REPETITIVE AND MONOTONOUS WORK AMONG WOMEN

Repetitive and monotonous work among women

Psychophysiological and subjective stress reactions, muscle activity
and neck and shoulder pain

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Abbreviations

ANS	Autonomic nervous system
CNS	Central nervous system
CO ₂	Carbon dioxide
DBP	Diastolic blood pressure
ECG	Electrocardiogram
EMG	Electromyography
HPA system/axis	Hypothalamic-pituitary-adrenocortical system/axis
HR	Heart rate
HRV	Heart rate variability
PNS	Parasympathetic nervous system
SAM system	Sympathetic adrenal-medullary system
SBP	Systolic blood pressure
SEMG	Surface electromyography
SNS	Sympathetic nervous system
VDU	Visual display unit
WMSDs	Work related musculoskeletal disorders

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1 INTRODUCTION

Currently, the most commonly reported work-related health problems in the European Union are musculoskeletal pain, stress and overall fatigue (European Agency for Safety and Health at Work, 2002; European Foundation, 2001). This picture is reflected in the long-term sick leave cases (more than 60 days per year) in Sweden, where diagnoses related to the musculoskeletal system and diagnoses such as depression (including burn-out), anxiety- and stress-related disorders are the most common today. In addition, musculoskeletal disorders are the most common reason for early retirement and work-related disorders in Sweden (Swedish National Social Insurance Board, 2004). Accordingly, the costs associated with musculoskeletal disorders are substantial, making this probably one of the most expensive disease categories in the industrialized World (Goossens, 2002). According to a report from the European Agency for Safety and Health at Work (Buckle & Devereux, 1999), workers in the European Union are becoming more exposed to workplace risk factors for musculoskeletal disorders, and it is thus likely that these disorders and their associated symptoms will actually increase in the future, if counteracting measures are not taken.

Musculoskeletal disorders can be classified into those that are work-related and non work-related, whereby the former has "a proven or hypothetical work-related causal component" (Hagberg et al., 1995, p. 5). It is important to stress that working conditions do not need to be the only causative factor for work-related musculoskeletal disorders (WMSDs), but constitute one causal factor among others that significantly contributes to the development or exacerbation of the disorder (World Health Organization, 1985). This is in line with the common view that WMSDs are multi-factorial in nature (e.g., Bernard, 1997; Blair et al., 2003; Bongers, de Winter, Kompier & Hildebrandt, 1993; Hagberg et al., 1995; Huang, Feuerstein, & Sauter, 2002; Melin & Lundberg, 1997; National Research Council and Institute of Medicine, 2001), and a complex interplay between different factors is considered to contribute to the development and maintenance of these disorders. The risk factors associated with WMSDs may be classified into physical, psychosocial and individual (e.g. Bongers, Kremer & ter Laak, 2002).

Associations between physical (i.e., ergonomic/biomechanical) workplace factors and musculoskeletal disorders were observed already in the 18th century (Fee, Brown, Franco & Franco, 2001), and today the role of physical workplace factors such as repetitive and stereotyped motions, force and pos-

ture is well established (e.g., Bernard, 1997; Buckle & Devereux, 1999; Hagberg et al., 1995; Kilbom, 1994 a; Punnett & Wegman, 2004). According to a recent review, today there is "...an international near-consensus that musculoskeletal disorders are causally related to occupational ergonomic stressors, such as repetitive and stereotyped motions, forceful exertions, non-neutral postures, vibration, and combinations of these exposures" (Punnett & Wegman, 2004, p.19). In line with this, WMSDs are common not only in physically demanding jobs, but also in repetitive and monotonous work with a light to medium physical workload (e.g., Bernard, 1997; Ekberg et al., 1994; Kilbom, 1994 a; National Research Council and Institute of Medicine, 2001; Ohlsson et al., 1995; Tittiranonda, Burastero & Rempel, 1999). This type of work is common today. Three of ten (31%) workers in the European Union (EU) perform repetitive hand/arm work tasks, and four of ten (40%) perform work that includes monotony, according to a survey on working conditions in the EU (European Foundation, 2001).

However, repetitive and monotonous work is unevenly distributed between different occupational groups. For example, in the EU repetitive hand/arm movements varied between 14% in professionals to 54% in machine operators. At the same time, monotonous work tasks varied between 25% in professionals to 57% in machine operators and persons with elementary occupations (European Foundation, 2001). Furthermore, repetitive and monotonous work tasks are often frequent in "low status" jobs performed mainly by women, such as assembly line work, simple data entry work at video display units, and cashier work in supermarkets. New types of repetitive work, such as call center work, are also emerging and growing rapidly (Norman, Nilsson, Hagberg, Wigaeus Tornqvist & Toomingas, 2004). According to the Swedish Work Environment Authority and Statistics Sweden (2003a), 44.9% of Swedish employed women and 36.5% of Swedish employed men had an occupation classified as repetitive in 2001. According to the same report, 17% of all Swedish employed women and 13% of all employed men (i.e., not only restricted to occupations classified as repetitive) were performing repetitive and monotonous work during at least 75% of their working hours. Moreover, in 2003, 38.5% of Swedish employed women compared with 34.5% of Swedish employed men reported computer work during at least half of their working time, and 19.7% of the women compared with 13.4% of the men reported computer work during almost all their working time (Statistics Sweden, 2005). Besides the established physical risk factors related to the repetitiveness and static muscle activity found in these jobs, these work environments are also often characterized by psychosocial factors that, according to well-known stress theories and empirical findings, may induce psychophysiological stress reactions with potential implications for health. In addition, compared with more flexible jobs, empirical findings have generally shown larger and more persistent stress reactions in repetitive and monotonous work (Lundberg & Johansson, 2000).

Epidemiological research has also repeatedly shown associations between work-related psychosocial factors and musculoskeletal disorders, and accordingly, the role of psychosocial factors and stress in these disorders has received increased attention (e.g. Moon & Sauter, 1996). Systematic reviews have reported associations between musculoskeletal disorders and work-related psychosocial factors such as high workload/demands, high perceived stress, low social support, low job control, low job satisfaction and monotonous work (e.g., Bernard, 1997; Bongers et al, 1993, 2002; National Research Council and Institute of Medicine, 2001; Vingård & Nachemson, 2000). However, the role of work-related psychosocial factors in WMSDs remains unclear. The majority of published studies have been cross sectional, which omits the possibility to determine temporal relations between exposure variables and outcome measures. However, the number of prospective studies are increasing, and several have identified psychosocial risk factors for WMSDs, after controlling for a variety of potential confounders such as physical workload, gender and age, among other factors (Andersen et al., 2003; Feveile, Jensen & Burr, 2002; Harkness, Macfarlane, Nahit, Silman & McBeth, 2002; Leino, 1989; Leino & Hänninen, 1995; Miranda, Viikari-Juntura, Martikainen, Takala & Riihimäki, 2001; van den Heuvel, van der Beek, Blatter, Hoogendoorn & Bongers, 2005). Besides the work-related physical and psychosocial risk factors mentioned above, additional prospective studies have identified individual risk factors for musculoskeletal complaints, such as depressive symptoms (Leclerc, Chastang, Niedhammer, Landre & Roquelaure, 2004; Leino & Magni, 1993), psychological distress and psychosomatic problems (Leclerc et al., 1999). These and other individual factors related to behavior and lifestyle may interact with work-related factors in the complex and multi-factorial etiology of WMSDs (e.g., Linton 2000; Lundberg, 2002).

Work-related musculoskeletal disorders is an umbrella term that includes a wide range of disorders and conditions affecting not only muscles but also tendons, ligaments, peripheral nerves, joints, bursa and blood vessels (Hagberg et al., 1995; Punnett & Wegman, 2004). Some of these disorders, such as epicondylitis, bursitis, carpal tunnel syndrome, osteoarthritis, etc., can be described as clinical syndromes whereas others can be described as being less well standardized because the pathological mechanisms are not yet known. Muscle pain (i.e., myalgia) in the neck and shoulders, low back pain and other regional pain syndromes belong to this latter group of disorders and conditions (Punnett & Wegman, 2004), also referred to as non-specific disorders in contrast to the former group of specific disorders/clinical syndromes (e.g., Blair et al., 2003). The focus in this thesis is on non-specific muscle pain in the neck and shoulder region associated with repetitive and monotonous work with a low to medium physical load, exemplified by data entry work and supermarket cashier work. This pain condition can be referred to as trapezius myalgia, i.e., pain in the anatomical region where the

trapezius muscle is located (see figure 1). This anatomical region is very often affected by pain, especially among women (Hagberg et al., 1995; Swedish Work Environment Authority & Statistics Sweden, 2004), and the trapezius muscle is a common site for complaints in female workers performing highly repetitive work tasks (Ranney, Walls & Moore, 1995). In addition to pain, tenderness in the muscles in the neck and shoulder region is common in trapezius myalgia. Feelings of discomfort and fatigue are other common symptoms associated with WMSDs in general (Hagberg et al., 1995). A distinction is often made between (low) back disorders and upper extremity disorders including the neck, shoulder, arm, wrist and hand (e.g., National Research Council and Institute of Medicine, 2001). Since the focus in this thesis is on the neck and shoulder region, musculoskeletal problems associated with the low back (and lower extremities) are not particularly addressed; nor are the arm, wrist or hand regions.

Figure 1. The trapezius muscle (reproduced with kind permission from Bryant. Willig AB/Jenny Bryant)

Generally, women contract musculoskeletal disorders more often than men do (Macfarlane, Jones & McBeth, 2006; Statistics Sweden, 2005). The reason for this is unknown, but gender difference in exposure at work is one likely explanation. Since the Swedish labor market is markedly gender segregated (Westberg, 1998), this means that repetitive work is more frequent among employed Swedish women compared with men, as shown by the figures given above (Kilbom & Messing, 1998). Female cashiers seem to be a particularly exposed group. According to an occupational classification system (Standard för svensk yrkesklassificering, SSYK), female cashiers (in a broad sense: SSYK 421, i.e., cashiers, tellers and related clerks) were the most exposed occupational group in Sweden, with 93.3% performing repetitive work for at least 50% of their working hours (Swedish Work Environment Authority & Statistics Sweden, 2003a). Work-related psychosocial factors also seem to be unfavorable in this group. It was the occupational group who experienced the lowest control during work; Low job control was reported by 84.9% of the women in this group compared to 53.4% of all employed women. In addition, they reported high demands to a significantly higher degree (68.3%) than did employed women on average (57.6%). However, in the case of low (insufficient) social support (42.3%) they did not differ significantly from all employed women (35.4%) (Swedish Work Environment Authority & Statistics Sweden, 2001). The figures above relate to cashiers in a more broad sense, yet the repetitive nature of cash register work in supermarkets is obvious (Lannersten & Harms-Ringdahl, 1990), and unfavorable psychosocial work factors have also been reported among supermarket cashiers, the occupational group in focus in this thesis (Drejhammar & Karlqvist, 2004). In line with the multi-factorial etiology, factors outside paid work such as household tasks and child rearing that add to the demands that paid work induces have also been proposed to contribute to the development of WMSDs (e.g., Melin & Lundberg, 1997). This may be of importance particularly for women, since the main responsibility for such unpaid duties, due to prevailing gender roles, in many cases still lies with women. However, general empirical findings have shown that having several roles is positive for one's health, both in men and women, and the assertion that multiple roles should first and foremost be perceived as stressful has been argued against (Barnett & Hyde, 2001).

Even though the results from an increasing number of epidemiological studies with prospective designs indicate the importance of psychosocial factors on the development of WMSDs, it is unclear why this is the case. How do adverse psychosocial factors lead to WMSDs? Different possible pathways have been proposed to elucidate the complex interactions that are presumed to exist between psychosocial factors, stress responses, physical load and individual characteristics. In short, psychosocial factors have been considered to contribute to WMSDs either through physiological stress responses (e.g. hormonal, immunological) and other physiological mecha-

nisms such as increased muscle activity, or through effects on physical parameters such as work postures, exerted forces, velocity and acceleration of movements, etc., that may be changed due to stressful work conditions. Individual factors related to personality, coping style, perception and attribution of symptoms, functional capacity, etc., are also assumed to interact in the process leading to WMSDs (Bongers et al., 1993, 2002). Accordingly, there seem to be several possible pathways from adverse psychosocial factors to WMSDs, and it is important to note that workplace factors are assumed to interact with factors outside paid work (e.g., Melin & Lundberg, 1997). Among these mentioned possible pathways between psychosocial factors and WMSDs, the area of exploration in this thesis best corresponds to the first, since the focus there is on the complex relations between psychophysiological stress responses, subjective stress reactions and muscle activity in the neck and shoulder region (trapezius muscle).

There are reasons to believe that the factors of importance for the development of WMSDs have changed over the past few decades (e.g. Melin & Wigaeus Tornqvist, 2005). Today, the work situation is generally characterized more by mental demands, e.g. high work pace, deadlines, etc., and less by physical work demands. Thus, the importance of psychosocial factors is probably of greater significance today, and in line with this, the importance of understanding the mechanisms involved in WMSDs and other stress-related health problems has increased (Lundberg & Melin, 2002). Stress research has focused mainly on cardiovascular responses while muscle activity in relation to stress has been investigated much less (Krantz, Forsman & Lundberg, 2004), and accordingly there is still limited knowledge of the complex associations between psychophysiological stress responses (e.g. hormonal, cardiovascular), subjective stress reactions and muscle activity. However, during recent years several explanatory models that to varying degrees consider stress as a possible contributing factor to the development of WMSDs have been proposed (e.g., review by Lundberg & Melin, 2002). Still, the pathophysiological mechanisms involved in the transition from adverse psychosocial factors in the workplace to manifest pain conditions remain poorly understood (e.g., Blair et al., 2003). Furthermore, there has been limited success thus far in preventing and treating these disorders (Blair et al., 2003; Linton & van Tulder, 2001). However, one often proposed intervention strategy to counteract WMSDs in repetitive and monotonous work is job rotation, i.e. changing between different work tasks on the job, but the effects from this type of intervention remain largely unexplored and the studies that do exist show inconsistent results (Mathiassen & Christmansson, 2004). Taken together, continued research efforts are needed to understand the role of stress in WMSDs. This is of great importance both from a work life perspective and from the individual perspective, given the large number of people who are bothered by these problems today.

1.1 Aims of the thesis

1.1.1 General aim

The general aim of this thesis was to study relations between psychophysiological and subjective stress reactions, muscle activity of the trapezius muscle, and neck and shoulder pain among women performing repetitive and monotonous work tasks. These variables were studied during real work-life conditions in supermarket cashiers/employees, both cross-sectionally and in a follow-up study evaluating the introduction of a job rotation model (i.e., less repetitive and monotonous work) among these women. Furthermore, in the laboratory setting the effects of repetitive and monotonous computer work were studied with respect to psychophysiological (cardiovascular) stress reactions and subjective stress responses.

1.1.2 Specific aims

1. To examine the cardiovascular and subjective stress reactions to a combined physical and mental workload, and the effect of rest periods, during repetitive computer work in a laboratory setting (Study I).
2. To examine the relations between subjective stress reactions, psychophysiological stress responses and muscle activity measured by surface electromyography (SEMG) in the trapezius muscle, during work at a supermarket (Study II)
3. To examine how long-term SEMG activity patterns in the trapezius muscle are related to neck and shoulder pain in daily work at a supermarket, and how they correspond to the pain-adaptation model (Study III)
4. To evaluate the effects of the introduction of a job rotation model on supermarket cashiers, with respect to psychophysiological and subjective stress reactions, muscle activity of the trapezius muscle and musculoskeletal symptoms in the neck and shoulders (Study IV).

2 CONCEPTS AND DEFINITIONS

Unfortunately, several of the concepts within this research area are poorly defined. Hence, some clarification regarding the use of some concepts in this thesis is required. The two concepts "repetitive work" and "monotonous work" are intimately associated, however not synonymous (Kilbom, 1994 a). This relationship is reflected in the meaning of the two words repetitive and monotonous. According to the Oxford American Dictionary (1980, p.431) "monotonous" means "lacking in variety or variation, tiring or boring because of this", and according to the Collins Concise Dictionary (1989, p. 831) "monotonous" means "tedious, esp. because of repetition". Both concepts imply that the work consists of work tasks performed again and again, and that the demands of the work task are very similar to each other (Kilbom, 1994 a). However, the demands of repetitive work are always physical to some degree due to muscle activity and movements needed to perform the work tasks, whereas the demands of monotonous work do not necessarily have to be physical. On the contrary, they may often be cognitive or sensory and imply psychological responses such as mental fatigue and stress reactions (Kilbom, 1994 a). Clearly, it is not always easy to separate the two. For example, short work cycles in repetitive work (a physical characteristic) may be related to time pressure and perceived job demands (cognitive demands/ psychosocial characteristics), as noted by Bonde et al., (2005).

Repetitive work has been defined as "...similar physical work tasks performed repetitively" (Kilbom, 1994 a, p. 61). This type of work is performed in short work cycles, such as the work performed by a check-out cashier. No precise time limit can be given, although Kilbom (1994 b) considers work consisting of work cycles shorter than 30 s as repetitive. Repetitive work of the upper extremities (i.e., including muscle contractions and movements of the shoulder, arm or hand) can from a physiological/biomechanical point of view be categorized as either intermittent static or dynamic. In the former type, external movements are small or negligible, whereas in the latter type movements can be easily distinguished (Kilbom, 1994 a). Thus, concerning the two types of repetitive work in this thesis, data entry work resembles the former type and cash register work the latter.

