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On the relation between psychosocial work environment and musculoskeletal symptoms

A structural equation modeling approach

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List of Papers

This thesis is based on the following four papers, which will be referred to in the text by their Roman numerals.

I. Byström P, Johansson Hanse J & Kjellberg A (2004) Appraised psychological workload, musculoskeletal symptoms, and the mediating effect of fatigue: A structural equation modeling approach. *Scandinavian Journal of Psychology,* 45, 331–341.

II. Larsman P, Sandsjö L, Klipstein A, Vollenbroek-Hutten M & Christensen H (2006) Perceived work demands, felt stress, and musculoskeletal neck/shoulder symptoms among elderly female computer users. The NEW study. *European Journal of Applied Physiology,* 96, 127–135.

III. Larsman P & Johansson Hanse J. A longitudinal study of the relation between appraised psychological workload, job satisfaction and musculoskeletal neck/shoulder symptoms with general fatigue as a mediating variable. *Submitted for publication.*

IV. Larsman P, Pousette A & Johansson Hanse J. A longitudinal study of appraised psychological workload, mechanical workload and musculoskeletal neck/shoulder symptoms: A structural equation modelling approach. *Submitted for publication.*

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Contents

Introduction

The term “psychosocial work environment” has been widely used in connection with health, and a large number of studies have shown associations between psychosocial factors at work and (ill) health and well-being. Several theoretical approaches in the work stress framework address the issue of the design of healthy work (Kompier, 2003; Le Blanc et al., 2000) such as the job characteristics model of Hackman and Oldham (1980), the Michigan organization stress model (Caplan et al., 1975), the Karasek (1979) job demands – control model, the effort-reward imbalance model (Siegrist, 1996, 1998) and the vitamin model (Warr, 1994). These theoretical approaches differ e.g. in that they emphasize different perspectives of the work environment and hypothesize different roles for personality factors (Kompier, 2005). However, although focusing on different characteristics of the work environment and the worker and their interplay, certain concepts occur as important job features in most of these models. Among these critical job features are job demands, autonomy/job control, skill variety/skill discretion, social support and feedback (Kompier, 2003). Other vital components of these models are workload and stress perceptions.

A vast number of studies show an association between aspects of the psychosocial work environment and adverse health effects in general, including musculoskeletal symptoms. A number of recent reviews have concluded that there is evidence for significant associations between psychosocial factors at work (e.g. high job demands and workload, low job control and lack of social support) and musculoskeletal symptoms (Ariens et al., 2001b; Bongers et al., 1993; Hoogendoorn et al., 2000; NIOSH, 1997). However, the results are somewhat contradictory, evidence for the relation is inconclusive and the role of the psychosocial work environment in the development of these symptoms is not yet clearly understood (see e.g. Warren, 2001).

Musculoskeletal symptoms constitute an important health problem and have become one of the major medical problems in the industrialized world – in spite of the considerable ergonomic improvements that have been made at the workplaces (Johansson, 1994). Melin and Wigaeus Tornqvist (2005) further note that, despite the diminished physical load levels in many occupations, the prevalence of musculoskeletal symptoms has grown over recent decades. The low back, neck and upper extremities are the regions most affected. Sick leave is an important work-related problem, where musculoskeletal disorders constitute a high percentage of sick leave days and sick leave pensions. Musculoskeletal disorders are a common cause of early retirement pensions in Sweden (Vingård & Hagberg, 2001). These disorders impose a substantial economic burden in compensation costs, lost wages and loss of productivity. The financial costs associated with musculoskeletal disorders are high (Buckle & Devereux, 2002; Punnett et al., 2005). In a recent study of trends in work-related musculoskeletal disorder reports (Morse et al., 2005) it is concluded that rates of upper extremity musculoskeletal disorders are not decreasing over time. It is thus important to extend our knowledge of the work-related factors involved in the aetiology of these disorders and the mechanisms by which they operate.

Psychosocial work environment

There is no single agreed upon definition of what constitutes a "psychosocial stressor". The present thesis follows the view of Warren (2001) where psychosocial stressors are defined as "nonphysical aspects of the work environment that have a psychological and physiological impact on the worker" (p. 1299). There is clear evidence of the relation between psychosocial factors at work and health (e.g. Kalimo, 1987; Karasek & Theorell, 1990; Kompier & Cooper, 1999). Sauter and Swanson (1996) illustrated a generic psychosocial stress model (see fig. 1).

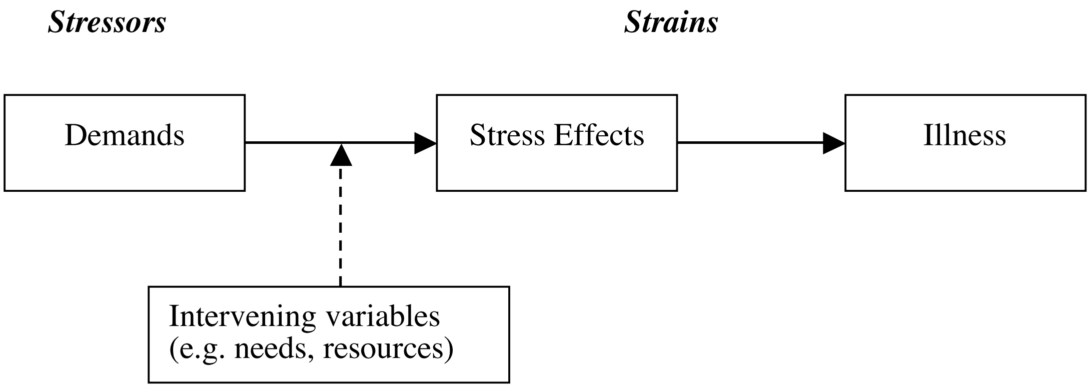

Figure 1. The psychosocial stress model (adapted from Sauter and Swanson, 1996).

This process model gives primacy to work environmental factors, and individual factors are considered intervening variables. The employee is in constant interchange with the work environment. These interactions require continuous adaptation by the employee. When these transactions are perceived as uncontrollable (an assessment process, "cognitive appraisal") (Lazarus, 1991a; Sarafino, 1990), the situation generates a condition of psychological distress that, if persistent or frequent, can lead to negative health outcomes. Cognitive appraisal is inherent as a mediating step in the process between working conditions (stressors) and strains in many influential stress theories. The experience of stress is partly dependent on the persons' abilities to cope with the demands placed on them by their work. Individual characteristics such as coping strategies thus may influence the stress perceptions and the resulting strain. Person-related risk factors for musculoskeletal symptoms have been identified (see e.g. Viikari-Juntura & Riihimäki, 1999; Viikari-Juntura et al., 2001). However, individual characteristics are not included in the present thesis since the primary focus is on the psychosocial work environment and its effects on (ill) health. This focus on the work environment as the main risk factor reflects the view that work should be (re-) designed in order to fit the employees, and not the other way around. Such a view is in accordance with e.g. the ISO standard on mental workload, where mental stress or the factors influencing it are viewed as external to the individual which means that, as far as work design is concerned, it is “the working conditions that have to be tackled, not the individual and his or her perceptions, responses or coping strategies” (Nachreiner & Schulteus, 2003, p.8). Moreover, as regards the relation between the psychosocial work environment and musculoskeletal neck/ shoulder and back symptoms, although many psychosocial risk factors have been suggested in the literature, the present thesis focuses on two such factors, job demands and psychological workload, as these factors are included as important concepts in many theories on work stress and ill health.

Job demands

Job demands, as a perceived work characteristic (stressor perception, Frese & Zapf, 1988), refer to employees’ perceptions of the demands that are imposed upon them by the work and the work environment. Job demands as a critical job feature can be found in almost all of the most prominent theoretical approaches within the work stress framework (Kompier, 2005). Psychological job demands (e.g. “how hard you work”) is one of the key components of the Karasek Job Demand – Control model (Karasek, 1979). In this model the concept of job demands deals with “the psychological stressors involved in accomplishing the work load, stressors related to unexpected tasks, and stressors of job-related personal conflict” (Karasek, 1979, p. 291). These job demands are considered detrimental to health especially when combined with low levels of decision latitude (decision authority and intellectual discretion) (Karasek, 1989). Job demands, as an extrinsic source of high effort, is also an important concept of the effort-reward imbalance model (Siegrist, 1996). In this model a high effort (e.g. high job demands and/or high individual need for control) coupled with low reward (e.g. low status control, low esteem, low salary) is regarded as particularly stressful and detrimental to health. Such a combination of high effort and low reward at work has been found to be associated with a higher prevalence of risk factors for coronary heart disease (Peter et al., 1998) as well as with poor subjective health (Ertel et al., 2005). In the Vitamin model (Warr, 1994) job demands are included in the environmental feature of “externally generated goals”. Externally generated goals (e.g. job demands, task demands, quantitative or qualitative workload, environmental demands, time demands, role responsibility, time pressure, required concentration, conflicting demands, role conflict) are hypothesized to have a non-linear relation to (mental) ill health, such that too high as well as too low levels of externally generated goals may have detrimental health effects (Warr, 1994).

Different operationalizations of job demands are found in the literature using different measurement instruments. Using the Job Content Questionnaire (JCQ) psychological job demands are measured using the items “work fast”, “work hard”, “no excessive work”, “enough time” and “conflicting demands” (Karasek & Theorell, 1990) sometimes also including the items “intense concentration”, "tasks interrupted", "hectic job" and "wait on others" (Karasek et al., 1998). Other instruments for the measurement of job demands include e.g. the Copenhagen Psychosocial Questionnaire (COPSOQ) (Kristensen et al., 2002) which distinguishes between five different dimensions of job demands: quantitative demands (e.g. time pressure, fast work pace), cognitive demands (e.g. having to remember many things, to make quick decisions), sensorial demands (e.g. vision, movements, precision), emotional demands (e.g. emotional involvement), and demands for hiding emotions.

Psychological workload

As regards appraisals of the work situation (stressor appraisal, Frese & Zapf, 1988), the present thesis focuses on psychological workload. The concept of workload is widely used in different research traditions where it is given different connotations. Workload is regarded in some circumstances as an environmental stimulus condition (Koeske & Koeske, 1989) or as a work characteristic (Smith et al., 2001) rather than as an appraisal of a set of work characteristics. In such circumstances it seems that the concept of workload deals with (quantitative and qualitative) aspects of the work *task* rather than with appraisals of the work *situation*. Sometimes the terms "workload" and "job demands" seem to be used interchangeably (Jönsson, 2005; Macdonald, 2003; Spector, 1997), or "workload" is considered a subcategory of job demands (Smith et al., 2001). For example the "recommended version" (Karasek et al., 1998) of the Job Content Questionnaire includes measures of cognitive workload (concentration and mental work disruption) under the category of "psychological demands and mental workload". According to Macdonald (2003) the construct of "mental workload" as used in the domain of human factors psychology refers to the gap between the demands of a task and a person's ability (when motivated) to cope with these demands, and the "workload level is primarily a function of task demands in relation to personal coping capacity" (Macdonald, 2003, p.105). A similar definition is given by Welford (1978) who, in the context of mental workload, propose that "work-load can be expressed as the ratio of demands to average maximum capacity, or as the percentage of capacity to meet demand" (p. 151), i.e. mental workload is regarded as a function of the demands of the task and the capacity of the subject.

Psychological workload as used in the present thesis refers to employee assessments of the total psychological workload imposed upon them by the work and the work environment, which may lead to feelings of work overload, mental pressure and of being pushed at work i.e., an appraisal of the work situation. An optimal workload is regarded in accordance with Rubenowitz (1989) as "neither too heavy, exigent or stressing physically or psychologically, nor too easy, boring or inactive" (Rubenowitz, 1989, p. 6). In the present thesis the psychological workload is considered to result from the individual's perception of the psychosocial work environment in total, including such aspects as the perceived job demands, the perceived control and possibilities for development at work, and the perceived social support provided by colleagues and superiors at work. Supervisor support has been found to be related to workload (Hemingway & Smith, 1999). Pousette and Johansson Hanse (2002) found job autonomy to be negatively associated with psychological workload among elderly- and child-care workers and white-collar (but not blue-collar) workers. In that study skill discretion was negatively associated with psychological workload among blue-collar workers, while this association was positive among white-collar workers (i.e., higher levels of skill discretion were associated with a higher level of psychological workload) and not significant among elderly- and child-care workers. Other studies have found autonomy and control at work to influence the subjective evaluation of quantitative workload among blue-collar workers (Lindström, 1994).

Felt stress

In order to recognize psychosocial aspects of work organization it is important to analyze the concept of stress at work and evaluate the findings of research in relation to health and well-being. There are different theories within the work stress framework dealing with the connection between the psychosocial work environment and ill health. However a basic hypothesis in work stress theory is that psychosocial stressors in the work environment, such as qualitative and quantitative over- and underload, monotonous or repetitive work tasks, lack of control and social support, and the interactions of such conditions, may generate strain. Overload has been shown to be a major associate of work-related strain in various studies (Aronsson, 1989; Levi, 1987; Moorhead & Griffin, 1992; Warr, 1996).

Individual control is recognized as a central concept in the understanding of relations between stressful experiences, behavior and health (Frankenhaeuser, 1991; Johansson, 1991). The influence and control over work is assumed to protect against stress and disease, both *indirectly* because the worker feels that he/she has the situation under control and that the situation tomorrow can be predicted, and *directly* because the worker can control the duration and frequency of the load.

Stress has been defined in a number of ways. Grandjean (1988) e.g. defines occupational stress as a subjective phenomenon that “exists in people’s recognition of their inability to cope with the demands of the work situation” (Grandjean, 1988, p. 176). Three main approaches to stress can be found in the literature (e.g. Le Blanc et al., 2000; Cox et al., 2000; Melin, 1992). The first approach considers stress a stimulus, e.g. an aversive characteristic of the work environment such as a high level of job demands or a low level of job control. The second approach considers stress a behavioral and/or physiological response (e.g. job strain) to a stressor. The third approach considers stress an interaction (“stress as a mediational process”, Le Blanc et al., 2000) between the individual and his/her work environment, or a function of the incompatibility between individual and environment.

Lazarus (1991b) describes a transactional approach to stress. This approach emphasizes that two conditions must be fulfilled for a relation between an individual and his/her work environment to be stressful. The individual must feel that the outcome is of personal importance and that the demands (external and/or internal) tax or exceed his/her resources. Thus:

> "Stress is not a property of the person, or of the environment, but arises when there is a conjunction between a particular kind of person that leads to a threat appraisal" (Lazarus, 1991b, p. 3).

There are numerous reviews of research on stress and several general models of occupational stress have emerged that define work stress and explain how certain aspects of work can contribute to the experience of stress. In this approach the psychological aspects of the stress process are taken into account and the process is seen as an interplay between the person and the environment. These models typically propose the existence of a set of stressors, which are generally defined as environmental demands, and responses to these stressors, often referred to as strains (Sarafino, 1990).

Each individual's reaction to a psychosocial work environment stressor (as well as other stressors) thus depends on his/her appraisal of the demands of the situation and the coping resources that are available to him/her. Because a stressor such as job demands may elicit different threat appraisals and therefore different reactions in different individuals and in different situations it is valuable also to include some measure of the stress level of each individual when investigating the relation between the psychosocial work environment and musculoskeletal (as well as other) ill health. Objective measures of physiological stress reactions commonly used in workplace settings include heart rate, blood pressure and urinary catecholamines (adrenaline and noradrenaline) and cortisol (e.g. Lundberg et al., 1989; Lundberg, 2002; Melin, 1992). In regarding stress as a psychological state resulting from the interplay between an individual and his/her work environment, the measurement of this state (mood, emotion) is of central importance (Kjellberg & Wadman, 2002). In such circumstances subjective self-reports of (felt/perceived) stress are commonly used. Aspects of the psychosocial work environment that have been found to be related to such self-reports of stress include psychological demands and lack of control (e.g. Frankenhaeuser, 1991; Kjellberg et al., 2000; Kjellberg & Wadman, 2002; Melin & Lundberg, 1997).

In general, psychophysiological (catecholamine and cortisol secretion) stress responses and self-reports (e.g. distress and effort) of stress seem to be closely related (Frankenhaeuser & Johansson, 1986; Lundberg et al., 1989). However, Kang et al. (2003), in their study of subjective stress, urinary catecholamine concentration, PC game room use and musculoskeletal upper limb symptoms, found subjective stress to be related to neck and shoulder symptoms, a finding that according to the authors may be due to psychological stress increasing the static load of the neck and shoulder girdle muscles. In their study, however, urinary catecholamine was related to neither subjective stress nor musculoskeletal symptoms, a finding which Kang et al. (2003) argue suggests perceived stress to be a more important determinant of musculoskeletal upper extremity disorders than is the level of sympathetic nervous activity. These results further underline the importance of including self-reports of the level of felt stress in studies investigating e.g. the effects of work-related stressors on musculoskeletal symptoms.

Although the present thesis distinguishes between psychological workload, as an appraisal of the work situation, and felt stress, as the resulting mood/feeling induced by this appraisal, it must be acknowledged that some overlap exists between these two concepts. This overlap is clearly shown in their respective conceptualizations; for example, two of the items used in the present thesis to measure psychological workload, "pushed with work" and "mental pressure" (Rubenowitz, 1989), are in content fairly close to two of the items used to measure felt stress, "stressed" and "pressed" (Kjellberg & Iwanowski, 1989).

The present thesis takes the perspective that a number of psychosocial (as well as other) stressors in (and outside of) the work environment may lead to individuals' feelings of stress, which may lead to harmful stress effects, which may, in turn, lead to an increased risk of developing musculoskeletal symptoms. It is important to note, however, that short-term stress reactions (a rise in stress hormones, increased muscle tension) often are beneficial and seldom health threatening. It is a long-term high arousal that may have health detrimental effects (Frankenhaeuser, 1991).

Job satisfaction

There are many definitions and theories of job satisfaction (Judge & Church, 2000; Spector, 1997). Locke (1976) defines job satisfaction as "a pleasurable or positive emotional state resulting from the appraisal of one's job or job experiences" (p.1300), thus consisting of both affective and cognitive components (Judge & Church, 2000). Spector (1997) defines job satisfaction as an attitudinal variable and states that:

> "Job satisfaction is simply how people feel about their jobs and different aspects of their jobs. It is the extent to which people like (satisfaction) or dislike (dissatisfaction) their jobs" (Spector, 1997, p. 2).

The value-percept theory (Locke, 1976) focuses on what people desire or consider important (values) and what is received. Job satisfaction in this theory thus depends on the discrepancy between what is desired and what is received and how important that particular facet of the job is to the individual. According to the Job characteristics model (Hackman & Oldham, 1975, 1976) certain core job characteristics induce psychological states that in turn lead to outcomes such as (general) job satisfaction. These core characteristics are skill variety (the utilization of different skills in performing a job), task identity (the performance of an entire job as opposed to the performance of isolated pieces of a job), task significance (work is seen as important), autonomy (freedom in performing work), and feedback (information about effectiveness of performance). These core characteristics may lead to employee feelings of meaningfulness of work (skill variety, task identity and task significance), feelings of responsibility (autonomy) and knowledge of results (feedback). These psychological states may, in turn, influence employee job satisfaction, job performance, motivation and turnover. It has also been noted that individual characteristics (personality traits) seem to be related to job satisfaction (Judge & Church, 2000; Spector, 1997). This has led to a dispositional approach to job satisfaction (Staw & Ross, 1985) that has e.g. found job satisfaction to be fairly stable over time, even when jobs change. Among the personality factors suggested to be related to job satisfaction are core self-evaluations, comprising self-esteem, self-efficacy, internal locus of control and low neuroticism (Judge et al., 1998). Personality factors may influence job satisfaction both directly and indirectly, e.g. through their effects on the perceptions of work characteristics (Judge et al., 1998) and through selection (self-selection as well as selection by the organization) mechanisms (Dormann & Zapf, 2001). Research support exists for all of these theories/approaches to job satisfaction, and it should be noted that they are not mutually exclusive but rather compatible approaches with somewhat different foci (see Judge & Church, 2000).

In the present thesis, job satisfaction refers to the degree to which employees are satisfied with their job, e.g. positive feelings towards work, enjoy working for the organization/company and general task satisfaction, and is considered to result from the individual's perception of the psychosocial work environment in total, including such aspects as the perceived job demands, the perceived control and possibilities for development at work, and the perceived social support provided by colleagues and superiors at work.

There are many different, multiple- as well as single-item, instruments that are designed for the measurement of job satisfaction focusing on overall job satisfaction and/or different facets of job satisfaction. Two of the most widely used instruments are the Job Descriptive Index (JDI) (Smith et al., 1969), which measures satisfaction with pay, promotion, co-workers, supervision and work itself, and the Minnesota Satisfaction Questionnaire (MSQ) (Weiss et al., 1967), which covers 20 different facets of job satisfaction that can be divided into intrinsic (the nature of the work itself, such as independence, variety, authority and ability utilization) and extrinsic (e.g. compensation, recognition) satisfaction.

