

PHYSICAL CAPACITY

AND WORK-RELATED MUSCULOSKELETAL SYMPTOMS

The study presented in this thesis was performed at the Institute for Research in Extramural Medicine (EMGO Institute) of the VU University Medical Center, Amsterdam, The Netherlands. This was done in close collaboration with TNO Quality of Life, Hoofddorp, The Netherlands. The EMGO Institute participates in The Netherlands school of Primary Care Research (CaRe), which was re-acknowledged in 2000 by the Royal Netherlands Academy of Arts and Sciences (KNAW).

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VRIJE UNIVERSITEIT

**Physical capacity
and work-related musculoskeletal symptoms**

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CHAPTER 1

INTRODUCTION

BACKGROUND

In the working population, muscle fatigue and musculoskeletal discomfort are common,^{1;2} which, in the case of insufficient recovery, may lead to musculoskeletal pain.^{3;4} Musculoskeletal pain is common both in the working and non-working population⁵ and is most commonly situated in the low back, neck, and shoulder regions.⁶ In 2000, the one-year prevalence rates of chronic back and neck pain in the Netherlands were 21% and 14%, respectively.^{6;7} Musculoskeletal pain at work may lead to medical consumption,^{6;8} sickness absenteeism, or disability claims⁹⁻¹² with high costs for society.^{13;14}

OVERVIEW OF RISK FACTORS FOR MUSCULOSKELETAL PAIN

Several factors have been found that may increase the risk of future musculoskeletal pain among workers. First, individual risk factors can be mentioned,¹⁵ such as gender,^{16;17} age,¹⁸⁻²³ and previous pain,²⁴⁻²⁶ but also lifestyle factors, such as obesity, diabetes mellitus, and smoking behaviour have been found to be associated with musculoskeletal pain in several studies.^{27;28} Second, specific work-related risk factors for musculoskeletal pain should be mentioned,¹⁵ i.e. exposure to physical or psychosocial factors. In the literature, evidence was found for lifting, manual material and patient handling, awkward postures, heavy physical work, and whole-body vibration as physical risk factors for future low back pain.^{2;15;29-31} Furthermore, evidence was found for high force demands, working in awkward postures, hand-arm vibration, workplace design, and repetitive movements as physical risk factors for future neck and/or shoulder pain.^{15;29;32-34} The results of studies on psychosocial work-related risk factors for low back or neck/shoulder pain were less consistent than those for physical work-related factors. Some reviews found evidence for high job demands, poor social support, job dissatisfaction, mental stress, perceived ability to work, belief that work is dangerous, and emotional effort.^{29;34-37} However, other reviews found insufficient evidence^{31;38} or evidence for no relation.³⁹

Physical capacity includes measures of muscle strength, muscle endurance, and mobility or flexibility, but also cardiovascular fitness. In this thesis, we focus on muscle strength, muscle endurance, and mobility of the spine. With respect to low physical capacity as a potential independent risk factor for future musculoskeletal pain among workers, we performed a systematic review and found several longitudinal studies on low back pain, but only three on neck or shoulder pain.⁴¹ We concluded that there was strong evidence for an absence of a relationship between trunk muscle endurance and the risk of low back pain, but

inconclusive evidence for a relationship with muscle strength or mobility and the risk of low back pain. Furthermore, we found inconclusive evidence for a relation between physical capacity and the risk of neck/shoulder pain.

The generally accepted conceptual model of physical capacity and exposure to physical factors states that workers with high physical capacity can better deal with high exposure to work-related physical factors than those with low physical capacity.²⁹ This model is commonly used in everyday occupational health care as an explanation for musculoskeletal pain. However, there is little empirical evidence to support the plausibility of this model. We could only find one longitudinal study on this topic.⁴⁰ In this study, higher incidence of musculoskeletal injuries was found among healthy workers who did not demonstrate the lifting strength that was required for the job, compared to those who did have the physical capabilities.

Despite contradictory results on a potential relationship between physical capacity and future musculoskeletal pain, physical exercises to increase physical capacity have been found as one of the few interventions with strong evidence to be primary preventive for low back⁴²⁻⁴⁷ or neck pain.^{44;45} There is however, insufficient evidence to recommend for or against any specific type or intensity of exercise.⁴² Furthermore, contradictive results have been found regarding general physical activity to be preventive for musculoskeletal pain.^{48;49} This may, however, be due to low intensity or non-specific training.

CONCEPTUAL MODEL

This thesis is based on the conceptual model of physical capacity and exposure to physical factors as shown in Figure 1.1. This generally accepted model states that an imbalance between physical capacity and exposure to work-related physical factors (i.e. low capacity in combination with high exposure) may lead to musculoskeletal pain. Despite contradictory results in the literature on the relation between physical capacity and future musculoskeletal pain, we assume that both low physical capacity and high exposure to work-related physical factors might be independent risk factors for musculoskeletal discomfort at short-term and pain at long-term. Furthermore, we assume that an imbalance between these two risk factors might be a stronger risk factor than each of these variables on its own. On the other hand, we assume that high physical capacity in combination with low exposure may be protective against musculoskeletal pain. This may lead to musculoskeletal discomfort in and around muscles, tendons and joints at short-term, which can become manifest as tension, muscle fatigue, soreness, heat, tremor, et cetera. In the case of insufficient

recovery, short-term effects may end as long-term effects, i.e. musculoskeletal pain. These relations may be confounded or interacted by several individual factors, such as gender, age, physical load during leisure time, general health status, psychosocial work-related factors, et cetera. We assume that physical capacity is dependent of age and gender, and physical training leads to an increase of physical capacity.