While repetitive work seems fairly well defined, monotonous work, on the other hand, is a concept with a more ambiguous meaning reflected in different lines of research emphasizing different aspects of this concept (Johansson, 1991). In work life, repetitive work is frequently associated with

monotony, and this type of monotony has been called repetitive monotony (Johansson, 1991). It is found in, for instance, assembly line work in industry and in simple clerical work such as data entry tasks. These jobs are often characterized by psychosocial work conditions such as low to moderate control of work pace, low task complexity, high predictability, poor social interaction, restricted social support, poor collective control, and piece-rate payment. Furthermore, they are often associated with a light to moderate physical workload, restricted physical mobility, and multiple exposures in the physical work environment (e.g., noise, cold/heat, etc.) (Johansson, 1991; Lundberg & Johansson, 2000). Besides, and not surprisingly, these psychosocial factors are more prevalent in jobs with low occupational status and low income (Lundberg & Melin, 2002). Thus, relevant in this thesis is that repetitive work in many cases is associated with adverse psychosocial factors, whereby monotony is one important factor among others. The term repetitive and monotonous work was chosen in this thesis to underline this double nature characterizing these jobs.

The concept of psychosocial factors has been used to encompass a multitude of conditions, related to the job and work environment, the extra-work environment (e.g., family), and the individual worker (Bernard, 1997). In this thesis the concept of psychosocial factors refers to “the subjective aspects of work organisation and how they are perceived by workers and managers”, in accordance with the usage of Hagberg et al. (1995, p. 11). For example, cashier work at a supermarket can be organized (objective nature of the work process) such that it requires repetitive cash register work to be performed several hours in a row. This work situation may be perceived as monotonous (subjective aspect) by the individual worker. However, it can be noted that this concept can also be used with a more broad or narrow meaning. In epidemiological research, the concept is used in a broad sense when psychosocial factors (e.g., perceived demands, control, and social support) are statistically related to health outcomes such as muscle pain, etc. In experimental research, on the other hand, the concept often refers to mental stress and cognitive strain, factors that are studied in relation to muscle activity and other physiological parameters in search for mechanisms of relevance to the development of muscle pain, etc. (Melin & Wigaeus Tornqvist, 2005).

The concept of stress has been used in different ways that have more or less underlined the role of stressful events, responses (mainly physiological), or the relationship between the environment and the person (individual appraisals of situations) as most characteristic of stress (Cohen, Kessler & Underwood Gordon, 1995; Lazarus & Folkman, 1984). According to Cohen et al. (1995, p. 3), it can be assumed that these different traditions focus on different stages “in a process in which environmental demands tax or exceed the adaptive capacity of an organism, resulting in psychological and biological changes that may place persons at risk for disease”. Cohen et al. (1995)

distinguish between the different components in this process using a different terminology at each step. Principally, this view is followed in this thesis, the term stress referring to the general process of stress described in the quotation above. In addition, stressful factors in the environment are referred to as demands or stressors. Responses to these demands or stressors are referred to as stress responses or the synonymous stress reactions. In addition, the term psychophysiological stress response/reaction is another term considered here as synonymous with these other two terms. Thus, these concepts refer to different physiological responses. In contrast to these objectively measured physiological responses, positive and negative mood reactions experienced by the individual when faced with the work environment/stressors are referred to as subjective experiences of stress, subjective stress response/reaction, or negative/positive stress reactions. Admittedly, these different concepts may confuse the reader; however, their use in this thesis reflects the current scientific literature. In addition, in recent years the concept of allostasis has complemented the older stress concept (see paragraph 3.4 below).

Finally, the term muscle activity refers to the electrical signals associated with muscle contractions, objectively measured by electromyography (EMG), while the term muscle tension in this thesis refers to a subjective feeling (related or not related to muscle activity).

3 STRESS – THEORIES AND MODELS

Various models and theories are presented below. The intention is not to give an inclusive and complete overview, but merely to briefly present some models and theories that seem relevant to this thesis.

3.1 General models of stress

Stress can be seen from different perspectives and can be broadly conceptualized into stimulus models, response models and interactional models (Marks, Murray, Evans & Willig, 2000). Stimulus models have focused on stressful factors in the environment (e.g., noise), stressful life events (Holmes & Rahe, 1967) and daily hassles (Kanner, Coyne, Schaefer & Lazarus, 1981). Response models, on the other hand, have mainly focused on physiological responses, although theoretically both psychological and behavioral consequences of stress could be studied from this perspective (Marks et al., 2000). Thus, these models have been common within physiology and medicine, and it was within these disciplines that the early part of stress research was performed by scientists such as Walter B. Cannon (e.g., 1932) and Hans Selye (e.g., 1956). The psychological perspective on stress derives from Lazarus (1966). Stress is seen here as an interactional process between the individual and the environment. Central in this view is the cognitive appraisal and coping processes of the individual, i.e., how the individual perceives (stressful) situations and available resources to meet those situations, and how he/she actually handles them (Lazarus, 1966; Lazarus & Folkman, 1984). (For a historical account on stress see Cooper & Dewe, 2004.)

3.2 Models of work-related stress and health

The biopsychosocial model of stress (Frankenhaeuser, 1986, 1991, 1993) is in line with the view of Lazarus (1966). It implies a multidisciplinary way to look at stress whereby the interplay between biological, psychological and social factors is considered. It emphasizes the interaction between the environment and the individual and defines stress in terms of an imbalance between the two. Thus, when a person perceives the external demands in the

workplace (and elsewhere) as exceeding the perceived resources to meet those demands, stress reactions are elicited. According to this model, both quantitative (e.g., too much work to do, too fast work pace) and qualitative (e.g., too much responsibility) overload as well as under-stimulation may disturb the balance (Frankenhaeuser & Gardell, 1976). The latter situation may be found in repetitive and monotonous work such as data entry work and traditional assembly line work, where work tasks can be perceived as too simple and the resources (e.g., skills, education, and experiences) of the individuals as underutilized (Lundberg, 2002).

Another work-related stress model, and probably the currently most well known, is the Demand-Control Model proposed by Karasek (1979) and Karasek and Theorell (1990), which was later expanded with a social support dimension (Johnson & Hall, 1988). According to this model, high psychological demands (such as time pressure, mentally difficult and demanding work tasks, etc.), in combination with lack of control and influence over the work situation (i.e., low decision latitude), result in high work strain. This situation has potential negative health consequences such as fatigue, anxiety, depression and physical illness (Karasek & Theorell, 1990). Several studies have confirmed the hypotheses that high work strain increases the risk of cardiovascular disease (e.g. Schnall, Belkic, Landsbergis & Baker, 2000), however there are different associations between work environment factors and cardiovascular health in men and women (Theorell, 1991). The model has also been associated with musculoskeletal symptoms and disorders, both cross-sectionally (Ahlberg-Hulthén, Theorell & Sigala, 1995; Toomingas, Theorell, Michélsen & Nordemar, 1997) and prospectively (Leino & Hänninen, 1995; Rugulies & Krause, 2005). In addition, a recent review indicates that poor social support in the workplace is a risk factor for musculoskeletal morbidity also in prospective studies (Woods, 2005). In general, low control has repeatedly been associated with various negative health outcomes, whereas the results concerning the demand dimension have been less conclusive (Lundberg, 2000a).

Yet another, more recent, work-related stress model is the Effort-Reward Imbalance Model proposed by Siegrist (1996). According to this model, the lack of reciprocity between effort spent at work and rewards such as income, occupational status, career opportunities, etc., result in emotional distress, autonomic arousal and neuroendocrine stress responses. When exposures to these circumstances are prolonged, the risk for stress-related disorders is assumed to be greater. In contrast to the Demand-Control Model mentioned above, which focuses on the psychosocial environment at work, this model has a more transactional perspective whereby the combination of situational and personal factors are taken into consideration. According to this model, individuals with a high level of over-commitment and in constant need of approval and reward are assumed to be especially prone to subsequent health risks (Siegrist, 2000). Prospective studies have shown associations between

failed reciprocity at work and incident cardiovascular disease, depression or alcohol dependence (Siegrist, 2005), and sleep disturbances and fatigue were recently shown to be associated with effort-reward imbalance (Fahlén et al., 2006). However, the results concerning over-commitment are currently inconsistent (van Vegchel, de Jonge, Bosma & Schaufeli, 2005). To date, this model has been rarely examined in relation to WMSDs. However, a recent cross-sectional study indicates that an imbalance of high effort and low reward among police officers was associated with a twofold risk for musculoskeletal pain in the neck, back and hips, even after controlling for different factors such as physical workload, age and gender (von dem Knesebeck, David & Siegrist, 2005). In general, the Effort-Reward Imbalance Model seems relevant to repetitive and monotonous work, since this kind of work is often of a "low status" character, and hence rewards such as income, occupational status and career opportunities in many cases can be assumed to be limited compared with the situation in "high status" jobs. An indirect support for this assumption is that blue-collar workers generally increase their catecholamine levels on the job markedly more than white-collar workers (Lundberg & Johansson, 2000). Furthermore, health problems are more common in this group of workers compared with white-collar workers with more stimulation, variation and influence on their jobs (Lundberg, 1999b).

According to Sauter and Swanson (1996, p. 5), a common theme in these models and other work-related stress models and theories is that "psychological stress is understood as a process involving the interaction of environmental demands with individual attributes (needs, expectations, resources, etc.), which leads to acute psychological, behavioral, and physiological reactions and ultimately affects physical health". Different models/theories emphasize the role of the individual, the environment, or the balance between the two in this process (Sauter & Swanson, 1996). The Allostatic load model (McEwen & Stellar, 1993) presented below constitutes a general and biologically oriented framework for understanding how work-related stress reactions may impair health.

3.3 Conceptual models linking stress to WMSDs

Several models have been proposed that conceptually link stress to WMSDs, for instance the ecological model of musculoskeletal disorders by Sauter and Swanson (1996), the balance theory of job design and stress by Carayon, Smith and Haims (1999) and the work style model of job stress and musculoskeletal disorders by Feuerstein (1996). These and other models present different theoretical approaches but also share core features and contribute in different ways to the understanding of the impact that psychosocial factors may have on the development of WMSDs. (See overviews by Carayon et al., 1999; Huang, Feuerstein, & Sauter, 2002; Moon & Sauter, 1996; National

Research Council and Institute of Medicine, 2001.) One of these models is the biopsychosocial model of job stress and musculoskeletal disorders proposed by Melin and Lundberg (1997). This model is influenced by both the biopsychosocial model of stress (e.g., Frankenhaeuser, 1991) and the allostatic load model (McEwen & Stellar, 1993), and focuses on WMSDs in light physical work. The model is distinguished from other models in its recognition of physiological after-effects and the impact from unpaid domestic workload. According to this model, physical as well as mental demands during work separately produce physiological responses such as increased levels of cortisol and catecholamines, and increased muscle activity. However, the model proposes that the combination of physical load and mental demands/stressors induce an even greater increase in these physiological responses. Furthermore, mental demands during work, for instance in monotonous and repetitive work, may lead to a slow physiological unwinding process after work, i.e., the work induces prolonged physiological arousal reflected in elevated hormonal levels and possibly in muscular activity. Moreover, unpaid domestic workload such as child care and household work may further add to the physiological arousal induced by paid work. This last feature of the model is of special relevance for women due to the gender roles in society regarding unpaid domestic work (see figure 2).

Fig 2. A biopsychosocial model of job stress and musculoskeletal disorders (from Lundberg & Melin, 2002. Reproduced with permission, see List of publications).

3.4 Allostasis and allostatic load model

The concept of allostasis, introduced by Sterling and Eyer (1988), can be regarded as a complement to the earlier well-known but also vague and diverse concept of stress, used already in the beginning of the 20th century by Cannon (e.g., 1914, 1935), and first defined by Selye (1936). In order to adapt to or ultimately survive a stressful situation, animals as well as humans must be able to change their behavior and physiology. Allostasis is the coordinated process that promotes such adaptation and increases the chance of survival (e.g., McEwen, 2000a). For example, in response to an intensive emotional stressor the sympathetic branch of the autonomic nervous system is activated and the adrenal medulla secretes epinephrine (i.e., adrenaline). This prepares the individual for intense and vigorous physical activity by mobilizing energy resources. The blood flow is redirected to the skeletal muscles, heart and brain. The heart and respiratory rates, as well as arousal and vigilance, increase. The behavior is changed towards an appropriate level of aggressiveness, etc. – the "fight-or-flight response" described by Cannon (e.g., 1914, 1935; see also McCarty, 2000). When the adaptation to a stressor is successful, the allostatic responses protect the body and help the individual to cope effectively. However, in order not to impose unnecessary wear and tear on the organism, the physiological responses should return to baseline (i.e., resting values) quickly after the challenge or threat has terminated, and a period of rest and recovery should follow before a new challenge is encountered. The evolutionary basis for this defense reaction is very old, but in modern society mental and social stressors probably elicits it more often than do physical threats that require a vigorous effort and thus make use of the energy mobilized (Nesse & Young, 2000). It should be emphasized that allostasis is a normal adaptive process that helps us to face any change or challenge, not only intensive or life-threatening stressors as described above. For instance, just getting out of bed in the morning requires the allostatic, or adaptive, systems to change their activity (e.g., by increasing blood pressure and heart rate) (McEwen & Norton Lasley, 2002). Thus, not all situations that require allostatic responses can be regarded as "stressful". Furthermore, important to the concept of allostasis is the supreme role of the brain in regulating physiological processes, thereby emphasizing the potential role of psychological and social processes in health and disease (Sterling & Eyer, 1988).

Allostasis focuses on variability (the Greek root *allo* meaning variable), in contrast to the older concept of homeostasis (Cannon, 1932) which focuses on the importance of maintaining a constant internal environment, and accordingly allostasis can be translated as "stability through change" (Sterling & Eyer, 1988, p. 636). This refers to the principle that an organism, in order to achieve (homeostatic) stability, must have the ability to vary its physiology to match different challenges or demands of varying severity. However,

these two principles can be seen as representing different ways of functioning for different physiological systems. The allostatic or adaptive systems such as the cardiovascular, endocrine and immune systems show much greater fluctuations (i.e., variability) than do other systems that must be maintained within much more narrow ranges, such as body temperature, blood pH, etc. (McEwen, 2000a).

According to the concept of allostasis, a balance between activity and rest is important for sustaining health. In physiological terms, this can be described as a necessary balance between catabolism (i.e., when energy is used) and anabolism (i.e., when energy is stored and tissues are repaired) (Sterling & Eyer, 1988). When this balance is disrupted, for instance due to chronic psychosocial stress, the excessive and sustained activation of the allostatic systems and mediators results in allostatic load, a term coined by McEwen and Stellar (1993). According to the allostatic load model, the allostatic responses are beneficial in the short perspective since they promote adaptation. In the long run, however, they may lead to allostatic load, which can be described as the cumulative wear and tear on the organism, sometimes referred to as the price of adaptation (Seeman, Singer, Rowe, Horwitz & McEwen, 1997). According to McEwen and Seeman (1999) and McEwen (2000a), at least four situations can lead to allostatic load: First, frequent activation of the allostatic systems without necessary time for rest and recovery; Second, failure to adapt or habituate to repeated exposure to the same stressor; Third, failure to shut off the allostatic responses, leading to a prolonged exposure to mediators of allostasis, such as glucocorticoids and catecholamines; Fourth, failure to activate an adequate allostatic response in one allostatic system may cause other systems to increase their activity in a compensatory way. Thus, too much use of the allostatic systems or dysfunction (over- or underactivity) of them results in a cumulative wear and tear on the organism that over long periods promotes pathophysiological changes and may lead to various pathological conditions and diseases. Examples in the literature are atherosclerosis, hypertension, insulin resistance, abdominal obesity, type II diabetes, cognitive dysfunctions related to the impairment of the hippocampus, and autoimmune and inflammatory disorders (McEwen, 2000b; McEwen & Seeman, 1999; McEwen & Stellar, 1993). These processes leading to allostatic load are complex and are influenced not only by the impact of stressful events and daily hassles from work or outside work that accumulate over long periods (i.e., "chronic stress"). Genetic factors, early life experiences, personality characteristics and lifestyle factors such as exercise, diet and alcohol consumption (among other factors) also contribute (McEwen & Seeman, 1999).

4 PHYSIOLOGICAL STRESS

4.1 The physiological stress system

Allostasis is promoted by different stress reactive systems and mediators in the body, helping the individual to adapt to stressful situations by concerted behavioral and physiological changes with a multitude of central as well as peripheral effects. Two neuroendocrine systems are of central importance for these adaptive processes. These systems are often referred to as the sympathetic adrenal-medullary (SAM) system and the hypothalamic-pituitary-adrenocortical (HPA) system, also called the HPA axis (e.g., Lundberg 1999a). These two systems mediate directly or indirectly many of the physiological and behavioral responses associated with psychological as well as physical stressors.

The central control stations of the two systems, located in the hypothalamus (HPA axis) and the brain stem (locus ceruleus and other noradrenergic cell groups) (SAM system) interact with each other in a reciprocal way. Thus, activation of one system tends to activate the other as well (Goldstein, 2000), although the two systems also show a specificity to different kinds of stressors (e.g. Henry, 1993). In addition, these control stations have mutual interactions with higher brain areas such as the amygdala, the hippocampus, the mesocortical and mesolimbic dopamine systems, and the arcuate nucleus (Chrousos & Gold, 1992; Tsigos & Chrousos, 2002). Through these neural interactions the stress system activates these higher brain areas but is also influenced by them. This affects, among other things, emotional analyses of information and fear-related behaviors (amygdala), memory and learning (hippocampus), anticipatory phenomena and cognitive function (mesocortical system), reward and motivation (mesolimbic dopamine system), and pain sensation (arcuate nucleus) (Chrousos & Gold, 1992, 1998; Tsigos & Chrousos, 2002). In addition, the SAM system and the HPA axis are connected to the periphery of the body where the hormonal end products of the two systems – catecholamines in the case of the SAM system and glucocorticoids in the case of the HPA axis – have multiple effects on different effector organs. Thus, the stress system can be described (very simplistically) in a hierarchical way as follows: 1) Higher brain areas perceive and interpret a situation as stressful and initiate the stress process; 2) The SAM and HPA systems have an executive role via different mediators such as catecholamines and glucocorticoids; 3) These mediators affect different effector organs in

the body. The overall purpose of this process is to change the behavior and redirect the energy resources to meet the perceived threat or challenge in the most efficient way (Chrousos & Gold, 1992). In addition, the system is controlled by feedback inhibition at different levels of the central nervous system (Kuhn, 1989).