Although not consistently, such aspects of the psychosocial work environment as job demands (de Croon et al., 2002; de Jonge et al., 2001; Petterson et al., 1995), job autonomy/control (Agho et al., 1993; Fried, 1991; Landeweerd & Boumans, 1994; Pousette & Johansson Hanse, 2002), skill discretion (Fried, 1991; Pousette & Johansson Hanse, 2002), social support (Amick & Celentano, 1991; de Jonge et al., 2001; Tharenou, 1993) and role ambiguity (Glisson & Durick, 1988; Karsh et al., 2005) have been found to be related to job satisfaction. Furthermore, psychological workload and job satisfaction are thought to co-vary such that optimal levels of workload co-vary with job satisfaction (and similarly, too high or too low levels of workload are associated with job dissatisfaction). This assumption is (partly) supported by e.g. Pousette and Johansson Hanse (2002), who found a negative association between psychological workload and job satisfaction among white-collar workers as well as elderly- and child-care workers, but not among blue-collar workers.

Perceived fatigue

Feelings of fatigue are common in the general (Lewis & Wessely, 1992) as well as in the working (Bültmann et al., 2002c) population and constitute an important problem. A recent large-scale study among European employees show overall fatigue to be the third most common work-related health problem, with 23 per cent of the respondents reporting such problems (Merllié & Paoli, 2001). Feelings of fatigue have been shown to be a strong predictor of future sick leave (Janssen et al., 2003) and future disability pension (van Amelsvoort et al., 2002). It is therefore important to understand the (work-related) causes of fatigue as well as the underlying mechanisms in order to be able to prevent and/or reduce these symptoms. A factor that makes the understanding of these processes (more) difficult is that, although the concept of fatigue has been extensively used in research, there is no single agreed upon definition, and hence no single conceptualization or measurement method.

A number of different definitions of fatigue have been proposed, e.g. by Cameron (1973), who regards fatigue as a generalized response to stress over a period of time, and by Grandjean (1970, 1988), who views muscular fatigue as reduced performance of a muscle after stress and proposes a neurophysiological model of general fatigue, which he considers a state of the central nervous system controlled by the activity of the activating and the inhibitory system of the brain stem. It has been concluded that fatigue is a complex term that involves many dimensions (Bass & Barrett, 1972) and that is probably best viewed as a continuum (Lewis & Wessely, 1992). Research has focused on different types of fatigue such as physical fatigue, mental fatigue and sleepiness, and also usually distinguishes between acute ("normal") and chronic fatigue. For example, Grandjean (1988) makes a distinction between muscular fatigue and general fatigue with the latter being further divided into visual fatigue, general bodily fatigue, mental fatigue, monotony, chronic fatigue and circadian or nyctemeral fatigue. In a recent survey of the scientific knowledge compiled by the Swedish council for working life and social research (FAS) and directed at the general public it is suggested that a generally accepted meaning of fatigue is that it describes a signal that the ongoing activity should be ended because problems or injuries are about to develop (Åkerstedt, 2004).

Different aspects of fatigue have been investigated using a multitude of measures, both physiological and self-reports. Physiological measures often used to study fatigue include electromyography (EMG) for the measurement of muscle fatigue (e.g. Chan et al., 2000; Palmerud et al., 2002; Sundelin, 1993) and electroencephalogram (EEG) for the measurement of mental fatigue (e.g. Okogbaa et al., 1994). Perceived, self-reported fatigue has been measured using unidimensional measures such as rated perceived exertion (RPE) (Borg, 1970), CR10 (Borg, 1998), the Fatigue Assessment Scale (FAS) (Michielsen et al., 2003) and single items e.g. "tired in the head" (Åkerstedt et al., 2004) and "often felt tired during the last two weeks" (Åkerstedt et al., 2002) as well as by using multi-dimensional questionnaires such as the Checklist Individual Strength (CIS) questionnaire

(Beurskens et al., 2000), the Schedule of Fatigue and Anergia (SOFA) (Hadzi-Pavlovic et al., 2000), the vitality scale of the SF-36 (Ware & Gandek, 1998) and the Swedish Occupational Fatigue Inventory (SOFI) (Åhsberg, 2000), the latter of which was specifically constructed for the measurement of work-related fatigue.

Psychosocial work environment and perceived fatigue

Despite the multitude of different conceptualizations and definitions, and hence also measurement instruments, of fatigue there is substantial research evidence for a relation between psychosocial work environment and fatigue. Janssen and Nijhuis (2004) found an association between positive changes (at a 1-year interval) in perceived work characteristics (i.e. an increase in social support, an increase in decision latitude, and decreased psychological demands) and a decrease in fatigue. *Job demands* (Åhsberg, 2000; Åkerstedt et al., 2004; Hardy et al., 1997; van Yperen & Hagedoorn, 2003; van Yperen & Janssen, 2002) or dimensions thereof such as psychological demands (Bültmann et al., 2002a, b; Pelfrene et al., 2002; Schreurs & Taris, 1998), emotional demands (Bültmann et al., 2002a, b), supervisor demands (De Croon et al., 2002) and hectic work (Åkerstedt et al., 2002) have consistently been related to fatigue. There is also fairly strong evidence for a relation between *workload* and fatigue (de Croon et al., 2002; Michielsen et al., 2004). Inconsistent results are reported for the relation between dimensions of *job control* (e.g. "decision latitude", "decision authority", "skill use", "autonomy and control") and fatigue, such that some studies support such a relation (Åhsberg, 2000; Bültmann et al., 2002a, b; de Croon et al., 2002; Pelfrene et al., 2002) while other studies do not (Åkerstedt et al., 2004; Bültmann et al., 2002a; Hardy et al., 1997). Inconsistent results are also reported for the relation between dimensions of *social support* (e.g. "supervisor support", "co-worker support") and fatigue. Social support was found to be associated with fatigue in the studies by Bültmann et al. (2002b), Pelfrene et al. (2002) and Åkerstedt et al. (2004), while Hardy et al. (1997) did not find social support to be associated with fatigue and Michielsen et al. (2004) did not find social support at baseline to be related to follow-up fatigue.

Bültmann et al. (2002b) also tested the combined effects of job demands and decision latitude according to the job demand-control model of Karasek (1979). They found that people in high strain jobs (a combination of high job demands and low decision latitude) as well as in passive jobs (low job demands and low decision latitude) had higher risks for fatigue than people in low strain jobs (low job demands and high decision latitude), further indicating the detrimental health effects of both high job demands and low decision latitude. This study (Bültmann et al., 2002b) also found elevated risks for fatigue among people working in active jobs (high job demands in combination with high decision latitude) as compared to those working in low strain jobs, illustrating the detrimental health effects of work stress, whether this stress be considered "negative" or "positive". Van Yperen and Hagedoorn (2003) found that the association between (quantitative) job demands and fatigue was stronger when job control was low than when job control was high. The potential interaction effects between job demands and skill discretion and job demands and decision authority on fatigue were also addressed by Schreurs and Taris (1998): however this study did not find any evidence of such interaction effects.

Musculoskeletal symptoms

Musculoskeletal disorders have been defined as "disorders of the soft tissues and their surrounding structures not resulting from an acute or instantaneous event (e.g., slips or falls)" (Hales & Bernard, 1996, p. 679) or as "injuries and illnesses of the muscles, tendons, ligaments, joints, nerves, vessels and supporting structures that are involved in locomotion" (Silverstein, 2001, p. 1621). Musculoskeletal disorders are considered work-related when the work environment and the performance of work contribute significantly to their causation (WHO, 1985). The focus of the present thesis is musculoskeletal *symptoms*, which are considered to be (self-reported) feelings of ache, pain or discomfort (Kuorinka et al., 1987) in these body parts, whether there exists a disorder or not, i.e. what is measured is the subjective awareness of bodily disorder (Theorell & Vogel, 2003). Moreover, all symptoms, not only those that could be considered work-related, are included. This is because it may be difficult for employees to assess the work-relatedness of their symptoms, and because the psychosocial work environment may not only cause the onset of such symptoms, but may also aggravate or impede the recovery from symptoms not of a work-related origin.

Musculoskeletal symptoms are often assessed using questionnaires and/or clinical examinations. In general, one reason for using self-reports is that such reports are easy to manage and are cheap to collect, especially if large groups of workers are studied. One of the most often used questionnaires is the Nordic Musculoskeletal Questionnaire (NMQ) developed by Kuorinka and co-workers (Kuorinka et al., 1987). The use of self-reports of musculoskeletal symptoms is supported by e.g. Ohlsson et al., (1994a) who, in a study of the assessment of neck and upper extremity disorders by questionnaire and clinical examination, found that self-reports of symptoms, measured with the NMQ (Kuorinka et al., 1987), gave a fairly good picture of the neck and upper extremity status of a working female population. However, the 12-month period prevalence used in the NMQ has been discussed in the literature, and claims for a three-month period prevalence have been made in order to reduce the risk of memory bias (Björkstén et al., 1999; Brulin, 1998, Örhede, 1994). In a recent study regarding musculoskeletal pain assessment in a workplace setting, a retrospective period of three months was used. The results indicate that subjects are able to recall and rate the severity of pain/discomfort for a period of three months (Brauer et al., 2003). Self-reports of symptoms have been found both to overestimate (Nordander et al., 1999) and to underestimate (Hagberg et al., 1989) the prevalence and the associated risks as compared to clinical examinations. Juul-Kristensen et al. (2006), in a study of elderly female computer users, found a fairly good agreement between self-reported neck/shoulder symptoms and clinical diagnoses in that 60 per cent of those subjects reporting symptoms (ache/pain/discomfort) for at least 30 days during the previous 12 months also had clinical diagnoses (most commonly trapezius myalgia, tension neck syndrome and cervicalgia), while only 7 per cent of the subjects without self-reported symptoms showed such clinical diagnoses. In that study it was also found that tests of physical function differed between self-reported cases and non-cases, and the authors argue that tests of physical function be included in investigations of musculoskeletal health (Juul-Kristensen et al., 2006). It is thus important to note that, although clinical investigations of musculoskeletal health, considered an "objective" measure, often are treated as the gold standard against which self-reports of symptoms should be compared, it may be the case that self-reports contain the most accurate and adequate information and that clinical examinations are not sensitive enough to detect these symptoms. In summary it appears that subjective reports (questionnaires) give a fairly good picture of clinically assessed disorders (Björkstén et al., 1999; Ohlsson et al., 1989).

Job demands, psychological workload, job satisfaction, felt stress, perceived fatigue and musculoskeletal neck/shoulder and back symptoms

It should be clear from the above discussion of job demands, psychological workload, felt stress, job satisfaction, fatigue and musculoskeletal symptoms that there are no general agreed upon definitions, conceptualizations and measurements of the respective constructs. Thus "job demands/workload/stress/ satisfaction/fatigue/symptoms" in one study does not necessarily refer to the same concept as "job demands/workload/stress/satisfaction/fatigue/symptoms" in another study, which must be remembered when studies are combined in order to investigate research support for e.g. hypotheses regarding the relation between aspects of the psychosocial work environment and (ill) health.

There are several theoretical or conceptual models dealing with the association between psychosocial work environment and musculoskeletal symptoms (see e.g. Faucett, 2005) and several psychosocial pathways to musculoskeletal disorders have been presented. The NIOSH (1997) review discusses four different general pathways: the psychosocial work environment may lead to an increased muscle tension, the psychosocial work environment may lead to an increased awareness and reporting of symptoms, pain initially caused by physical load may lead to a dysfunction in the nervous system (physiological and psychological) that perpetuates a chronic pain process, and psychosocial stressors may vary as a result of variation in physical stressors.

A number of nonspecific biobehavioral mechanisms have been hypothesized to explain how stress may affect the physiological processes involved in common musculoskeletal disorders (e.g. Bongers et al., 1993; Melin & Lundberg, 1997). Sjøgaard et al. (2000) presented a model of the inter-relation between various mechanisms that may be involved in the development of musculoskeletal disorders, where the stressor high mental load is hypothesised to affect muscle fatigue and pain perception. These efforts have not identified specific pathways linking work stress to back or upper extremity pain. Nevertheless, they do provide general ideas that offer a preliminary framework for identifying such pathways.

Although not consistently, job demands have been found to be related to musculoskeletal neck/shoulder and back symptoms in a number of studies. Ariens et al. (2001a), in a prospective study in a mixed occupational population, found high quantitative job demands to be related to neck pain, Holness et al. (1998) in a study of workers handling paper currency found psychological job demands to be the key predictive factor for upper extremity symptoms, Polanyi et al. (1997) in a study among newspaper employees found psychological demands to be related to upper limb (including neck and shoulder) symptoms, Hagen et al. (1998) in a study in the forestry industry found high psychological demands to be related to both neck/shoulder and low back pain, and Jensen et al. (2002) found high quantitative job demands to be related to neck symptoms among computer users. Not only too high but also too low job demands are thought to influence musculoskeletal symptoms (Melin & Lundberg, 1997).

Psychological workload, as measured using the same instrument (although not identical versions) as in the present thesis, has in many studies been found a particularly important risk indicator for musculoskeletal symptoms in relation to other aspects of the work environment (e.g. Engström et al. 1999; Johansson et al., 1993; Johansson, 1995; Ohlsson et al., 1994b; Rundcrantz et al., 1991). In a review of the epidemiologic literature on psychosocial work factors and musculoskeletal symptoms, Bongers et al. (1993) found that, among others, a high perceived workload was related to musculoskeletal symptoms. In another review (NIOSH, 1997) it was concluded that an intensified workload was consistently associated with neck/shoulder musculoskeletal symptoms.

A recent meta-analysis (Faragher et al., 2005) of the relation between job satisfaction and health found a small correlation between job satisfaction and musculoskeletal symptoms, not distinguishing between different symptom locations. In the NIOSH (1997) review of the epidemiologic evidence for work-related musculoskeletal disorders it was concluded that job (dis)satisfaction was positively associated with low back symptoms and appeared to be positively associated with neck/shoulder musculoskeletal symptoms, although the data were not consistent across studies. Hoogendoorn et al. (2000) found strong evidence for low job satisfaction as a risk factor for back pain. Ariens et al. (2001b) concluded that there was some support for low job satisfaction as a risk factor for neck pain and van der Windt et al. (2000) concluded that results were not consistent across studies for job dissatisfaction as a risk factor for shoulder pain. Davis and Heaney (2000) found (some) support for a relation between job dissatisfaction and low back pain. Similarly, Burdorf and Sorock (1997) in their review study on positive and negative evidence of risk factors for back symptoms found some evidence for job dissatisfaction as a risk factor, but concluded that evidence was not consistent across different studies and study designs.

A possible pathway by which aspects of the psychosocial work environment (such as job demands and psychological workload) may influence musculoskeletal symptoms is through an increase in felt stress (e.g. Bongers et al., 1993; Sauter & Swanson, 1996). Davis and Heaney (2000) concluded in a review of studies on the relation between psychosocial work characteristics and low back pain that the employee reactions, such as e.g. work stress, to these work characteristics were more consistently related to symptoms than were the work characteristics themselves. Linton (2000) concluded in a review of psychological risk factors in back and neck pain that stress, distress or anxiety, as well as mood and emotions, cognitive functioning and pain behavior, were found to be significant risk factors for back and neck pain. In a more recent review Bongers et al. (2002) found that a high perceived work stress was consistently associated with upper extremity symptoms. A number of cross sectional studies have shown self-reported stress to be associated with musculoskeletal neck, shoulder and back symptoms (e.g. Bru et al., 1997; Zetterberg et al., 1997). Recent longitudinal studies confirm these findings, suggesting a causal relation between subjective stress and musculoskeletal symptoms. Miranda et al. (2001) found mental stress at baseline to be related to the incidence of shoulder pain at follow up. However, mental stress was not related to shoulder pain when looking at severe persistent pain over the measurements, perhaps indicating that felt stress might be a crucial factor for the development/onset of musculoskeletal symptoms but less important for the maintenance of severe pain, where other factors are probably more influential. Nahit et al. (2003) found stressful work to be related to low back and shoulder pain when comparing stressful work either or both years as compared to neither year. In this study stressful work was also related to common pain (including low back, shoulder, knee, and forearm pain). Viikari-Juntura et al. (2001) found mental stress to be related to radiating neck pain. Contradictory results exist, however. For example, in a community-based four-year prospective study by Eriksen et al. (1999), psychologically stressful work at baseline was not related to incident or persistent neck pain. Kang et al. (2003) found felt stress to be (cross sectionally) related to neck and shoulder symptoms but not to other upper limb symptoms i.e. elbow, wrist and finger symptoms. These results agree with previous research (e.g. Hales et al., 1994) that has found neck and shoulder muscles to be more sensitive to mental stress than are muscles in the more peripheral body regions.

The biopsychosocial approach (Frankenhaeuser, 1986, 1991) to work stress is based on the notion that

> "neuroendocrine responses to the psychosocial work environment reflect its emotional impact on the individual. The emotional impact, in turn, is determined by the person's cognitive appraisal of the severity of the demands in relation to his or her own coping resources" (Frankenhaeuser, 1986, p. 101).

Melin and Lundberg (1997), in extending this approach, propose a model of the relation between mental and physical stressors during paid and unpaid (e.g. domestic) work and musculoskeletal symptoms, where (unsatisfying) psychosocial factors in and outside the workplace lead to increased psychological stress, which increases the risk for musculoskeletal disorders through an increase in muscle activity and secretion of cortisol and catecholamines. In this model, work stress (physical or psychological) is defined as any task or situational demand that creates a condition of over- or under-stimulation. Research shows mental stress to induce muscle tension (Lundberg, 2002; McLean & Urquhart, 2002), e.g. Lundberg et al. (1999) found an association between work stress, muscle tension and musculoskeletal symptoms among female cashiers. This model also specifies lack of unwinding after work as an important mechanism in the relation between mental demands, physical load and musculoskeletal problems (Frankenhaeuser, 1991; Melin & Lundberg, 1997) in that the speed of unwinding will influence the total load on the organism (Frankenhaeuser, 1986). Psychosocial factors may inhibit the shutting off of the physiological activation during work breaks and after work, thus reducing restitution and contributing to sustained muscle activity (Sjøgaard et al., 2000).

Psychosocial stressors have not only been found to cause increased (and sustained) muscle activation (e.g. Westgaard, 1999) but also to reduce the frequency of EMG gaps (e.g. McLean & Urquhart, 2002; Warren, 2001). Such a lack of muscular rest has been shown to be associated with musculoskeletal symptoms (e.g. Hägg & Åström, 1997; Sandsjö et al., 2000; Thorn et al., cond. accepted; Veiersted et al., 1993), although contradictory results exist (Nordander et al., 2000; Vasseljen & Westgaard, 1995).

One possible explanation of how felt stress could contribute to musculoskeletal symptoms can be found in the "Cinderella" hypothesis (Hägg, 1991) saying that the motor units first recruited stay active as long as the muscle is activated. In the case of stress-related muscle activity, these motor units would be engaged as long as the stressful condition is at hand. This way, stress induced muscle activity (Lundberg et al., 1994, 2002) could lead to musculoskeletal symptoms as the first recruited motor units – the Cinderella units – get overused and damaged, which might lead to the perception of pain. Stress perceptions are also important in that the resulting activation may prevent repair of already damaged muscle fibers (Lundberg, 2002). Other alternative and/or complementary mechanisms have been proposed. Research has e.g. shown a relation between work stress and blood pressure, and it has been suggested that increased blood pressure may cause reduced blood flow to the extremities, which may lead to tissue damage (Carayon et al., 2001). Muscle tension may also cause such a high intramuscular pressure that blood circulation is hampered, similarly leading to tissue damage (Järvholm et al., 1988). Schleifer et al. (2002) focus on stress induced hyperventilation that leads to reduced levels of CO_2 in the blood which, in turn, may have adverse effects on musculoskeletal health, such as e.g. elevated muscle tension. These models and other proposed pathomechanisms of muscle pain in light manual work (such as e.g. computer work) are discussed by Thorn (2005).

There may also be a behavioral mechanism between work related stress and musculoskeletal symptoms such that feelings of stress lead to the use of improper work methods and forceful working techniques (Carayon et al., 2001). Feuerstein (1996) propose a model of work style, "how the individual worker approaches work" (Feuerstein, 1996, p. 177), that focuses on employee responses to psychosocial work factors; among these being behavioral responses such as increased force and poor work postures, which may contribute to the development, exacerbation and maintenance of work-related musculoskeletal symptoms (Nicholas et al., 2005).