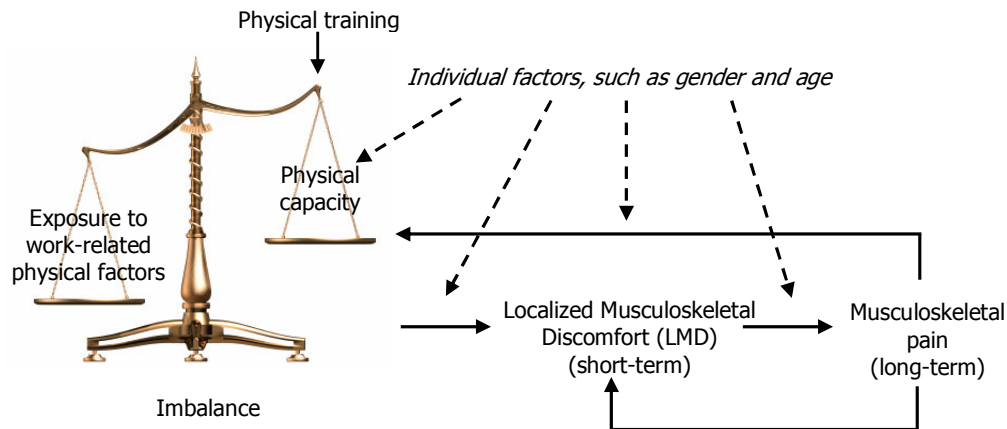


Figure 1.1. Conceptual model of physical capacity and exposure to physical factors.

Definitions of variables of interest

In this thesis, we speak about the conceptual model of physical capacity and exposure to physical factors. In the literature, different names and different types of figures have been used to describe this model, i.e. the (biomechanical) load-tolerance model,²⁹ the model of work capacity and workload,^{50;51} or the model of work capability and work demands,⁵² which is used in the Functional Capacity Evaluations literature. Confusion with the *psychosocial* demand-control(-support) model, and the effort-reward imbalance model has to be avoided. These psychosocial models state that high psychological job demands in combination with low control, or low rewards is a risk factor for several work-related health problems.⁵³

In this thesis, physical capacity includes isokinetic muscle strength, static muscle endurance, and mobility of the lumbar spine. Muscle strength is defined as “the ability of the muscle to exert force”; muscle endurance as “the ability to execute contractions for a prolonged period of time”. Muscle endurance and muscle strength can be referred to as “muscular capacity”. Mobility (or flexibility) is defined as “the ability to move a joint through its complete range of motion”.⁵⁴ An imbalance between physical capacity and exposure to physical work-related factors is defined as low capacity in combination with high exposure.

In literature, several definitions of discomfort are used, for instance “perceived local discomfort” or “postural discomfort”. We focused on discomfort of the musculoskeletal tissues and defined discomfort as “localized musculoskeletal discomfort”, i.e. “the perception of tension, muscle fatigue, soreness, heat, tremor, pressure in muscles, or feelings of effort (at a particular working day)”.⁵⁵ A distinction has to be made between pain, disorders and injuries. An injury means a mechanical disruption of the tissue, due to a traumatic incident, which results in pain. The onset of an injury is sudden, while the onset of pain can be gradual.⁵⁶ Furthermore, disorders are diagnosed by means of physical examination, and pain can be measured by self-reports. In this thesis, we focus on self-reported musculoskeletal pain during the past 12 months, using a Dutch adapted version of the Nordic Questionnaire.^{57;58} We defined an incident case of low back, neck, or shoulder pain if a pain-free episode (no, or sometimes pain in the past 12 months) was followed by an episode with pain (regular, or prolonged pain in the past 12 months).

Pathogenesis of musculoskeletal pain

Figure 1.1 can be derived from several hypotheses that have been proposed for the pathogenesis of work-related musculoskeletal discomfort and pain, but detailed knowledge is still lacking.^{59;60}

In ergonomics, it is generally assumed that perceived muscular discomfort is an early sign of musculoskeletal pain.⁶¹ In many studies reporting on short-term musculoskeletal discomfort as an indication of the effect of an ergonomic intervention, the authors assume that musculoskeletal discomfort can predict musculoskeletal pain at long-term.⁶¹⁻⁶⁶ However, to our knowledge, this relationship was studied in only one longitudinal study,^{67;68} in which a relationship was found between baseline neck or shoulder discomfort and future upper extremity tendonitis.

The aetiology of musculoskeletal pain in the low back, neck, and shoulders is multifactorial.³⁴ In general, pain can originate from morphological changes in one or more tissues, i.e. muscles, tendons, ligaments, cartilage, bones, and joints.⁵⁹

With respect to exposure to work-related physical factors as a causal factor for musculoskeletal pain, several potential mechanisms have been proposed that can explain this relationship. One of these mechanisms states that muscle cell damage, especially that of type I (Cinderella) motor units, due to overexertion or sustained muscle activity, may be a primary cause of musculoskeletal pain. Furthermore, sub-optimal blood flow could contribute to musculoskeletal pain.⁶⁰ In the biomechanical literature, it has been theorised that manual material handling tasks could not only cause muscular overexertion, but would - especially when involving spinal flexion or torsion - also lead to high mechanical loads on the lumbar

spine. This may cause fractures of the intervertebral endplates and degenerative changes of the intervertebral disc.⁶⁹

With regard to low physical capacity as a potential causal factor for musculoskeletal pain, disuse of the musculoskeletal system, or lack of physical activity may lead to several deconditioning-related physiological changes -such as muscle atrophy, metabolic changes, or osteoporosis- and to functional changes -such as decreased muscle strength, impaired motor-control- or decreased cardiovascular capacity.^{70;71} When looking at the different physical capacity measures more specifically, decreased muscle strength may be caused by muscle atrophy, and changes in muscle composition. Decreased muscle endurance may lead to decreased capabilities to maintain motor control, and increased muscle fatigue. The relationship between mobility of the spine and musculoskeletal pain is less clear, but one can imagine that both stiffness and hyper flexibility may lead to musculoskeletal pain, due to either a restricted range of movement, or compensation in muscle activity, and thus muscle fatigue. Physical training may lead to several physiological changes in the muscular tissues, i.e. muscle hypertrophy, increased protein synthesis, increased force generation, and increased motor performance,⁷² and can therefore be seen as primary preventive for musculoskeletal pain.⁴²

Objective and research questions

In this thesis, we have several hypotheses with regard of the conceptual model of physical capacity and exposure to physical factors. First, we hypothesise that low physical capacity is an independent risk factor for future musculoskeletal pain, but an imbalance between physical capacity and exposure to work-related physical factors is a stronger risk factor than either physical capacity or exposure to physical factors on its own. Furthermore, we hypothesise that musculoskeletal pain is preceded by musculoskeletal discomfort, and, therefore, that discomfort can predict future pain.

