen van de belasting. Het reduceren van precisievereisten bij computerwerk kan in veel gevallen beïnvloed worden door de gebruiker, bijvoorbeeld door grote lettertypes en iconen te kiezen. Het is wellicht nog beter dat ontwerpers van software en invoermiddelen meer aandacht gaan besteden aan lage precisie vereisten als één van de ontwerpcriteria.

Dankwoord

"With a Little Help From My Friends"

Ook bij laag intensieve arbeid is een beetje hulp zeer welkom en zeker ook zeer gewaardeerd. Deze twee pagina's zijn een poging om die waardering te verwoorden.

Een welgemeend: '**hartelijk bedankt !**' richt ik tot eenieder (familie, vrienden en collega's) die in de afgelopen jaren belangstelling toonde, me sterkte wenste of me anderszins een hart onder de riem stak.

Natuurlijk zijn er ook personen die ik speciaal wil bedanken omdat ze veel meer dan 'a little help' hebben geboden.

Allereerst bedank ik mijn promotor, Jaap van Dieën. Jaap, ik ben blij dat jij mijn promotor bent, ik vind je niet alleen een heel erg goede wetenschapper maar ik vind je ook een zeer positieve en stimulerende baas. Je hebt me niet op m'n huid gezeten, terwijl je natuurlijk wel zag dat het promotieonderzoek vaak het ondergeschoven kindje in mijn werkzaamheden was. Je was altijd, met zeer goede bijdragen, beschikbaar op die momenten dat ik wel volop op het onderzoek dook. Veel dank.

Mijn Copromotoren, Michiel de Looze en DirkJan Veeger, en Marjolein Douwes als lid van de begeleidingscommissie, bedank ik alledrie voor hun bijdragen aan het onderzoek. Jullie commentaren op voorstellen en conceptartikelen heb ik zeer gewaardeerd.

Aan ERGOcare, mijn thuisbasis op de faculteit, ben ik veel dank verschuldigd. Ik ben vaak uit de wind gehouden door mijn collega's, en vooral de fietsers onder ons weten hoeveel dat scheelt!! Mijn paranimfen komen, vanzelfsprekend, uit deze hechte groep. Het voelt goed om, samen met een groot aantal van jullie, aan een volgend groot project te beginnen: EXPres, Expertisecentrum voor Revalidatie Ergonomie en Sport. Paul, Eric, Annieck, Marianne, Wiebe, Robin en Margriet, bedankt.

De rol van een kamergenoot moet niet onderschat worden, en dat doe ik dan ook niet. Het is goed om een gezellige, opgeruimde, geordende vraagbaak in de buurt te hebben. Marco, ik ben blij dat je 'meeverhuist' richting EXPres om daar mijn buurman te worden.

De Teams 40 en 44 bij TNO Arbeid wil ik hartelijk danken voor hun gastvrijheid als ik een plekje innam te Hoofddorp of (wat ongeveer net zo vaak voorkwam) deelnam aan een team-uitje. Ook de TNO-ers van de TPD: bedankt.

Heel veel dank ben ik verschuldigd aan de studenten die in het kader van hun onderzoekstage vaak keihard gewerkt hebben aan projecten waar ik nu goede sier mee maak. Ieders bijdrage was groot(s). Elsbeth, Ingrid, Hank, Maaike, Lottie, Liesbeth, Ferdie, Thijmen, Afke, Tamara, Heleen, Miriam, Christine, Bertwin en Matthijs bedankt.

De proefpersonen waren onmisbaar, zonder jullie vrijwillige inzet was er niets van terecht gekomen. Bedankt voor het uitvoeren van type-, knijp-, muis-, klik-, tik- en andere taken.

I want to thank Bente Jensen and Pernille Kofoed Nielsen for their kind collaboration and their contribution to 'the blood flow experiment'. The hospitality of the National Institute of Occupational Health is very much appreciated. Also on behalf of Heleen and Miriam, I want to thank you very much.

Natuurlijk wil ik ook mijn dank voor de technische ondersteuning niet ongenoemd laten. Veel TOD'ers zijn behulpzaam geweest, allen bedankt, en in het bijzonder Leon, Jos, Hans en Rink.

Mijn directe collega's binnen de lijnen A6 en A4 (en nu TA1), bedankt voor zowel de onderzoeksinhoudelijke gesprekken als de fijne (werk-)sfeer in het algemeen.

Rients Rozendal verdient een plek in dit dankwoord omdat hij 14 jaar geleden al het vertrouwen in me uitsprak en me stimuleerde om het meer fundamentele onderzoek niet uit het oog te verliezen. Volgens hem zou dat zowel goed zijn voor mijn persoonlijke ontwikkeling als voor de kwaliteit van het toegepast onderzoek.

Paul, je staat al in dit dankwoord, maar je grote betrokkenheid bij mijn wel en wee rechtvaardigen zeker een tweede vermelding. Paul, Astrid en Giesse het is fijn om zulke vrienden te hebben.

Monique, jij hoort ook in dit dankwoord thuis. Het is fijn dat je het promotietraject van het begin tot het eind intens meebeleeft.

Piet, jou bedanken zonder Pien is moeilijk, gelukkig heb ik jullie samen al eens laten weten hoe blij ik ben, dat jullie me zoveel vertrouwen gaven dat ik er zelfvertrouwen uit kon ontwikkelen.

Lieve Lies, jij bent het mooiste wat het onderzoek me heeft opgeleverd. Je bent geweldig !