Another potential link between the psychosocial work environment and musculoskeletal symptoms is (work related) fatigue. A number of mechanisms have been proposed to explain a relation between (muscular) fatigue and musculoskeletal symptoms. Muscular fatigue is characterized by reduced power and slower movement and is accompanied by impaired coordination and increased liability to accidents (Grandjean, 1988). The differential fatigue theory (Kumar, 2001) suggests that muscular fatigue, i.e. localized muscle fatigue as measured by EMG, is an important component in the development of musculoskeletal injuries. Fatigue may lead to altered muscle kinetics, which may lead to muscle injuries. The cumulative load theory (Kumar, 2001) suggests that cumulative fatigue may lead to a reduced capacity for stress, which may reduce the threshold stress at which the muscle tissue fails. Björklund et al. (2000) suggest that (self-reported) fatigue leads to a reduced position sense acuity, which may lead to musculoskeletal disorders through disturbed motor control.

Mechanical workload and musculoskeletal neck/shoulder and back symptoms

The role of potential physical stressors (e.g. mechanical workload) in the development of musculoskeletal symptoms has been discussed in several review papers (Burdorf & Sorock, 1997; Morken, 2003; NIOSH, 1997; Winkel & Westgaard, 1992). Heavy physical work, heavy or frequent manual lifting and repeated rotation of the trunk are likely to be risk indicators for musculoskeletal symptoms. Among the suggested physical risk indicators for neck and shoulder symptoms are repetitive work with the arms/hands and extreme or static work postures such as long exposure to work with the arms raised above shoulder level, flexion of the neck, and static contractions (NIOSH, 1997). The overall effect of the work environment on musculoskeletal health no doubt contains both psychosocial and physical dimensions. Psychosocial factors may interact with physical (mechanical) load (Devereux et al., 2002). In several review articles possible pathways between psychosocial factors at work, physical load, and musculoskeletal symptoms have been proposed (e.g. Bongers et al., 1993), and it has been suggested that, for example, stress at work may increase the effect of the physical workload (Melin & Lundberg, 1997) and that the association between monotonous work and neck or shoulder complaints may be influenced by the psychosocial work environment (Winkel & Westgaard, 1992). Linton (1990) found that a combination of exposure to both psychosocial factors (i.e. work content, social support and workload) and ergonomic factors (e.g. monotonous work and uncomfortable posture) produced higher risk estimates than either of these factors alone.

In some cases, psychosocial stressors seem to co-vary with physical stressors. Previous research is contradictory. Using a principal component analysis Johansson (1995) reported a two-factor solution in which psychosocial factors (job control, psychological work load, social support) and physical load (lifting, awkward postures) showed low co-variation. In contrast, Johansson and Nonås (1994) found significant correlations between repetitive movements and psychosocial stressors (low job control, poor social support), and MacDonald et al. (2001) reported a factor analysis that showed shared variance between some physical and psychosocial stressors. Warren (2001) argues that this link between psychosocial and physical stressors makes it difficult to estimate their associations with (ill) health separately. Multivariable methods containing both psychosocial and physical stressors as well as their interaction terms are recommended (Punnett, 2004).

Processes of mediation and moderation

Generally speaking, overall effects of the work environment on health are underpinned by complex associations between physical and psychosocial stressors by means of direct, indirect and moderation effects (Cox & Ferguson, 1994). It is important to make a conceptual distinction between processes of *mediation* and processes of *moderation* in the psychosocial work environment and health relation. Cox and Ferguson (1994) define the different processes as:

> "A *mediator* variable is one that is responsible for the transmission of an effect, but does not alter the nature of that effect /---/ On the other hand, a *moderator* variable is one whose presence or level alters the direction or strength of the relationship between two other variables /---/ mediator variables, such as appraisal or stress, offer some explanation of *how* the work environment exerts an effect on health /---/ while moderator variables specify *when* certain health effects may or may not occur" (Cox & Ferguson, 1994, p. 101).

Frazier et al. (2004) state the moderator/mediator questions somewhat differently in the context of counselling psychology namely that:

> "Whereas moderators address 'when' or 'for whom' a predictor is more strongly related to an outcome, mediators establish 'how' or 'why' one variable predicts or causes an outcome variable" (Frazier et al., 2004, p. 116).

A variable functions as a mediator to the extent that it accounts for the relation between the independent and dependent variables (Baron & Kenny, 1986). Mediation can either be complete or partial. A relation is completely mediated if, when in the presence of the mediator, the independent variable is not significantly associated with the dependent variable, and partially mediated if, when in the presence of the mediator, the path from the independent variable to the dependent variable is reduced in size but still significant. In other words, complete mediation means that all of the effect an independent variable has on a dependent variable can be attributed to the mediating variable, i.e. when the effect transmitted through the mediating variable is taken into account, no effect of the independent variable on the dependent variable remains. Partial mediation means that some, but not all, of the effect of the independent variable on the dependent variable can be attributed to the mediating variable, i.e., over and above the effect transmitted through the mediator, the independent variable also has a direct effect on the dependent variable. This effect could either constitute a direct effect of the independent variable on the dependent variable, or an effect mediated by some other variable not included in the analysis.

A variable functions as a moderator to the extent that it affects the relation (direction and/or strength) between an independent and a dependent variable (Baron & Kenny, 1986). In the literature the terms moderator effect and interaction effect are often used interchangeably (as is also done in the present thesis). Jaccard and Wan (1996) note that the distinction between these terms lies on the theoretical level. The term "moderator" effect implies an asymmetric interaction effect (Jaccard & Wan, 1996). When discussing moderator effects the focus is thus on the relation between an independent and a dependent variable which is somehow influenced by a third independent variable called a moderator. However, this is a theoretical distinction since it is not (statistically) possible to determine which of the independent variables involved in the moderator effect acts as the moderator variable. Thus:

> "a moderator effect is nothing more than an interaction whereby the effect of one variable depends on the level of another" (Frazier et al., 2004, p. 116).

Testing for mediation

There are different ways to test for mediation. MacKinnon et al. (2002) discriminate between three groups of mediational tests: causal steps tests, difference in coefficients tests, and product of coefficients tests. Mediation in studies employing manifest (directly observed) variables has often been tested in accordance with the Baron and Kenny (1986) proposal (a causal steps test) that a series of regression analyses should be performed, estimating the regression coefficients a) of the mediating variable regressed on the independent variable, b) of the dependent variable regressed on the independent variable and c) of the dependent variable regressed on the independent and the mediating variables simultaneously. To establish mediation, Baron and Kenny (1986) argue that the following conditions must hold: a) the independent variable affects the mediating variable in the first equation, b) the independent variable affects the dependent variable in the second equation, and c) the mediating variable affects the dependent variable in the third equation. If mediation is present, the effect of the independent variable on the dependent variable is smaller when the mediator is included in the equation (Baron & Kenny, 1986). However, Kenny et al. (1998) argue that the essential steps in establishing mediation are a) that the independent variable is related to the mediator and b) that the mediator affects the outcome variable, and that mediation could be present even if the independent variable is not related to the dependent variable. Circumstances in which a mediating effect could be present, although no relation between the independent and dependent variables have been a priori established, include the presence of several inconsistent mediating processes that cancel each other out (Collins et al., 1998) and a distal causal process (Shrout &

Bolger, 2002) i.e. the independent variable exerts its influence on the dependent variable over a long period of time in which the process may e.g. be affected by competing causes and random factors.

The Baron and Kenny approach is based on the assumptions that the mediating variable is free from measurement error and that the dependent variable does not cause the mediating variable (Baron & Kenny, 1986). This approach to testing mediation has been shown to have low statistical power, and it also has other limitations e.g. in that it does not provide a joint test of the conditions it argues needs to be fulfilled, does not give an estimate of the size of the indirect effect of the independent variable on the dependent variable through the mediator, and does not provide standard errors with which to construct confidence limits (MacKinnon et al., 2002).

Mediation can also be assessed by comparing the relation between the independent and dependent variables when the mediating variable is excluded from the equation as compared to when it is included in the equation (a difference in coefficients test). There are many different types of differences in coefficients tests, testing different types of hypotheses by estimating an intervening variable effect and its standard error (MacKinnon et al., 2002). This method has not been considered in the present thesis and will not be further discussed.

The third group of mediational tests described by MacKinnon et al. (2002) is the product of coefficients tests, which tests the significance of the indirect effect (the product of the direct effect of the independent variable on the mediator and the direct effect of the mediator on the dependent variable) by dividing it by its standard error. This standard error can be calculated using e.g. the Sobel formula (Sobel 1982, 1986) or other, similar formulas (see e.g. Baron & Kenny, 1986; MacKinnon et al., 2002). Other methods of significance testing, such as using asymmetric confidence limits for the distribution of the product of the direct effect of the independent variable on the mediator and the direct effect of the mediator on the dependent variable, are discussed in MacKinnon et al. (2002). In a Monte Carlo study comparing 14 methods to test the significance of the intervening variable effect, MacKinnon et al. (2002) found that the best balance of Type I error rates and statistical power across all cases tested was the product of coefficients test. Shrout and Bolger (2002) recommend that, with small to moderate samples, bootstrap methods should be used in testing mediation, as the bootstrap approach has more power than the conventional approach when the distribution is skewed away from zero.

For studies employing latent variables Brown (1997) proposes the use of structural equation modeling in testing mediation since this approach allows for the incorporation of measurement error and testing of mediation in nonrecursive (containing reciprocal relations and/or correlated disturbance terms) structures. This approach to testing mediation (a product of coefficients test) focuses on estimating direct, indirect and total effects that are calculated using the regression coefficients obtained when all aspects of the model are simultaneously included in the equations. The direct effect is the influence a variable has on another variable in a direct linkage, the (total) indirect effect consists of all paths from one variable to another variable that are mediated by one or more additional variables, the specific indirect effect is the decomposition of the total indirect effect into specific indirect paths, and the total effect is the sum of the direct and total indirect effects (Brown, 1997). Brown (1997) also provides a method for assessing the proportion of mediation in a model by looking at the ratio of the total indirect effect to the total effect.

Serious criticism on the testing of mediational hypothesis using hierarchical linear regression with cross-sectional data has however been put forth. Cole and Maxwell (2003) note that fairly restrictive assumptions have to be met in order for mediational testing with cross sectional data to be accurate, and that even more restrictive assumptions must hold in order for estimated mediational effect sizes to be correct (see Cole & Maxwell, 2003 for a description of these assumptions.) They further argue that the conditions under which cross sectional data accurately reflect longitudinal mediational effects are highly restrictive and exceedingly rare (Cole & Maxwell, 2003). Gollob and Reichardt (1985, 1987) state that, when these conditions do not hold, cross sectional studies provide biased and potentially very misleading estimates of mediational processes. Lindenberger and Pötter (1998) argue that using hierarchical linear regression (and methods based on the logic of hierarchical linear regression, e.g. linear structural equation modeling) does not offer a test of the basic mediation assumption and state that:

> "when doing so [testing hypotheses of mediation using hierarchical linear regression analysis] it has to be kept in mind that all interpretations based on such models are *conditional on the truth of the mediational assumption*. Thus, the interpretability of the absolute and relative magnitude of direct and indirect effects in such a model rests entirely on the basic assumption of the model – namely, that the mediator variable does in fact act as a mediator of the causal effect of the exogenous variable on the dependent variable" (Lindenberger & Pötter, 1998, p. 225).

The importance of testing hypotheses of mediation using longitudinal data thus cannot be overstated. If mediation is viewed in accordance with Collins et al. (1998) as an intra-individual chain reaction where

> "*first* there is an independent variable /…/, which *then* causes a change in the mediator /…/, which *then* causes change in the dependent variable /…/" (Collins et al., 1998, pp. 296-297)

then at least three measurement points are required in order to test hypotheses of mediation. However Cole and Maxwell (2003) argue that when a study has only two waves and the focus is on an ongoing process (as opposed to a process that does not start until the independent variable has been measured) "all is not lost" and present a framework for testing hypotheses of mediation using longitudinal data with two measurement points. They recommend using a pair of longitudinal tests (1) estimating the regression coefficient of the independent variable at time 1 on the mediator at time 2, controlling for the mediator at time 1 and (2) estimating the regression coefficient of the mediator at time 1 on the dependent variable at time 2, controlling for the dependent variable at time 1. The rationale behind this is that if stationarity can be assumed (i.e. if it can be assumed that the effect of the mediator on the outcome remains the same over time) the regression coefficient of the mediator at time 1 on the dependent variable at time 2 would be the same as that of the mediator at time 2 on the dependent variable at time 3 (Cole & Maxwell, 2003). In that case they argue that the product of the regression coefficients of the independent variable at time 1 on the mediator at time 2 and the mediator at time 1 on the outcome at time 2 gives an estimate of the mediational effect of the independent variable on the outcome through the mediator. This product of direct effects can be significance tested using the same formulas as described above for product of coefficients tests using cross sectional data, e.g. the Sobel formula (Sobel 1982, 1986). The proportion of mediation, however, cannot be assessed given that the significance of the direct effect of the independent variable on the dependent variable cannot be tested (Cole & Maxwell, 2003).

Testing for moderator effects

As is the case in mediation testing there are also different ways to test for moderation. In studies employing manifest (directly observed) categorical variables (e.g. gender, treatment condition etc.) interaction effects are often investigated using (two way) analysis of variance (ANOVA). When it comes to testing potential moderator effects using manifest continuous variables it is relatively common to treat the proposed moderator as a categorical variable, i.e. to artificially create e.g. a dichotomous variable by dividing the initially continuous variable into groups based on e.g. a median split. However, this practice entails a loss of information and may lead to a reduction in power to detect moderator effects (Frazier et al., 2004). It may also lead to spurious main and interaction effects (MacCallum et al., 2002) when both independent and moderator variables are dichotomized (Maxwell & Delaney, 1993) and when only the moderator variable is dichotomized (Bissonnette et al., 1990). Thus, this practice of dichotomizing originally continuous variables in order to simplify the testing of moderator effects has been discouraged (see e.g. MacCallum et al., 2002) and it has been recommended that moderated multiple regression be used instead (Bissonnette et al., 1990).

However, also in the context of testing for moderation, the presence of measurement error can lead to low statistical power (see e.g. Jaccard & Wan, 1996). As is the case in studying mediation, the use of structural equation modeling with multiple indicators of an underlying latent construct enables the effect of measurement error to be estimated and taken into account when analyzing relations between true latent variables (Jaccard & Wan, 1996).

When analysing latent continuous independent and categorical manifest moderators, multi-group SEM provides an effective test of interaction effects (Rigdon et al., 1998). In such a case the invariance of structural parts of the SE model (i.e. regression coefficients) can be tested over the different groups, with invariance over groups meaning no interaction effect. If, on the other hand, invariance testing shows that the regression coefficient(s) under investigation is statistically different in at least one of the groups (i.e. a model with equality constraints on the particular coefficient shows a significantly worse model fit than the model without such a constraint) the hypothesis of no interaction effect should be discarded. This is an easy to use method that can be performed using all of the major computer programs for SE modeling.

When addressing hypotheses of interaction involving continuous latent independent variables, however, the analysis techniques, as well as the decision strategies, become more complicated. Recently Marsh et al. (2004) note that

> "despite the widespread use of SEM for the purposes of estimating relations among latent variables and the importance of interaction effects, there have been very few substantive applications of SEM to estimating interactions between two latent variables" (Marsh et al., 2004, p. 275).

This lack of substantive SEM applications in testing interaction effects is probably due to problems in the specification of such models (Rigdon et al., 1998), the many different approaches available to estimate latent interactions and the difficulty in deciding how to construct or select the indicators for the latent interaction term (Marsh et al., 2004). Among the many decisions that must be made are how many indicators of the interaction term should be calculated, how these should be calculated (one pair, all possible pairs, matched pairs; using mean centered variables or not?) and which constraints should be imposed on the model.

Marsh et al. (2004) compare different approaches to testing latent variable interactions in a series of simulation studies, including the latent moderated structural equations approach (the only approach considered in the present thesis) (Klein & Moosbrugger, 2000). In this approach the interaction term is a product of the original latent (exogenous) variables and no indicators for this latent interaction variable have to be formed (Klein & Moosbrugger, 2000). The hypothesis of no interaction effect is tested by comparing the interaction model to a linear structural equation model (i.e. a model not including the interaction effect) (Klein & Moosbrugger, 2000). Marsh et al. (2004) conclude that all of the approaches tested were relatively unbiased for normally distributed indicators and that the latent moderated structural equations approach had more power, but also higher Type I error rates, and were more biased for non-normal data than were (most of) the other approaches. It is important to include also potential moderator effects in testing process models of the relation between psychosocial work environment and musculoskeletal symptoms. The latent moderated structural equations approach provides a feasible solution to creating interaction terms and testing such effects in these models.

Process model of psychosocial work environment and musculoskeletal symptoms

Although several studies on the relation between psychosocial work environment and musculoskeletal symptoms have been published, many questions still remain unanswered, for example, questions regarding possible mechanisms linking psychosocial work environment (stressors) and musculoskeletal symptoms. In addition, although there are many proposed models of such mechanisms, in the framework of work-related musculoskeletal disorders (Armstrong et al., 1993; NIOSH, 1997) rather few studies have empirically tested *path models* (psychosocial pathways) using multivariate data analysis, specifically testing these proposed mechanisms. Traditionally, separate links in these models are tested using ordinary (multiple) regression analysis however, such analyses do not provide estimates of indirect (mediated) effects. Employing the analysis technique of structural equation modeling however allows for the testing of complete process models (see e.g. fig. 2) including one or more proposed mediators, as it allows for the simultaneous estimation of several regression equations where variables can act as both dependent variables in one link and as independent variables in the following link. Furthermore this analysis technique does not assume indicators measured without error, but instead allows for the incorporation of measurement error in the equations, and it provides a means for testing interaction effects of latent variables. The present thesis is based on a conceptual model of stressors (psychosocial and physical factors), potential mediating variables (felt stress and perceived fatigue) and strain/illness (musculoskeletal symptoms), as illustrated in fig. 2.

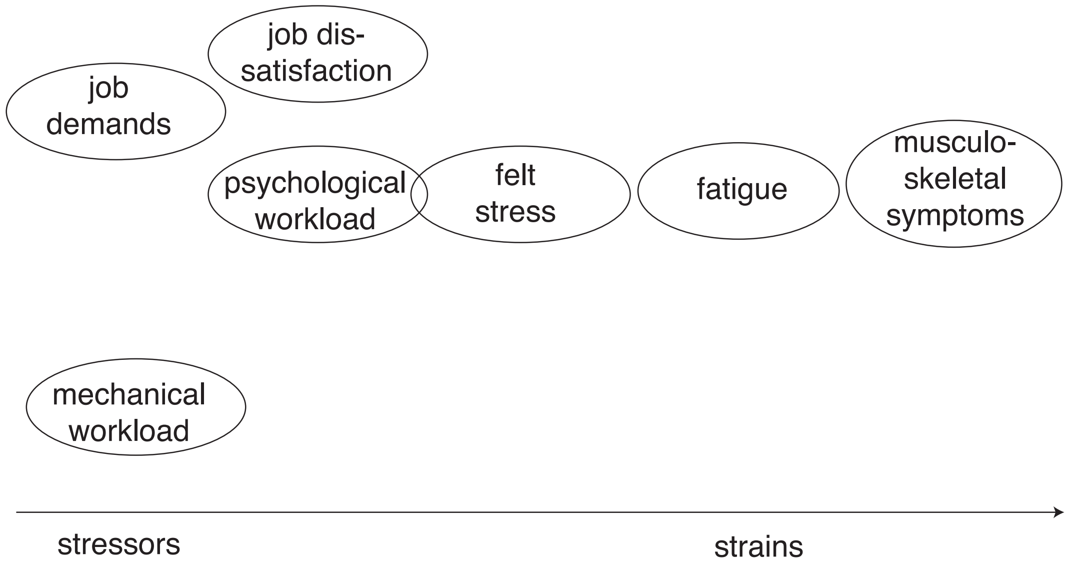

Figure 2. Conceptual model of the stressors and strains investigated in the present thesis.

The present studies

Aims

The overall aim of the thesis was to investigate the relation between aspects of the psychosocial work environment and musculoskeletal symptoms including the testing of models of the potential mediating mechanisms of felt stress and perceived fatigue, and the potential moderating mechanism of physical workload.

Study I
The aim of study I was to test two structural models of the relation between one aspect of the psychosocial work environment – psychological workload – and musculoskeletal symptoms in the neck, shoulder, and upper and lower back, with different aspects of perceived fatigue as mediating variables.

Study II
The aim of study II was to test a structural model of the relation between another aspect of the psychosocial work environment – job demands – and musculoskeletal neck/shoulder symptoms with felt stress as a proposed mediating variable.