With regard to the different physical capacity measures, we hypothesise to find reduced static endurance, rather than muscle strength, or mobility of the spine, as a more pronounced risk factor for future musculoskeletal pain. This may be due to physiological mechanisms, such as sub-optimal blood-flow or muscle fatigue,⁴ or to psychological factors, such as motivation, and pain attitude, which we expect to be stronger related to endurance time than to other measures of physical capacity.^{5;6} Furthermore, with regard to static muscle endurance, we expect to find a stronger relationship with neck pain than with low back pain, because this capacity measure might counteract with long-term exposure to static muscle activity at work, which has been found to be a risk factor for future neck/shoulder pain.⁷ For isokinetic muscle strength, we expect to find a stronger relationship with low back pain,

because this capacity measure might counteract with lifting at work, which has been found to be a risk factor for future low back pain.⁸⁻¹² Regarding mobility of the spine, we do not have clear expectations, due to lack of information on a potential pathogenesis, but assumed no strong relationship with future low back pain.

The main research question of this thesis is as follows:

"What is the impact of physical capacity on the development of work-related musculoskeletal pain?"

More specifically, the objective of this thesis is to investigate the different pathways in the generally accepted conceptual model of physical capacity and exposure to physical factors as shown in Figure 1.1. The sub-questions focus on the different pathways of the model:

1. *What are the age-related and gender-specific differences in physical capacity in a working population, and to what extent are these dependent on sports participation?*
2. *To what extent is low physical capacity an independent risk factor for future work-related musculoskeletal pain,*
3. *To what extent is an imbalance between physical capacity and exposure to work-related factors a risk factor for future work-related musculoskeletal pain?*
4. *To what extent is musculoskeletal discomfort predictive for future musculoskeletal pain among symptom-free workers?*
5. *What is the effectiveness of a resistance-training program on muscle strength, muscle fatigue, and musculoskeletal discomfort during simulated work tasks?*

Outline of the thesis

Chapters 2 to 4 of this thesis present studies on workers' physical capacity. Chapter 2 describes age-related and gender-specific changes in physical capacity among a working population. The results are stratified for sports participation. In chapters 3 and 4, the independent association between physical capacity and incidence of low back, and neck/shoulder pain is reported. Chapter 3 is a systematic literature review, and chapter 4 is a prospective cohort study on this topic.

Chapter 5 deals with an imbalance between physical capacity and exposure to work-related physical factors, in relation to incidence of low back, neck, or shoulder pain. The question whether peak or cumulative musculoskeletal discomfort at work is predictive for future musculoskeletal pain among symptom-free workers, is investigated in chapter 6.

Chapter 7 presents the effect of a resistance-training program on muscle strength, muscle fatigue, and musculoskeletal discomfort during simulated work tasks.

Finally, chapter 8 contains the general discussion. It brings the results of the different chapters together, and discusses general strengths and weaknesses of the studies. Furthermore, this chapter gives the answers on the different research questions leading to some practical implications as well as recommendations for future research. This thesis ends with a summary of all chapters, both in English and in Dutch.

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CHAPTER 2

AGE-RELATED DIFFERENCES IN MUSCULAR CAPACITY AMONG WORKERS



Submitted as:

Hamberg-van Reenen HH, van der Beek AJ, Blatter BM, van Mechelen W, Bongers PM. Age-related differences in muscular capacity among workers.

Abstract

Objective: To quantify the age-related, and gender-specific changes in isokinetic muscle strength and static muscle endurance in a working population, and to investigate whether these changes are dependent on sports participation.

Methods: Data were used from the longitudinal Study on Musculoskeletal disorders, Absenteeism, Stress and Health (SMASH), a prospective cohort study among almost 1800 workers with a follow-up of three years. At baseline, isokinetic muscle strength and static muscle endurance of the low back, neck and shoulder region were assessed, and measurements of static muscle endurance were repeated at follow-up. Data on the frequency of sports participation were assessed using a questionnaire (never, <0 and <3 hours, and ≥ 3 hours). Data were analysed both cross-sectionally and longitudinally.

Results: Men had higher isokinetic muscle strength than women, and performance was lower at older ages than at younger ages with optima between 19 and 33 years. Cross-sectionally, the mean performance for static back endurance had its optima at 29 and 42 years of age among men and women, respectively. For the neck and shoulder muscles, performance was higher among older workers. In contrast, muscle endurance decreased longitudinally among all age-groups. Younger workers who participated in sports 3 hours per week or more had the best performance, but older workers who participated between 0 and 3 hours per week had better performance than those who were inactive or more active.

Conclusions: There were age-related differences of isokinetic muscle strength, and static muscle endurance of the back and neck/shoulder muscles. For isokinetic muscle strength and static endurance of the back muscles, the performance was highest among younger workers. For static endurance of the neck and shoulder muscles, the age-related differences were opposite. In contrast, after follow-up, decreased static muscle endurance was found for all ages. (Moderate) sports participation seems to be effective in keeping aging workers suitable for the relatively growing work demands.