The adaptive responses include both central and peripheral effects. Examples of the former are increased arousal, alertness, vigilance, attention and, when necessary, aggression. Examples of the last are release of glucose and free fatty acids from the liver into the blood stream, redirection of blood carrying oxygen and nutrients to the brain, heart and muscles, increased heart- and respiratory rate, etc. (Chrousos & Gold, 1992). However, these adaptive processes that serve the body by mobilizing energy are catabolic in nature, and while they are activated anabolism is hampered. This is indicated by, for instance, decreased levels of sex and growth hormones and inhibition of sexual activity and feeding, behaviors that are inappropriate when the organism perceives the situation as threatening and is ready for battle (Berne & Levy, 1993). Below is a short overview of the HPA- and SAM systems and some other systems that are activated during stress, with a primary focus on the systems and associated assessment methods that are relevant to this thesis.

4.2 The HPA axis and the cortisol response

The HPA axis is responsible for secretion of glucocorticoid hormones, mainly cortisol in humans, from the adrenal cortex into the circulating blood (Berne & Levy, 1993; Fink, 2000; Tsigos & Chrousos, 2002). In a healthy and non-stressed individual, the adrenal cortex secretes cortisol spontaneously in a distinct circadian and pulsatile fashion regulated by feedback systems (Kirschbaum & Hellhammer, 1989). Cortisol levels are highest in the early morning hours and decrease throughout the day (with the exception of an increase in response to meals at lunchtime) and the lowest concentrations of cortisol are found at midnight (Kirschbaum & Hellhammer, 2000). However, in response to different stressors, the feedback systems are overridden and the HPA axis is activated. The HPA axis has been found to be especially sensitive to affective aspects of stress, such as feelings of anxiety and distress (Lundberg, 1999a) and anticipation of threatening events (Kirschbaum & Hellhammer, 1989). Furthermore, high ego-involvement, low controllability, low predictability, ambiguity and novel conditions have been found to activate the HPA axis (Hellhammer & Wade, 1993; Kirschbaum & Hellhammer, 1994). However, cortisol levels are generally uninfluenced by the ordinary and regular work conditions since they habituate rapidly in this situation (Lundberg, 2005), except if the workload is heavy, such as a regular work week of more than 50 hours (Lundberg & Hellström, 2002). In ad-

dition to psychological and psychosocial stress, physical stressors such as infection, fever, burns, tissue damage, starvation, and prolonged and strenuous exercise, etc. (Berne & Levy, 1993; Guyton, 1984) also affect the HPA axis and lead to increased cortisol output.

Cortisol is considered to play a pivotal role in the bodily response to stress and maintenance of homeostasis by means of allostatic regulation, but is also important under normal physiological functioning (Guyton, 1984; Kirschbaum & Hellhammer, 2000; Kuhn, 1989; Tsigos & Chrousos, 2002). As a general metabolic hormone that affects the metabolism of glucose, fat and protein in the body, it is of central importance in acute stress when an increased metabolic demand is at hand and cortisol mobilizes and provides the organism with necessary energy resources. Elevated cortisol levels during such short periods of stress, followed by recuperation and return to baseline hormonal levels when the threat or challenge is over, has a protective effect that promotes adaptation and can thus be described as a healthy and dynamic stress response (Kristenson, Eriksen, Sluiter, Starke & Ursin, 2004). Besides playing a central role in metabolism, cortisol also affects numerous other physiological systems and processes of importance from a stress perspective, such as the SAM, the cardiovascular and immune systems and the inflammatory, cognitive and affective processes (Berne & Levy, 1993; Kuhn, 1989; McEwen, 2000a).

When the cortisol levels are excessive and sustained in chronic stress conditions, the adaptive function is lost and the catabolic properties of cortisol can take over and have a serious impact on health (e.g., Chrousos & Gold, 1998; McEwen & Seeman, 1999). Under these circumstances, cortisol has been associated with immunosuppression and deleterious health effects such as insulin resistance, dyslipidemia, dyscoagulation, visceral obesity and hypertension (i.e., the so-called metabolic syndrome X) and diseases such as depression and osteoporosis (Chrousos & Gold, 1998). Furthermore, prolonged stress with elevated cortisol levels has been related to cognitive deficits and structural changes in the hippocampus (McEwen, 1999; Sapolsky, 2000). In contrast to these health outcomes associated with elevated cortisol levels, reduced cortisol levels have been found in other medical conditions, such as chronic fatigue syndrome (Cleare & Wessely, 2000) and fibromyalgia (Theorell, 2000), two disorders with varying degrees of musculoskeletal pain as prominent symptoms (Afari & Buchwald, 2003). Thus, chronic stress seems to change the regulatory mechanism of the HPA axis, leading in some cases to hypercortisolism and in others to hypocortisolism (Theorell, 2000; Kristenson et al., 2004). However, these low levels of cortisol observed in patients with chronic fatigue syndrome and fibromyalgia may actually be an adaptive response protecting the organism from the damaging effects of glucocorticoids produced by an otherwise chronic overactive HPA axis, as proposed recently by Fries, Hesse, Hellhammer and Hellhammer (2005).

4.2.1 Assessment of cortisol

Cortisol can be measured in blood (commonly in plasma), urine or saliva (Lundberg, 1995). The last method mentioned has become an important tool in stress research due to several advantages, especially compared with collection of blood samples. For example, measuring cortisol in saliva makes it possible to collect noninvasive samples (i.e., no venipuncture-induced stress) in field studies among persons in their natural environment. In addition, it is associated with less concern about ethical problems since it does not cause harm or pain. Furthermore, it provides an easy collection procedure with the possibility to store the samples at room temperature for at least four weeks, although longer storage is possible if frozen (-20°C or lower) (Kirschbaum & Hellhammer, 2000; Lundberg, 1995). Since the unbound fraction of cortisol in blood enters the oral cavity by passive diffusion, it is independent of saliva flow rate and the concentration of cortisol in the saliva is highly correlated (usually $r \geq .90$) with the concentration of free cortisol found in the blood. In addition, the time lag between a peak cortisol concentration found in blood and the peak concentration in saliva is less than 2-3 min (Kirschbaum & Hellhammer, 2000). In contrast to urinary measurement of cortisol, which provides an integrated measurement over a more extended time period, salivary cortisol reflects relatively rapid stress responses (Lundberg, 1995). A sterilized cotton swab called Salivette (Sarstedt Inc., Rommelsdorf) is a currently often used and convenient sampling method. It is gently chewed upon for about 2 min to stimulate saliva flow and is then put in a plastic tube, before being stored and analyzed. Since the collection procedure is easy, multiple, frequent measurements can be made (Kirschbaum & Hellhammer, 1994).

Several potential influencing factors have to be considered when measuring cortisol. These include the use of nicotine, caffeine, alcohol and medications that must be either controlled for or held constant. Thus, participants are asked to either refrain from using these substances or consume the same amount across the different measurement sessions, for instance regarding coffee or cigarettes. In addition, the influence of the circadian rhythm is controlled for by obtaining endocrine measurements at the same time of day but on two separate days (Lundberg, 1995)

4.3 The SAM system and catecholamine responses

The important role of the SAM system in response to psychological (emotional) stressors was first demonstrated in animal research by Cannon in the beginning of the 20th century (e.g. Cannon, 1914). Based on experiments such as exposing cats to barking dogs (a natural stressor for cats), Cannon proposed the "emergency function" theory of the adrenal medulla, realizing

that the sympathetic arousal and concomitant active defense reaction seen in these animals served the function of increasing their chance of survival by "fight-or-flight" (Lundberg, 2000b; see also Mason, 1972, for a historical account of early research on the SAM system).

Activation of the SAM system causes secretion of the catecholamines epinephrine (adrenaline) and norepinephrine (noradrenaline), with important functions for energy mobilization and cardiovascular activity during stressful conditions (Lundberg, 2000b). Epinephrine (and small amounts of norepinephrine) is produced by the adrenal medulla and is secreted into the bloodstream in response to sympathetic stimulation, whereas norepinephrine is released mainly as a neurotransmitter by nerve endings in the sympathetic nervous system (Frankenhaeuser, 1971). The SAM system is immediately activated in response to stress, and within a minute the concentration of catecholamines in blood rises (Lundberg, 2000b). However, their effects can also be turned off rapidly, since the lifespan of catecholamines in the circulation is very short, ranging from one to three minutes (Berne & Levy, 1993). A difference between the two catecholamines is that epinephrine is related more to mental stress and is usually a good indicator of the perceived stimulus intensity of a stressor, whereas norepinephrine is associated more with body posture and physical activity. In addition, norepinephrine is important in blood pressure regulation (Hjemdahl, 2000; Lundberg, 2000b). In contrast to cortisol, epinephrine is relatively insensitive to the emotional quality of a stressor (Lundberg, 1995). Moreover, and as mentioned earlier, the two neuroendocrine stress systems (i.e., SAM and HPA) interact with each other with mutually reinforcing responses. Thus, epinephrine and norepinephrine increase the activity in the HPA axis releasing cortisol, whereas the corticotrophin-releasing hormone that activates the HPA axis stimulates the sympathetic nervous system and hence ultimately the release of catecholamines (Berne & Levy, 1993; Lundberg, 2000b).

Like cortisol, catecholamines show a robust diurnal variation. Epinephrine and norepinephrine show high levels in the daytime with a peak in the middle of the day, and low levels during sleep at night. Besides this diurnal variation, and the already mentioned influence of psychological stress and physical demands, several other factors such as nicotine, caffeine, alcohol and medications such as beta-blockers and diuretics influence the production of catecholamines, and hence must be considered when assessing these hormones (Lundberg, 2000b).

4.3.1 Assessment of catecholamines

The circulating catecholamines in the blood, released from the adrenal glands, are to a small and relatively constant part excreted into the urine (Frankenhaeuser, 1971; Lundberg, 2000b). This makes it possible to measure epinephrine and norepinephrine in blood (usually plasma) as well as in

urine, and there is a generally good concordance between the results of studies based on blood and urine samples (Lundberg, 2000b). Depending on type of research and aims, any of these two measurement options are more or less suitable. In general, urine measurements of catecholamines are preferable in field studies (i.e. outside the laboratory setting) and in the study of longer periods of stress or chronic psychosocial stress, whereas blood measurements are more or less restricted to laboratory studies and are suitable for measurements of acute responses to short-term stress exposure (Lundberg, 1995, 2000b). Urine samples are relatively easy to collect, even in field studies, and do not cause harm or pain to participants which can be the case with venipuncture, contributing to increased stress in itself. Furthermore, urine measurements do not interfere with the normal activities or habits of participants, thus enabling them to perform their normal work tasks, leisure-time activities, etc. Urinary measurement represents the mean catecholamine level under a particular period of time, since it provides an integrated measurement, depending on the time between the two urine samplings (normally 2-3 hrs using voluntary voiding) (Lundberg, 1995, 2000b). In order to determine the amount of urinary catecholamines, three variables must be known: the time between samplings, the concentration of the sample, and the total urine volume. In addition, the pH level of the samples has to be adjusted to 3.0 using hydrochloric acid, and the samples must be kept in a freezer (-18°C) until they are analyzed (the current most common method is high-performance liquid chromatography with electrochemical detection) (Lundberg, 2000b; Riggins & Kissinger, 1977).

4.4 The cardiovascular system and influences from the autonomous nervous system and the endocrine system

The cardiovascular system consists of the heart and the pulmonary and systemic circulation and vasculature. The basic function of the cardiovascular system is to provide oxygen and nutrients to all tissues in the body. In addition, hormones and other substances are transported by the blood and metabolic waste products are removed (e.g., Guyton, 1984; Turner, 1994). The cardiovascular system is regulated by control mechanisms located both inside and outside the heart (Andreassi, 1995). The heart has its own intrinsic rate of about 90-100 beats/min (in young adults) due to its own natural "pacemaker" located in the sinoatrial node in the wall of the right atrium (Berne & Levy, 1993; Hjelm Dahl, 2000). However, the autonomic nervous system (ANS) (controlling internal bodily functions and associated behaviors important to homeostasis, such as body temperature, digestion, blood pressure, feeding, initiation of stress reactions, etc.) has a great external im-

impact on heart rate regulation by descending nerve impulses from the brain to the sinoatrial node. The ANS consists of two branches - the sympathetic (SNS) and parasympathetic (PNS) systems (the latter also called the vagal system due to the fact that most parasympathetic nerve fibers run in the vagal nerve) (Kamath & Fallen, 1993; Kristal-Boneh, Raifel, Froom, & Ribak, 1995). These two branches have a complementary and reciprocal effect on heart activity, and the beat-to-beat fluctuations of the heart are determined mainly by the balance between the SNS and the PNS. Thus, an increased heart rate can be a result of either a decrease in PNS activity, an increase in SNS activity or a combination of the two mechanisms (Andreassi, 1995; Guyton, 1984; Rushmer, 1989). The role of PNS activity is important since it acts as a "vagal brake" that dampens the intrinsic heart rate and holds it down to approximately 70-80 bpm (Andreassi, 1995; For an interesting discussion of the evolution and role of the vagus nerve see McEwen, 2002; Porges, 1995, 2003). In addition to an increased heart rate, sympathetic stimulation also increases the vigor of cardiac contraction and the rapidity of conduction of the cardiac impulse through the heart, whereas parasympathetic stimulation has the opposite effects (Guyton, 1984). Besides effects on the heart, the SNS affects the vasculature that is innervated only by this branch of ANS. An increase in sympathetic activity constricts blood vessels in the skin and abdomen and dilates them in skeletal muscles, with effects on blood pressure and direction of blood flow. The opposite effects are caused by a decrease in sympathetic activity (Guyton, 1984). During rest and relaxation the parasympathetic nervous system is dominant, but stress, induced for instance by psychosocial factors in the workplace, shifts the balance toward sympathetic dominance (Wickens, 2005).

The endocrine system also contributes to changes in cardiovascular activity. As mentioned earlier, sympathetic activation of the adrenal medulla causes the release of epinephrine (and a minor portion of norepinephrine) into the blood, which increases cardiac activity (Guyton, 1984). However, taken together the cardiovascular responses to stress are mediated mainly by neurogenic factors (i.e. changes in sympathetic activity and the release of the neurotransmitter norepinephrine), even though the "stress hormone" epinephrine reflects the arousal and perceived stress of the individual (Hjemdahl, 2000).

4.4.1 Assessment of heart rate and blood pressure

Given the important role of the cardiovascular system in allostasis, it is not surprising that the assessment of different cardiovascular responses is widely used in stress research. A variety of measures are available, however, the focus here is on the type of measurements relevant to this thesis. (For more detailed discussions of cardiovascular assessment see, e.g., Krantz & Falconer, 1995; Schneiderman, Weiss & Kaufmann, 1989; Turner, 1994.)

The electrical impulses that are associated with each heartbeat can be recorded by electrodes placed on the skin, since a portion of these impulses spreads to the body surface where they can be monitored by the electrocardiogram (ECG). The normal ECG consists of three major components, the P-wave, the QRS complex, and the T-wave. These components are associated with different phases of the contraction of the heart, with the QRS complex being related to the excitation of the ventricles. The R wave of the QRS complex is the most prominent component of the ECG, and is the basis for heart rate (HR) recordings. HR is usually determined by counting the number of R waves over a one-minute period (beats per minute) (Andreassi, 1995; Turner, 1994). However, the time between one R wave and the next (R-R interval) is another measurement, and this is the basis for a different analysis of HRV (see more below) (van Ravenswaaij-Arts, Kollée, Hopman, Stoelinga & van Geijn, 1993). HR can be measured using different techniques; from simply counting the pulse through manual palpation to continuous recordings by the ECG. Like HR, blood pressure can also be measured using different techniques. Direct measurements imply the insertion of a sensing device into an artery, and are not of relevance in this thesis. Indirect measurements, on the other hand, are widely used in stress research, in both the laboratory setting and the natural environment of individuals (Schneiderman et al., 1989). Blood pressure is expressed as the ratio of the systolic (SBP) over the diastolic (DBP) pressure in millimeters of mercury (mmHg). SBP is associated with the peak pressure during heart contraction, while DBP reflects the minimum pressure between heart contractions (Pinel, 2003).

4.5 Heart rate variability

Heart rate is one of the most commonly used measures of cardiovascular activity. However, since both branches of the ANS participate in heart rate regulation, a measure of heart rate alone cannot show the underlying neural influences related to heart rate alterations. To assess this, other and more sophisticated measures of cardiac function such as heart rate variability must be used (Krantz & Falconer, 1995). Heart rate variability (HRV) refers to spontaneous fluctuations in heart rate over time due to both internal and external processes (Kristal-Boneh et al., 1995). For instance, under resting conditions there are beat-to-beat alterations in heart rate detectable by the electrocardiogram (ECG). One of these rhythms in heart rate fluctuates with the normal phase of respiration; during inspiration the heart rate increases and during expiration it decreases, a phenomenon called respiratory sinus arrhythmia that reflects the parasympathetic (or vagal) modulation of the heart (e.g., Kamath & Fallen, 1993). However, psychosocial stress also elicits changes in heart rate variability, because stress alters the function of the

ANS toward sympathetic predominance and therefore changes the neural control of the cardiovascular system (cf. the fight-or-flight response). Generally, this causes a decreased HRV, i.e., during stress the heart beats more regularly (Ericson, 2002). This has been shown in healthy individuals exposed to mental stress under experimental conditions (e.g. Pagani et al., 1991) as well as during daily living using ambulatory measurements (e.g. Sloan et al., 1994). However, there are also experimental studies that show no effect on HRV from mental stress (e.g. Wahlström, Hagberg, Johnson, Svensson & Rempel, 2002). Heart rate variability has been discussed in relation to allostasis and allostatic load. A decreased HRV seen during stress has been interpreted as a lack of ability to respond through physiological variability, which is the core feature of allostasis and is regarded as being of central importance in sustaining health. As a result, the individual becomes more physiologically rigid and vulnerable (Horsten et al., 1999). This immediate effect on HRV seen during acute stress has also been described as a dynamic marker of load, whereas the decline of HRV associated with increasing age has been described as a marker of cumulative load, or cumulative wear and tear, i.e. allostatic load (Kawachi, 1997). Besides studies on healthy individuals, HRV has also been a tool used in cardiology, since a decreased HRV has been shown to predict mortality after heart attack (myocardial infarction) (Vanoli, Adamson, Cerati & Hull, 1995).