Study III
The aim of study III was to test a structural model of the longitudinal relations between psychological workload, job satisfaction and musculoskeletal neck/shoulder symptoms with general fatigue as a proposed mediating variable.

Study IV
The aim of study IV was to test a structural model of the longitudinal relations between psychological workload, mechanical workload and neck/shoulder musculoskeletal symptoms, including a potential interaction effect of psychological and mechanical workload on neck/shoulder symptoms.

Model specification

The proposed structural equation models are presented in figs. 3 to 9.

Study I
The first model tested in study I is presented in fig. 3.

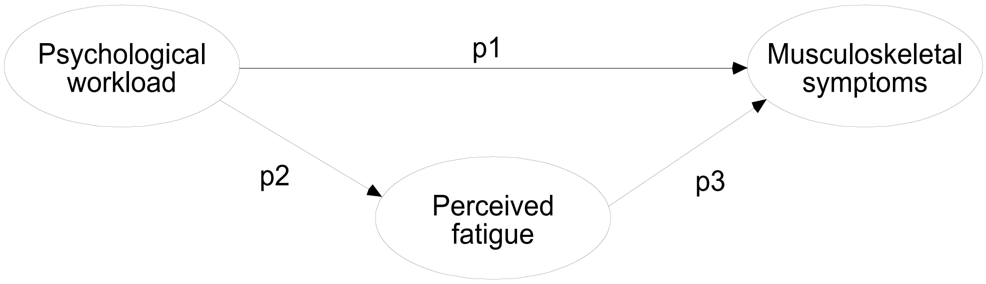

Figure 3. Specification of the first structural equation model tested in study I. Separate models were tested for each dimension of fatigue (lack of energy, physical exertion, physical discomfort, lack of motivation, and sleepiness). Musculoskeletal symptoms refer to symptoms in the neck, shoulder, and upper and low back. Only latent variables and their relations are depicted.

This model consists of the exogenous latent variable psychological workload, the proposed mediating latent variable perceived fatigue and the endogenous latent variable musculoskeletal symptoms. The model was tested for each of the five dimensions of perceived fatigue measured by the SOFI (Åhsberg, 2000).

Psychological workload was hypothesized to be positively related to musculoskeletal symptoms (p1), i.e. the higher the psychological workload the higher the level of symptoms. Psychological workload was also hypothesized to be positively related to different aspects of perceived fatigue (p2), i.e. the higher the psychological workload the higher the levels of aspects of perceived fatigue. Finally, perceived fatigue was hypothesized to be positively related to musculoskeletal symptoms (p3), i.e. the higher the levels of different aspects of perceived fatigue the more symptoms. The relation between psychological workload and musculoskeletal symptoms was hypothesized to be partially mediated by perceived fatigue.

The second model tested in study I (see fig. 4) consists of the exogenous latent variable psychological workload, the proposed mediating latent variables of specific perceived fatigue and general perceived fatigue, and the endogenous latent variable musculoskeletal symptoms. This model was tested for each of the four specific dimensions of perceived fatigue.

Consistent with the first model proposed, psychological workload was hypothesized to be positively related to musculoskeletal symptoms (p1). Psychological workload was also hypothesized to be positively related to the different specific fatigue dimensions (p2) as well as to the general dimension of perceived fatigue (p3). The different specific fatigue dimensions were hypothesized to be positively related to both the general fatigue dimension (p5) and to musculoskeletal symptoms (p4). Finally the general fatigue dimension was hypothesized to be positively related to musculoskeletal symptoms (p6). The relation between psychological workload and musculoskeletal symptoms was hypothesized to be partially mediated by both the specific and the general dimensions of perceived fatigue.

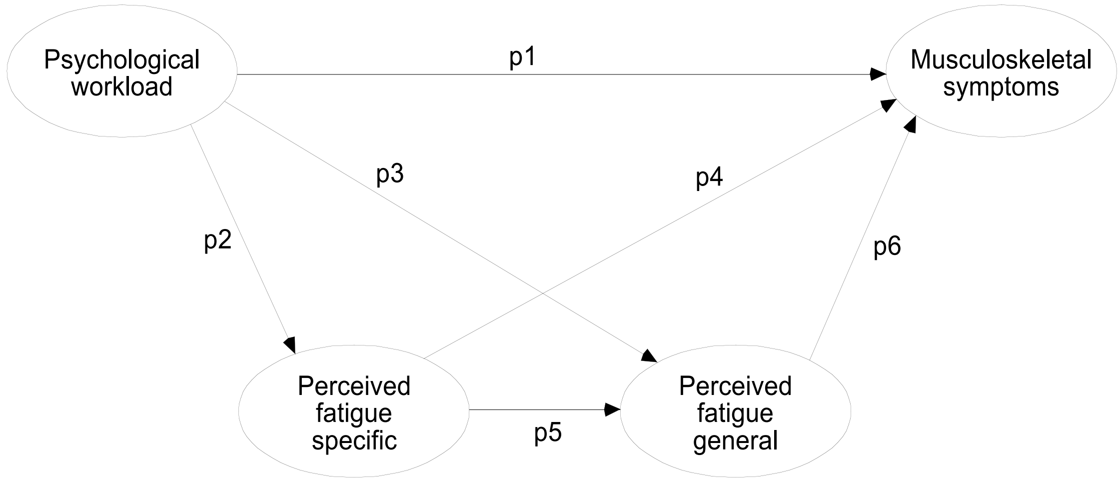

Figure 4. Specification of the second structural equation model tested in study I. Separate models were tested for each of the four specific dimensions of perceived fatigue (physical exertion, physical discomfort, lack of motivation, and sleepiness). Musculoskeletal symptoms refer to symptoms in the neck, shoulder, and upper and lower back. Only latent variables and their relations are depicted.

Study II

The proposed model tested in study II (see fig. 5) consists of the exogenous latent variable work demands, the proposed mediating latent variable felt stress, and the manifest endogenous variable musculoskeletal neck/shoulder symptoms. The perceived work demands were hypothesized to be positively related to felt stress, i.e. the higher the perceived work demands the higher the level of felt stress. Felt stress was hypothesized to be positively related to musculoskeletal neck/shoulder symptoms, i.e. the higher the level of felt stress the higher the risk of suffering from symptoms. Felt stress was further hypothesized to act as a mediating variable in the relation between perceived work demands and neck/shoulder symptoms, i.e. the perceived demands were thought to influence the level of symptoms to the extent that they influenced the level of felt stress.

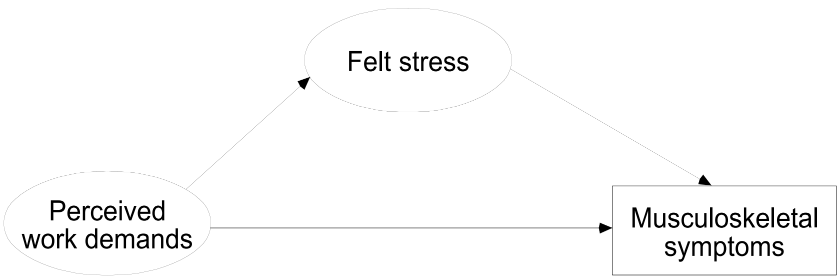

Figure 5. Specification of the structural equation model tested in study II. Musculoskeletal symptoms refer to symptoms in the neck and shoulder. Only latent exogenous variables and their relations to each other and to the manifest outcome variable are depicted.

Study III

The proposed models tested in study III are presented in figs. 6 and 7. The first model tested in this study (model 1) consists of the independent variables psychological workload and job satisfaction at baseline (T1), fatigue at baseline (T1), which is considered a mediating variable, and the dependent variable musculoskeletal neck/shoulder symptoms at follow-up (T2) (see fig. 6). Because this study focused on the development of neck/shoulder symptoms, only those study participants considered symptom free at wave 1 measurements were included in the analyses.

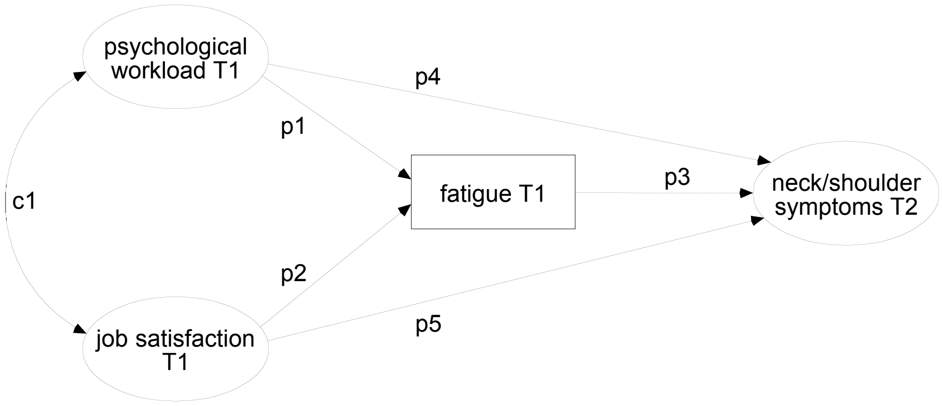

Figure 6. Specification of the first structural model tested in study III. Only latent variables and their relations are depicted. Regression weights (paths) are labelled p1 to p5, and the correlation is labelled c1. The measurement model is not shown.

Psychological workload and job satisfaction at t1 were hypothesized to be negatively inter-correlated (c1), i.e. higher levels of psychological workload were hypothesized to be associated with lower levels of job satisfaction and vice versa. Psychological workload was hypothesized to be positively related to fatigue (p1), i.e. the higher the psychological workload the more fatigue. Job satisfaction was hypothesized to be negatively related to fatigue (p2) such that a higher job satisfaction is related to less fatigue. Fatigue was hypothesized to be related to neck/shoulder symptoms at follow-up (p3) such that higher levels of fatigue are related to higher levels of musculoskeletal symptoms. Psychological workload (p4) and job satisfaction (p5) were hypothesized to have direct effects on musculoskeletal symptoms, i.e. effects not mediated by fatigue. Partial mediation was hypothesized such that both psychological workload and job satisfaction were hypothesized to influence musculoskeletal symptoms partly (but not solely) through their effects on fatigue.

The second model tested in this study (model 2) consists of the independent variables psychological workload and job satisfaction at baseline (t1), fatigue at follow-up (t2), which is considered a mediating variable, and the dependent variable musculoskeletal neck/shoulder symptoms at follow-up (t2).

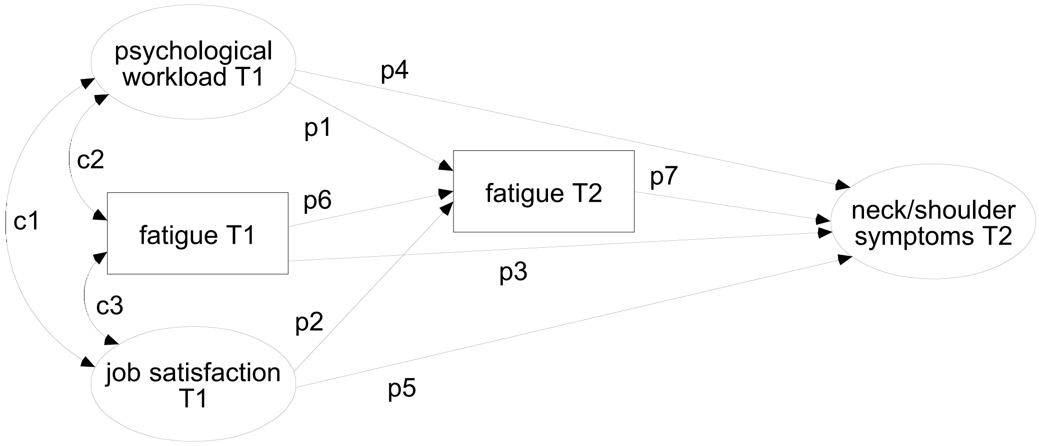

Figure 7. Specification of the second structural model tested in study III. Only latent variables and their relations are depicted. Correlations are labelled c1 to c3 and regression weights (paths) are labelled p1 to p7. The measurement model is not shown.

This model was based on the same hypotheses as was model 1, with a few modifications. When testing mediation in (two-wave) longitudinal studies it is important to control for the effects of baseline levels of the proposed mediator (Cole & Maxwell, 2003). Thus, in the second model, treating fatigue at follow-up as the proposed mediator, baseline fatigue was also included in the model (see fig.7). This leads to the following additional hypotheses:

Fatigue at t1 was hypothesized to be positively associated with psychological workload (c2) and negatively associated with job satisfaction (c3). Fatigue at t1 was hypothesized to be positively related to fatigue at t2 (p6). The addition of p6 also entails the hypothesis that the relation between fatigue at t1 and neck/shoulder symptoms at t2 is partially mediated by fatigue at t2. Furthermore, fatigue at T2 was hypothesized to be related to neck/shoulder symptoms at follow-up (p7).

Study IV

In study IV, two different models were tested, one focusing specifically on the development of symptoms, i.e. containing only those participants considered symptom free at the first measurement occasion (restricted sample), and one not differentiating between different processes, i.e. containing all participants regardless of their musculoskeletal status at the initial measurement (total sample). These cross-lagged autoregressive models are presented in figs. 8 (restricted sample) and 9 (total sample), and they consist of the independent variables psychological workload, mechanical workload and musculoskeletal neck/shoulder symptoms at wave 1 (T1) and the dependent variables psychological workload, mechanical workload and musculoskeletal neck/shoulder symptoms at wave 2 (T2).

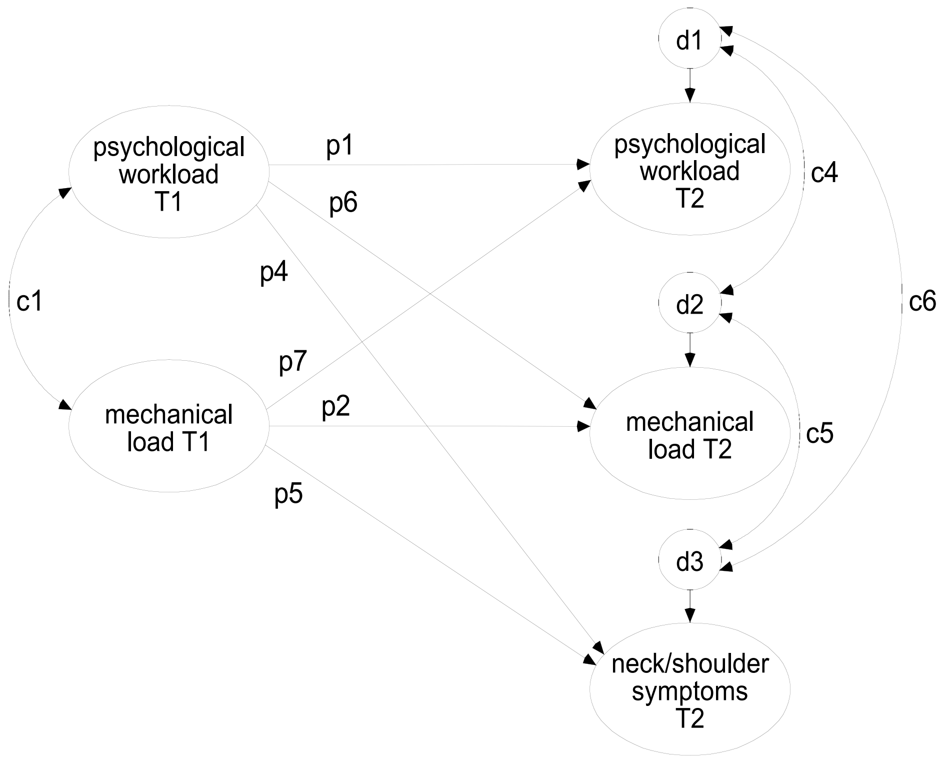

Figure 8. Specification of the structural model for the restricted sample tested in study IV. Only latent variables and their relations are depicted. Correlations are labelled c1 to c6, regression weights (paths) are labelled p1 to p7, and disturbance terms (residual variances) are labelled d1 to d3.

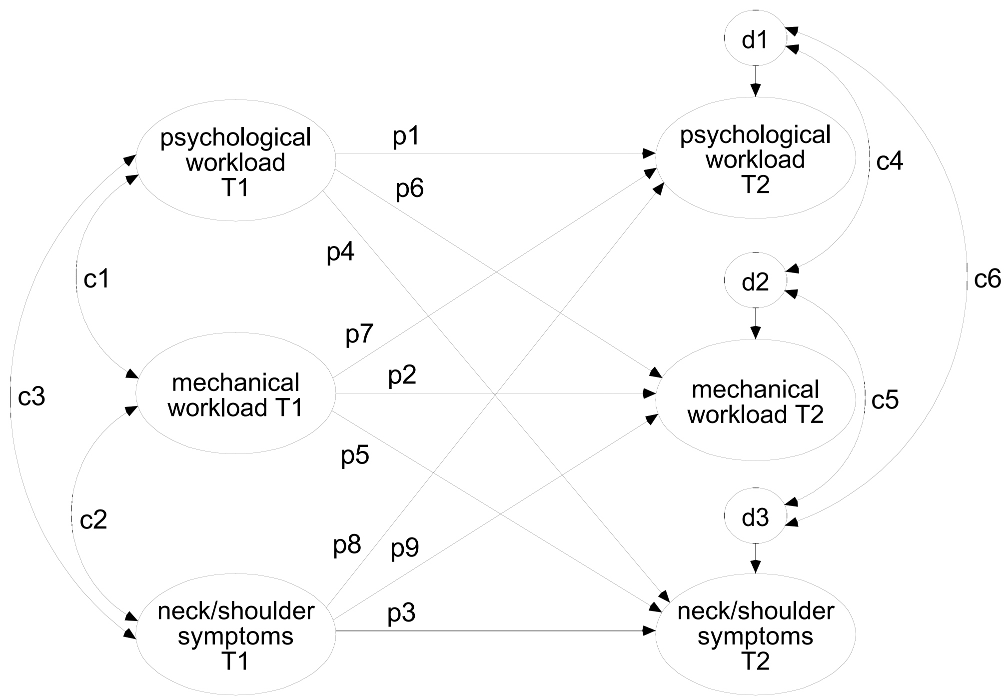

Figure 9. Specification of the structural model for the total sample tested in study IV. Only latent variables and their relations are depicted. Correlations are labelled c1 to c6, regression weights (paths) are labelled p1 to p9, and disturbance terms (residual variances) are labelled d1 to d3.

Psychological workload, mechanical workload and neck/shoulder symptoms at T1 were hypothesized to be positively inter-correlated (c1-c3). The autoregressive regression weights (p1-p3) (psychological workload at T1 on psychological workload at T2, mechanical load at T1 on mechanical load at T2, and neck/ shoulder symptoms at T1 on neck/shoulder symptoms at T2) were hypothesized to be positive and large in magnitude. When controlling for baseline symptoms (total sample) and mechanical workload (restricted and total samples), psychological workload was hypothesized to be positively related to neck/shoulder symptoms at T2 (p4), i.e. the higher the psychological workload at baseline the more symptoms at follow-up measurements. When controlling for baseline symptoms (total sample) and psychological workload (restricted and total samples), mechanical workload was hypothesized to be positively related to symptoms at T2 (p5), i.e. the higher the mechanical load at baseline the more symptoms at follow-up. In order to examine the inter-relations between psychological and mechanical workload, paths from workload at T1 to mechanical workload at T2 (p6) and from mechanical workload at T1 to psychological workload at T2 (p7) were freely estimated. To test also for reversed effects, paths from neck/shoulder symptoms at T1 to psychological workload at T2 (p8) and to mechanical workload (p9) were included in the model tested in the total sample (but not in the restricted sample, since this sample only consists of initially symptom free participants).

Method

Design and procedure

Both studies I and II were cross sectional studies based on questionnaire surveys. Study I was part of the research program called "COPE" (Co-operative for Optimization of industrial production systems regarding Productivity and Ergonomics) (Winkel et al., 1999) and was based on a questionnaire survey among blue-collar workers at three Swedish assembly plants. Study II, which was part of the NEW (Neuro-muscular assessment in the Elderly Worker) study (Läubli et al., 2006; Merletti et al., 2004; Sjøgaard et al., 2006), a European case-control study among elderly female computer users, was based on a questionnaire survey (see Sandsjö et al., 2006) that participants completed when they entered the case-control study.

Studies III and IV were two-wave longitudinal cohort studies based on questionnaire survey data collected during the 1990s among employees in Swedish human service organizations (Pousette & Johansson Hanse, 2002).

Participants

Study I. The study sample of study I consisted of 275 blue-collar workers at three different Swedish assembly plants, dealing with car manufacturing, and mounting and testing of electric and electronics components. The average age of the participants was 32.4 yr (SD = 9.9), and 36.6 per cent were female.