INTRODUCTION

Nowadays, the percentage of older workers is rising, due to an increasing life expectancy, an increasing retirement age, and an increasing societal demand on continued participation of older workers. In the Netherlands, the percentage of workers older than 45 years increased from 28% in 1996 to 36% in 2005.¹

The aging worker is in many aspects different from the younger worker, due to physical and mental differences associated with aging. Between the ages of 25 and 70, the body composition changes, characterized by a doubling of the total body fat proportion, a loss of muscle fibers, and bone loss.^{2;3} These changes lead to a decrease in muscle strength.^{2;4-6} In general, muscle strength reaches its optimum between the second and the third decade, for women a few years earlier than for men, and declines for both sexes after that age. The muscle strength of a 65-year old person is on average about 75 to 80% of the maximal muscle strength.^{2;5;7;8} Savinainen et al. reported a decline in muscle strength of the back and arm muscles, flexibility of the spine, and aerobic capacity during 16 years of follow-up among 45 middle-aged subjects who were 52 years of age at the start of the study.¹⁴ Izquierdo et al. reported lower values of muscle strength of the quadriceps muscles, and aerobic capacity among 21 elderly men (mean age of 65 years) compared to 26 middle-aged men (mean age of 42 years).⁴

Muscle endurance had received much less attention in the literature. Unless different physiological changes in the muscle tissue, and muscle blood flow among older subjects,⁹ muscle endurance was found to be unaffected by age, or even to increase with age in some studies.^{5;9-12} Older subjects were often found to be more muscle fatigue resistant than younger subjects when sustaining static contractions.¹⁰ Alaranta et al. found no statistically significant differences in performance on a static back endurance test among four age-groups between 35 and 54 years of 508 employees.¹¹ Bembien et al. did not find any age-related differences in muscle endurance of finger and foot muscles among 153 men aged 20 to 74 years. Hunter et al. found longer static muscle endurance time of the elbow flexor muscles among eight old men (aged 67-76 years) compared to eight younger men (aged 18-31 years).^{9;10}

Next to musculoskeletal changes, cardiovascular and respiratory capacity decrease with age, even at a higher degree than the decrease in muscular capacity.^{4-6;13} Inter-individual differences in the age-related changes of physical capacity are enormous among workers, due to differences in the physical activity level. Age-related declines in physical capacity can be slowed down by regular physical training.^{2;5;8;15;16} However, high physical workload was not found to have a long-lasting training effect on the muscle strength of aging

workers. Savinainen et al. found that, among employees with high perceived workload, muscle strength was poorer than among subjects with low perceived workload, especially among women.⁶ Furthermore, Ilmarinen found that the decline in muscle strength by age was similar for blue-collar workers and white-collar workers.⁸

In several jobs, the work demands for aging workers are at the same level as for younger workers.^{5;17;18} Due to the decreasing working capacity, the resulting workload might change from an acceptable load into daily physical “overload”, which might result in long-term health effects with chronic musculoskeletal symptoms as the main effect.^{19;20}

Most studies on age-related differences in muscle strength or static muscle endurance consisted of a small study population with a small age-range. Furthermore, few studies focused on a working population, while the age-related decline in physical capacity has important consequences in the aging worker because of the risk of an overload at work. In this study, we describe the age-related differences in muscle strength and muscle endurance of the low back, neck and shoulder muscles in approximately 1500 male and female workers with different professions in the Netherlands. With regard to static muscle endurance, we studied the relation with age both cross-sectionally and longitudinally with a follow-up of 3 years within the same dataset. Due to large differences in muscular capacity between men and women, we stratified for gender. In order to account for a potential physical training effect,^{2;5;8;15;16} we also stratified for sports participation.

The objective of the present study is twofold: 1) to quantify the age-related, and gender-specific differences in muscle strength and static muscle endurance in a working population, and 2) to investigate whether these are different for workers who participate in sports and those who do not.

METHODS

The longitudinal Study on Musculoskeletal disorders, Absenteeism, Stress and Health (SMASH) is a prospective cohort study among almost 1800 workers from 34 different companies with a follow-up of three years. At baseline in 1993, we assessed muscular capacity, including isokinetic muscle strength and static muscle endurance in the low back, neck and shoulder region. After three years of follow-up, measurements of static muscle endurance in the low back, neck and shoulder region were repeated, but for practical reasons, muscle strength was only measured once at baseline.

We selected a study population based on the following inclusion criteria. First, workers had to complete the baseline questionnaire (N=1789). Furthermore, workers had to

work at least one year in their current job for more than 20 hours per week, and should not receive a sickness benefit or a permanent disability pension (N=1578). Finally, data on muscular capacity at baseline or after three years of follow-up had to be available (N=1531 for the low back region, N=1463 for the neck region, and N=1482 for the shoulder region, respectively).

Measurement of isokinetic muscle strength and static muscle endurance

Trained physiotherapists performed the different tests of muscular capacity. At baseline, isokinetic muscle strength of the back and neck/shoulder muscles was measured. Both at baseline and after three years of follow-up, sub-maximal endurance time of static contraction of the back, neck, and shoulder muscles was measured.

Isokinetic muscle strength of the low back and neck/shoulder muscles was measured using the Aristokin dynamometer (Lode BV Medical Technology, Groningen, the Netherlands). The muscle strength was measured during two lifting movements with maximum effort and a velocity of 40 cm/sec, both from floor to hip level, and from hip to shoulder level. After practicing, workers had to lift the box three times with maximum effort. Isokinetic lifting strength (in Newtons) was defined as the average outcome of the second and third lifts.

Static endurance of the back, neck and shoulder muscles was defined as the number of seconds during which the workers could keep a position, while carrying a gender-specific load (maximized at 240 and 420 seconds, for the low back and the neck/shoulder regions, respectively). The Biering-Sørensen test²¹ was used for the back extensors. Workers were lying prone on a table and had to keep their unsupported upper part of the body in a horizontal position with fixation of the buttocks and legs. For the measurement of the static endurance of the neck extensors, the workers had to keep their head flexed in a sitting position, while carrying a loaded helmet. For the measurement of the static endurance of the shoulder elevators, workers had to keep their arms elevated at 90 degrees in a sitting position, while carrying a load. The endurance tests were finished when considerable discomfort was reported.