4.5.1 Assessment of heart rate variability

HRV can be non-invasively measured through shorter (minutes) or longer (e.g., 24-hour ambulatory) electrocardiogram recordings and can be analyzed using different methods in the time or frequency domain, the latter involving so-called spectral analysis of HRV. This method reveals different frequency components (two of interest here) in the HRV spectrum: First, a low-frequency (0.06-0.15 Hz) component associated with baroreceptor-mediated blood pressure control, reflecting sympathetic activity with vagal modulation; Second, a high-frequency (0.15-0.40 Hz) component reflecting the respiratory influences on the heart (respiratory sinus arrhythmia, see above) and generally considered to reflect the parasympathetic (vagal) modulation of the heart (For more details on analysis of HRV see Bigger, 1995; and reviews by e.g., Kamath & Fallen, 1993; Kristal-Boneh et al., 1995; van Ravenswaaij-Arts et al., 1993). The ratio between these two frequency components, the LF/HF ratio, can be calculated and used as an index of the balance between the sympathetic and parasympathetic nervous system activity, and is often referred to as sympatho-vagal balance or autonomic balance (Malliani, Pagani, Lombardi & Cerutti, 1991; Malliani, Lombardi & Pagani, 1994). For example, a study during daily living showed that self-reported psychological stress throughout the day, even after controlling for individual differences and physical position, was associated with a higher LF/HF ratio, indicating a

shift in the cardiac sympatho-vagal balance toward a sympathetic predominance (Sloan et al., 1994).

5 THE MUSCULAR SYSTEM

There are three types of muscles in humans: First, skeletal muscles are the voluntary muscles that enable us to move around; Second, involuntary smooth muscles in the walls of hollow organs control the movements of these organs through innervation of the autonomic nervous system; Third, cardiac muscles have properties intermediate between those of the skeletal and smooth muscles (e.g., Berne & Levy, 1993). Interestingly, all three types of muscles are related to stress. Obviously, skeletal muscles are intimately related to human behaviors in general, and not only to stress, since they are needed to perform and execute different behaviors. However, an obvious example is during the fight-or-flight reaction, when massive muscular activity is needed to fight or run away. At the same time, the activity of the cardiac muscle is increased and smooth muscles in peripheral vessels are constricted due to increased activity in the sympathetic nervous system. However, the focus in this thesis is on skeletal muscles, especially the trapezius muscle which covers the neck, shoulders and upper back. This muscle acts primarily to stabilize the shoulder blade and thus fix the shoulder girdle, enabling arm and hand movements, for instance during repetitive work tasks. In addition to this static function, it also has an active one during various movements of the shoulder girdle (Platzer, 1986).

5.1 Muscle fibers, motor units and recruitment patterns

Skeletal muscles consist of muscle fibers innervated by motor neurons in the spinal cord or brainstem. The smallest functional unit of a skeletal muscle is the motor unit, which consists of a single motor neuron and a number of muscle fibers innervated by that motor neuron. When the motor neuron fires, all of the muscle fibers in that motor unit contract simultaneously, although anatomically the muscle fibers are spread out in the muscle (Berne & Levy, 1993). The number of muscle fibers in a motor unit differs considerably between muscles. In those with very selective motor control (e.g., in fingers and eyes) the fewest muscle fibers per motor unit is found (less than ten), whereas the opposite is found in large leg muscles, for instance (several hundred) (Carlson, 2001). Skeletal muscle fibers are often classified into two

basic types, fast and slow (in addition, there are a variety of intermediate muscle fibers) (e.g., Pinel, 2003; see also Berne & Levy, 1993). Simply, fast muscle fibers (also called type II) produce very forceful and fast contractions but fatigue rapidly, while slow muscle fibers (also called type I) have the capacity for endurance but produce less force and contract more slowly (Berne & Levy, 1993). In a given motor unit all muscle fibers are of the same type, and therefore the basic distinction between fast and slow muscle fibers also applies to motor units. However, motor units are called large (larger) and small (smaller) instead of fast and slow. This terminology is logical, since the sizes of cell bodies and axons of a motor nerve increase with the number of muscle fibers in the motor unit (Berne & Levy, 1993). Thus, large motor units normally consist of many, type II, muscle fibers that are recruited in forceful contractions, whereas small motor units consist of few, type I, muscle fibers that are frequently active and are always recruited first in contractions, due to a lower excitability related to their relatively smaller membrane areas (Berne & Levy, 1993). This hierarchical recruitment of motor units is referred to as the "size principle" (Henneman, Somjen & Carpenter, 1965) and enables the muscle to increase force by recruiting successively more and larger motor units. Besides this, the force production of a muscle is also dependent on the firing rate (i.e. stimulation frequency) of each motor unit. Small type I motor units are not only recruited first (and are hence also called low-threshold motor units), but also remain active as long as any part of the muscle is contracting, according to the "size principle". Thus, the activity level in these motor units may be high, even though the activity level of the muscle as a whole is very low, and as a consequence they may be susceptible to "overload" with possible implications for the development of muscle pain (Hägg, 1991, 2003).

5.1.1 Assessment of muscle activity

Muscle activity can be measured using electromyography (EMG), i.e., recording the electrical signals related to the contraction of muscle fibers (the myoelectrical signal) in analogy with electrocardiography recording the electrical signals of the heart muscle. Either the muscle activity can be recorded using surface EMG, i.e., applying electrodes to the surface of the skin above superficially located muscles (e.g., the trapezius muscle) or inserting electrodes into a muscle as in intramuscular EMG. These two methods provide different information: Surface EMG is a more "global" measure, reflecting the activity in the muscle as a whole, while intramuscular EMG has the possibility to record the activity in single motor units very close to the insertion of the electrode(s) inside the muscle. The former method is widely used in ergonomic field studies evaluating work-related muscle activity through ambulatory monitoring of EMG, while the latter is confined to laboratory

research and clinical applications (Sandsjö, 2004; For a review of electromyographic techniques, see Basmajian & De Luca, 1985)

6 PSYCHOLOGICAL FACTORS, STRESS AND MUSCLE ACTIVITY

Obviously, muscle activity is needed to perform different work tasks. This muscle activity is related to biomechanical needs for force production (that enable movements) and stabilization of body parts (i.e., postural stabilization) (Waersted, 2000). However, besides this muscle activity related to biomechanical needs, vocational muscle activity also includes another type of muscle activity, namely one that is suggested to be related to mental load, emotional load and individual characteristics. This type of muscle activity, which resembles static muscle activity, has been labeled non-biomechanical muscle activity (Waersted, 2000), but other terms such as stress-induced muscular activity and attention-related muscle activity, among others, have also been used (see Waersted, 1997): First, the mental effort demanded by a work task results in a mental (cognitive) load; Second, the emotional state and attitude of the individual performing the work task induce an emotional load; Third, individual characteristics such as anxiety and type-A behavior pattern (i.e., trait characteristics) may contribute to additional load. Studies support the assertion that non-biomechanic muscle activity is actually induced by all three sources (for a thorough review of early studies, see Goldstein, 1972; see also Melin & Lundberg, 1997; Wærsted, 1997; 2000; Westgaard, 1999).

For example, Wærsted, Bjørklund and Westgaard (1991) found that a subgroup of persons consistently increased their muscle activity in the trapezius muscle, when simple reaction time tasks presented on a VDU screen were changed to more complex two-choice reaction-time tasks, although posture and body movement were unchanged and physical load (in both conditions) was restricted to key press on two push buttons placed on arm rests. In another study by Wærsted, Bjørklund and Westgaard (1994), also with physical load minimized, trapezius muscle activity increased during a complex two-choice reaction-time task when a money-reward condition was introduced, indicating the importance of attitudes and motivational level for the muscular response. In two other studies, the EMG activity of the trapezius muscle increased significantly in response to mental stress induced by mental arithmetic and the Stroop color word test (Lundberg et al., 1994), and mental arithmetic (Lundberg et al., 2002), respectively. Both of these studies used verbal reports from the participants (naming the color of the print of

each color word or naming the final result in the mental arithmetic task), and thus biomechanical needs for movements were not needed at all.

Thus, these and other studies (for references, see reviews mentioned above) indicate that muscle activity can be induced by mental and emotional factors and individual characteristics, even when the physical load is controlled for (minimized or absent) in experimental studies. This is of theoretical importance; however, from a work-life perspective it may be of less relevance since repetitive work always includes physical effort requiring muscular activity to some extent. Furthermore, cognitive or mental load is probably often colored with emotions in real work-life situations and is not easy to distinguish. Thus, from a work-life perspective it may be more relevant to consider psychological stress induced by psychosocial factors in a broader sense (including mental, cognitive and emotional aspects) than the more narrow mental load perspective often applied in experimental studies. A relevant question would then be whether psychological stress can induce an additional muscle activity above the level that biomechanical needs induce (Melin & Wigaeus Tornqvist, 2005).

In the study by Lundberg et al. (1994) cited above, it was found that the combination of a physical load (test contraction) and mental stress (Stroop color word test) increased the EMG activity significantly more than during the physical load alone. Moreover, the increase in muscle activity related to the mental stressor was more pronounced in combination with the physical load than when the mental stress was presented alone, indicating a multiplicative effect rather than an additional effect between the two factors. A study by Weber, Fussler, O'Hanlon, Gierer and Grandjean (1980) also indicated an interaction effect between physical workload and mental stress. However, other studies have failed to show this additive (or multiplicative) effect from the combination of physical load and mental stress (e.g. Blangsted, Sjøgaard, Christensen & Sjøgaard, 2004). Interestingly, studies from occupational settings have also shown divergent results concerning the role of combined exposures. For example, a study by Devereux, Vlachonikolis and Buckle (2002) suggested an interaction effect between physical and psychosocial workplace factors, indicated by more prevalent musculoskeletal symptoms (of the hand or wrist and upper limb, but not the neck) among workers highly exposed to both risk factors, compared with workers only highly exposed to one or the other. A study by Huang, Feuerstein, Kop, Schor and Arroyo (2003), however, did not indicate any interaction effects.

From a stress perspective, it is obviously of interest to know whether increased muscle activity is part of a general stress response, as proposed by, e.g., Melin and Lundberg (1997), or constitutes a separate physiological reaction. While the majority of stress research has centered around physiological stress responses related to the cardiovascular system (e.g., Schneiderman et al., 1989), much less attention has been paid to the relations between these responses and muscle activity (Krantz et al., 2004). Thus, this

issue is currently not thoroughly elucidated. This is reflected in the following quotation, for instance: "Also, if biological pathways linking job stress to work-related musculoskeletal disorders exist, it is currently unknown whether they are specific to these disorders or, more likely, represent the final common pathway by which exposure to both work-related and non-work-related stressors exert an effect on a number of health disorders (e.g., cardiovascular disease). That is, the specificity of these pathways is unknown." (National Research Council and Institute of Medicine, 2001, p. 288). However, from an evolutionary and functional perspective it is quite obvious that the muscular system is an integrated part of the stress system, at least under acute and intense circumstances. Otherwise there would be no possibility to fight or run away in a life-threatening situation. In addition, it is well known that sympathetic nervous system activity affects muscle function in different ways, for instance regarding muscle blood flow and the contractility of muscle fibers (Passatore & Roatta, 2003). There are also indications that support the view that increased muscle activity is part of a general stress response. Under well controlled laboratory conditions it was recently found that trapezius muscle activity was highly and significantly correlated with different indicators of sympathetic arousal (systolic and diastolic blood pressure, and heart rate) induced by mental (mental arithmetic, Stroop color word test) and physical (cold pressor test) stress (Krantz et al., 2004). This was also found in an earlier laboratory study by Lundberg et al., (1994), in which surface EMG activity of the trapezius muscle was significantly correlated with cardiovascular activity as well as norepinephrine (which plays an important role in blood pressure regulation). In that study, systolic blood pressure and heart rate were significantly elevated when the Stroop color word test was combined with a physical load compared to when the physical load was administered alone (Lundberg et al., 1994). Another experimental study among women performing computer-mouse work showed that initial introduction of a memory demand had a different effect compared to when it was reintroduced later in the experiment. The first time (during the main session), it resulted in increased EMG activity (of two forearm extensors and one finger flexor muscle), as well as increased heart rate, systolic and diastolic blood pressure. However, reintroduction of the memory demand (during the reintroduction session) was followed only by increased EMG activity (of one of the extensor muscles), whereas no change in cardiovascular response was seen (Finsen, Sogaard, Jensen, Borg & Christensen, 2001).

Taken together, experimental findings support the hypothesis that psychological stress (mental, cognitive, emotional demands) can induce muscle activity in the neck and shoulder region (trapezius muscle), even in the absence of physical load. In addition, this muscle activity is possibly accompanied by other physiological responses associated with sympathetic activity, suggesting that increased muscle activity in this region is part of a general stress response. Thus, a speculation can be made that psychosocial factors in

the workplace (and elsewhere) have the potential to elicit stress responses with an impact on both allostatic systems (e.g. the endocrine- and cardiovascular systems as described above, and the immune system) and the muscular system, with potentially deleterious effects on musculoskeletal health in the long run (Carayon, et al., 1999; Lundberg & Melin, 2002; Sjøgaard, Lundberg & Kadefors, 2000).

7 WORK-RELATED MUSCULOSKELETAL DISORDERS

7.1 Prevalence, trends and economic impact

Work-related musculoskeletal disorders are very common. They clearly constitute an important health problem in industrialized countries where a large number of people suffer from these disorders, and the economic impact on society is substantial (e.g., Buckle & Devereux, 1999; National Research Council and Institute of Medicine, 2001). In the Nordic countries, for example, it has been estimated that yearly costs amount to about 0.5-2.0% of the countries' gross national products (GNP) (Toomingas, 1998). Similar figures concerning the total costs associated with WMSDs have been estimated in the United States (National Research Council and Institute of Medicine, 2001). Only a smaller fraction of these costs is related to direct health care utilization, while the main part is related to sick leave, early retirement pensions, etc. (Goossens, 2002). In Sweden, for instance, about 38% of the long-term sick leave cases (more than 60 days per year) between 1999-2002, about 39% of the early retirement pensions in 2002, and about 61% of reported work-related disorders in 2001 were related to musculoskeletal disorders (Swedish Work Environment Authority & Statistics Sweden, 2003b; Swedish National Social Insurance Board, 2004).

However, the exact size of the problem is not known and there are several reasons for this. For example, a lack of standardized diagnostic procedures, different inclinations to report complaints due to different compensation systems in different countries, methodological differences in research, among other things, make comparisons regarding the prevalence of WMSDs across countries difficult (Buckle & Devereux, 1999; McBeth & Macfarlane, 2002; Punnett & Wegman, 2004). However, it has been estimated that up to 80% of the general population will suffer from low back pain at some occasion during their lifetime, and up to 50% will suffer from neck pain (Nachemson, Waddell & Norlund, 2000). Hence, it is not surprising that the current most commonly reported work-related health problems in the European Union are back pain (33%) and pain in the neck and shoulders (23%). Besides these pain problems, stress (28%) and fatigue (23%) are the most commonly reported work-related health problems (European Foundation, 2001).

Musculoskeletal disorders not only constitute a very common health problem, they also seem to present an increasing health problem, at least in the upper parts of back or neck. In 2003, 41.9% of Swedish employed women and 26.1% of Swedish employed men reported pain in the upper parts of their back or neck every week (Statistics Sweden, 2005). Between 1989 and 2003, pain in this anatomical area every week increased in women from 31.8% to 41.9% (an increase of 32%) and in men from 18.9% to 26.1% (an increase of 38%) (Swedish Work Environment Authority & Statistics Sweden, 2002; Statistics Sweden, 2005). This increase was especially related to the younger part of the work force (25-44 years) and to milder pain symptoms (Swedish Work Environment Authority & Statistics Sweden, 2002; Statistics Sweden, 2005). However, prevalence rates are affected by numerous factors and it has also been questioned as to whether musculoskeletal disorders have actually increased and are more prevalent today than before (McBeth & Macfarlane, 2002; Nachemson et al., 2000). An alternative interpretation of this increase in milder pain symptoms, which has also been found in Britain (change in back pain between the late 80's and late 90's) is a change in people's awareness of pain symptoms and their willingness to report them (Palmer, Walsh, Bendall, Cooper & Coggon, 2000).

During very recent years, diagnoses related to long-term sick leave cases (more than 60 days per year) have changed in Sweden, with a decline in diagnoses related to the musculoskeletal system and a large increase in diagnoses related to mental illnesses such as depression (including burn-out), anxiety- and stress-related disorders. Musculoskeletal disorders, however, were still the most common reason for long-term sick leave for men in 2003 (36%) followed by diagnoses related to mental illnesses (26%). For women, the reverse was found; diagnoses related to mental illnesses were the leading cause in 2003 (33%) followed by diagnoses related to the musculoskeletal system (31%) (Swedish National Social Insurance Board, 2004). Whether this reflects a real change in symptoms and disorders or can be attributed to, for instance, a general shift in focus towards stress-related and mental illnesses in media and society in general during recent years, is outside the scope of this thesis. However, noteworthy is the fact that pain problems often constitute one symptom among others in disorders often considered to be stress related, such as chronic fatigue syndrome and fibromyalgia (Aaron et al., 2001; Cleare & Wessely, 2000; Mc Ewen & Norton Lasley, 2002).