Study II. The sample of study II consisted of 148 female European office workers aged 45 or older, working at least part time (i.e. 20 hours per week or more).

There were 45 participants from the Netherlands, 44 from Sweden, 31 from Denmark and 28 from Switzerland.

Studies III and IV. The sample of studies III and IV consisted of non-managerial elderly- and child-care workers. The analyses in study III were based on 629 respondents who participated in the study in both waves, and who were considered symptom free at the first wave. The analyses in study IV were based on 1 277 respondents who participated in both waves. Almost all (97%) of the participants in these studies were female.

Measures

Psychosocial work environment. In study II the short version of the Copenhagen Psychosocial Questionnaire (COPSOQ) (Kristensen et al., 2002) was used to assess the participants' psychosocial work environment. This study focused on the perceived *job demands* consisting of quantitative and emotional demands. The items "work very fast", "unevenly distributed workload" and "not having time to complete all work tasks" were used as indicators of self-rated perceived quantitative work demands, while the items "work puts me in emotionally disturbing situations", "emotional involvement in work" and "work requires me to hide my emotions" were used as indicators of self-rated perceived emotional work demands. Each of these items had five fixed response alternatives (0 to 4) ranging from "always/almost always" to "never/hardly ever". The composite reliability for this latent variable was .77.

In studies I, III and IV the employee perceptions of their psychosocial work environment were assessed using a "standardized" questionnaire ("PAK") developed by Rubenowitz (1989, 1997, 2004). Each PAK factor comprises five items and each item has five fixed response alternatives that are given points from 1 to 5. Studies I, III and IV focused on one specific aspect of the psychosocial work environment – *the psychological workload* – that was analyzed using a short version of PAK (Pousette & Johansson Hanse, 2002). This consisted of the manifest variables "pushed with work", "work overload" and "mental pressure". Study III also included *job satisfaction* consisting of the manifest variables "feelings towards your work", "enjoys working for the organization" and "general task satisfaction".

The composite reliability for psychological workload was .70 in study I (for all different models), .71 in study III (for both models), and in study IV .71 at wave 1 and .70 at wave 2 for the restricted sample and .71 at wave 1 and .72 at wave 2 for the total sample. For job satisfaction, the composite reliability was .77 for both models in study III.

Felt stress. In study II felt stress was proposed to be a mediating variable. It was assessed using the two-dimensional mood adjective checklist (Kjellberg & Iwanowski, 1989; Kjellberg et al., 2000). This checklist, which was constructed to be used to describe mood during work, contains two mood dimensions – stress and energy. In study II only the stress dimension was considered. It was measured using the items "rested" (inverted score), "relaxed" (inverted score), "calm" (inverted score), "tense", "stressed" and "pressured". The respondents were instructed to think about how they usually felt at the end of a normal workday. There were six fixed response alternatives ranging from 0 "not at all" to 5 "to a very great degree". The composite reliability for this latent variable was .88.

Fatigue. Perceived fatigue was proposed to be a mediating variable in study I. It was assessed using the Swedish Occupational Fatigue Inventory (SOFI) (Åhsberg et al., 1997, 2000), which is an instrument for the measurement of work-related perceived fatigue (Åhsberg, 2000). The version of SOFI used in study I consisted of 25 expressions evenly distributed over five latent factors: lack of energy (overworked, spent, drained, worn out and exhausted), physical exertion (breathing heavily, out of breath, warm, sweaty and palpitations), physical discomfort (aching, hurting, stiff joints, numbness and tense muscles), lack of motivation (uninterested, passive, indifferent, lack of concern and listless) and sleepiness (sleepy, yawns, drowsy, fall asleep and lazy). The 25 expressions in the SOFI each had seven fixed response alternatives that were given points from 0 "not at all" to 6 "to a very high degree". Only these two extreme values of the numerical scale were verbally defined. The participants were asked in completing the questionnaire to think of the fatigue felt at the end of a typical day of work. The composite reliabilities were (for both models) .90 for lack of energy, .86 for physical exertion, .89 for physical discomfort, .89 for lack of motivation and .86 for sleepiness.

In study III feelings of fatigue were proposed to be a mediating variable. It was assessed using one item from the PAK questionnaire (Rubenowitz, 1989, 1997, 2004) "feeling fatigued and spent after work". This item had five fixed response alternatives ranging from "not at all" (1) to "most of the time" (5).

Mechanical workload. Mechanical workload was included in study IV and assessed using eight questionnaire items about self-assessed work postures (Wiktorin et al., 1991, 1992, 1993). The items were seven illustrated questions regarding different work postures, "trunk bent forward 20-60°", "trunk bent forward >60°","trunk rotation >45°", "work with the hands above shoulder level", "head bent forward", "head bent backward" and "head heavily rotated", and an additional question concerning "repetitive work movements" (Johansson & Rubenowitz, 1994). Each of these questionnaire items originally had six fixed response alternatives ranging from "not at all" to "almost all the time". However, as recommended by Balogh et al. (2001), these six response alternatives were collapsed into three categories: "not at all" and "about 1/10th of the time" into low exposure, "about 1/4th of the time" and "about half the time" into medium exposure, and "about 3/4th of the time" and "almost all the time" into high exposure. The composite reliability for this latent variable was .74 at wave 1 and .75 at wave

2 for the restricted sample and .74 at wave 1 and .76 at wave 2 for the total sample.

Musculoskeletal symptoms. Musculoskeletal symptoms (self-reported) were in all studies measured using the general Nordic Musculoskeletal Questionnaire (NMQ) (Kuorinka et al., 1987), which refers to the human body as divided into nine anatomical regions and requires the respondent to indicate whether she/he has had symptoms (ache, pain, discomfort) during the previous 12-month period. However, in study I, this instrument was slightly modified, obtaining information about symptoms during the previous three-month period. In studies II, III and IV the special NMQ questionnaires (Kuorinka et al., 1987) for neck and shoulder symptoms were also employed.

Study I dealt with symptoms (yes/no) in the neck, shoulder, and upper and lower back. The composite reliability for this variable ranged between .58 and .61 for the different models tested in study I.

Study II dealt with symptoms in the neck and the shoulder regions. Only *cases*, defined as having had symptoms in the region of interest for more than 30 days during the previous 12-month period, and *controls*, defined as having had symptoms for a maximum of seven days during the same period in the region of interest, were asked to participate in the study. Neither cases nor controls were allowed to have had symptoms for more than 30 days during the past 12 months in more than three body regions in total (neck and shoulder together were regarded as one body region) (Sjøgaard et al., 2006). According to these criteria there were 55 neck/shoulder cases and 93 neck/shoulder controls in the study sample.

Studies III and IV dealt with number of days with symptoms in the neck and shoulders during the past 12 months. In study III only those participants (n = 629) considered symptom free at baseline measurements were included in the analyses. The composite reliability for the latent variable neck/shoulder musculoskeletal symptoms was .71 for the model treating fatigue at baseline as the mediator and .72 for the model treating fatigue at follow-up as the mediator. In study IV analyses were based both on the total sample (n = 1 277) and a restricted, initially symptom free (n = 630) sub-sample. The composite reliability for the musculoskeletal neck/shoulder symptoms was .70 at wave 2 for the restricted sample and .76 at both waves for the total sample.

Statistical analysis

Missing values. For all studies, missing values were handled with the EM algorithm in SPSS (versions 10.0, 11.0 and 11.5.1, respectively) (Hill, 1997). Values were imputed from the other variable values within each latent exogenous or latent mediating variable (psychological workload and perceived fatigue in study I, perceived work demands and felt stress in study II, psychological workload and job satisfaction in study III, and psychological and mechanical workload in study IV), i.e. estimations were made for the missing values based on the values for the other variables that each individual respondent had filled out within that factor.

Subjects who had filled out less than a predefined percentage (33% for psychological workload in studies I, III and IV, 33% for job satisfaction in study III, 50% for mechanical workload in study IV, 60% for the fatigue dimensions in study I, and 50% for work demands and felt stress in study II) of the questionnaire items within each latent variable were excluded from the analyses. Missing values were not imputed for the endogenous variables musculoskeletal symptoms.

Parcelling. Questionnaire items concerning perceived fatigue and musculoskeletal symptoms in study I, perceived work demands and felt stress in study II and mechanical workload in study IV were parcelled using unidimensional parcelling (Kishton & Widaman, 1994), which means that items measuring the same construct were added into parcels. Items within each factor were parcelled in such a way that three approximately normally distributed variables were obtained. Two or three items were added into a parcel that was then represented by its mean value, with the exceptions of a) musculoskeletal symptoms in study I, where the parcels consisted of the sum of two body regions, and b) work demands in study II, where the third parcel consisted of only one item, since there were originally five items in this factor.

Structural equation modeling. In all studies, structural equation modeling, in which the measurement (CFA) and the structural aspects of the model were tested simultaneously, was performed. In studies I and III structural equation modeling was performed using AMOS (versions 4 and 5, respectively) (Arbuckle & Wothke, 1995). In study II the modeling was performed using Mplus version 2 (Muthén & Muthén, 2001), and in study IV both AMOS version 5 (Arbuckle & Wothke, 1995) and Mplus version 3 (Muthén & Muthén, 1998-2004) were used. In all studies, input data consisted of the raw data that were stored in SPSS.

As follows from the dichotomous nature of the outcome variable musculoskeletal neck/shoulder symptoms (i.e. a subject being either a case or a non-case), probit regression weights were estimated in study II when this variable was entered into the equations, while, for equations not containing this variable, linear regression weights were estimated (Muthén & Muthén, 2001). In studies I, III and IV linear regression weights were estimated. In studies I, III and IV Maximum Likelihood (ML) estimation was performed, while the estimator in study II was mean and variance adjusted weighted least squares (WLSMV).

A number of fit indices were employed in testing the fit of the proposed models to the empirical data:

I. The χ^2 statistic that is a goodness-of-fit measure that assesses the magnitude of the discrepancy between the sample covariance matrix and the estimated covariance matrix (Hu & Bentler, 1995). Jöreskog and Sörbom (1993) propose that the χ^2 statistic be regarded as a measure of fit rather than as a test statistic, i.e. a measure of overall fit of the model to the data. A large, statistically significant value of the χ^2 in relation to its degrees of freedom indicates poor model fit. However, the χ^2 statistic is sensitive to sample size and, with a large sample size, even trivial differences may result in the rejection of the specified model (Hu & Bentler, 1995).

II. The normed χ^2 that is the ratio of the χ^2 to its degrees of freedom. Values below 1.0 indicate an "overfitted" model (Schumacker & Lomax, 1996), and values larger than 2.0, or the more liberal limit of 5.0, indicate that the model does not fit the observed data and needs improvement.

III. The root mean square error of approximation (RMSEA) that is a measure of the discrepancy per degree of freedom for the model (Browne & Cudeck, 1993). Values of about .05 or less indicate a close fit of the model to the data and values of about .08 or less indicate a reasonable error of approximation (Browne & Cudeck, 1993).

IV. The comparative fit index (CFI) that is an incremental fit index (Kline, 1998) with values greater than .90 indicating acceptable model fit.

Only the proposed models were tested, and in no instances were post hoc modifications such as correlated indicator error terms or indicator cross loadings allowed. The fit indices reported for each model thus represent the fit of the original hypothesized model to the empirical data (i.e. no model trimming was done).

Testing for mediation. The hypotheses of mediation were tested in studies I, II and III using structural equation modeling as proposed by Brown (1997), estimating direct, indirect and total effects. In studies I and III these effects were estimated using AMOS (versions 4 and 5, respectively), and their standard errors were estimated using the bootstrap function of AMOS. In study II Mplus version 2.0 was used for modeling owing to the need for an estimation program that estimates relations between a mixture of continuous and categorical variables. However, that estimation program could not estimate indirect and total effects and did not contain a bootstrap function. In study II, therefore, the indirect effect was hand calculated as the product of all the direct effects in the respective linkage (e.g. MacKinnon et al., 2002). The total effects were calculated as the sum of the direct and indirect effects. The standard error for the indirect effect was calculated using the Sobel formula (Sobel, 1982, 1986). The significance of the total effect was tested using a procedure proposed by Kline (1998), which entails testing the significance of the regression coefficient omitting the proposed mediating variable from the equation, thereby estimating an effect that consists of both the direct effect and the indirect effect.

Testing for moderation. The hypothesis of moderation addressed in study IV was tested using the latent moderated structural equations approach (Klein & Moosbrugger, 2000) to testing latent variable interaction included in Mplus version 3 (Muthén & Muthén, 1998-2004). The log likelihood value for the proposed model with and without the interaction term were compared, and a statistically significant value for the –2LL difference given its degrees of freedom would imply the existence of an interaction effect.

Testing for factorial invariance. In study IV factorial invariance was considered a necessary prerequisite for studying change and relations over time in the latent variables. For the purpose of investigating factorial invariance, a hierarchy of increasingly stringent tests of factorial invariance described by Meredith (1993) was employed and tested in accordance with Conroy et al. (2003). A baseline model only requiring the number and pattern of factor loadings to be equal across waves (configural invariance) was tested for model fit and compared to models subsequently adding the constraints of equality of factor loadings across waves (weak factorial invariance), equality of intercepts of the manifest variables related to each latent construct (strong measurement invariance) and equality of error terms for the manifest variables (strict factorial invariance).[1] In order to set the metric for the latent variables, the means for the latent variables at T1 were set to 0, while their variances were set to 1. In addition, the mean values for the disturbance terms of these latent variables at T2 were set to 0. The results of these invariance tests determined the specification of parameter constraints for the testing of the hypothesized models, i.e. parameters in the models tested were constrained according to the level of invariance achieved.

Results

Study I

Model 1. The first proposed model (see fig. 3) was tested separately for the general fatigue dimension of lack of energy and for each of the four specific fatigue dimensions: physical discomfort, physical exertion, lack of motivation and sleepiness. Graphic portrayals of the resulting models for each dimension of fatigue are depicted in fig. 10.

The proposed models showed good fit to the data for the fatigue dimensions of lack of energy ($\chi^2 = 20.53$, df = 17, $p > .05$, RMSEA = .03), physical exertion ($\chi^2 = 21.35$, df = 17, $p > .05$, RMSEA = .03), physical discomfort ($\chi^2 = 13.88$, df = 17, $p > .05$, RMSEA = .00) and lack of motivation ($\chi^2 = 24.49$ df = 17, $p > .05$, RMSEA = .04). For sleepiness, the model showed a significant value for χ^2 ($\chi^2 = 27.73$, df = 17, $p < .05$) while other fit indices indicated acceptable model fit (e.g. RMSEA = .05). Psychological workload was positively related to musculoskeletal symptoms, which means that a high psychological workload was related to a high level of musculoskeletal symptoms. It was also positively related to the different fatigue dimensions, meaning that a high psychological workload was related to high levels of fatigue. The relation between psychological workload and musculoskeletal symptoms was unmediated by the general fatigue dimension of lack of

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[1] Other tests of invariance are described in the literature, and other terminology is sometimes used. See e.g. Vandenberg (2002) for an overview.

energy. However, it was partially mediated by physical discomfort and lack of motivation but not by the other specific fatigue dimensions.

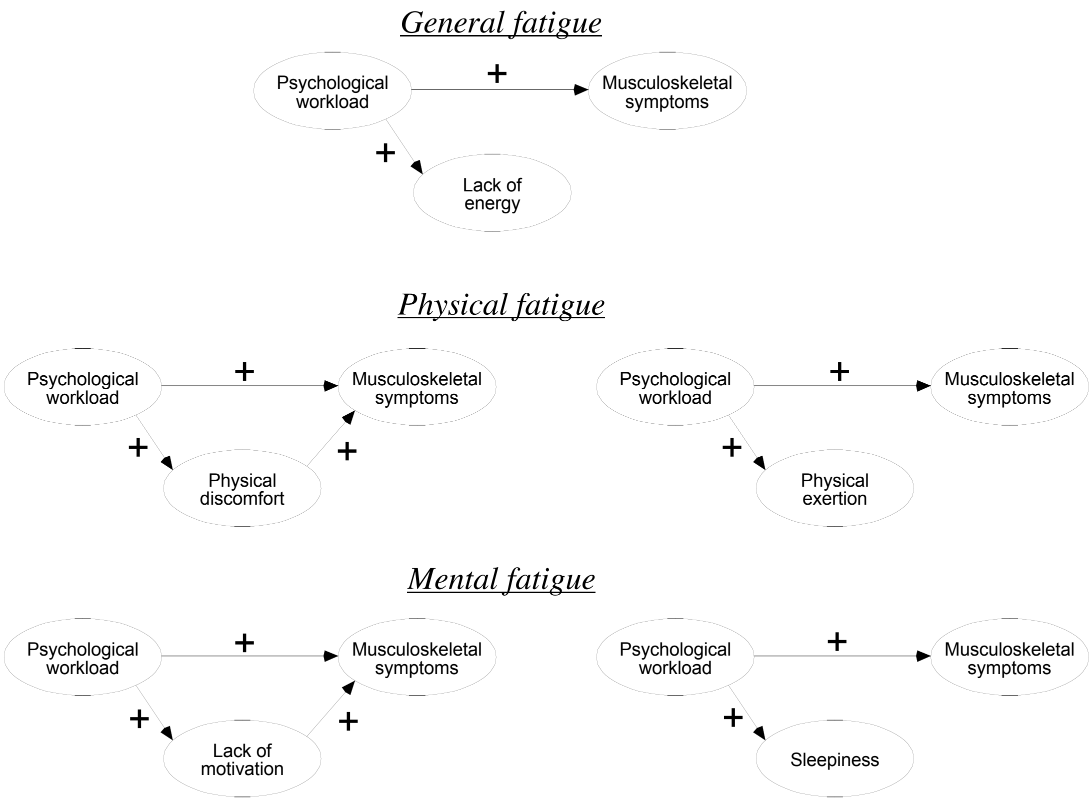

Figure 10. Graphic portrayal of the relations between psychological workload, perceived fatigue and musculoskeletal symptoms for each of the five dimensions of perceived fatigue. Significant relations are depicted with their respective sign. Only latent variables and their relations are depicted.

Model 2. The second proposed model (see fig. 4), containing both a specific fatigue dimension and the general fatigue dimension, was tested separately for each of the four specific dimensions of fatigue. Graphic portrayals of the resulting models for each specific fatigue dimension are depicted in fig. 11.

All four alternative models showed significant values for χ^2 while the other fit indices indicated acceptable model fit (for physical discomfort $\chi^2 = 71.48$, df = 38, $p < .05$, RMSEA = .06, for physical exertion $\chi^2 = 62.19$, df = 38, $p < .05$, RMSEA = .05, for lack of motivation $\chi^2 = 95.27$, df = 38, $p < .05$, RMSEA = .07, and for sleepiness $\chi^2 = 73.63$, df = 38, $p < .05$, RMSEA = .06).

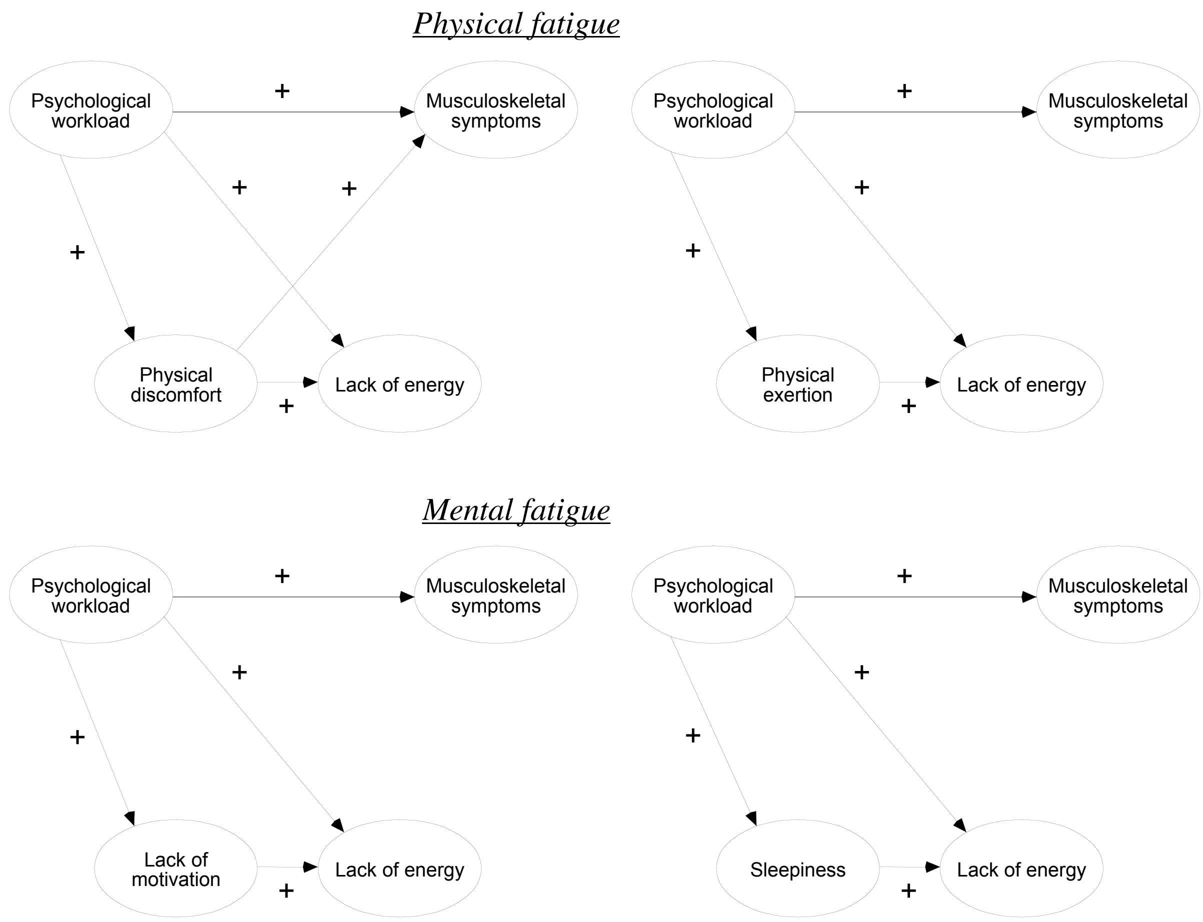

Figure 11. Graphic portrayal of the relations between psychological workload and musculoskeletal symptoms, with both a specific and the general dimension of perceived fatigue simultaneously included as mediating variables, for each of the four specific dimensions of perceived fatigue. Significant relations are depicted with the respective sign. Only latent variables and their relations are depicted.