Workers with contraindications (such as cardiovascular diseases, fever, or pregnancy) that might involve a health risk, or that might have an effect on the results of the tests, were excluded from the physical capacity tests. In addition, workers who reported a discomfort rating on a ten-point scale²² of 4 point or higher were also excluded from the tests. Further details on the different tests of muscular capacity were described in a previous article.²³

Assessment of sports participation

Data on sports participation were assessed using a questionnaire at baseline. The workers were asked for physically demanding sports during the preceding 12 months. Those who never participated in sports in that year were distinguished from those who did participate in sports. Furthermore, a distinction in frequency was made, i.e. participation for 3 hours per week or more and participation with a lower frequency than 3 hours per week.

Data analyses

We analyzed the course of isokinetic muscle strength and static muscle endurance by age among men and women. For isokinetic muscle strength, we analyzed this relation only cross-sectionally at baseline, but for static muscle endurance, we assessed the age-related differences both cross-sectionally and longitudinally during the follow-up period of three years. To take account of the mathematically parabolic relations of muscle strength with age, we analyzed the cross-sectional data using quadratic regression analyses. For static muscle endurance, we assumed a parabolic function as well. We added a squared age term as an independent variable to the regression functions. To correct for the dependency of age and squared age, we used the square of age minus mean age.²⁴ Longitudinally, we analyzed the mean differences in static muscle endurance time at baseline and after three years of follow-up for 5-year age-groups. This was presented as lines from the middle of the 5-year age-groups at baseline to the middle of the 5-year age-groups three years later. The number of workers for the longitudinal analyses was smaller than the number of workers for the cross-sectional analyses, due to loss to follow-up.

Furthermore, we presented stratified results for frequency of sports participation (i.e. never, <0 and <3 hours, and ≥ 3 hours). To analyze to what extent muscular capacity was statistically significantly different for gender- and sport-groups, we added interaction terms to the regression functions.

RESULTS

Almost 70% of the workers was male. At baseline, the mean age was 35 years (37 years among men, and 33 years among women); the youngest worker had an age of 19 and the oldest an age of 59. Figure 2.1 shows the age distribution of the study population (N=1578).

Tables 2.1.a and 2.1.b present the mean, median and standard deviations of performance in tests of isokinetic muscle strength, and static muscle endurance time among

men and women. With respect to isokinetic muscle strength, only baseline results were available. It can be seen that the isokinetic muscle strength of the back and neck/shoulder muscles among the men was respectively 1.6 and 1.9 times higher than the isokinetic muscle strength among the women. With respect to static muscle endurance time, both baseline results and results after three year of follow-up are presented. There were no differences in static endurance time of the back and neck muscles between men and women.

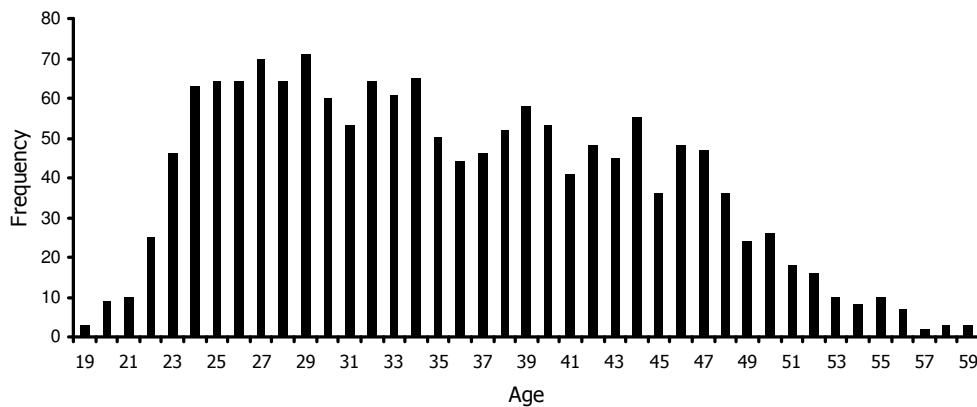


Figure 2.1. Age distribution of the SMASH working population (N=1578).

Table 2.1.a. Performance in tests of isokinetic muscle strength at baseline among men and women.

	Isokinetic muscle strength back muscles T0 (N)		Isokinetic muscle strength neck/shoulder muscles T0 (N)	
	Men	Women	Men	Women
N	864	359	869	353
Mean	565	344	255	131
Median	551	340	257	129
SD	223	137	91	46

Table 2.1.b. Performance in tests of static muscle endurance at baseline and after three years of follow-up among men and women.

	Static endurance time back muscles (sec)				Static endurance time neck muscles (sec)				Static endurance time shoulder muscles (sec)			
	Men		Women		Men		Women		Men		Women	
	T0	T3	T0	T3	T0	T3	T0	T3	T0	T3	T0	T3
N	823	731	327	264	936	679	386	238	906	757	365	290
Mean	94	67	96	65	285	210	288	196	274	213	220	167
Median	90	60	90	60	276	205	283	180	270	210	210	150
SD	44	41	49	41	107	98	114	102	98	92	103	86

However, with regard to the shoulders, the performance among the men at baseline and at follow-up was respectively 1.2 and 1.3 times higher than the performance among the women. Furthermore, it can be seen that the performance in the different static muscle endurance tests after three years of follow-up was on average 72% of the performance at baseline.

Figure 2.2 shows the course of isokinetic muscle strength according to age among men (black lines), and women (gray lines). Among the men, those aged 23 years had the highest isokinetic muscle strength of the back muscles, and those aged 59 years had the lowest strength, which was 64% of the optimum. Among the women, the isokinetic muscle

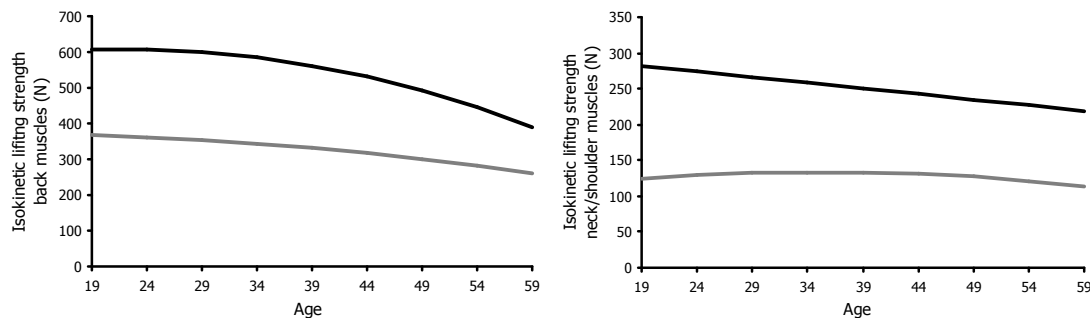


Figure 2.2. Regression functions of baseline isokinetic muscle strength of the back muscles (a) and the neck/shoulder muscles (b) by age among men (black lines) and women (gray lines).