7.2 Gender differences

Generally, women suffer from musculoskeletal disorders more often than men, especially regarding complaints about the neck and shoulders (e.g. Buckle & Devereux, 1999; de Zwart, Frings-Dresen, & Kilbom, 2001; Hagberg et al., 1995; Hooftman, van Poppel, van der Beek, Bongers & van

Mechelen, 2004; Linton, 1990; Statistics Sweden, 2005). The reason for this gender difference is not known, but several explanations have been proposed and it has been suggested (Hoofman et al., 2004; Kilbom & Messing, 1998) that the current most valid explanation concerns the segregated labor market. In Sweden, for example, 90% of employees work in segregated occupations, and thus only 10% work in non-segregated, where 40-60% of the employees are woman or men (Westberg, 1998). As a consequence, women and men are not exposed to the same working conditions, physically as well as psychosocially, and women are thus seen as being in "high risk" occupations to a larger extent than men (Kilbom & Messing, 1998). However, an extensive study by de Zwart et al. (2001) among 16 874 employees in 21 different occupational classes in the Netherlands did not support this differential occupational exposure theory in relation to upper extremity musculoskeletal complaints.

In addition to different exposures in the workplace, men and women are also exposed differently outside work since gender roles regarding main responsibility for unpaid duties such as housekeeping and child rearing still show a traditional division between men and women (Lundberg, 1996; Lundberg & Frankenhaeuser, 1999; Lundberg, Mårdberg & Frankenhaeuser, 1994). For example, a study in which data collection was performed in 1990 among 679 women and 501 men (matched groups) in the white-collar sector in Sweden revealed traditional gender differences regarding household duties and child care, i.e., women spent more time taking care of their children and performing household work than men did. In addition, women reported more role conflicts and stress from paid work, but also more control over household work. Not surprisingly, total workload (number of hours per week) increased with number of children at home. However, this increase was greater for women than for men, and in families with three children or more, the total workload in women was about 20 hours more per week compared with men (Lundberg, Mårdberg & Frankenhaeuser, 1994). A study with a similar design and about the same number of participants from the white-collar sector was then performed in 2001 (Lundberg, Krantz & Berntsson, 2003). The results from the latter study showed that the overall pattern regarding responsibility for unpaid duties in the household was almost identical to that found eleven years earlier, although both men and women now spent more time with their children.

Thus, there is good reason to believe that women more often than men are exposed to a greater total workload (i.e., the sum of paid and unpaid work; see Mårdberg, Lundberg & Frankenhaeuser, 1991). Several studies have shown elevated physiological arousal in women compared with men, during paid work, after work and during weekends at home (Lundberg & Frankenhaeuser, 1999; Lundberg, Mårdberg & Frankenhaeuser, 1994; Rissler, 1977). Several studies indicate that these physiological differences between men and women are related to gender roles and psychological factors and not

primarily to biological differences such as the influence of steroid sex hormones, etc. (see review by Lundberg, 1996). Thus, having several roles may lead to role conflicts, overload and associated health risks, according to the "multiple role" hypothesis (Sorensen & Verbrugge, 1987). On the other hand, according to the "role expansion" model, having several roles such as being employed, married and a parent, is thought to enhance health due to an expansion of resources and rewards, as well as increased sources of satisfaction and self-esteem (Sorensen & Verbrugge, 1987).

Another possible explanation for the gender difference in prevalence of WMSDs is biological factors that, hypothetically, would render women more vulnerable to different exposures (Hooftman et al., 2004). For example, factors related to steroid sex hormones, differences in pain thresholds/tolerance, muscle fiber composition and the regulation of blood flow cannot be excluded as possible factors related to the increased prevalence of WMSDs in women (Lundberg, 2002). Furthermore, the fact that women on average are shorter and have lower muscle force and a lower aerobic capacity than men do leads to a higher relative workload for women when exposed to the same physical factors as men (Hooftman et al., 2004). However, monotonous and repetitive work is more often characterized by light to moderate physical workload and thus these biological factors are probably not of such relevance to this type of work, although they may be of importance in some more physically demanding jobs (Kilbom & Messing, 1998). Also, the prevalence of WMSDs in female white-collar workers is more than twice as high as in male white-collar workers, although these kinds of jobs require very little muscular strength or aerobic fitness (Lundberg, 2002). Thus, biological factors are not currently considered to be as important as the difference in exposure related to the segregated labor market mentioned above (Hooftman et al., 2004; Kilbom & Messing, 1998). However, as long as the physiological pathomechanisms of WMSDs are not yet known, more research is clearly needed regarding biological factors also, such as mechanisms on the cellular and molecular levels (Forde, Punnett & Wegman, 2002). Other suggested explanations are related to different coping strategies between men and women and the possibility that women are more prone to expressing different symptoms, such as pain (Hooftman et al., 2004).

8 REPETITIVE AND MONOTONOUS WORK, PHYSIOLOGICAL STRESS REACTIONS AND HEALTH IMPLICATIONS

Several studies have shown that repetitive and monotonous work, both under real life working conditions and in laboratory settings, is associated with increased physiological stress levels compared with more varied work tasks. Furthermore, unwinding after repetitive and monotonous work has been found to take a longer time compared with unwinding after more varied work tasks, indicated by a slower deactivation of hormonal levels (Johansson & Aronsson, 1984; Johansson, Aronsson & Lindström, 1978; Lundberg, Melin, Evans & Holmberg, 1993; Melin, Lundberg, Söderlund & Granqvist, 1999; Weber et al., 1980. See also review by Lundberg & Johansson, 2000). Moreover, in a relatively recent study among female sewing machine operators performing repetitive work, it was found that these women had an increased catabolic metabolism and a lowered anabolic metabolism, compared to control workers with more varied work tasks (Hansen, Kaergaard, Andersen & Netterstrøm, 2003). Furthermore, repetitive work with a short work cycle time (<1 min) was positively associated with risk factors for coronary heart disease (CHD) in a study by Melamed, Ben-Avi, Luz and Green (1995). Repetitive work was positively associated with blood pressure and serum lipid levels in female blue-collar workers, and with blood pressure in male blue-collar workers. According to the earlier mentioned Allostatic Load Model (McEwen & Stellar, 1993), the increased stress levels found during repetitive and monotonous work and the slower physiological deactivation following such work may have a negative impact on health if exposure is prolonged.

Epidemiological studies have also shown that repetitive work is associated with an increased risk for WMSDs in the neck and shoulder region (as well as in other body regions) (e.g., Bernard, 1997; Ekberg et al., 1994; Kilbom, 1994 a; National Research Council and Institute of Medicine, 2001; Ohlsson et al., 1995). Among afflicted groups with a high prevalence of WMSDs are cashiers/checkout workers (e.g. Drejhammar & Karlqvist, 2004; Hinnen, Läubli, Guggenbühl & Krueger, 1992; Lundberg et al., 1999) and computer users (e.g. Punnett & Bergqvist, 1997; Tittiranonda et al.,

1999). Exposure-response relationships have been found in computer users, i.e., an increased duration of computer work is associated with an increased prevalence of symptoms in the musculoskeletal system (Blatter & Bongers, 2002; Jensen, Finsen, Søgaaard & Christensen, 2002; Karlqvist, Wigaeus-Tornqvist, Hagberg, Hagman & Toomingas, 2002). Furthermore, and in line with the general picture, more women than men performing computer work have been found to report musculoskeletal symptoms (Ekman, Andersson, Hagberg & Hjelm, 2000; Karlqvist et al., 2002), although there are studies that do not confirm this picture (see review by Tittiranonda et al., 1999). Interestingly, the study by Karlqvist et al. (2002) showed that variation of work tasks was lower among women than among men. Also, women performed continued computer work without taking breaks to a higher proportion than men did, and this exposure variable showed the strongest association with symptoms from the neck and shoulder (as well as from the elbow, forearm and hand), both in men and women. Furthermore, high job strain was twice as common in women compared to men, although the number of participants experiencing this situation was relatively small (6% vs. 3%). Thus, this study indicated that women were exposed to adverse physical as well as psychosocial work conditions more often than men, and hence supports the hypothesis of different exposure between men and women in the work environment as an important contributing factor to WMSDs.

9 MUSCLE PAIN AND STRESS

A multitude of physiological mechanisms are involved in the development of (chronic) muscle pain, from peripheral mechanisms in the local muscle to structural changes in the central nervous system due to neuroplasticity (Blair et al., 2003). In addition psychological and behavioral factors are of importance from the very onset to the chronic stage of pain (Linton, 2000). Some of these mechanisms are mentioned here very briefly, followed by some specific models that are relevant particularly to musculoskeletal disorders in light physical and stressful work. (For an extensive text on pain, see e.g. McMahon & Koltzenburg, 2006.)

9.1 A brief overview on some mechanisms involved in muscle pain

Pain sensation is initiated by nerve cell endings called nociceptors. As regards skeletal muscles, these nociceptors are located between muscle fibers and are activated due to tissue damage/irritation causing the release of various chemical substances with algogenic (i.e., pain producing) properties such as bradykinin, prostaglandins, histamine, etc. The nociceptive information is then transmitted to the CNS by peripheral nerves entering the spinal cord via the dorsal roots, before ascending to the brain, where the sensation of pain is experienced (Purves et al., 1997). When nociceptors are repeatedly stimulated due to tissue damage they increase their responsiveness to painful stimulation. In other words, the threshold for pain is lowered (cf. just touching sunburned skin is painful). This phenomenon is called nociceptor sensitization (peripheral sensitization) and has been proposed to be a starting point on the path from acute to chronic muscle pain. Later in this process, sensitization of neurons in the CNS (central sensitization) is believed to occur (Ursin, Endresen, Håland & Mjellem, 1993). However, pain is a very complex sensory modality, and is highly influenced by emotional, cognitive and contextual aspects that contribute to the subjective variability of pain. Descending pathways modulate ascending pain signals at different levels of the CNS, from the brainstem down to the dorsal horns of the spinal cord and endogenous opioids play an important role in this process (Purves et al., 1997). This modulatory system has connections with brain structures such as the hypo-

thalamus and the limbic system including the amygdala, which indicates why psychological factors such as fear, attention and expectancy can affect pain sensation (Fields, Basbaum & Heinricher, 2006). Acute pain also induces increased arousal by activating the sympathetic nervous system. However, the role of SNS activity in non-specific chronic muscle pain currently seems unclear. The question of whether SNS activity is part of the genesis of this type of muscle pain or is a consequence of pain, since pain can be a very potent stressor, has no definite answer yet. Pain and SNS activity are possibly intertwined in feedback loops constituting a vicious circle (Roatta, Kalezić & Passatore, 2003).

9.2 Explanatory models linking stress to WMSDs: possible mechanisms

Current knowledge regarding pathophysiological mechanism behind WMSDs in light physical work is limited (e.g. Blair et al., 2003; National Research Council and Institute of Medicine, 2001). However, relatively recently several new explanatory models have been proposed that address the question of how individuals in occupations that require a low degree of muscle activity but at the same time are often stressful can develop musculoskeletal disorders. These models focus on different physiological mechanisms, but all recognize the effect of mental stress on the mechanism in question (although to varying degrees) (Blair et al., 2003; Lundberg, 2002; Melin & Wigaeus Tornqvist, 2005). Some of these models are presented briefly below.

Hägg (1991) proposed the “Cinderella hypothesis”, a model named after the fairy tale of the same name, in which Cinderella was the first to rise and the last to go to bed and was thus likely to be fatigued in the long run. Through this analogy, the Cinderella hypothesis suggests that work-related myalgia is caused by selective overloading of low-threshold motor units (Type I fibers), i.e., motor units that are always recruited first and derecruited last according to the Henneman size principle (Henneman et al., 1965). Thus, these motor units are assumed to be constantly active as long as the muscle is contracting and are shut off only during complete relaxation, and are hence susceptible to fatiguing overload and, in the long run, metabolic disturbances, degenerative processes, damaged muscle fibers and pain. The Cinderella hypothesis is based on two cornerstones, namely the ordered recruitment of motor units mentioned above (i.e., the size principle), and findings of muscle fiber abnormalities (ragged red fibers), hypothetically caused by overload of low-threshold motor units, in persons suffering from muscle pain. However, nociceptive mechanisms per se are not included in the Cinderella hypothesis (Hägg, 2003).

According to Hägg (2003), activity of single motor units has been confirmed not only during isometric/static arm positions in laboratory settings, but also when individuals are performing occupational-like tasks of up to 30 min. in duration. However, this is not found in every individual (or at least not in those particular motor units under study in those individuals). Moreover, it has been questioned whether this fixed recruitment pattern actually represents a "normal muscle function" or, as Fallentin (2003, p. 134) suggests, a "system failure". One reason for this is that motor unit rotation or substitution - a potential protective mechanism - has been found in some studies during prolonged low-level static contraction (e.g., Fallentin, Jørgensen & Simonsen, 1993; Westgaard & De Luca, 1999). The second cornerstone concerning muscle fiber abnormalities is supported by the detection of so-called ragged red fibers (Larsson, Björk, Henriksson, Gerdle & Lindman, 1988), indicating mitochondrial disturbances, in persons exposed to occupational static load. However, these abnormalities have been found in persons both with and without muscle pain exposed to static load, making the role of these findings in relation to pain uncertain (Hägg, 2000).

A model by Schleifer and Ley (1994) is concerned with the premise that there is a possible relationship between stress-induced hyperventilation and the development of musculoskeletal disorders. According to this model, psychosocial stress factors in the workplace can elicit emotional strain that leads to hyperventilation, i.e., breathing that exceeds the metabolic requirements for oxygen. This causes a disruption of the acid-base equilibrium by a drop in arterial CO₂ levels and a rise in blood pH levels, which in turn initiates different physiological reactions relevant for the musculoskeletal system, such as increased muscle tension and enhanced sensitivity to catecholamines (Schleifer, Ley & Spalding, 2002). In addition, hyperventilation often alters the breathing pattern from abdominal (diaphragmatic) breathing to chest (thoracic) breathing, with the effect that ancillary muscles such as the trapezius muscle in the neck and shoulder region is recruited (Schleifer et al., 2002). Interestingly, clinicians associated musculoskeletal symptoms such as pain and tremor with hyperventilation already many decades ago, and breathing therapy is assumed to have a positive effect on muscle tension (Fried & Grimaldi, 1993).

Muscle tension (muscle activity) is often assumed to play a causal role in the genesis of muscle pain, through mechanisms related to hypoxia, effects of energy deficits or cell damage due to accumulation of intracellular calcium (Knardahl, 2002). This was recently questioned by Knardahl (2002), who instead proposed a hypothesis suggesting that the interaction between blood vessels and nociceptors (i.e., pain receptors) is of central importance in the genesis of muscle pain – resembling the association between blood vessel mechanisms and pain in migraine – by potential mechanisms such as vasodilation stretching the vessel wall and producing mechanical activation of nerve endings, vascular production and release of algogenic factors (e.g.,

prostaglandins, bradykinin), and inflammatory processes activating or sensitizing nociceptors (Knardahl, 2002).

A model proposed by Johansson and Sojka (1991) is centered around the muscle spindle system, i.e. sensory organs embedded in the muscles important for proprioception, coordination of movements and reflex-mediated muscle stiffness (i.e., muscle tonus). In brief, the model states that static and/or repetitive work causes accumulation of metabolites (e.g. lactic acid) and inflammatory substances (e.g. bradykinin) in the muscles. This condition will increase the activity in the muscle spindle system, which in turn increases the reflex-mediated muscle stiffness and thereby the production of metabolites. Thus a "vicious circle" or a positive feedback loop is generated, a process that may also spread to muscles other than the initial one. In addition, the proprioception and coordination of movements may be affected by the altered activity in the muscle spindle system, and accumulation of metabolites may affect the sympathetic nervous system (Crenshaw, Lyskov & Johansson, 2001).

A recently proposed hypothesis is the "Nitric oxide/oxygen ratio hypothesis" (Eriksen, 2004), which is interesting from a stress perspective, since it explicitly addresses psychosocial stress at work as an important contributing factor to the development of neck myalgia. According to this hypothesis, pain in the neck region can be evoked in work situations in which low-level contractions in the trapezius muscle are combined with psychological stress or prolonged head-down neck flexion. Both these situations may increase sympathetic nerve activity, causing constriction of blood vessels (i.e. vasoconstriction) followed by a sequence of physiological reactions leading to an increased nitric oxide/oxygen concentration ratio in the muscle fibers and a depletion of adenosine triphosphate (the intracellular substance that provides the energy for almost all cellular functions, including muscular contractions; Guyton, 1984). This would elicit production/efflux of lactic acid into the connective tissue where nociceptive fibers would be activated, causing muscle pain (Eriksen, 2004). In cases of insufficient muscle rest, the mechanisms described in the nitric oxide/oxygen ratio hypothesis would be intensified and speeded up, which points to a possible close connection between this hypothesis and the Cinderella hypothesis, according to Thorn (2005).

In several of the models presented above, muscle activity plays an important role and several theories proposing that muscular hyperactivity contributes or causes pain have been presented over the years (see Graven-Nielsen, Svensson & Arendt-Nielsen, 2003 for an overview; Knardahl, 2002). Another – opposing – view to the relation between muscle activity and pain is that increased muscle activity is a consequence of pain. This is proposed in the pain-adaptation model (Lund et al., 1991), which also assumes that muscle pain has the potential to change the muscle co-ordination that is required to perform movements. Movements of body parts require coordination of different muscles. Basically, an opposing set of muscles, a flexor and an

extensor, is needed to bend a joint and allow a movement to be performed. When one of these muscles (i.e., the agonist muscle) contracts the other one (i.e., the antagonist muscle) is relaxed (Berne & Levy, 1993; Wickens, 2005). Pain seems to have the potential to change this co-ordination between agonist and antagonist muscles by reflex mediation. According to the pain-adaptation model the muscle activity in the agonist muscle will be decreased, if pain is present here, while the muscle activity in the antagonist muscle instead is increased. This can be understood as a protective mechanism that limits the range and velocity of movements in a painful area. Thus, this is an adaptation to pain, and the pain-adaptation model does not describe the underlying reason for chronic muscle pain per se (Graven-Nielsen et al., 2003).