Consistent with model 1, psychological workload was positively related to musculoskeletal symptoms. Psychological workload was also positively related to both the general and the specific fatigue dimensions. All specific fatigue dimensions were, as hypothesized, positively related to the general fatigue dimension. The indirect effect of psychological workload on musculoskeletal symptoms through both the respective specific fatigue indicators and the general fatigue indicator of lack of energy was non-significant for all four specific fatigue dimensions, which means that the relation between psychological workload and symptoms was unmediated by this hypothesized chain of double mediators. In this alternative model, only the specific fatigue indicator of physical discomfort was significantly related to musculoskeletal symptoms. The analysis indicates that this relation between physical discomfort and musculoskeletal symptoms was unmediated by the general fatigue dimension of lack of energy.

Study II

The proposed model (see fig. 5) showed good fit to the data ($\chi^2 = 12.11$, df = 8, p > .10, RMSEA = .06). A graphic portrayal of the resulting model is presented in fig. 12. There were positive direct effects of perceived work demands on felt stress, and of felt stress on musculoskeletal symptoms. There was also an indirect positive effect of perceived work demands on musculoskeletal symptoms through felt stress, which means that the higher the perceived work demands the higher the risk of suffering from symptoms. The effect of work demands on symptoms was completely mediated by felt stress. As regards the percentage of explained variance in the dependent variables, about 36 per cent of the variation in felt stress was explained by perceived work demands, and about 20 per cent of the variation in musculoskeletal symptoms was explained by the combination of perceived work demands and felt stress.

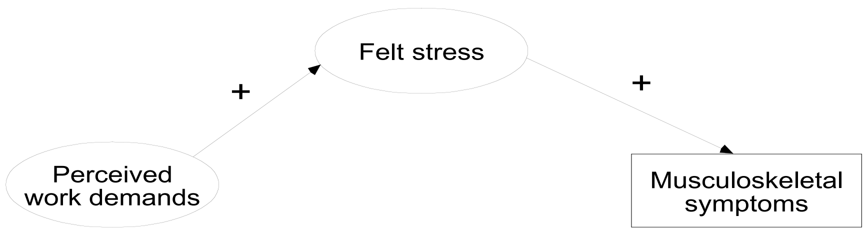

Figure 12. Graphic portrayal of the relations between perceived work demands, felt stress and musculoskeletal symptoms in the neck and shoulder. Significant relations are depicted with their respective signs. Only latent (in circle) exogenous variables and their relations to each other and to the manifest (in square) outcome variable are depicted.

Study III

Two structural models were tested. In the first model the relation between psychological workload at baseline and musculoskeletal symptoms at follow-up was tested with fatigue at baseline as a hypothesized mediating variable (model 1) (see fig. 6), and in the second analysis this relation was tested with fatigue at follow-up (controlling for fatigue at baseline) as the hypothesized mediator (model 2) (see fig. 7). Both these models showed acceptable fit to the data (e.g. RMSEA = .04 and .03, respectively), although with significant values for χ^2 ($\chi^2 = 40.40$, df = 22, p < .05 and $\chi^2 = 41.86$, df = 27, p < .05, respectively). The resulting models are graphically depicted in figs. 13 and 14.

Psychological workload and job satisfaction at baseline were negatively correlated, which means that low levels of job satisfaction were associated with high levels of workload. In model 2 (where fatigue at follow-up was the proposed mediator and fatigue at baseline was included as an independent variable in order to control for the effects of baseline fatigue) fatigue at baseline was positively associated with baseline psychological workload and negatively associated with baseline job satisfaction.

Psychological workload at baseline was related to neck/shoulder symptoms at follow-up for both models such that the higher the psychological workload at baseline the higher the level of neck/shoulder symptoms at follow-up. Psychological workload at baseline was similarly associated with fatigue at baseline (model 1) and fatigue at follow-up (model 2). Feelings of fatigue at baseline were not related to neck/shoulder symptoms at follow-up (model 1) but feelings of fatigue at follow-up, with control for baseline fatigue, were positively related to neck/shoulder symptoms at follow-up (model 2). The relation between psychological workload at baseline and neck/shoulder symptoms at follow-up was not mediated by feelings of fatigue at baseline, but was partially mediated by feelings of fatigue at follow-up. When controlling for the effects of baseline psychological workload, job satisfaction was not related to either feelings of fatigue at follow-up or to neck/shoulder symptoms at follow-up.

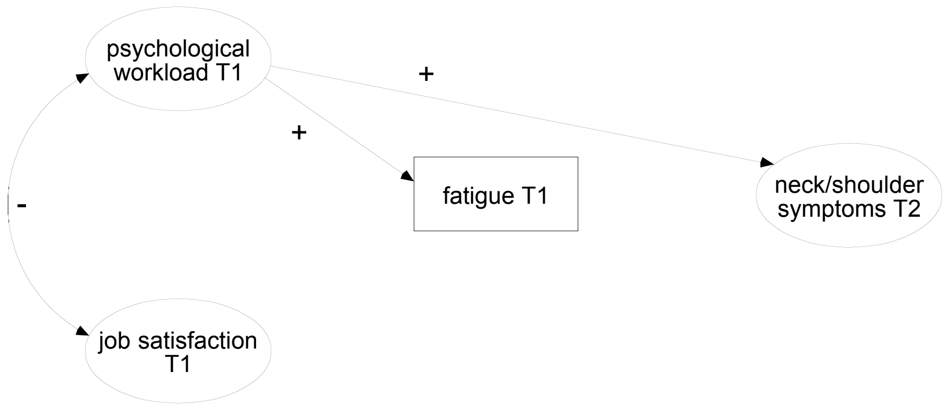

Figure 13. Graphic portrayal of the resulting relations between psychological workload, job satisfaction, fatigue and neck/shoulder symptoms. Model 1 treated fatigue at baseline as a potential mediating variable. Significant relations are depicted with the respective sign. Only latent variables, the manifest variable fatigue and their relations are depicted.

As regards the percentages of explained variance in model 1, about 40 per cent of the variance in feelings of fatigue at baseline was explained by the combination of psychological workload and job satisfaction, and about 5 per cent of the variance in neck/shoulder symptoms at follow-up was explained by psychological workload, job satisfaction and feelings of fatigue at baseline. In model 2, about 30 per cent of the variance in feelings of fatigue at follow-up was explained by the combination of psychological workload, job satisfaction and feelings of fatigue at baseline. In the same model, about 10 per cent of the variance in neck/shoulder symptoms at follow-up was explained by the combination of psychological workload, job satisfaction and feelings of fatigue at baseline and feelings of fatigue at follow-up.

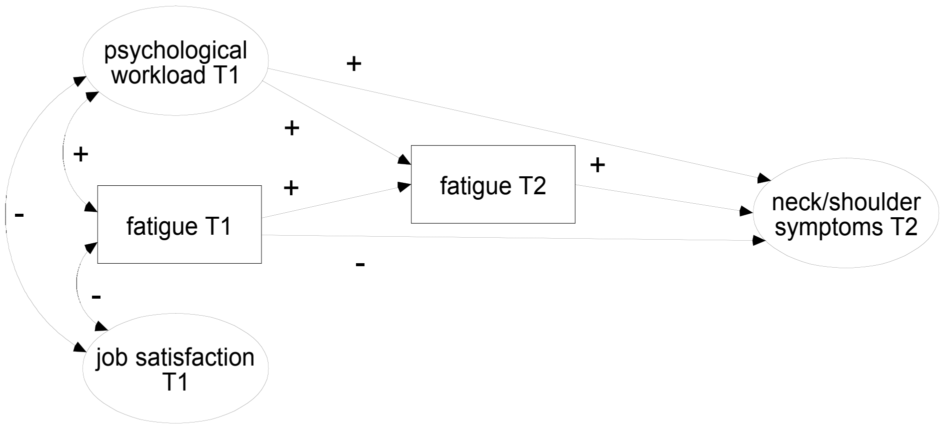

Figure 14. Graphic portrayal of the resulting relations between psychological workload, job satisfaction, fatigue and neck/shoulder symptoms. Model 2 treated fatigue at follow-up as a potential mediating variable. Significant relations are depicted with the respective sign. Only latent variables, the manifest variable fatigue and their relations are depicted.

Study IV

Factorial invariance. Tests of factorial invariance over measurement occasions in both the total and the restricted sample showed that strong factorial invariance was obtained for the entire measurement model. This means that factor loadings and intercepts did not differ significantly between the measurement occasions, while the error variances did.

Restricted sample. The proposed model (see fig. 8) showed good fit to the data in the restricted sample ($\chi^2 = 64.08$, df = 69, p > .05, RMSEA = .00). A graphic portrayal of the resulting model is presented in fig. 15. The autoregressive regression weights were positive and significant, i.e. psychological workload at T1 was related to psychological workload at T2 and mechanical workload at T1 was related to mechanical workload at T2. Psychological workload at T1 was significantly related to neck/shoulder symptoms at T2 when controlling for mechanical workload at T1, whereas mechanical workload at T1 was not related to neck/shoulder symptoms at T2 when controlling for psychological workload at T1. There was no interaction effect between psychological and mechanical workload and symptoms (-2LL difference = 0.05, df = 1, p > .05).

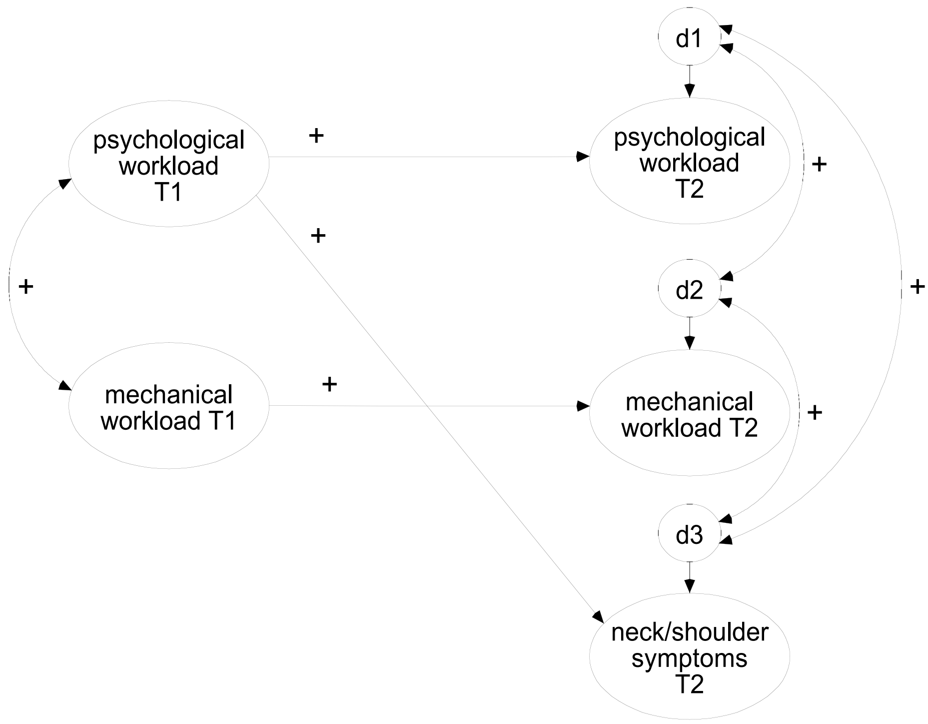

Figure 15. Graphic portrayal of the relations between psychological workload, mechanical load and musculoskeletal neck/shoulder symptoms. Significant relations are depicted with their respective signs. Only latent variables and their inter-relations are depicted.

As regards the percentage of explained variance, about 50 per cent of the variance in psychological workload at T2 was explained by the combined effects of psychological workload at T1 and mechanical workload at T1, about 40 per cent of the variance in mechanical workload at T2 was explained by the combination of mechanical workload at T1 and psychological workload at T1, and 4 per cent of the variance in neck/shoulder symptoms at T2 was explained by the combination of psychological workload at T1 and mechanical workload at T1.

Total sample. The proposed model (see fig. 9) showed acceptable fit to the data in the total sample (e.g. RMSEA = .02), although the model showed a significant value for χ^2 ($\chi^2 = 133.95$, df = 91, $p < .01$). A graphic portrayal of the resulting model is presented in fig. 16. Also in the total sample, all of the autoregressive regression weights were positive and significant, i.e. psychological workload at T1 was related to psychological workload at T2, mechanical workload at T1 was related to mechanical workload at T2, and neck/shoulder symptoms at T1 was related to neck/shoulder symptoms at T2. When controlling for these autoregressive regression weights, the only other significant relation was that of neck/shoulder symptoms at T1 on psychological workload at T2. Neither psychological nor mechanical workload at T1 was related to symptoms at T2. There was no interaction effect between psychological and mechanical workload and symptoms (-2LL difference = 0.76, df = 1, $p > .05$).

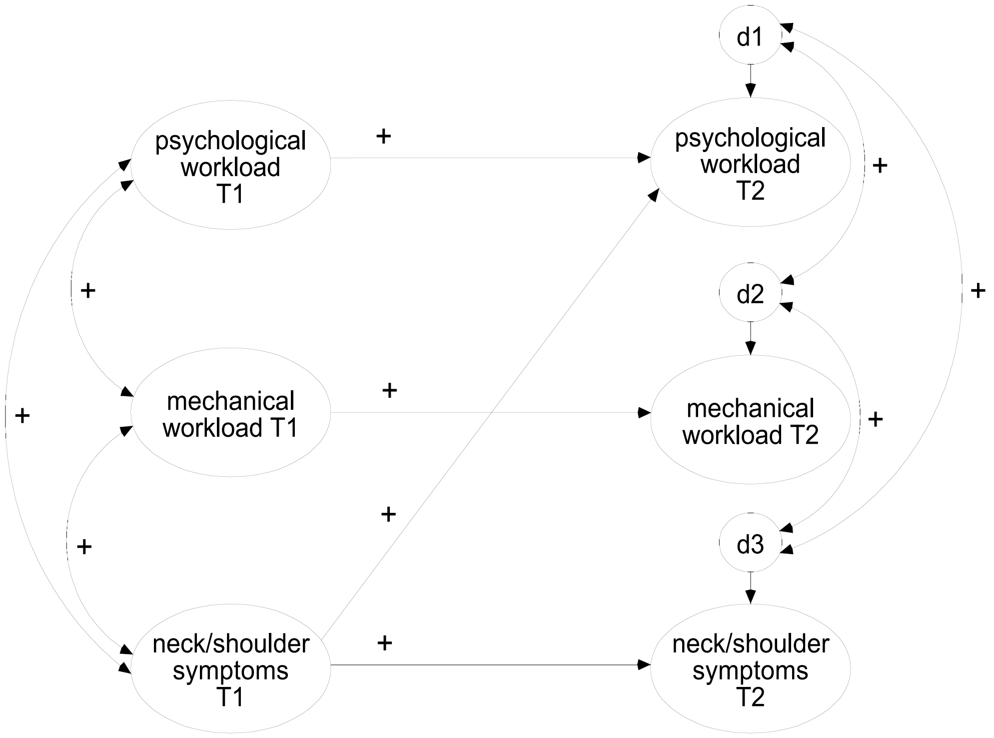

Figure 16. Graphic portrayal of the relations between psychological workload, mechanical load and musculoskeletal neck/shoulder symptoms. Significant relations are depicted with their respective signs. Only latent variables and their inter-relations are depicted.

As regards the percentage of explained variance, about 50 per cent of the variance in psychological workload at T2 was explained by the combined effects of psychological workload at T1, mechanical workload at T1 and neck/shoulder symptoms at T1. About 40 per cent of the variance in mechanical workload at T2 was explained by the combination of mechanical workload at T1, psychological workload at T1 and neck/shoulder symptoms at T1. About 50 per cent of the variance in neck/shoulder symptoms at T2 was explained by the combination of neck/shoulder symptoms at T1, psychological workload at T1 and mechanical workload at T1.

Discussion

There are many theoretical process models of the relation between psychosocial work environment and ill health, including potential mediating mechanisms and interaction effects. However, as has been previously noted, although there is a vast literature on the effects of risk factors on the incidence and prevalence of outcomes, in the framework of work-related musculoskeletal disorders there are few studies that empirically test these theoretical process models using multivariate data analysis in order to specifically test these proposed mechanisms. The main advantage of the present thesis is the use of analysis techniques that enable the empirical testing of such process models in the area of the psychosocial work environment and musculoskeletal symptoms. The empirical results found in the present studies, which carried out these analyses, adds further to the knowledge of the relations in this area, particularly as regards the relation between psychological workload and the development of neck/shoulder symptoms, and contributes to the further understanding of the potential mechanisms of stress and fatigue involved in these processes.

Psychosocial work environment and musculoskeletal symptoms

Appraised psychological workload was positively related to musculoskeletal symptoms in both study I (cross-sectional) and study III (longitudinal). These results can be viewed in accordance with general theoretical models of work and health, e.g. the psychosocial stress model (Sauter & Swanson, 1996) where psychosocial stressors influence health through cognitive appraisals of the work situation. These findings are consistent with those of earlier studies, e.g. with the review studies by Bongers et al. (1993), who found that, among others, a high perceived workload was related to musculoskeletal symptoms, and by NIOSH (1997), where it was concluded that intensified workload was consistently associated with neck/shoulder musculoskeletal symptoms. In study IV, consistent with studies I and III, psychological workload at baseline was found to be positively related to neck/shoulder symptoms at follow-up when controlling for the effects of baseline mechanical workload in the restricted sample (containing only those subjects considered symptom free at the baseline measurement). This means that the higher the psychological workload at baseline the more neck/shoulder symptoms at follow-up. Because the restricted sample consisted only of participants with no symptoms at baseline, this result can be interpreted such that psychological workload has an effect on the development of musculoskeletal symptoms. However, in the total sample, psychological workload at baseline was not related to symptoms at follow-up (when controlling for baseline symptoms and mechanical workload). On the contrary, for the total sample, reversed causality was indicated such that the more symptoms at baseline the higher the psychological workload at follow-up. There are several plausible interpretations of this finding. It has e.g. been suggested that persistent symptoms may affect the employee's reports of workload (Faucett & Rempel, 1994). This finding may also be interpreted as a feedback effect, supporting the reciprocal effects of musculoskeletal symptoms on e.g. psychological strain suggested by Sauter and Swanson (1996). Furthermore, "reversed" causality may be the operating mechanism, such that the presence of neck/shoulder symptoms may lead to the worker being forced to adopt new work techniques and/or being forced to reduce the work pace which, especially in combination with a maintained level of productivity and perceived job demands, may lead to an increase in the appraisal of the workload. Since the total sample consisted of all participants regardless of their baseline musculoskeletal status, this model does not distinguish between different processes such as the development, persistence or recovery from symptoms. The results can therefore be interpreted such that, although psychological workload seems to be important for the development of symptoms, it may be of less importance for the other processes. This finding is somewhat inconsistent with the results of study I, where psychological workload was related to neck/shoulder symptoms in a total sample also not distinguishing from different symptom processes. However, these results should not be considered directly comparable as they have different designs, different samples and somewhat different outcome variables (see "methodological considerations" for a discussion of these issues).