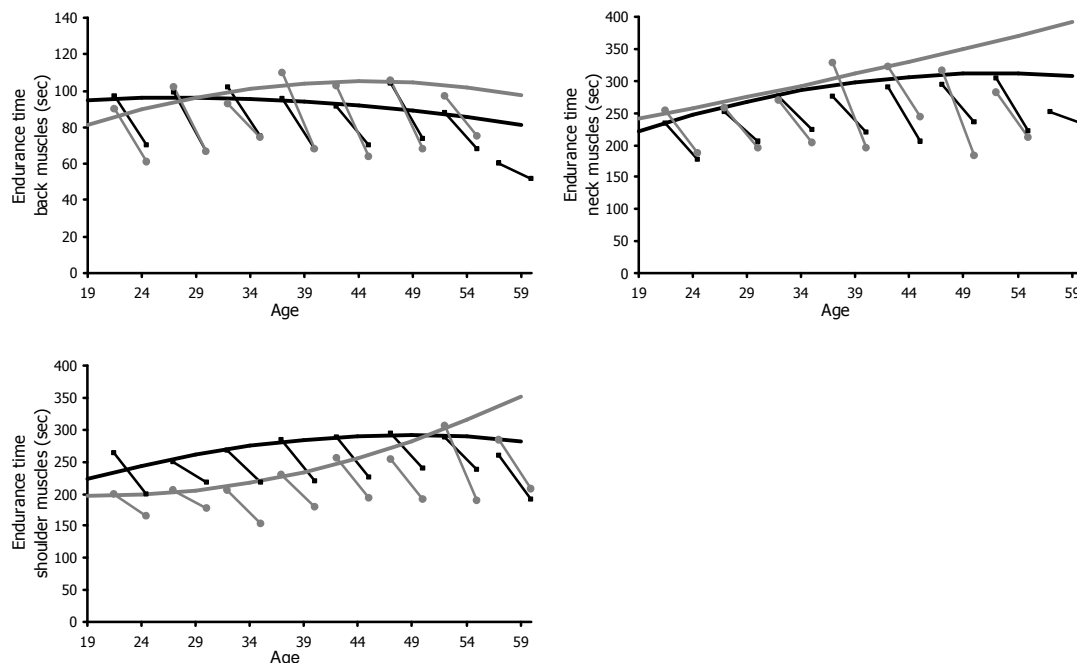


Figure 2.3. Cross-sectional regression functions of baseline static muscle endurance time of the back muscles (a), the neck muscles (b), and the shoulder muscles (c) by age among men (black lines) and women (gray lines). Longitudinal means by age-groups at baseline (upper dots at the middle of the age-groups (19-24 to 54-59 years)) and after three years of follow-up (lower dots at the middle of the age-groups (22-27 to 57-62 years)).

strength of the back muscles at the age of 59 years was 70% of the highest value at the age of 19 years. Among the men, the isokinetic muscle strength of the neck/shoulder muscles at the age of 59 years was 77% of the highest value at the age of 19 years. Among the women, isokinetic muscle strength of the neck/shoulder muscles had its optimum at the age of 33 years with 85% of that optimum at the age of 59 years. For both the low back and the neck/shoulder muscles, the differences in isokinetic muscle strength between younger and older age-groups were statistically significantly higher among men than among women (p interaction term ≤ 0.05).

Figure 2.3 presents the course of static muscle endurance time according to age among men and women. This figure presents both the cross-sectional relations at baseline (continuous lines), and the mean differences between baseline and follow-up for different age-groups (longitudinal analyses represented by the lines between upper dots at baseline and lower dots after three years of follow-up at the middle of the age-groups). It can be seen that there were only small differences between men and women. For the neck and shoulder muscles, these differences were statistically significant (p interaction term ≤ 0.05). Cross-sectionally, the mean performance for static endurance time of the back muscles had its optima at the age of 29 years among the men and at the age of 42 years among the women, with 86% and 93% of that optimum at the age of 59 years, respectively. For the neck and shoulder muscles, static muscle endurance time at the age of 59 years was between 1.3 and 1.8 times higher than static muscle endurance time at the age of 19 years. In contrast, from the longitudinal analyses, it can be seen that static muscle endurance time of the back, neck, and shoulder muscles decreased statistically significantly ($p \leq 0.05$) among all age-groups with values of 77% on average after three years of follow-up compared to the baseline values.

Figure 2.4 presents baseline isokinetic muscle strength by age among men and women stratified for three groups with regard to sports participation. The figure shows the highest isokinetic muscle strength among young workers who participated in sports 3 hours per week or more, and among older workers who participated in sports less than 3 hours per week. However, these differences were not statistically significant (p interaction term >0.10). The differences in isokinetic muscle strength by age were significantly larger among workers who participated in sports for 3 hours per week or more than among those who were less active.

Figure 2.5 shows static muscle endurance time by age among men and women stratified for sports participation. It can be seen that there were only small differences between the gender and sports participation groups. For the neck and shoulder muscles, there seems to be a pattern that young workers who participated in sports for 3 hours per

week or more had the longest static muscle endurance time, as well as older workers who participated in sports less than 3 hours per week. However, these differences were only statistically significant among the men (p interaction term ≤ 0.10).