10 REORGANIZATION OF WORK: POSSIBLE IMPLICATIONS FOR WMSDS

Job rotation is one frequently proposed intervention strategy for reducing the risk for contracting WMSDs (Frazer, Norman, Wells & Neumann, 2003; Kilbom, 1994 b; Mathiassen & Christmansson, 2004). The rationale behind this strategy is that job rotation is expected to change load and postures, thus allowing different muscle groups to be activated in different work tasks. For example, rotation can be made between one work task that primarily requires upper-limb muscle activity and another that primarily engages the lower back (Frazer et al., 2003; Mathiassen & Christmansson, 2004). Thus, job rotation is assumed to increase the exposure variability, obviously in terms of physical load, but psychological/mental load is also expected to be positively affected by this intervention strategy (Möller, Mathiassen, Franzon & Kihlberg, 2004). Based on epidemiological studies showing an increased risk for WMSDs in repetitive and monotonous work compared with more varying work (e.g. Bernard, 1997; Punnett & Wegman, 2004), this assumption seems logical and sound. However, the effects of job rotation on WMSDs currently seem largely unexplored, and the studies from occupational settings that do exist show inconsistent results (see overview by Mathiassen & Christmansson, 2004). Below are some examples from field studies in which the work tasks have become either more or less physically varied, due to either introduction of job rotation or other organizational changes of work.

An earlier study among female cashiers found that job rotation was associated with a much lower rate of musculoskeletal disorders, but only in cashiers operating laser scanners and not among those operating conventional cash registers with keyboard for price registration (Hinnen et al., 1992). In another study, female workers in the electronics industry were followed for two years in a study by Jonsson, Persson and Kilbom (1988). The first year, all workers performed repetitive electronics manufacturing work, and the number of workers with musculoskeletal symptoms (from the neck, shoulder, arm/hand and upper back) increased. However, after one year a subgroup of workers were reallocated to more varied and dynamic work tasks. It was found that the group of workers who were reallocated improved significantly during the second year, whereas the other workers who continued to

perform repetitive work task got worse. In addition, a group of workers remained healthy throughout the two years. Interestingly, this was predicted by work satisfaction at the onset of the study period, but also by a "correct" working technique. Furthermore, a study among women in the fish-processing industry compared the prevalence of musculoskeletal symptoms in the upper limbs before and after introduction of a new manufacturing process called the flow-line. Already before the introduction of this production line consisting of conveyor belts, the work tasks were highly repetitive, but the workers were able to rotate between different workstations. After introduction of the flow-line, rotation became difficult, work tasks were simplified and less varied and the duration of repetitive work increased. The effect on the musculoskeletal system was an increase of symptoms in the upper limbs. However, symptoms in the lower limbs decreased (Ólafsdóttir & Rafnsson, 1998).

A reorganization of work in the automobile industry was also associated with a deterioration of musculoskeletal health as was partly shown in the fish-processing industry described above (Fredriksson, Bildt, Hägg & Kilbom, 2001). The work was changed from lineout to line production in an automobile assembly plant, resulting in objectively measured improvements regarding some ergonomic factors (better work postures, less repetitive work, more evenly distributed work over the workday), but the work cycle time decreased considerably. Contrary to what might be expected, there was a significant increase in perceived physical exertion after the reorganization, and musculoskeletal disorders increased. Some work-related psychosocial factors were also markedly changed in an unfavorable direction, namely stimulation from work, opportunities to influence work, and occupational pride. The implementation of the new line production was not accomplished in a participatory way as seen from the workers perspective, and the great importance of psychosocial factors in the reorganization of work was stressed by the authors in the study. Additionally, in a one-year prospective study among male refuse collectors in the Netherlands it was found that job rotation between collecting two-wheeled containers and driving a refuse truck increased the risk of low back complaints more than twice compared with a reference group. In addition, a reduced need for recovery was associated with job rotation. However, according to Kuijer, van der Beek, van Dieën, Visser and Frings-Dresen (2005), who performed the study, various selection effects may have influenced the results.

11 THE EMPIRICAL STUDIES

11.1 Background, general methods and design

The data in this thesis were collected both in a laboratory setting (Study I) and during real work-life conditions (Studies II-IV). In Study I the data collection was performed in a laboratory experiment undertaken within the larger research project, "Prevention of muscular disorders in operation of computer input devices" (PROCID). This project was a Concerted Action financed under the European Union research program BIOMED-2, and consisted of researchers from Sweden, Denmark, Switzerland and Italy (Christensen & Sjøgaard, 1999; Sandsjö & Kadefors, 2001). The particular experiment in Study I was performed in Denmark in collaboration between Danish and Swedish researchers from the fields of physiology and psychology. Studies II, III and IV were based on a data collection performed in 1998-1999 among female employees at four different supermarkets in the greater Stockholm area in Sweden. This data collection was a follow-up of an earlier study (Lundberg et al., 1999) among the same group of women after introduction of job rotation at these supermarkets. Thus, Studies I-III were cross-sectional in nature whereas Study IV, evaluating the effects of the introduction of job rotation, had a follow-up design studying the same group of women already studied cross-sectionally by Lundberg et al. (1999). Studies I-IV all used a psychobiological methodology (e.g. Lundberg, 1995). The time between the two waves of data collection in study IV varied between 3 to 4.5 years between the different supermarkets.

11.2 Participants

Twelve female students participated in Study I. Their mean age, height and body mass were 23.7 (SD 4.8) years, 1.70 (SD 0.05) m and 62.6 (SD 5.8) kg, respectively. They were all experienced computer users, reported no discomfort in their upper body regions within the week prior to data collection, and had no prior experience of laboratory experiments. Eleven of twelve subjects were right-hand dominant, while one was left-hand dominant. All participants gave informed consent, and the local ethical committee of Copenhagen approved the study.

Studies II, III and IV were based on data collection performed among employees at supermarkets. This data collection was a follow-up of an earlier study among the same group of employees after introduction of job rota-

tion (see above). From the original sample of 72 female cashiers (Lundberg et al., 1999), 38 were still employed by the company at follow-up. Thirty-one of these volunteered to participate, five were excluded due to sick leave, maternity leave or study leave, and two declined to participate. The mean age of the 31 women was 43.7 years (range: 23-61 years), and they had been employed for between 4.3 and 22.0 years (mean=12.4 years), and worked between 18 and 40 hours/week (mean=28.2 hours). All participants were right-hand dominant. Inclusion criteria were participation in the earlier study and not suffering from any disease requiring treatment with diuretics or beta-blockers. Study III was based on only 24 of these cashiers, since the analyses in this study only included participants with complete EMG data. Accordingly, the figures above related to age, employment time and weekly working hours differ slightly from Studies II and IV (see Study III). The study was approved by local ethical committees.

Table 1 Overview of the studies included in the thesis

	Study I	Study II	Study III	Study IV
Design	Cross-sectional	Cross-sectional	Cross-sectional	Follow-up
Study population	Female students	Female super-market employees	Female super-market employees	Female super-market employees
Number of participants	12	31	24	31
Setting	Laboratory	Work environment	Work environment	Work environment
Type of repetitive work	Standardized computer work	Cash register and department work	Cash register work	Cash register and department work
Type of psychological stressors	"Standardized" cognitive and emotional stressors	Naturally occurring stressors in the workplace	Naturally occurring stressors in the workplace	Naturally occurring stressors in the workplace
Pain status	Pain-free	Both pain-afflicted and pain-free	Both pain-afflicted and pain-free	Both pain-afflicted and pain-free

	Study I	Study II	Study III	Study IV
<i>Principally analyzed outcome variables</i>				
Subjective stress	Yes	Yes	Yes	Yes
Blood pressure	Yes	Yes	No	Yes
Heart rate	No	Yes	No	Yes
Heart rate variability	Yes	No	No	No
Muscle activity (surface EMG)	No	Yes	Yes	Yes
Catecholamines and cortisol	No	Yes	No	Yes
Pain	No (all were pain-free)	Yes	Pain-afflicted vs. pain-free were compared	Yes
Workload	No (standardized)	Yes	No	Yes
Work postures	No	No	No	Yes
Psychosocial factors by questionnaire	No	No	No	Yes

11.3 Summary of investigations

Study I The effect of mental stress on heart rate variability and blood pressure during computer work

This laboratory study aimed at investigating cardiovascular and subjective stress responses to a combination of physical workload and mental stressors, and the effect of rest periods. The participants were twelve female students without prior experience of laboratory experiments. The physical work consisted of a standardized computer work task: the participants were seated on a height-adjustable chair at a table with arm support and keyed in six-digit numbers with their dominant hand. Random numbers were presented on the computer screen for 4 sec. Three work sessions were performed, namely an introductory session (IS), a stress session (SS) and a control session (CS). These sessions were not randomized because the effect of being a novice in the laboratory setting was one of the stressors, and this novelty effect was expected to decline and be least pronounced in the last session (i.e., control session). Each of these sessions consisted of four work periods of 3 min each, separated by short breaks lasting 30 sec. In addition, the three sessions were followed by longer breaks, each lasting 8 min. The computer work task was externally paced and thus the physical workload could be kept constant throughout all three sessions. The psychological demands consisted of a blend of mental, cognitive and emotional stressors, with the intention of simulating a real work-life situation. During the IS and SS, the experimenter showed a neutral/strict attitude toward the participant (lack of support) and was unfriendly toward the colleagues. Additional stressors consisted of surveillance by a video camera and a memory test, besides the already mentioned externally paced work task and the presumed novelty effect due to a lack of earlier experience of laboratory experiments. In the CS these stressors were eliminated to the extent possible, while the computer work was the same. Blood pressure and electrocardiogram (ECG) were recorded continuously during the laboratory experiment. Heart rate variability (HRV) variables were later calculated from the ECG recordings. Baseline blood pressure recordings were performed before the experiment in a separate room after 10 min of rest. In addition, subjective experiences of stress were reported before the first work session and after each of the three work sessions. The results showed that the combination of psychological stressors and physical load induced by repetitive computer work had a marked influence on cardiovascular response during work sessions compared with rest periods. In addition, the high frequency component of HRV (indicating parasympathetic nervous activity) was significantly reduced in the SS compared with the CS. A significantly increased low- to high-frequency ratio (LF/HF ratio) was also observed in the SS compared with the CS. However, the low-frequency component of HRV was unchanged. Taken together, the shift

from the SS to the CS was clearly reflected in HRV variables. Furthermore, the stressors induced increased and sustained blood pressure throughout the experiment compared to baseline. Thus, the CS had no effect on blood pressure variables. Diastolic pressure was even higher in the CS than in the SS. The prolonged breaks, however, showed a significant decrease in blood pressure compared with the sessions of computer work, but the blood pressure remained significantly elevated during rest compared to baseline. Thus, a dissociation between HRV and blood pressure variables was observed. The subjective experience of stress did not change significantly between the SS and the CS. However, a time trend in exhaustion was seen, i.e. significantly more exhaustion was reported in the SS and CS compared to the IS. The results indicate that HRV may be a more sensitive and selective measure of mental stress compared to blood pressure recordings.

Study II Surface EMG and psychophysiological stress reactions in women during repetitive work

The present study aimed at exploring the relations between subjective stress reactions, psychophysiological stress responses and muscle activity measured by surface electromyography in the trapezius muscle among 31 women employed at supermarkets. Seven of ten of these women had pain in the neck-shoulder region. The participants shifted between cash register work at the checkout counters and more variable work in different departments in the supermarket. Before the data collection, each participant took part in an introductory session with the purpose of reducing novelty effects during the subsequent data collection. In addition, a clinical examination was performed by a qualified physiotherapist and information about the medical history of the participant was collected. Data were then collected while the participants performed their normal work tasks for two hours, according to a proportional model containing both cash register and department work, individually determined for each participant. Thereafter followed one hour during which baseline values were collected. The measurements included surface electromyographic (SEMG) activity of the trapezius muscle, heart rate, blood pressure, urinary catecholamines and salivary cortisol. In addition, self reports of positive (stimulated, concentrated, happy) and negative (stressed, exhausted, tense) reactions during work were collected and questions regarding average pain intensity and duration of pain were answered. In addition, pain afflicted participants completed a pain drawing and were asked to report in a diary, every evening for a week, musculoskeletal pain from different parts of the body. The workload during cash register work was also measured by recording the number of customers and the number and weight of all the items that each participant registered and handled. In addition, work postures were observed continuously during department work, and the time spent in different postures was estimated and reported on a six-point scale.

Moreover, a questionnaire regarding background data and some work-related issues was answered by the participants. The results showed a high level of psychophysiological arousal during work. Significant positive correlations were found between trapezius EMG activity and scores on an index indicating negative reactions (stressed, tense, exhausted) during work. In contrast, no significant correlations were found between EMG activity and positive reactions (stimulated, concentrated, happy). In addition, significant negative correlations were found between muscle rest (i.e. the percentage of the recorded time that the muscle was below a "work-rest-threshold" individually determined for each participant) and negative reactions during work. Thus, a higher degree of negative reactions during work was associated with higher trapezius muscle activity and a lower amount of muscle rest. Furthermore, no associations were found between trapezius muscle activity and average pain estimated during the introductory session or between negative reactions and pain. Objectively measured workload, indicated by the number of customers and the number and weight of all the items handled and registered during cash-register work, was not significantly associated with EMG activity. In addition, physiological stress responses did not correlate significantly with trapezius muscle activity, although systolic blood pressure showed positive, but not significant, correlations with muscle activity. Taken together, the results indicate that negative reactions like perceived stress, tension and exhaustion may have a specific influence on muscle activity. This might be of importance regarding musculoskeletal disorders in jobs with a low to moderate physical load and concurrent negative psychosocial factors.

Study III Trapezius muscle activity, neck and shoulder pain, and subjective experiences during monotonous work in women

The aim of this study was to investigate how long-term EMG activity patterns in the trapezius muscle are related to neck and shoulder pain during cash-register work at a supermarket, and how they correspond to the pain-adaptation model. The electromyographic activity patterns of the trapezius muscle were examined among 18 female supermarket employees with neck and shoulder pain, and were compared to the activity patterns of six pain-free employees. As mentioned earlier, Studies II-IV were based on the same data collection, and the design and procedure related to Study III is described in conjunction to Study II (see above). The results indicated a different muscle activity pattern in women reporting pain compared with pain-free women. The former group tended to show a lack of both low and high EMG activity levels (i.e., a more static muscle activity pattern), a lower percentage of muscle rest (significant in the non-dominant side), and an equal amount of muscle rest in both the dominant and non-dominant sides of the trapezius, indicating a bilateral muscle activation or co-contraction. Taken together, these results are in line with the pain-adaptation model and can be inter-

preted as a reflex-mediated protective mechanism that limits the range and velocity of motion and thus helps the individual with musculoskeletal pain to reduce further injury and pain. Another finding was that participants with pain were significantly shorter than their pain-free fellow workers. This may indicate that ergonomic factors such as work-station design were not optimal for all employees. Furthermore, self-reports of negative (stressed, exhausted, tense) versus positive (concentrated, stimulated, happy) reactions during work showed that negative reactions were somewhat (although not significantly) higher in women reporting pain, while positive reactions appeared to be equally high in both groups.

Study IV Psychophysiological stress reactions, trapezius muscle activity, and neck and shoulder pain among female cashiers before and after introduction of job rotation

The aim of this follow-up study was to evaluate the effects of the introduction of a job rotation model (i.e., a less repetitive and monotonous work) among 31 female supermarket cashiers, with respect to psychophysiological and subjective stress reactions, trapezius muscle activity and musculoskeletal symptoms in the neck and shoulders. In short, the employees were investigated before and after job rotation was introduced. Before the reorganization, the participants only performed cash register work at the checkout counters. After the reorganization, they shifted between cash register work and more flexible work in different departments in the supermarket. On average, 40% of the work was performed at the checkout counters and 60% in different departments. As mentioned earlier, Studies II-IV were based on the same data collection and most of the design and procedure related to Study IV is described in conjunction with Study II (see above). The results indicate that the introduction of job rotation was associated with some positive health effects, as at follow-up diastolic blood pressure was significantly lower and trapezius muscle activity had significantly decreased on the left side. Musculoskeletal symptoms of the neck and shoulders were only partly changed in a positive direction, and the prevalence of pain (70%) was unchanged. From questionnaires it was suggested that the introduction of job rotation had been experienced as positive in several regards, and eight of ten of the employees were "very satisfied" or "somewhat satisfied" with work at follow-up. However, the perception of stress and hurry were the same at follow-up, and self reports of negative (stressed, exhausted, tense) reactions during work did not change significantly but were generally low.

12 DISCUSSION

The general aim of this thesis was to study relations between psychophysiological and subjective stress reactions, muscle activity of the trapezius muscle, and neck and shoulder pain in women performing repetitive and monotonous work tasks. These variables were studied during real work-life conditions in supermarket cashiers/employees, both cross-sectionally and in a follow-up study evaluating the introduction of a job rotation model (i.e., less repetitive and monotonous work) among these women. Furthermore, in the laboratory setting the effects of repetitive and monotonous computer work were studied with respect to psychophysiological (cardiovascular) stress reactions and subjective stress responses.

The results from this thesis are discussed and integrated with previous research findings below.