Study III also included another appraisal of the psychosocial work environment – job satisfaction. In that study, job satisfaction was not related to the development of neck/shoulder symptoms neither in bivariate analyses nor when controlling for the effects of psychological workload. This finding is partly in accordance with that of Pousette and Johansson Hanse (2002) who, in a multi group study, found job satisfaction to be related to ill health (including musculoskeletal symptoms) among white-collar workers, but not among blue-collar or elderly- or child-care workers when controlling for the effects of psychological workload. The absence of a relation between job satisfaction and neck/shoulder symptoms is also consistent with the review studies reporting inconclusive evidence for job dis-satisfaction as a risk factor for neck/shoulder symptoms (Ariens et al., 2001b; van der Windt et al., 2000) and with the review study by Bongers et al. (2002), who found no evidence for poor job satisfaction as a risk factor for upper arm/shoulder symptoms. These results are further in accordance with Engels et al. (1998), who did not find a significant relation between job satisfaction (task content and decision latitude e.g. "do you find the work most of the time pleasant?", daily leadership e.g. "is the daily leadership OK?", and job appreciation e.g. "is your salary in accordance with the work you perform?") and musculoskeletal (back, neck, shoulder and leg) symptoms among Dutch home nursing staff. However, contradictory results exist. For example Leclerc et al. (1999) found high job satisfaction (e.g. satisfaction with the work station and co-worker relations) to be a protective factor for the one-year incidence of neck symptoms, while it was not protective for the one-year persistence of neck symptoms.

The mediating mechanisms of perceived fatigue and felt stress

Although the present thesis distinguishes between the potential mediating mechanisms of stress and fatigue, these concepts are probably interrelated. The present thesis is based on the assumption that there are two main mechanisms by which aspects of the psychosocial work environment may influence fatigue. An adverse psychosocial work environment may be directly related to fatigue e.g. through monotonous, uninteresting work tasks leading to a decreased level of arousal and/or motivation, or through a high level of sensorial and/or information processing demands etc (Finkelman, 1994). There may also be an indirect relation through stress such that fatigue is the result of a prolonged exposure to stress (Cameron, 1973) and trying to adapt to the stressful situation. A high level of stress may further interact with fatigue by inhibiting adequate recovery. The relation between stress and fatigue has however not been investigated in the studies in the present thesis and needs to be considered in future research.

Psychological workload was positively related in study I both to the general aspect of perceived fatigue – lack of energy – and to the different specific aspects of perceived fatigue: physical exertion, physical discomfort, lack of motivation, and sleepiness. The results thus indicate that an increase in psychological workload cause an increase both in all measured aspects of perceived fatigue and in musculoskeletal symptoms. In study III psychological workload at baseline was related to general fatigue, both at baseline and at follow-up. The results of study III thus concur with those of study I. However, although the measurement of psychological workload was identical in these studies, the measurement of fatigue was not. In study I general fatigue ("lack of energy") was measured using multiple items, "overworked", "spent", "drained", "worn out" and "exhausted", while in study III general fatigue was measured using a single item, "fatigued and spent after work".

Fatigue in the present thesis is viewed in accordance with Grandjean (1970) as a phenomenon having a partly protective function that makes us avoid further stress, thus enabling recovery when exposure has reached a critical level. This means that perceived fatigue signals that recovery is needed and that, unless recovery is obtained, the individual might suffer harmful consequences such as musculoskeletal injuries. Fatigue was therefore hypothesized to partly mediate the relation between psychological workload and musculoskeletal symptoms, which means that a high workload in part should be harmful to the extent that it causes fatigue.

As regards the potential mediating mechanism of perceived fatigue, studies I and III yield somewhat inconsistent results. The results of study I indicate that the relation between psychological workload and musculoskeletal symptoms is not mediated by the general fatigue indicator of "lack of energy". In study III, however, the relation between psychological workload and the development of neck/shoulder symptoms was partially mediated by general fatigue at follow-up (but not at baseline). It is important to remember that, with regard to testing this mediating mechanism, these studies differ in that they have different designs and different study populations, and in that they investigate different symptoms and symptom processes.

In study I the relation between psychological workload and musculoskeletal symptoms was partly mediated by "physical discomfort" (aching, hurting, stiff joints, numbness and tense muscles) and "lack of motivation" (uninterested, passive, indifferent, lack of concern and listless) but unmediated by "physical exertion" (breathing heavily, out of breath, warm, sweaty and palpitations) and "sleepiness" (sleepy, yawns, drowsy, fall asleep and lazy). The relation between psychological workload and symptoms was only partially mediated by physical discomfort, which means that psychological workload had a unique effect on musculoskeletal symptoms not through the intermediary of physical discomfort. A possible interpretation of this result is that a high psychological workload may cause musculoskeletal symptoms without first causing perceived muscular discomfort. The results of study I thus indicate that it may not be sufficient to use a unidimensional, unspecific indicator of perceived fatigue in an analysis of the role of perceived fatigue in the development of musculoskeletal symptoms. Such indicators are likely to be affected both by critical aspects of fatigue and aspects that are irrelevant for the understanding of musculoskeletal problems. The indicators of physical discomfort used in this study (aching, hurting, stiff joints, numbness and tense muscles) partly deal with localized fatigue and are in content rather close to the outcome variable musculoskeletal symptoms, although more general and not restricted to the neck, shoulder and back regions. These results concur with previous research that indicates that (subjective) perceived muscular tension, a concept in content fairly close to physical discomfort (e.g. compare "muscular tension" with the physical discomfort indicator "tense muscles"), is related to neck/shoulder pain (Holte et al., 2003; Wahlström et al., 2004). The indicators of physical exertion (breathing heavily, out of breath, warm, sweaty and palpitations) may be regarded as indicators of general (whole) body fatigue. The (partial) mediation of localized fatigue but not general whole body fatigue found in study I is consistent with results of experimental studies. In a study investigating both self-reported fatigue and fatigue as measured using EMG, Gorelick et al. (2003) found that specific fatigue, but not non-specific widespread fatigue, produced significant changes in the timing of trunk muscle activation during a stoop lift, and that short-duration motor tasks could lead to muscular injury without causing high levels of perceived general fatigue. They conclude that work tasks commonly found in manual-handling activities may lead to an increased risk of injury without the workers perceiving a high level of fatigue. Thus, even though fatigue can be viewed as a warning signal that the ongoing activity should be ended because problems or injuries are about to develop (Åkerstedt, 2004), it is possible that light manual work does not induce warning signals, i.e. sensations of fatigue, or that individuals may have learned to ignore such sensations (Sandsjö, 2004).

The present thesis is based on the hypothesis that fatigue mediates the relation between psychosocial work environment and musculoskeletal symptoms, and thus the assumption that an adverse psychosocial work environment causes (work related) fatigue, which, in turn, causes musculoskeletal symptoms. However, at least three other models may be invoked to understand the relations between psychosocial work environment, fatigue and symptoms. An alternative set of causal relations may operate such that an adverse psychosocial work environment causes musculoskeletal symptoms, and (muscular) fatigue can be viewed as an early manifestation of symptoms, i.e. fatigue precedes but does not cause symptoms. Another plausible interpretation of these relations is that an adverse psychosocial work environment causes both fatigue and symptoms, which are two simultaneous, correlated, but not causally related outcomes. Furthermore, reversed causality may operate such that musculoskeletal symptoms cause fatigue and an adverse psychosocial work environment (i.e. all of the arrows in the hypothesized model would be reversed). These different types of models are statistically equivalent, i.e. they would yield the same covariance matrix and hence an identical model fit (see e.g. Kline, 2005, for a discussion of equivalent models in structural equation modeling). Distinctions between these different models of causality thus cannot be made on the basis of the results of study I. Study III is based on two-wave longitudinal data and provides an opportunity to test the temporal relations between aspects of the psychosocial work environment (psychological workload and job satisfaction) and neck/shoulder musculoskeletal symptoms. However, since there were only two waves, the testing of mediational hypotheses could not fully take temporal aspects into consideration, i.e. one part of the structural model had to be cross sectional, and the study can be viewed as having a "half-longitudinal" design (Cole & Maxwell, 2003). It may be argued that the results of study III yield stronger support for the hypothesis that *general* fatigue and neck/shoulder symptoms are correlated (but not causally related) outcomes, as fatigue at baseline was not directly related to neck/shoulder symptoms at follow-up (when controlling for the effects of the other independent variables) while fatigue at follow-up was related to symptoms at the same measurement occasion. On the other hand, this lack of a relation may also be due to a non-optimal (too long) spacing between the waves that leads to an underestimation of the true effect (Zapf et al., 1996).

Perceived work demands were positively related in study II to felt stress (rested, relaxed, calm, tense, stressed and pressured). This finding is in accordance with previous research (e.g. Kjellberg et al., 2000; Kjellberg & Wadman, 2002). Felt stress was positively related to musculoskeletal neck/ shoulder symptoms, which is also in accordance with previous research, e.g. with the review study by Linton (2000), who concluded that stress was a significant risk factor for neck pain, and with the review study by Bongers et al. (2002), who found high work stress to be consistently associated with upper extremity symptoms.

There was an indirect positive effect of work demands on musculoskeletal symptoms (through stress) in study II, such that the higher the perceived work demands the higher the risk of having symptoms in the neck and shoulder. This result is consistent with e.g. Jensen et al. (2002), who in a study among computer users found high quantitative job demands to be a predictor of neck symptoms, and Ariens et al. (2001a), who in a prospective study among a general working population found high quantitative job demands to be a risk factor for neck pain. This indirect effect of job demands on neck/shoulder symptoms through the intermediary of felt stress provides empirical support for (parts of) the model proposed by Melin and Lundberg (1997) where unsatisfying psychosocial factors (such as too high job demands) lead to increased psychological stress, which increases the risk for musculoskeletal disorders.

The results of study II further showed no direct effect of job demands on musculoskeletal symptoms, which means that all of the effect of job demands on symptoms was transmitted through felt stress, or, in other words, that high perceived job demands cause musculoskeletal symptoms only to the extent that they cause a person to feel stress. Kristensen et al. (2002) conclude in a study of socio-economic status and psychosocial work environment that the optimal level of demands depends on the resources of the individual worker and thus that demands cannot be considered harmful in themselves. The results of study II are in accordance with such an interpretation since, if no consideration is given to the individual levels of felt stress, there is no relation between demands and symptoms.

Emotional stress could probably be an overall contributor to muscle tension and feelings of musculoskeletal discomfort (Goldstein, 1964; Ursin et al., 1988). Muscle tension has been reported to be associated with various pain states, for example headaches and low back pain (Sarafino, 1990). Theorell et al. (1991) found a significant association between high job demands and muscle tension. Furthermore, they also found an association between muscle tension and an index of neck, shoulder and back symptoms, and they concluded that muscle tension could be a pathway from poor psychosocial conditions at work (work characteristics) to musculoskeletal symptoms.

The finding in study II that work demands influence musculoskeletal symptoms through the stress mechanism could be explained by the Cinderella hypothesis (Hägg, 1991). The results could be interpreted such that the presence of felt stress leads to activation of low threshold trapezius muscle motor units that is sustained over a long period of time. These results are in accordance with Lundberg et al. (2002) who, in an experimental study, found results indicating that mentally induced stress might contribute to keeping low threshold motor units active, and who concluded lack of mental rest to be an important risk factor for the development of muscular pain.

The results of study II can be viewed as providing empirical support for the psychosocial stress model (Sauter & Swanson, 1996), where stressors (demands) cause stress effects and subsequent illness (see fig. 1). In this study, the structural equation modeling analysis showed a path from the perceived work characteristic (stressors, i.e. work demands) via an appraisal of the psychosocial work situation (i.e. felt stress) to musculoskeletal symptoms (illness). Thus psychosocial work characteristics (e.g. work demands) affect workers through the mediation of appraisal (e.g. felt stress) and may thereby cause musculoskeletal symptoms. The appraisal of person-environment interactions in terms of e.g. work demands on the one hand and the worker's abilities (capacity) on the other have an effect on the musculoskeletal system. This is in accordance with general theoretical models of work and health (Levi, 1994).

Psychosocial and physical work environment and musculoskeletal symptoms; potential interaction effects

The aim of study IV was to test the longitudinal (two-wave) relations between psychological and mechanical workload and musculoskeletal neck/shoulder symptoms. Because psychosocial and physical stressors are thought to interact (e.g. Devereux et al., 2002; Winkel & Westgaard, 1992), this study also tested for a potential interaction effect of psychological and mechanical workload on symptoms.

In study IV self-reported mechanical workload at baseline was not related to musculoskeletal neck/shoulder symptoms at an 18-month follow-up when controlling for baseline symptoms and psychological workload, neither in the total nor in the restricted sample. There were also no interaction effects between psychological and mechanical workload on neck/shoulder symptoms, in any of the samples. These results are contrary to those of Balogh et al. (2001) who, in a study among a general population, found mechanical load, as measured with a similar index as in the present study ("lying down", "kneeling or squatting", "back rotated a lot", "back bent forward a lot", "head bent backward", "head bent forward a lot", "arms elevated or stretched forward", "repetitive arm movements", "precise movements", "vibrating hand tools", "lifting and carrying a few 100 grams"), to show an exposure-effect relation for the one-year incidence of neck/shoulder pain. Our results are somewhat contrary to those of Östergren et al. (2005) who, in a study among vocationally active elderly (i.e. between 45 and 65 years old) Swedes, found high mechanical exposure to be related to the one-year incidence of shoulder/neck pain among both men and women, while high job strain was related to the incidence of shoulder/neck pain among women solely. That study (Östergren et al., 2005) further found a synergistic effect of mechanical load and job strain among women but not among men.

The absence of a relation between mechanical workload at baseline and neck/shoulder symptoms at follow-up in study IV should not be interpreted as implying that mechanical load is not important for the development of musculoskeletal symptoms. Instead, several alternative explanations are possible. First, the absence of a relation could be interpreted as an indication that the questionnaire instrument lacks in precision (see Burdorf & van der Beek, 1999 and Winkel & Mathiassen, 1994 for a discussion on the measurement of self-assessed physical load using questionnaires). Second, it may also be argued that other types of physical stressors than the mechanical workload included in the present study, such as forceful exertion (NIOSH, 1997), are important predictors of neck/shoulder symptoms and/or that the mechanical load for most workers included in the present study was not high enough to exceed the critical threshold beyond which the loading becomes harmful.

Magnitude of the relation

As regards the estimated sizes of stressor-strain relations in general, Zapf et al. (1996) and Frese and Zapf (1988) argue that small relations should be expected both from a content (e.g. because of the multi-causality of the phenomenon) and from a methodological (e.g. because of moderated effects, healthy worker effects and the use of erroneous time lags) point of view. The association/relation between aspects of the psychosocial work environment, stress, fatigue and musculoskeletal symptoms found in most studies show small to moderate odds ratios, risk ratios, standardised regression weights or correlation coefficients.

Psychosocial work environment and fatigue. As regards the relation between psychosocial work environment and fatigue, Bültmann et al. (2002b) found odds ratios ranging between 1.26 and 2.70 for single risk factors and between 1.63 and 3.48 for a combination of two risk factors, with the highest odds ratio for people working in high strain jobs, i.e. exposed both to high job demands and low decision latitude, as compared to people working in low strain jobs, i.e. exposed to neither high job demands nor low decision latitude. In longitudinal analyses based on the same study (the Maastricht Cohort Study) Bültmann et al. (2002a) found odds ratios for single risk factors ranging between 1.41 and 2.25. In yet another (cross sectional) study based on the Maastricht Cohort Study using the same measures, Bültmann et al. (2001) found that occupation in combination with all the psychosocial variables (psychological demands, decision latitude, co-worker and supervisor support, emotional demands, conflict with supervisor and co-worker, and job insecurity) and physical demands explained about 17 per cent of the variation in fatigue. The above mentioned odds ratios are in accordance with those found in Pelfrene et al. (2002), ranging between 1.21 and 1.70. They also concur with the odds ratios found in Åkerstedt et al. (2002) and Åkerstedt et al. (2004). The studies that carried out linear regression or correlation analyses report standardized regression coefficients ranging between .09 and .26 (De Croon et al., 2002) and between .16 and .31 (Schreurs & Taris, 1998) and correlation coefficients with a maximum value of .33 (Åhsberg, 2000). The study by Schreurs and Taris also reports percentage of explained variance, showing that a model where job demands were the only significant predictor explained 3 per cent of the variation in fatigue among software engineers and 10 per cent of the variation in fatigue among university staff. The longitudinal study of Michielsen et al. (2004) reports a standardized regression coefficient of .10 for fatigue at follow-up regressed on workload at baseline with control for baseline fatigue, emotional exhaustion and strength of inhibition.

Psychosocial work environment and musculoskeletal symptoms. Reviews of previous research on the relation between psychosocial work environment and musculoskeletal neck/shoulder and back symptoms usually find odds ratios/risk ratios ranging from 1.1 up to about 3.0 (see e.g. Hansson, 2001; Hoogendoorn et al., 2000; van der Windt et al., 2000). A recent meta-analysis (Faragher et al., 2005) found a correlation coefficient of about .08 for the association between job satisfaction and musculoskeletal symptoms. For the relation between stress and musculoskeletal symptoms, previous research has found odds ratios ranging between 2.24 and 2.90 in cross sectional studies (Kang et al., 2003) and odds ratios of up to about 2.00 in longitudinal studies (Miranda et al., 2001; Nahit et al., 2003; Viikari-Juntura et al., 2001). Higher odds ratios have been reported, e.g. by Viikari-Juntura et al. (2001), who found odds ratios of 2.2 and 6.4 for the risk factors “mental stress to some extent” and “much mental stress” as compared to “no mental stress at all”. In another study, Bru et al. (1997) found both total and work-related stress to be correlated with neck, shoulder and low back complaints, with correlation coefficients ranging from 0.14 to 0.31.

The size of the relations between aspects of the psychosocial work environment, stress, fatigue and musculoskeletal symptoms found in the present studies are thus of the magnitude that could be expected given the findings of previous research. For example, in the present studies (papers I – IV), the regression coefficients (total effects) of psychological workload on musculoskeletal symptoms range from about .20 (longitudinal study with control for mechanical load and the autoregressive effect of baseline symptoms) to .47 (cross sectional study without such control), while the (standardized) regression coefficient of stress on symptoms (in a cross sectional study) is .51, and the (standardized) regression coefficients of fatigue on symptoms range between .20 and .48 (cross sectional analyses).

Methodological considerations

In the present thesis structural equation modeling was used to test hypothesized models against empirical data. This analysis technique was chosen mainly because of its ability to deal with latent variables and to simultaneously test all relations included in complex process models, thus providing estimates of indirect (mediated) effects. A common theme in criticism of structural equation (SE) modeling has been that some researchers may believe that performing SE modeling on cross sectional data implies performing causal modeling (see e.g. Brannick, 1995), which is, of course, not true. Structural equation models are based on certain assumptions of causality, assumptions which, using cross sectional data, cannot be tested. It must however be remembered that this argument holds equally true when analyzing cross sectional data using other types of analysis techniques such as ordinary regression models. As stated by Kelloway (1995):

> “The primary basis for causal inference in structural equation modelling is the same as the basis for causal inference in any other statistical technique; the design of the data collection” (Kelloway, 1995, p. 216).

It may even be argued (or at least hoped for) that, because specifying SE models requires making the hypotheses about causality explicit, there is a greater awareness of the importance of theoretical support for these hypotheses (Williams, 1995). Either way, it seems that this criticism of structural equation modeling should be reframed as a note of caution on drawing causal inference in general, regardless of the analysis technique used. Perhaps this apparent limitation of the methods instead reflects shortcomings of the users (Williams, 1995).

The structural equation modeling in studies I and II indicates significant relations between aspects of the psychosocial work environment and musculoskeletal symptoms. The models tested in studies I and II must however be considered "as if" models of causality (Kline, 1998). The construction of the models and the interpretation of the results involved assumptions considering temporality. The models were specified such that aspects of the psychosocial work environment (psychological workload in study I and perceived work demands in study II) cause certain psychological perceptions/appraisals (perceived fatigue and felt stress, respectively) and that these aspects of the psychosocial work environment and these psychological perceptions/appraisals cause musculoskeletal symptoms. These assumptions are based on previous research and on theoretical considerations and, as such, are considered plausible. However, other patterns of causality such as e.g. reversed or reciprocal causality might also be plausible. It is e.g. possible that a lack of motivation[2] causes a person to perceive his or her workload as higher, that musculoskeletal symptoms cause lack of motivation (study I), that felt stress influences the perception of musculoskeletal symptoms, or that suffering from musculoskeletal symptoms causes a person to perceive higher work demands and a higher level of felt stress (study II). Because of the cross sectional design of these studies, i.e. all data were collected at the same time, it is difficult to make causal inferences, i.e. it is (in general) not possible to establish the direction of causality or different strengths of potential reciprocal effects (Blossfeld & Rohwer, 2002). However, results from the longitudinal analyses in studies III and IV in general also indicate significant relations between aspects of the psychosocial work environment and musculoskeletal symptoms, which can further contribute to the evidence of causality in the relation between psychosocial work environment and musculoskeletal symptoms.