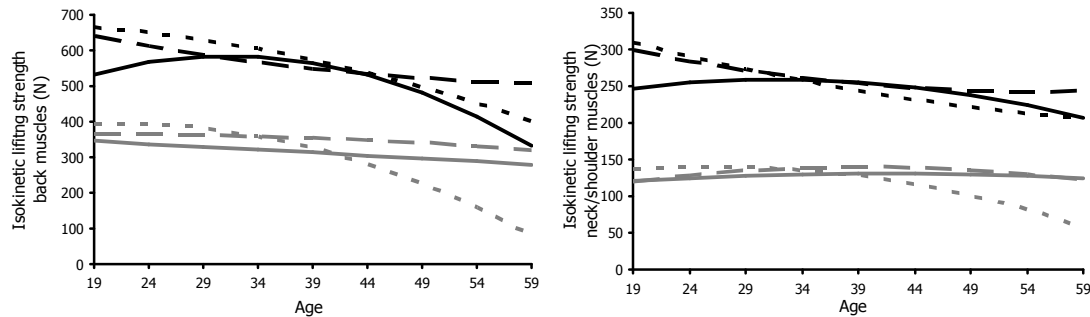


Figure 2.4. Cross-sectional regression functions of isokinetic muscle strength of the back muscles (a) and the neck/shoulder muscles (b) by age among men (black lines) and women (gray lines). Stratified for sports participation: never (continuous lines), > 0 and <3 hours per week (large dotted lined), and ≥ 3 hours per week (small dotted lines).

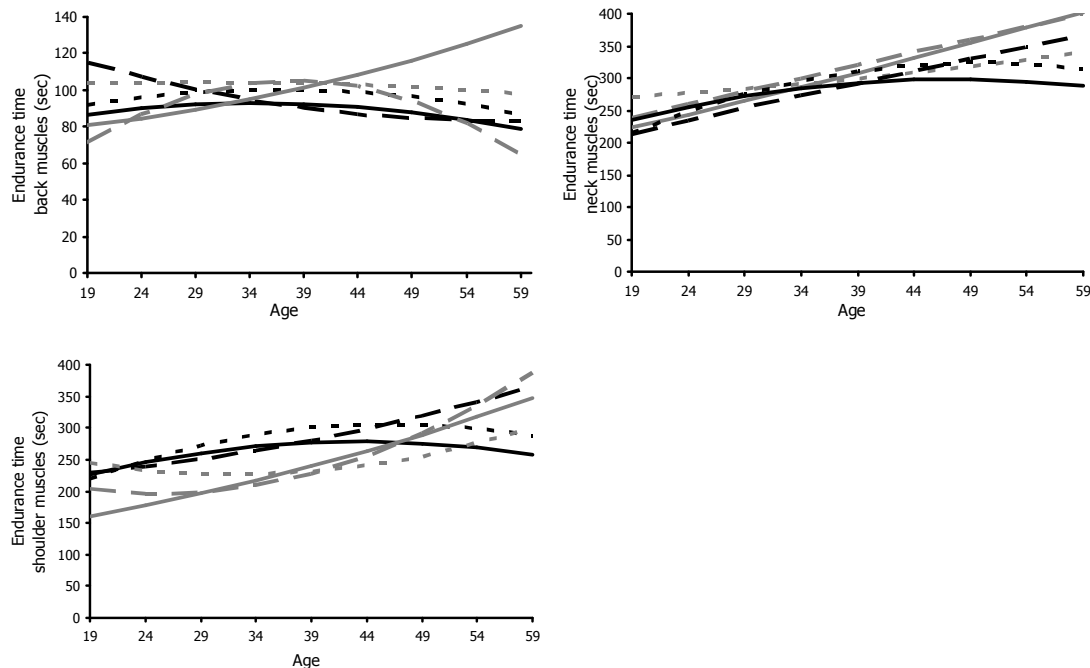


Figure 2.5. Cross-sectional regression functions of baseline static muscle endurance time of the back muscles (a), the neck muscles (b), and the shoulder muscles (c) by age among men (black lines) and women (gray lines). Stratified for sports participation: never (continuous lines), > 0 and <3 hours per week (large dotted lined), and ≥ 3 hours per week (small dotted lines).

DISCUSSION

Main results in comparison with previous research

In a large study population of workers from different professions we found, as expected, that isokinetic muscle strength was lower at older ages than at younger ages. The optimum of isokinetic muscle strength of the back muscles among men at the age of 23 was in line with previous research.^{5;7;8} However, we found an optimum of isokinetic muscle strength of the neck/shoulder muscles among women at 33 years of age. Furthermore, for isokinetic muscle strength of the low back muscles among women and of the neck/shoulder muscles among men, we found the highest values at 19 years of age. Expectedly, we found that men had higher isokinetic muscle strength than women, but the differences between young and older ages were also higher among the men.

Previous studies reported mixed results with regard to the age-related changes in muscle endurance.^{5;9-11} Cross-sectionally, we found optima of static endurance time of the back muscles at the age of 29 years among the men and at the age of 42 years among the women, with 86% and 93% of that optimum at the age of 59 years, respectively. However, for the neck and shoulder muscles, static muscle endurance time at the age of 59 years was between 1.3 and 1.8 times higher than at the age of 19 years. In contrast, longitudinally, we found that muscle endurance decreased for all age-groups. The direction of the aging effect was opposite when comparing the cross-sectional with the longitudinal results.

With regard to performance by sports participation, the results of this study suggested that younger workers who participated in sports for 3 hours per week or more had the highest isokinetic muscle strength and the longest static muscle endurance time. This was in line with results from previous studies.^{2;5;8;15;16} The differences by age were the largest in the group participating in sports for 3 hours per week or more, i.e. the plotted lines crossed over between the ages of 30 and 40. Furthermore, the results suggested that older workers who participated in sports between 0 and 3 hours per week had better performance in tests of physical capacity than those who were inactive or participated in sports for 3 hours per week or more, which was not in line with our expectation that the age-related differences would be smallest among the most active workers. However, the differences between the groups of sports participation were only statistically significant for endurance of the neck and shoulder muscles among the men.