12.1 Combined exposure of physical load and psychological stress

Study I showed that repetitive and monotonous computer work under laboratory conditions, involving a combination of different cognitive and emotional stressors and the light physical workload associated with repetitive data entry work, induced changes in heart rate variability and a sustained increase in blood pressure. However, no differences were found regarding perceived stress between the three work sessions (i.e. introductory, stress, and control sessions), except for a time trend in exhaustion. This study and that of Blangsted et al. (2004), which is based on the same experiment but reports the effects on muscle activity, point to some important issues, namely the difficulty of separating physical and mental demands, and the complexity of interpreting the outcomes.

As shown by Blangsted et al., (2004) no increase in trapezius EMG activity was found by adding the combination of different cognitive and emotional stressors to the physical workload. However, as mentioned earlier, other experimental studies have revealed an increased EMG activity when physical demands are combined with mental stress (Lundberg et al., 1994; Weber et al., 1980) and it is not clear how to interpret these differences between studies. One reason for the negative finding in the study by Blangstedt

et al. (2004) may, however, be a masking effect from the static muscle activity induced by the repetitive computer work. This type of masking effect from static muscle activity has been discussed before in relation to female computer users with and without neck/shoulder complaints (Thorn et al., 2006). In addition, the combination of different cognitive and emotional stressors in Study I may hypothetically have had a more pronounced effect than expected. Although different stressors were removed in the control session, all the work sessions were externally paced and the presumed decrease in "novelty effect" during the experiment may have been less than expected. This was indicated by a relatively high and sustained increase in blood pressure, no significant changes in perceived stress between the work sessions (except for increased exhaustion), and a low but relatively constant EMG activity seen during the short and long rest breaks (Blangsted et al., 2004). Thus, a separate effect on muscle activity from the mental and emotional stressors may have been masked by the physical workload during work sessions but observable during breaks. Hypothetically, the static muscle activity may also be an explanation for the dissociation found between HRV and blood pressure in Study I (i.e. changes in HRV, but sustained increase in blood pressure). The reason for this speculation is that peripheral mechanisms in the working muscles to some degree influence blood pressure responses, while heart rate is primarily regulated by "central command" mechanisms of ANS cardiovascular control (Rowell, 1986), which probably also mimics mental stress.

From a research perspective it is necessary and of great importance to be able to distinguish physical/ergonomic demands from psychological/mental demands. For example, Lundberg et al. (2002) were able to show that the same motor units were often active during both physical demands and mental stress – a finding of theoretical significance but also with potential implications for preventive work. However, demands in work life are probably always, but to different degrees, a reflection of the combination of physical/ergonomic loads and psychological/mental demands (Melin & Wigaeus Tornqvist, 2005). Thus, it seems difficult to separate physical load from psychological demands. This is true not only in "real life" but also in laboratory studies simulating repetitive and monotonous work tasks, as suggested by Study I. This is also recognized by Waersted (2000), who notes that it is often difficult to differentiate biomechanical from non-biomechanical reasons for changes in muscle activity. For example, it is difficult to decide whether an increase in shoulder muscle activity found in a mentally demanding task is related to truly non-biomechanical factors or is associated with an increased need for postural stabilization of the shoulder girdle or head during such work tasks (Waerstedt, 2000).

A study by Wahlström et al. (2002) showed that trapezius muscle activity increased when work was performed using a computer mouse if time pres-

sure and verbal provocation (trying to increase the speed of the participant by calling, e.g., "hurry up", "come on, you can do it faster") were added. In that study it was found that not only muscle activity in the right trapezius (and two other muscles) increased, but so did forces applied to the button of the computer mouse, and furthermore, wrist movements became more rapid in the stress session. According to Wahlström et al. (2002), these variables were probably affected by both stress and increased speed/productivity. Thus, the increased muscle activity was at least to some part a result of increased physical performance, as noted by Blangsted et al. (2004). However, from a stress perspective increased physical performance can be seen as adaptive, and an integrated part of a stress reaction consisting of physiological, as well as behavioral and psychological/emotional responses (e.g. Sauter & Swanson, 1996). Thus, this increased physical performance might not necessarily be treated as a confounder or alternative source of increased muscle activity. This highlights the complexity in interpreting results and the delicate matter of separating mental stress from physical variables such as force production, speed, etc. Naturally, it is of great importance to be able to distinguish between different exposure variables in experimental studies. However, this may to some extent be an artificial distinction since in real life situations these variables may be inseparable due to the fact that they are dependent on each other to varying degrees and are integrated in complex response patterns.

12.2 Perceived muscle tension as related to muscle pain and objectively measured muscle activity

As pointed out in the introduction, a common theme in work-related stress models is that psychosocial stressors interact with the individual in the workplace and this may lead to different psychological, behavioral and physiological reactions with possible consequences for health (Sauter & Swanson, 1996). For example, psychosocial factors may affect psychological mood states, which in turn influence physiological processes such as increased muscle activity, as suggested by Theorell, Harms-Ringdahl, Ahlberg-Hultén and Westin (1991). It is reasonable to assume that these processes are perceived by the individual and are expressed as, for instance, bodily or muscular tension and perceived stress. It has been suggested, for example, that "perceived general tension" may be an intermediate response variable between environmental stress and musculoskeletal pain in the neck and shoulder region (Vasseljen, Holte, & Westgaard, 2001). Several cross-sectional studies have also confirmed that an association exists between pain in this region and "perceived general tension" or related concepts such as "muscle tension" and "tension" (Lundberg et al., 1999; Ohlsson et al., 1995;

Theorell et al., 1991; Vasseljen, Holte & Westgaard, 2001; Vasseljen, Westgaard & Larsen, 1995). Also, a prospective study among male and female VDU users showed that perceived muscle tension was associated with an increased risk of developing neck pain, even after controlling for job strain, physical exposure and age in a multivariate model stratified by sex (Wahlström, Hagberg, Toomingas & Wigaeus Tornqvist, 2004).

Currently, the systematic and detailed knowledge of what this/these concepts actually entail(s) is scarce, despite the frequent usage of them in everyday language (Holte, Vasseljen & Westgaard, 2003). However, Holte et al., (2003) tried to obtain a clearer idea of this by performing qualitative interviews with 64 women. These interviews indicated that the tension concept was related to the work environment as well as to personal factors. Further, these interviews showed that the perception of tension was associated both with activation of the musculoskeletal system (81% of the responders), involving mainly the upper body region, and activation of the autonomic nervous system (42% of the responders). The participants were also asked about what caused their tension. Interestingly, a common factor was negative emotions such as irritation and frustration induced by interpersonal relations (with customers, colleagues, etc.), but time pressure was also a relatively common reason for perceived tension. Significant correlations have also previously been observed between muscle tension and negative emotional reactions like worry and anger (Theorell et al., 1991).

In Study II it was found that self reports indicating negative stress (i.e. an index consisting of the items stressed, exhausted and tense) during work were significantly and positively related to mean surface EMG activity of the trapezius muscle. Positive experiences (i.e. an index consisting of the items stimulated, concentrated, and happy), however, showed no such relationships. Interestingly, positive correlations were found between trapezius muscle activity and negative stress reactions both in participants with pain ($r = 0.43$, $P = 0.06$) and in participants without pain ($r = 0.64$, $P = 0.13$), although the correlations did not reach significance in either group. Thus, a speculation can be made that negative stress reactions (negative emotions) may have a specific influence not only on perceived tension but also on muscle activity patterns with potential importance for the development of pain. However, other studies concerning the association between muscle (EMG) activity and different concepts related to a sensation of tension have yielded mixed results (Holte et al., 2003; Vasseljen & Westgaard, 1995; Wahlström, Lindegård, Ahlborg Jr, Ekman & Hagberg, 2003; Westgaard, Vasseljen & Holte, 2001).

The results concerning the association found in Study II between negative stress (emotions) and muscle activity must be confirmed in future studies and currently interpreted with caution. However, if confirmed in future studies, the question remains regarding why some emotions are related to an increased muscle activity and others are not. A speculative and preliminary

hypothesis is based on an evolutionary perspective. From this perspective it may be argued that negative emotions are related more often to situations important to survival, such as threatening situations, than positive emotions are. Hence, negative emotions can be expected to be more closely associated with stress responses and increased muscle activity. These threatening situations may possibly be experienced in a "mild form" in, e.g., negative interpersonal relations with customers, colleagues, superiors, etc. This may be an explanation for the observed associations between negative emotions (negative stress) and muscular responses, while no associations were seen between positive emotions and muscle activity in Study II. Lundberg and Melin (2002) have discussed a possible evolutionary basis concerning the role of the trapezius muscle in emotions of importance for survival. It has also been found that negative and positive emotions tend to be related to different neuroendocrine responses (Frankenhaeuser, 1983, 1986), and that the frontalis (a facial muscle) and the trapezius react more strongly in response to cognitive and emotional stimuli than other compared muscles do (Wærsted & Westgaard, 1996).

In addition to perceived muscle tension, perceived stress has been suggested as another mediating variable between psychosocial factors in the workplace and WMSDs. Studies have shown an association between perceived stress and musculoskeletal symptoms (e.g. Bongers et al., 2002; Linton, 2000), and using structural equation modeling it has also been found that perceived work demands are related to musculoskeletal symptoms through the effect of perceived (or felt) stress (Larsman, Sandsjö, Klipstein, Vollenbroek-Hutten & Christensen, 2006). Taken together, the association found in Study II between mean surface EMG activity of the trapezius muscle and negative stress ratings including the items "tense" and "stressed" are in line with the findings discussed above.

12.3 Lack of muscle rest as related to the development of muscle pain

According to the Cinderella hypothesis, prolonged muscle activity of low-threshold motor units and too little muscle rest are risk factors for the development of work-related muscle pain (Hägg, 1991). In line with this, Study III showed that participants with neck and shoulder pain had a significantly reduced amount of muscle rest in the trapezius muscle during work compared with pain-free fellow-workers. This finding among supermarket employees is supported by cross-sectional studies among medical secretaries (Hägg & Åström, 1997) and elderly female computer users under laboratory conditions (Thorn et al., 2006). However, two other cross-sectional studies did not demonstrate any such differences between cases and controls in of-

fice work (Nordander et al., 2000; Vasseljen & Westgaard, 1995). Interestingly, the study by Thorn et al. (2006) showed less trapezius muscle rest in women with neck/shoulder complaints compared with those without complaints. However, this was found only under stressful conditions (Stroop color word task), and not under conditions with more physical work tasks (text typing, editing or mouse precision work task). According to Thorn et al. (2006), one reason for this may be a masking effect from physical demands, as discussed above in relation to Study I. Another explanation suggested by these authors is that individuals with neck/shoulder pain may react with a stronger motor response to psychological stress than those without muscle complaints. From the field of cardiovascular stress research, for example, it is known that considerable differences in cardiovascular responses exist between individuals in response to psychological stress (e.g. Turner, 1994). Future studies concerning individual differences in muscular reactivity, for instance investigating temporal stability, inter-task consistency, etc., would be of great interest.

Furthermore, in a prospective study female chocolate packers were followed over one year, and trapezius EMG activity was measured repeatedly during repetitive work as well as during accidentally occurring pauses (machine-stops). It was found that women who developed trapezius myalgia showed significantly higher muscle activity during the pauses, but not significantly so during work, compared with those who stayed healthy (Veierstedt, 1993). Furthermore, a low rate of EMG gaps (i.e. very short periods of unconscious muscle rest) predicted future trapezius myalgia (Veierstedt, Westgaard & Andersen, 1993). A more recent prospective study by Madeleine, Lundager, Voigt and Arendt-Nielsen (2003) showed that six of twelve newly employed and healthy female workers in the fish or poultry industry had developed neck-shoulder complaints after six months of employment. Those who developed complaints showed higher shoulder muscle EMG activity than did women who remained healthy, both at the start of employment and after six months. An additional study among female workers with and without neck and shoulder pain found that muscle activity recorded from the upper trapezius muscle in pain-afflicted workers and pain-free workers was low and similar in both groups during work. However, differences were found after work, i.e. during leisure time. Then, the muscle activity was unchanged in the pain-afflicted workers, but was significantly reduced in pain-free workers (Holte & Westgaard, 2002). This apparent inability to relax the trapezius muscle during leisure time among pain-afflicted workers was also found during sleep in a separate analysis (Mork & Westgaard, 2004). Moreover, a study concerning myofeedback training in individuals with work-related myalgia in the neck and shoulders showed that a reduction in pain was not related to a decreased muscle activity level, however, it was related to an increased ability to relax the muscles (Vollenbroek-Hutten, Hermans, Voerman, Sandsjö & Kadefors, 2006).

Thus, there seems to be growing evidence that sustained low-level muscle activity and lack of muscle rest are risk factors for muscle pain in the neck and shoulder region, thus supporting the Cinderella hypothesis. As suggested by Sjøgaard, Lundberg and Kadefors (2000), lack of muscle rest may be even more important than how often the muscle contracts (frequency) or the absolute level of muscle contraction (amplitude). In addition to the Cinderella hypothesis, the concept of allostasis (Sterling & Eyer, 1988), stressing the importance of a balance between activity and rest, is of relevance since a low amount of muscle rest may hinder necessary repair of damaged muscle fibers (i.e., anabolic processes) (Sjøgaard et al., 2000). As pointed out earlier in the introduction, long-term activation of the allostatic systems has been associated with an increased risk for several disorders.

Moreover, Study II showed that muscle rest was significantly and negatively associated with self-reports indicating negative stress (an index consisting of the items stressed, exhausted and tense), i.e. women scoring high on negative stress tended to have a reduced amount of muscle rest during work. Interestingly, this correlation was significant in subjects with pain (-.47, $p < .05$), but the correlation showed the same direction in women without pain (-.60, $p = .17$), although the correlation did not reach significance. This suggests that this relation may be unrelated to pain status (however, Study III showed that negative stress reactions were somewhat, but not statistically significantly, higher in pain-afflicted women). Furthermore, it suggests a possible pathway from psychosocial factors inducing perceived negative stress reactions to neck and shoulder pain via reduced muscle rest, in accordance with the Cinderella hypothesis and, more generally, the allostatic load model. Interestingly, it was recently found that perceived job demands were related to musculoskeletal symptoms in the neck and shoulders exclusively through their effect on felt stress (Larsman, Sandsjö, Klipstein, Vollenbroek-Hutten & Christiansen, 2006). Whether the findings discussed above as regards lack of muscle rest are related to individual factors such as psychological trait characteristics, work technique, etc., physical and/or psychosocial workplace factors inducing different mood states, or other factors, is currently not known. However, the individual response pattern related to muscle activity and muscle rest is often significant in studies (e.g. Sandsjö et al., 2000), likely a result of many different factors. Since the prevalence of WMSDs is higher in certain occupations it seems quite clear, however, that different workplace factors (physical and/or psychosocial) are of importance.

12.4 Objectively measured muscle activity as related to muscle pain

Study III revealed that female cashiers with neck and shoulder pain showed a different electromyographic (EMG) activity pattern during cash-register work compared with participants without pain. First, the time the trapezius muscle was at rest during work was significantly reduced in women with neck and shoulder pain (as discussed above). Second, the amount of muscle rest was equal in the right and left trapezius (i.e., the dominant and non-dominant sides) in this group, indicating a bilateral activation (co-contraction). Thirdly, the trapezius EMG activity of participants reporting pain tended to show a lack of both low and high levels, thus showing a more static, or less variable, activity pattern. Taken together, these findings are in line with the pain-adaptation model and could be interpreted as a stabilization of the shoulders in cashiers with muscle pain, in order to limit movement and reduce further pain.

No definite conclusions can currently be drawn regarding the role of muscle activity in the development of muscle pain in light physical work with concurrent psychological stress (Holte et al., 2003). Hypothetically, other parallel physiological mechanisms may account for the genesis of muscle pain, whereas low level muscle activity merely is a pointer to these mechanisms (Mork & Westgaard, 2004; Vasseljen & Westgaard, 1995; Westgaard, 1999). For example, it was recently shown that women with neck and shoulder pain had higher trapezius muscle activity and a more sustained activity pattern during sleep than did pain-free women (Mork & Westgaard, 2004). A speculation made by Mork and Westgaard (2004) is that these findings are related to an increased autonomic arousal during sleep in those with pain. This is interesting, since during sleep individuals are not under immediate psychological stress or aware of stressors in their life, thus suggesting a more complex role of the autonomic nervous system in relation to muscle pain than merely being triggered in a stressful situation when awake. The study by Mork and Westgaard (2004) showed no associations between trapezius muscle activity during sleep and perceived pain intensity the same day or exacerbation of pain during the night. In addition, activity in the deltoid muscle (covering the outer part of the shoulder) during sleep was higher than in the trapezius, in both pain-free and pain-afflicted women, although this region is often unaffected by pain. These findings add to the complexity of this issue. Besides the possible role of autonomic arousal in muscle pain conditions, other mechanisms not involving muscle activity per se are related to the peripheral or central nervous system, such as peripheral sensitization of muscle nociceptors, neurogenic inflammation or central hyperexcitability (Graven-Nielsen et al., 2003). Furthermore, the model proposed by Knardahl (2002) focusing on the interaction between blood vessels and nociceptors also leaves out muscle fiber activation as a causal factor in pain genesis.