In general, there is a lack of empirical research focusing on the issue of reversed causality in the work-stress and health relations (Kalimo, 2005) and not many models and mechanisms explaining such relations exist. The analyses in study IV were specifically designed to enable addressing the issue of reversed causality (see e.g. Kalimo, 2005; Zapf et al., 1996) in the psychosocial work environment-musculoskeletal symptom relation. This study found some evidence of reversed causality, as, in the total model, symptoms at baseline were related to the appraisal of the psychological workload at follow-up.

[2] It is important to remember that this study focuses on lack of motivation in general, as a dimension of fatigue (Åhsberg, 2000), and not on work-related motivation or motivators (e.g. Herzberg et al., 1993).

The results of the present studies may be influenced by a reporting bias, i.e. because the prevalence of musculoskeletal symptoms was measured by self-reports, it may have been over- or underestimated. Although clinical examinations should not be viewed as the "gold standard", previous research has found subjective reports (questionnaires) to give a fairly good picture of clinically assessed disorders (Björkstén et al., 1999; Ohlsson et al., 1989). However, the present studies focused on the subject's experiences of symptoms and not on clinical diagnoses; hence self-reports of symptoms were considered the most relevant source of information.

Another problem related to the use of self-reported data only is the possible effect of response bias. It is possible that subjects respond to the questionnaire items in a certain manner, so that those reporting high levels of symptoms also tend to report adverse psychosocial conditions. The results of the present studies may also be influenced by recall bias, i.e. that people affected by symptoms report more adverse psychosocial work conditions because they are more aware of these issues than are those unaffected by symptoms (see e.g. Hernberg, 1992 for a general discussion of recall bias). Theorell and Hasselhorn (2005) discuss potential problems inherent in using self-reports in (cross sectional) studies of the relations between psychosocial work environment and ill health, among these being: inflated relations due to the inclusion of subjects who "complain about everything" (i.e. over-report environmental as well as health problems) and/or subjects who "complain about nothing" (i.e. under-report both environmental and health problems), underestimation of risks because of a high proportion of subjects in the population who complain about nothing, and overestimation of risks because of a high proportion of subjects who complain about everything. They conclude, however, "cross sectional self-report assessments of psychosocial conditions and health have an important role in stress research" (Theorell & Hasselhorn, 2005, p. 521).

The results of the present studies might also have been influenced by the so called healthy worker effect (Hernberg, 1992), which is a negative bias that is caused by health-based selection in and out of employment (i.e. people with health problems not being employed, and employees developing health problems leaving their employment). The existence of such a bias would lead to an underestimation of the occurrence of symptoms. The healthy worker effect not only influences the frequency of reported symptoms but also leads to an underestimation of the true effect (Ahlbom et al., 1990), i.e. a decrease in the estimated relation between exposure and symptoms, which means that, if a healthy worker effect was present in the study, the relations between the variables are actually stronger than reported. In the present studies, the risk of a healthy worker effect is particularly high in study II. This is due to the design of the overall NEW case-control study, in which subjects with a high incidence of symptoms (i.e. reporting symptoms for more than 30 days during the past 12 months in more than three body regions) or having been on sick or other leave from work (other than vacation) for more than three consecutive months during the past five years were excluded from the study. The severe cases, those suffering from symptoms in many body regions and/or having been on a longer sick leave, were thus not included in the study, which may well have led to an underestimation of the true effect of work demands on musculoskeletal symptoms.

As already mentioned, different occupations have been sampled in the present studies. The first study deals with blue-collar workers at Swedish assembly plants (both male and female), the second study deals with elderly female computer users in European countries, and the third and fourth studies deal with (predominantly female) elderly- and child-care workers in Sweden. This means that the results of these studies are not directly comparable (see e.g. Pousette & Johansson Hanse, 2002 for a discussion of occupation specific versus generic models), and it should also be clear that it might be inappropriate to make generalizations outside of the respective occupations. Within each of the present studies, several different workplaces and/or occupations have been combined into a study sample. In study I, for example, three different plants dealing with different types of assembly work were combined into "blue-collar workers" and, in studies III and IV, elderly- and child-care workers at different workplaces were combined into a sample. In study II the study sample consists of a number of different occupations in a number of different organizations in four different European countries. Within each study sample, these different sub-samples were combined on the basis of the consideration that they represented workplaces with similar occupational exposures where similar relations between the variables under focus could be expected. This assumption was however not empirically tested in the analyses.

The present studies furthermore have different designs: cross sectional in studies I and II and longitudinal in studies III and IV, which also prohibits direct comparisons. When employing the definition of causality that a change in an independent variable causes a (subsequent) change in a dependent variable (see e.g. Blossfeld & Rohwer, 2002), longitudinal data containing information on within-subject change is the unit of analysis of interest. However, when analyzing cross sectional data, such information is lacking and inference can only be made about between-subject differences (Schaie & Hofer, 2001), which may not lead to similar conclusions. It has been shown that, because of the omission of time lags, autoregressive effects, and the effects of prior values of other variables, the cross sectional estimate of the "true" causal effect may be both an under- and an overestimation (Gollob & Reichardt, 1985, 1987) (note however that this does not mean that the time lag of 18 months employed in study IV is necessarily the "true" or "optimal" time lag). In practical social science research, cross sectional models have a tendency to overestimate the importance of the independent (explanatory) variables (Davies, 1987) for the reasons mentioned above. However, other mechanisms may work in the opposite direction (i.e. lead to underestimation of the importance of explanatory variables), e.g. the "healthy worker effect" (Hernberg, 1992).

The somewhat inconsistent results found in the present studies may also partly be due to different symptoms and symptom processes having been investigated, i.e. a mix of different symptoms (neck, shoulder and upper and lower back) and symptom processes in study I, presence or absence of neck/shoulder symptoms in study II, the development of neck/shoulder symptoms in study III, and the development of neck/shoulder symptoms and other neck/shoulder symptom processes in study IV. These different operationalizations of the outcome variable may partly explain the somewhat inconsistent results since there may be different risk factors for neck/shoulder as compared to back symptoms (see e.g. Ariens et al., 2001b; Bru et al., 1996; Hoogendoorn et al., 2000; NIOSH, 1997; van der Windt et al., 2000).

In order to study change over time in latent variables, measurement invariance is a critical condition, necessary for valid inference and interpretation (Cheung & Rensvold, 1999; Horn & McArdle, 1992). Because the focus of study IV in the present thesis was to study such latent variable change, factorial invariance was considered a critical prerequisite for the analyses of change. Tests of factorial invariance over measurement occasions showed that strong factorial invariance was obtained for the entire measurement model. This means that factor loadings and intercepts did not differ significantly between the measurement occasions, while the error variances did. However, it has been argued that testing for the invariance of the error parameters (variances and covariances) represents an overly restrictive test of the data (Byrne, 2004) and that strict metric invariance is not needed in many applied research situations (Cunningham, 1991). The lack of error variance invariance therefore, although it must be acknowledged, was not considered a major problem for the substantive interpretation of the present analyses.

In study IV interaction effects were tested using the latent moderated structural equations (LMS) approach (Klein & Moosbrugger, 2000). This choice of method may be questioned since simulation studies have shown that, in addition to a high power, it also has higher Type I error rates and is more biased for non-normal data than other approaches (Marsh et al., 2004). An underlying assumption of the LMS approach is that the manifest indicators of the independent variables involved in the interaction are normally distributed (Klein & Moosbrugger, 2000). No severe violations of this assumption were found in the present study, and the use of the LMS approach was thus considered appropriate.

Time lags and shapes of the unfolding effects: recommendations for future research

Although there is ample research support for a hypothesized relation between aspects of the psychosocial work environment and musculoskeletal symptoms, the temporal aspects of the development of musculoskeletal symptoms and the shapes of the unfolding effects (i.e. how the effect develops over time) remain unclear. It has been noted that, in longitudinal studies of the work stressors-strain relation, organizational/pragmatic reasons seem more important for the choice of time lag than theoretical considerations (Taris & Kompier, 2003; Zapf et al., 1996). This (arbitrary?) choice of time lag may also be a product of limited research and theory on what constitutes the optimal time lag. For example, it has not been established whether the development of (work-related) musculoskeletal disorders has a sudden onset or “over days, weeks, months or years of exposure (gradual onset) and in a cumulative fashion even in the presence of small exposures and/or in one or a series of overdose” (Forcier & Kuorinka, 2001, p. 1629).

An assumption of studies using panel designs is that the interval between waves is of approximately the same length as the true causal time lags (Blossfeld & Rohwer, 2002). However, if the optimal time lags are not known, this assumption will probably not hold. A related problem is that of the shapes of the unfolding effects, i.e. there may be different shapes of how the effect develops over time (Blossfeld & Rohwer, 2002). Frese and Zapf (1988) discuss five different models of how the effect of stressors on ill health may develop over time: *the stress reaction model,* where a stressor linearly increases ill health with exposure time, *the accumulation model,* where ill health develops as a result of accumulated stress and remains even after the stressor has been removed, *the dynamic accumulation model,* where a stressor continues to exert its effect even when it has been removed, *the adjustment model,* where there is first a linear effect of the stressor on ill health but at a certain point ill health decreases although the stressor remains the same, and *the sleeper effect model,* where the effect appears a long time after exposure to a stressor. Other models are also plausible; see e.g. Blossfeld and Rohwer (2002) for a discussion of shapes of the unfolding effect in the social sciences. In addition to these (longitudinal) non-linear models (*being non-linear as a consequence of the shapes of the unfolding effects*), other types of non-linearity should also be investigated. Non-linear relations may for example be expected when studying workload and (ill) health since it is a basic hypothesis in work stress theory that under- as well as over-load may generate strain. Warr (1994) in the “Vitamin model” specifies work characteristics such as opportunity for job control, skill use and interpersonal contact, which are expected to have non-linear relations with mental (ill) health as too high levels of these factors, as well as their absence, are expected to be detrimental to health.

Consistent with most of the previous (longitudinal) research in the organizational stress area (Zapf et al., 1996), the analyses made in the present thesis generally assume linear relations between stressors, mediators and strain (i.e., similar to the stress reaction model of Frese and Zapf, 1988), although the analyses in studies III and IV allow for different stressor-strain effects for the development of symptoms as compared to other symptom processes. It has been argued (Zapf et al., 1996) that, because there are different possible shapes of the unfolding effect, linear data analysis methods usually underestimate the true strength of stressor-strain relations. In order to be able to address these questions, longitudinal studies with multiple measurement points are required (Taris & Kompier, 2003).

In addition to the testing of process models, future research should thus focus on investigating the shapes of the unfolding effects and optimal time lags using longitudinal data and employing data collection designs and analysis techniques specifically designed for these purposes such as multilevel modeling, growth curve modeling and event history analysis. However, it must also be remembered that there is not only one “optimal” time lag, and thus many different time lags, and time specific indirect effects, must be studied in order to fully understand the causal effects (Gollob & Reichardt, 1985, 1991). When testing complex process models, it is plausible that different shapes of the unfolding effect operate for different stressors, such as e.g. psychological and mechanical workload (as well as for different mediators), and also that the time lags required to detect these effects differ for these different variables (see e.g. Frese & Zapf, 1988). This may of course further complicate the analyses, and, if erroneous time lags are employed e.g. due to the need to minimize the number of waves of data collection, there is a risk that inaccurate conclusions are drawn. Addressing these issues enables the proper design of data collection and specification of models to be tested against empirical data. In addition to these research questions and methods, intervention studies (quasi-experiments) could contribute to the understanding of the aetiology of musculoskeletal symptoms and to the knowledge of factors related to recovery from such symptoms (Theorell & Hasselhorn, 2005).

As regards the relation between the psychosocial work environment and musculoskeletal symptoms, the present thesis investigates job demands, psychological workload and job satisfaction as potential stressors. In order to further enhance the understanding of this relation, process models including also other job features such as e.g. autonomy/job control, skill variety/skill discretion, social support, feedback, role conflict and clarity, and rewards need to be tested. In accordance with the psychosocial stress model (Sauter & Swanson, 1996) the present thesis gives primacy to environmental factors, and individual factors such as needs and resources are considered intervening variables. In future research however it would be useful also to specifically consider such individual factors as e.g. coping strategies (see e.g. Lazarus, 1993), sense of coherence (SOC) (Antonowsky, 1985; 1993) and negative affectivity (NA) (Watson & Clark, 1984) when testing these process models, as these factors may be related to strain, both directly and through their influence on stress perceptions and/or the resulting strain (Albertsen et al., 2001; Chen & Spector, 1991; Höge & Büssing, 2004; Larsson & Setterlind, 1990; Söderfeldt et al., 2000).

Conclusions

In complex domains, single studies can seldom provide a conclusive verification of causal propositions. It is through replication and synthesis of evidence across studies, preferably with studies that use a variety of methods, that causal claims gain their inferential strength. In the present thesis, process models investigating the relation between aspects of the psychosocial work environment and musculoskeletal neck/shoulder and back symptoms including potential mechanisms of mediation and interaction effects were tested using structural equation modeling. The thesis attempts first and foremost to contribute to the basic research on process models in the field of work and organizational psychology and musculoskeletal symptoms. The findings of the studies here highlight the complexity of the testing of such process models.

Psychological workload was consistently found to be related to musculoskeletal symptoms in different occupational contexts and study samples both in cross sectional (paper I) and longitudinal (papers III and IV) studies. Study IV supports the hypothesis that there are different risk factors that are related to the incidence and the recurrence or persistence of symptoms, in that psychological workload in study IV was related to symptoms when analyzing only the development of symptoms but not when analyzing all symptom processes. The issue of the potential mediating mechanism of perceived fatigue in the relation between psychological workload and symptoms was addressed in studies I and III, where an indication of partial, but not complete, mediation by certain fatigue dimensions was found. Physical discomfort seems to be of particular importance for the development of symptoms. Job demands were related to neck/shoulder symptoms in study II, and this relation was completely mediated by felt stress, which means that job demands were related to symptoms only to the extent that they caused feelings of stress.

The results of the present studies add evidence to the research literature that highlights the importance of the psychosocial work environment in the aetiology of musculoskeletal ill health, and further contribute to the knowledge of the mechanisms underlying this relation. The implications of this knowledge in terms of work (re-)design should be clear; in order to manage the substantial problem of musculoskeletal ill health, it is important to pay attention to the psychosocial conditions at the workplace. In order to prevent and/or reduce musculoskeletal symptoms, it is important to keep stressors such as job demands at optimal levels and to provide the resources necessary for employees to cope with these stressors. Measures that can be taken to address these issues thus include changing the work tasks and/or their distribution, increasing the employee influence and control over his/her work situation, e.g. by ensuring that breaks can be taken when needed, and striving for an increased social support from supervisors and co-workers (see e.g. Karasek & Theorell, 1990). Furthermore training in issues regarding stress and health, especially for supervisors, may serve a means to improve the situation (Eklöf et al., 2004). What aspects of the work environment that should be changed needs to be discussed with the employees (Faragher et al., 2005), i.e. employee perceptions of the work environment (e.g. demands) as well as their appraisal of the environment (e.g. psychological workload) need to be carefully considered. Furthermore, as felt stress and fatigue may serve as important mechanisms by which the psychosocial work environment exerts its influence on musculoskeletal symptoms, these factors may be viewed as warning signals that should be carefully monitored in order to detect potentially harmful situations so that long-term stress effects (illness) can be avoided. As longitudinal studies in general show prior musculoskeletal symptoms to be strong predictors of future symptoms (e.g. Luime et al., 2004) the focus should be on relieving strain before long-term stress effects have developed (Kalimo et al., 2002).

In conclusion, stress at work and the relation to musculoskeletal disorders will remain a major challenge to occupational health. However, our ability to analyze and understand the relations is improving. It is important to continue and to extend the empirical testing of hypothesized process models in this area in order to identify models that can be empirically confirmed. When such models have been found they need to be implemented in applied research and further considered in organizational (re-)design, management and workplace preventive or health-promoting interventions.

Summary

Larsman P (2006). *On the relation between psychosocial work environment and musculoskeletal symptoms: A structural equation modeling approach.* Arbete och Hälsa 2006:2

The aim of the present thesis was to investigate the relation between aspects of the psychosocial work environment and musculoskeletal symptoms including the testing of process models of the potential mediating mechanisms of felt stress and perceived fatigue, and the potential moderating mechanism of physical workload.

This thesis is based on four empirical studies. Studies I and II were cross sectional studies based on questionnaire surveys among blue-collar workers at Swedish assembly plants and elderly female computer users in four European countries, respectively. Studies III and IV were two-wave longitudinal cohort studies based on questionnaire survey data among elderly- and child-care workers in Swedish human service organizations. In all of these studies, proposed models of the relation between aspects of the psychosocial work environment and musculoskeletal symptoms were tested against empirical data using structural equation modeling (SEM).

In general, the results indicate a significant relation between the psychosocial work environment (job demands and psychological workload) and musculoskeletal neck/shoulder and back symptoms. The results further suggest that, although psychological workload seems to be important for the development of symptoms, it may be of less importance for other processes such as recovery from symptoms. Support was found for the hypothesized mediating mechanisms of felt stress and perceived fatigue. No support was however found for the hypothesized interaction effect of psychosocial and physical stressors (psychological and mechanical workload) on musculoskeletal symptoms.

In order to enhance our understanding of stress at work and its relation to musculoskeletal symptoms, it is important to continue and to extend the empirical testing of hypothesized process models in this area. It is of crucial importance to investigate the shapes of the unfolding effects and optimal time lags (i.e. how the effects develop over time and what time frames should be considered). Addressing these issues will enable a proper design of data collection and specification of process models to be tested against empirical data.

Key words: Psychosocial work environment, felt stress, perceived fatigue, musculoskeletal symptoms, process models, mediation, moderation, structural equation modeling.

Sammanfattning

Larsman P (2006). *On the relation between psychosocial work environment and musculoskeletal symptoms: A structural equation modeling approach.* Arbete och Hälsa 2006:2

Syftet med föreliggande avhandling var att undersöka relationen mellan den psykosociala arbetsmiljön och muskuloskeletala symptom, och att testa processmodeller över de möjliga medierande mekanismerna upplevd stress och trötthet samt den möjliga modererande mekanismen fysisk arbetsbelastning.

Denna avhandling baseras på fyra empiriska studier. Studie I och II är tvärsnittsstudier baserade på enkätundersökningar bland arbetare vid svenska industriföretag respektive äldre kvinnliga datoranvändare i fyra europeiska länder. Studie III och IV är longitudinella kohort-studier med två mätpunkter baserade på enkätundersökningar bland anställda inom barn- och äldreomsorg i Sverige. I alla dessa studier testades hypotetiska modeller över relationen mellan psykosocial arbetsmiljö och muskuloskeletala symptom mot empiriska data med hjälp av strukturell ekvationsmodellering (SEM).

I stort indikerar resultaten en signifikant relation mellan den psykosociala arbetsmiljön (krav i arbetet och psykologisk arbetsbelastning) och muskuloskeletala nack-/skulder- och ryggbesvär. Resultaten tyder också på att trots att den psykologiska arbetsbelastningen tycks vara en viktig faktor för uppkomsten av symptom så kan den vara av mindre betydelse för andra processer såsom tillfrisknande från symptom. Hypotesen att upplevd stress och trötthet utgör medierande mekanismer i dessa samband fann stöd i studierna. Däremot fanns inget stöd för hypotesen att psykosociala och fysiska stressorer (psykologisk och mekanisk arbetsbelastning) hade en interaktionseffekt på muskuloskeletala symptom.

För att kunna utöka vår förståelse för arbetsrelaterad stress och dess relation till muskuloskeletala symptom är det viktigt med en fortsatt och utökad empirisk testning av hypotetiska processmodeller inom detta område. Det är mycket viktigt att studera hur effekterna utvecklas över tid och vilka tidsintervall som är de mest relevanta. Att dessa frågor undersöks är en förutsättning för att data skall kunna samlas in på ett lämpligt vis, och för att processmodeller skall kunna specifieras och testas mot empiriska data.

Nyckelord: Psykosocial arbetsmiljö, upplevd stress, upplevd trötthet, muskuloskeletala symptom, processmodeller, mediering, moderering, strukturell ekvationsmodellering.

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