Publications

Publications

The publications printed in **bold** are a part of the thesis

Articles in international journals - related (1999 – 2004)

Visser B, de Korte E, van der Kraan I, Kuijer P (2000) The effect of arm and wrist supports on the load of the upper extremity during VDU work. Clinical Biomechanics 15: S34-38

Visser B, de Looze MP, Veeger HEJ, Douwes M, Groenesteijn L, de Korte E, van Dieën JHv (2003) The effects of precision demands during a low intensity pinching task on muscle activation and load sharing of the fingers. J Electromyogr Kinesiol 13: 149-157

Visser B, De Looze MP, De Graaff MP, Van Dieën JHv (2004) Effects of precision demands and mental pressure on muscle activation and hand forces in computer mouse tasks. Ergonomics 47: 202-217

Visser B, Kofoed Nielsen P, de Kraker H, Smits M, Jensen BR, Dieën JHv, (under revision) The effects of shoulder load and pinch force on electromyographic activity and blood flow in the forearm during a pinch task

Visser B, Dieën JHv, (accepted for publication) Pathophysiology of work related upper extremity muscle disorders. J Electromyogr Kinesiol

Articles in international journals - non-related (1999 – 2004)

Bos J, Mol E, Visser B, Frings-Dresen M (2004) The physical demands upon (Dutch) fire-fighters in relation to the maximum acceptable energetic workload. Ergonomics 47: 446-460

Bos J, Mol E, Visser B, Frings-Dresen MHW (Accepted) Occupational risk for health complaints and related disability with respect to (Dutch) firefighters: a questionnaire study. Int Arch Occup Environ Health

Dieën JHv, Visser B (1999) Estimating net lumbar sagittal plane moments from EMG data. The validity of calibration procedures. Journal of Electromyography and Kinesiology 9: 309-315

Kuijer PPFM, Visser B, Kemper HCG (1999) Job rotation as a factor in reducing physical workload at a refuse collecting department. Ergonomics 42: 1167-1178

Kuijer P, Frings-Dresen M, Looze Md, Visser B, Beek Avd (2000) Work situation and physical workload of refuse collectors in three different time periods. International Journal of Industrial Ergonomics 26: 509-519

Kuijer PP, Hoozemans MJ, Kingma I, Van Dieen JH, De Vries WH, Veeger DJ, Van der Beek AJ, Visser B, Frings-Dresen MH (2003) Effect of a redesigned two-wheeled container for refuse collecting on mechanical loading of low back and shoulders. Ergonomics 46: 543-560

Kuijer PP, van der Beek AJ, van Dieen JH, Visser B, Frings-Dresen MH (2002) Effect of the number of two-wheeled containers at a gathering point on the energetic workload and work efficiency in refuse collecting. Appl Ergon 33: 571-577

Kuijer PPFM, Frings-Dresen MHW, Vries WHKd, Beek AJvd, Dieën JHv, Visser B (Accepted) Effect of Job Rotation on Work Demands, Physical and Mental Workload, and Recovery of Refuse Truck Drivers and Collectors. Human Factors

Praagman M, Stokdijk M, Veeger HE, Visser B (2000) Predicting mechanical load of the glenohumeral joint, using net joint moments. Clin Biomech 15: 315-321

Bookchapters - related (1999 – 2004)

Dieën JHv, Visser B, Hermans V (2003) The contribution of task-related biomechanical constraints to the development of work-related myalgia. In: Johansson H, Windhorst U, Djupsjöbacka M, Passatore M (eds) Chronic Work-Related Myalgia - Neuromuscular Mechanisms behind Work-Related Chronic Muscle Pain Syndromes. Gävle University Press, Gävle, Sweden, 83-93

Dieën JHv, Visser B, Frings-Dresen MH (2002) Het ontstaan van RSI. In: Peereboom KJ, Huysmans MA (eds) Handboek RSI / Risico's - oplossingen - behandeling. Sdu Uitgevers, Den Haag, 53-70

Visser B, Schollaardt F, Sietsma T (2002c) Helpt een polssteun op je muismat? In: Rhijn Gv, Scheijndel Pv, Dieën JHv (eds) Ergonomie: succesvolle praktijkvoorbeelden. Uitgeverij Kerckebosch bv, Zeist, 125-126

Visser B, Kuijer P (2001) Het toetsenbord is een technologische dinosaurus. In: Koning Jd, Savelsbergh G (eds) Stilstaan bij bewegen. Natuur & Techniek, Beek, 122-123

Visser B, Dieën JHv (2001b) RSI: hoe zwaar licht werk kan zijn. In: Koning Jd, Savelsbergh G (eds) Stilstaan bij bewegen. Natuur & Techniek, Beek, 124-125

Bookchapters – non related (1999 – 2004)

Visser B, Dieën JHv (2002) Tillen en dragen. In: Peereboom KJ, Huysmans MA (eds) Handboek Fysieke Belasting, vol 3e herziene druk. Sdu Uitgevers, Den Haag

Articles in Dutch journals - related (1999-2004)

Boersma AL, Vrusch THL, Visser B, Dieën JHv (2001) Preventie van RSI: oefenen of rusten? De invloed van actieve en passieve pauzes op de vermoeidheid van de schouderspieren. Tijdschrift voor Ergonomie 26: 14-21

Hoozemans MJM, Kuijer PPFM, van der Molen HF, de Looze MP, Visser B (2003) IEA 2003 - Ergonomics in the digital age. Wereldcongres Ergonomie in Seoul. Tijdschrift voor Ergonomie

Kraker Hd, Smits M, Visser B, Dieën JHv (2003) De invloed van schouderbelasting en knijpkracht op het ontstaan van RSI-klachten aan de onderarm of handen. Tijdschrift voor Ergonomie 28: 18-25

Visser B, Dieën JHv (2001) Ontstaansmechanismen van RSI. Gezondheidszorg InfoSpecial: 21-24

Visser B, Hoozemans MJM, Huysmans MA, Dieën JHv (2003) Precisie als risicofactor voor RSI. Het Handvat