12.5 Job rotation – an effective strategy to counteract WMSDs?

The introduction of job rotation among female supermarket cashiers was associated with positive health effects. This is indicated by a significantly lower diastolic blood pressure among cashiers at follow-up (Study IV). In addition, a separate analysis of muscle activity in a subgroup of 24 of these cashiers with complete EMG data showed a more dynamic and varied (less static) muscle activation pattern of the trapezius muscle during department work, compared with cash register work (Sandsjö et al., 2000). The results indicated that both higher and lower muscle activity levels were more frequent during department work than during cash register work, although only the highest level (90-percentile) was statistically significant. Thus, during department work the cashiers performed work tasks that required a greater physical activity more often compared to cash register work, but also tended to show a higher amount of lower EMG activity. However, the time that the trapezius muscle was at rest (i.e., under a predefined activity level determined individually in each participant) did not differ in a statistically significant way, and large individual differences were observed. Furthermore, significantly decreased muscle activity in the left trapezius muscle was found at follow-up (Study IV), and observations of work postures during department work showed that they mainly consisted of standing and walking, and that the former cashiers only rarely performed sedentary work tasks (Study IV). This was reflected in a markedly increased output of norepinephrine at follow-up (Study IV), which is known to be related to body movements and physical activity (Lundberg, 2000b). Thus, the introduction of job rotation, which combined check-out work (on average 40%) and department work (on average 60%) resulted in a greater variation of postures and body movements, and indicated that the former cashiers were able to break a more static muscle activation pattern associated with cash register work. One may further speculate that department work contributed to improved physical fitness in general, due to the fact that this work consisted mainly of walking and standing and only in exceptional cases was sedentary. This could be a possible reason for the significantly lower diastolic blood pressure seen at follow-up. Furthermore, it may also have had a positive effect on the musculoskeletal system to some extent, which is suggested by other studies that have found a positive effect from physical activity and exercise (Mattila, Malmivaara, Kastarinen, Kivelä & Nissinen, 2004; Miranda et al., 2001). However, since no measures focused directly on general fitness, this interpretation must be made with caution.

There is a common assumption that a greater variation in postures and movements during work is positive for musculoskeletal health (Aarås, 1994; Kilbom, 1994 b; Möller et al., 2004). A slight positive effect on pain was also seen at follow-up among the cashiers, since significantly more women

reported less pain, or the same amount of pain, as compared with the number who became worse (Study IV). However, the prevalence of pain in the neck and shoulders among the supermarket employees (70%) had not changed at follow-up and the intensity of pain rated during a period of seven days did not change significantly either (Study IV). Thus, the chronic character of musculoskeletal pain seems to be reflected in these findings. However, several years had passed between the two occasions. Thus, even a lack of increase in the prevalence of pain can be interpreted as a positive outcome. In the study by Jonsson et al. (1988) among female workers in the electronics industry mentioned in the introduction, there was a statistically significant improvement in neck and shoulder symptoms among those who were reallocated to more varying work tasks, suggesting that improvement is possible through this type of intervention. Comparisons between Study IV and the study by Jonsson et al. (1988) are hampered, however, since the participants in that study had been employed for a considerably shorter time than the cashiers had been. And possibly even more important, that study excluded participants who had been on sick leave or consulted medical expertise due to musculoskeletal pain twelve months prior to baseline. In contrast, seven of ten of the cashiers already had musculoskeletal pain before job rotation was introduced. This points to an important issue, namely that the effect of the introduction of job rotation probably has different impacts on musculoskeletal status depending on when it is introduced. In the study by Jonsson et al. (1988) the participants were in an early stage of their WMSDs, while the female cashiers in Study IV had chronic musculoskeletal problems. Thus, this suggests that job rotation can be a more effective method to counteract WMSDs in the initial stages of these disorders, but is less effective when chronic pain problems have already developed.

An interesting question is how the introduction of job rotation in Study IV affected the employees besides these changes related to muscle activity pattern and pain discussed above. For instance, does cash register work differ in cognitive and emotional workload compared to department work? Since cash register work is characterized by almost constant contact with customers one may speculate, for example, that perceived stress and emotions like irritation and frustration are experienced more often during this work compared to department work. The responsibility to register all items correctly may, additionally, require a higher level of concentration than is required during department work. The separate analysis by Sandsjö et al. (2000), comparing cash register work with department work (cross-sectionally at follow-up), showed that the employees had a significantly higher heart rate during cash register work, possibly supporting the hypothesis of a different cognitive and emotional workload from this type of work. However, no differences between the two work tasks regarding reports of negative (stressed, tense, exhausted) and positive (stimulated, concentrated, happy) stress reactions were found. Furthermore, negative stress ratings did not change significantly at

follow-up. However, positive reactions, including ratings of concentration, were significantly lower at follow-up (Study IV). Taken together, these results do not allow conclusions to be drawn regarding the experience of cash register work compared to department work from a cognitive/emotional perspective. Questionnaire data, however, indicated that some psychosocial factors (work pride, perceived appreciation, ability to plan and influence work) were improved at follow-up, and 81% of the employees were “very satisfied” or “somewhat satisfied” with work (Study IV). Thus, these results suggest positive reactions to the new way of organizing work. However, ratings of perceived general level of stress did not change (in line with the unchanged negative stress ratings mentioned above). This was supported by epinephrine output, reflecting the intensity of stress (Lundberg, 2000b), which also remained unchanged at follow-up (reported in Study II).

In the Introduction, some field studies primarily concerning the effect on musculoskeletal health from reorganizations of work were mentioned. These studies showed that interventions including job rotation or other organizational changes of work have very different outcomes. Theoretically the effects can be positive, negative or neutral. However, divergent results were also found within studies. For example, a reorganization of work including the introduction of new technology (flow-line) in the fish-processing industry resulted in increased symptoms in the upper limbs, but decreased symptoms in the lower limbs (Ólafsdóttir & Rafnsson, 1998). Another study showed that in spite of some ergonomic improvements, musculoskeletal health deteriorated when a poorly implemented reorganization was followed by negative psychosocial experiences (Fredriksson et al., 2001). Generally speaking, the results concerning the introduction of job rotation among the cashiers are in line with these results insofar as some variables being changed in a favorable direction whereas others were unchanged. However, noteworthy is that none of the outcome variables in Study IV was changed in a direction that is interpreted as directly unfavorable. However, one should also remember that while one group of workers may benefit from the introduction of job rotation, another may actually be more exposed to repetitive and monotonous work. For example, the reorganization among supermarket employees (Study IV) implied that those employees formerly only performing department work had to at follow-up mix those work tasks with repetitive cash register work. Besides, reorganizations probably seldom have an improved musculoskeletal health as a primary or sole goal, even though specific interventions can have that aim. Thus, even if musculoskeletal health deteriorates, other goals may be fulfilled. For example, in the study from both the fish-processing industry (Ólafsdóttir & Rafnsson, 1998) and the automobile industry (Fredriksson et al., 2001) mentioned above, production increased and thus, seen from this perspective, these reorganizations were successful. Obviously, however, it is better if both health and production improve simultaneously.

When discussing job rotation as a possible intervention strategy to prevent or reduce WMSDs, it is important not to forget that the multi-factorial etiology of WMSDs makes prevention or reduction of these disorders a complex process. In the literature it is frequently stated that it requires a preventive strategy whereby different aspects of the work environment, such as physical/ergonomic (e.g. repetition, force, and posture), organizational (e.g. job rotation) and psychosocial factors are taken into account simultaneously (e.g. Carayon et al., 1999; Hagberg et al., 1995). This approach is supported by a recent review that concludes that multi-component interventions appear to be most effective in reducing WMSDs (Silverstein & Clark, 2004). A participatory model that engages and actively involves those concerned is also important (Buckle, 2005; Westgaard & Winkel, 1997). Back and neck pain are also clearly related to individual psychological factors related to emotional, cognitive and behavioral domains, even after controlling for confounding factors (Linton, 2000), and in line with this another recommendation is modifier interventions focusing on workers at risk (Westgaard & Winkel, 1997). It has been found, for example, that screening for psychological risk factors and offering cognitive-behavioral interventions can be effective in reducing the risk of work disability due to musculoskeletal disorders (Linton, 2002). Thus, changing different work-related factors (physical, psychosocial, organizational) and simultaneously taking individual factors into consideration may lead to a better outcome. However, considering the fact that women are affected by WMSDs more often than men are, likely as a result of a segregated labor market leading to different exposures for women and men, it seems clear that these measures have to be combined with other measures on a societal level. In addition, gender roles still involve women to a higher degree than men in unpaid work at home, and this can be assumed to contribute to sustained activation of the allostatic systems and engage the muscular system even after paid work has terminated (Melin & Lundberg, 1997). Thus, this is another reason calling for additional counter-acting measures, such as political steps toward equal opportunities for women and men to combine work and family life (Lundberg & Melin, 2002).

12.6 Limitations of the studies and future research

In view of the cross-sectional nature of Studies I-III, causal mechanisms or causal relations between variables could not be established. For example, the different muscle activation pattern (EMG activity pattern) found in participants with pain compared with pain-free fellow-workers in Study III was in line with the pain-adaptation model (Lund et al., 1991) and could thus be interpreted as a protective mechanism subsequent to pain. However, the cross-sectional design does not permit the direction of causality to be estab-

lished. Actually, it could as well be the other way around, that is, pain being a consequence of an altered muscle activation pattern. A longitudinal design is required to give a more valid answer to this question. In addition, the relatively small sample sizes leading to a reduced statistical power may possibly have omitted significant findings between variables and thus limited interpretations. Furthermore, the analyses were based on univariate and bivariate statistics, possibly not discovering more complex relationships among the variables studied. Despite these limitations, the results in Studies I-III are in line with earlier research findings and can hopefully inspire future research.

In Study IV it was not feasible to include a control or reference group of employees; however, the same participants were studied on two occasions according to a repeated measure design, thus serving as controls for themselves as regards different individual variations. This is a weaker design but still has the possibility to provide valuable information, according to Silverstein and Clark (2004). Given the vast number of factors in the natural working environment, however, one cannot rule out the possibility that the results were affected in one way or the other, and thus alternative explanations to some of the findings may exist. For example, the significant decrease in trapezius muscle activity (on the left side) may not be solely a result from the greater variation of postures and body movements associated with the job rotation model *per se*, since the participants at follow-up had the possibility to choose between sitting or standing while performing cash register work (Sandsjö et al., 2000), whereas at the first wave of data collection they were almost exclusively seated at the checkout counters in front of the conveyer belt (Lundberg et al., 1999). It has been found that trapezius muscle activity is lower when cashiers perform their work standing compared to sitting (Lannersten & Harms-Ringdahl, 1990), and these postural changes during cash register work were not registered at follow-up. In addition, before the introduction of job rotation the merchandise on the conveyer belt always came toward the cashier from the right-hand side (Lundberg et al., 1999), while at follow-up this was the case in only about 40% of the participants, with about 60% the merchandise coming from the left-hand side (unpublished data). Thus, these technical/ergonomic changes not included in the job rotation model *per se* may have had an impact on muscle activity at follow-up. However, since only 40% of the work at follow-up consisted of cashier work and 60% consisted of department work, the likely contribution of this factor has to be considered less important compared to the more varied postures and body movements that department work contributed with. However, since it was not controlled for in the analyses it has to be regarded as a possible confounder. Furthermore, factors outside paid work such as family responsibilities, leisure time activities, physical activity, etc., may have changed between the two waves of data collection and possibly influenced the results to some degree. However, it could be argued that such presumed changes would probably not be systematic in a group consisting of 31

participants of different ages, number and age of children at home, marital status, etc., whereas the introduction of job rotation was a systematic and profound change affecting all of these women. However, since these factors were not controlled for this must be acknowledged as another possible source of confounding.

Furthermore, these studies were performed among specific groups of individuals: Young, pain-free, female students in Study I, and female supermarket employees with a high prevalence of chronic musculoskeletal pain in Studies II-IV. In addition, the supermarket employees were older (mean age) compared with the students. Thus, the participants cannot be considered representative of all women performing repetitive and monotonous work, either in a laboratory setting or real work life. Although this influences the external validity of the results, they are likely also of relevance for other groups performing repetitive and monotonous work.

Concerning future research, additional investigations are needed to explore the complex relations between psychophysiological and subjective stress responses, trapezius muscle activity, and neck and shoulder pain. For example, the results concerning the association between negative stress reactions (negative emotions) and muscle (EMG) activity/muscle rest found in Study II have to be confirmed in future studies. These studies would probably benefit from more extensive mood adjective checklists (e.g. Kjellberg, Johansson Hanse, Franzon & Holmberg, 2000; Kjellberg & Wadman, 2002; Stone, 1995). In addition, since the individual differences in response patterns related to muscle activity and muscle rest are often significant, future studies focusing on individual differences in muscular reactivity, for instance investigating temporal stability (in line with cardiovascular stress research, see e.g. Turner, 1994), would be of great interest. Although there is no support of a "pain-prone" personality, different personality factors are evidently associated with back and neck pain (Linton, 2000), and thus individual differences in muscular response patterns could also be investigated from this perspective.

More generally, it is important to continue to explore different effects from repetitive and monotonous work on humans, since these jobs are still common in our society and are associated with a high prevalence of WMSDs and stress responses that may constitute risk factors for ill health. This exploration should focus on not only physiological stress responses during work and after work (i.e. after-effects), but also emotional, cognitive and behavioral effects, in order to encompass a variety of possible consequences induced by these jobs. Since women perform repetitive and monotonous work tasks more often than men do, and are also more often affected by WMSDs in the neck and shoulders, a gender perspective on these issues is required. This should include the total workload of the individual, thus including both paid work and unpaid work/activities. Both acute and long-term effects are of interest, although from a health perspective the latter are of greater impor-

tance and hence, prospective and longitudinal research is preferred in real work-life studies. However, experimental studies testing new hypotheses under well-controlled conditions are needed in combination with real-life studies. In addition, given the enormous cost associated with WMSDs, research on interventions in the workplace is another related area of interest to explore further. For example, today there is a paucity of studies investigating the effect of job rotation on WMSDs in the neck and shoulders, especially using a psychobiological methodology (e.g. Lundberg, 1995) focusing on both muscle pain and the stress process (stressors → individual appraisals/coping → responses). In these studies, the effect of job rotation should be evaluated with respect to physical, psychophysiological and mental/cognitive/emotional variables.

13 CONCLUSIONS

With the limitations mentioned above in mind, the empirical findings in this thesis have contributed to further expand the understanding of the complex relations between psychophysiological stress responses, subjective stress reactions, trapezius muscle activity, and neck and shoulder pain in repetitive and monotonous work performed by women. In addition, the effects of the introduction of job rotation were evaluated among female supermarket cashiers performing highly repetitive and monotonous work, adding new knowledge to a relatively unexplored field of research.

The main findings were as follows:

In Study I a dissociation between HRV and blood pressure variables was found, indicated by an elevated and sustained blood pressure response throughout the experiment (i.e., the control session had no effect on blood pressure variables), whereas the shift from stress session to control session was clearly reflected in HRV variables (parasympathetic component (HF) of HRV and LF/HF ratio). This may indicate that HRV is a more sensitive and selective measure of mental stress compared with blood pressure recordings in light repetitive and monotonous work combined with mental, cognitive, and emotional stressors. Study I also found a significant time trend in exhaustion. However, no other significant change in subjective stress reactions between the stress session and the control session was observed.

Study II showed that a higher degree of perceived negative stress reactions (stressed, tensed, exhausted) during work were associated with higher trapezius muscle activity (surface EMG activity) and a lower amount of trapezius muscle rest. In contrast, no significant correlations were found between positive stress reactions (stimulated, concentrated, happy) and surface EMG activity or muscle rest. This indicates that negative mood reactions during work may have a specific influence on muscle activity in the neck and shoulder region, possibly of importance for musculoskeletal disorders in repetitive and monotonous work.

Study III indicated a different trapezius muscle activation pattern during cash-register work in women reporting pain compared with pain-free women. The pain-afflicted women tended to show a lack of both low and high EMG activity levels (i.e., a more static muscle activity pattern), a lower percentage of muscle rest (significant in the non-dominant side, i.e. the left-

hand side), and an equal amount of muscle rest in both the dominant and the non-dominant side of the trapezius indicating co-contraction (i.e. a bilateral muscle activation). These results are in line with the pain-adaptation model (Lund et al., 1991), although the cross-sectional design does not allow any causal directions to be established between muscle activity pattern and pain. Furthermore, Study III showed that pain-afflicted women were significantly shorter compared with their pain-free fellow workers. This may indicate that ergonomic factors such as workstation design were not optimal for all workers.

Study IV showed that the introduction of job rotation was associated with a greater variation of postures and body movements when cash-register work was combined with department work. This was reflected in significantly elevated norepinephrine levels during work. The reorganization of work was associated with positive health effects, indicated by a significantly lower diastolic blood pressure and a significantly decreased trapezius muscle activity on the left side at follow-up. Moreover, from questionnaires it was suggested that the introduction of job rotation had been experienced as positive in several regards, with 80% of the employees "very satisfied" or "somewhat satisfied" with work at follow-up. However, the perception of stress and hurry were the same at follow-up, and self-reports of negative (stressed, exhausted, tense) stress reactions during work did not change significantly, but were generally low. Neck and shoulder pain was partly changed in a positive direction, but the prevalence of pain (70%) among these women was unchanged at follow-up.

The most important finding in this thesis from a work environment perspective was that the introduction of job rotation indicated positive effects on diastolic blood pressure, trapezius muscle activity, and partly on neck and shoulder pain. However, the perception of stress remained unchanged. As the results indicated that job rotation only had a moderate effect on chronic neck and shoulder pain, this intervention strategy would possibly be more effective as a preventive measure to counteract WMSDs in supermarkets and other similar work environments. However, it is important to note that a variety of factors can influence the outcome, and physical as well as psychosocial factors inducing psychophysiological and subjective stress reactions have to be considered carefully when implementing job rotation. Furthermore, engagement and active involvement of those concerned are also of great significance (Buckle, 2005; Westgaard & Winkel, 1997). In addition, the finding that perceived negative stress reactions during work may have a specific influence on muscle activity and muscle rest in the neck and shoulder region can be of importance for WMSDs in repetitive and monotonous work with negative psychosocial factors, in accordance with current theories of stress and muscle pain. The empirical findings in this thesis are particularly relevant for women who, compared with men, more often perform stressful repetitive and monotonous work tasks, are more often affected by

neck and shoulder pain, and are also more often exposed to a greater total workload due to the combined load from paid and unpaid work.

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