Possible explanations for the differences between the cross-sectional and longitudinal results

The differences between the cross-sectional and longitudinal analyses were contrary to our expectations. Due to a potentially healthy worker effect, we expected to find equal or fewer age-related differences in within-worker comparisons compared to between-worker comparisons. However, the results suggest that there was no healthy worker effect. Several factors can contribute to the explanation of these differences. First, there could have been a period or measurement time effect²⁵ due to different test circumstances at follow-up compared to baseline. Possible differences in test circumstances could imply less motivation of the workers during the tests, other physiotherapists who supported the tests, or another test season. Test-retest reliability was found to be high for the isokinetic neck/shoulder lifting test and the trunk muscle endurance test and moderate for the other tests of muscular capacity in pilot studies.²³ However, in the present study, reproducibility between the tests at baseline and follow-up was found to be low (Spearman correlation coefficients were 0.47 for the back, 0.40 for the neck, and 0.51 for the shoulders), which would be an indication of a period effect. With respect to the motivation of the workers during the tests, most workers were well motivated both at baseline and at follow-up, but some were less motivated at follow-up than at baseline. Both at baseline, and at follow-up, the performance among workers who were well motivated was statistically significantly higher than among workers who were moderately or poorly motivated. However, the difference between performance at follow-up and at baseline was about the same for well-motivated compared to poorly motivated workers. This means that changes in motivation could not explain the differences between the cross-sectional and longitudinal analyses. With respect to potential differences between the 14 physiotherapists who supported the tests of muscular capacity, the mean performance differed statistically significantly between the different physiotherapists. This was in spite of a training before the data collection, and moderate inter-rater reliability in the pilot studies.²³ However, most workers were supported by another physiotherapist at follow-up than at baseline. Therefore, potential misclassification could not have been differential, which means that changes in physiotherapists could not explain the differences between the cross-sectional and longitudinal analyses. Finally, no differences were found regarding the season of testing. For all workers, the physical tests at follow-up were assessed more or less in the same month three years later with one-month difference at maximum. In conclusion, because we could not confirm differences in test circumstances, other unknown factors outside the test circumstances have to be sought to explain the period effect.

Second, there could have been a cohort effect,²⁵ because the population in the longitudinal analyses was different from the population at baseline in the cross-sectional

analyses due to loss to follow-up. The loss to follow-up rates were 15% for the low back tests, 31% for the neck tests, and 18% for the shoulder tests, respectively. In addition, we investigated if this loss to follow-up could have been selective by comparing the total mean performance at baseline among workers who became lost to follow-up to those who did not become lost to follow-up. The static endurance time of the shoulder muscles at baseline was significantly shorter among those who became lost to follow-up, although the mean difference was only 3 seconds (256 compared to 259 seconds). In contrast, we found significantly longer static endurance time of the neck muscles for that group (305 compared to 274 seconds). This means that there was selective loss to follow-up, but the difference for the shoulder muscles was very small, and the difference for the neck muscles was not in the expected direction. Therefore, it seems unlikely that a cohort effect on muscular capacity could have played a role in the differences between the cross-sectional and the longitudinal results.

Third, the statistical analyzing techniques were different, i.e. cross-sectionally, regression analyses were used, and longitudinal, a description of repeated means was presented for 5-year age-groups. However, if we had described means in the cross-sectional analyses as well, the results would have been quite the same compared to the estimated regression functions (data not shown). This means that it is unlikely that differences in statistical analyzing techniques would have contributed to the differences between the cross-sectional and longitudinal results.

Finally, a comment can be made on the longitudinal results, since we had only data at two measurements with a three-year interval. Due to this short interval, in particular compared to the duration of a general working lifetime, conclusions on the longitudinal results have to be taken with caution.

In conclusion, other factors than differences in test circumstances, selectiveness of loss to follow-up, or differences in statistical analyzing techniques have to be sought to explain the difference between cross-sectional and longitudinal results regarding the static muscles endurance.

CONCLUSIONS

The results of this study suggest age-related differences of isokinetic muscle strength, and static muscle endurance of the back and neck/shoulder muscles. For isokinetic muscle strength and static endurance of the back muscles, the performance was higher among younger workers than among older workers, but for static endurance of the neck and

shoulder muscles, the age-related differences were opposite. In contrast, after three years of follow-up, decreased static muscle endurance was found for all ages. Factors other than differences in test circumstances, or loss to follow-up have to be sought to explain the differences between cross-sectional and longitudinal results with respect to static muscle endurance.

The study results suggest that (moderate) sports participation seem to be effective in keeping aging workers suitable for their relatively growing work demands.

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CHAPTER 3

A SYSTEMATIC REVIEW OF THE RELATION BETWEEN PHYSICAL CAPACITY AND FUTURE LOW BACK AND NECK/SHOULDER PAIN



Published as:

Hamberg-van Reenen HH, Ariëns GAM, Blatter BM, van Mechelen W, and Bongers PM. A systematic review of the relation between physical capacity and future low back and neck/shoulder pain. Pain 2007;130:93-107.

Abstract

Objective: The results of longitudinal studies reporting on the relation between physical capacity and the risk of musculoskeletal disorders have never been reviewed in a systematic way. The objective of the present systematic review is to investigate if there is evidence that low muscle strength, low muscle endurance, or reduced spinal mobility are predictors of future low back or neck/shoulder pain.

Methods: Abstracts found by electronic databases were checked on several inclusion criteria. Two reviewers separately evaluated the quality of the studies. Based on the quality and the consistency of the results of the included studies, three levels of evidence were constructed.

Results / conclusion: The results of 26 prospective cohort studies were summarized, of which 24 reported on the longitudinal relationship between physical capacity measures and the risk of low back pain and only three studies reported on the longitudinal relationship between physical capacity measures and the risk of neck/shoulder pain. We found strong evidence that there is no relationship between trunk muscle endurance and the risk of low back pain. Furthermore, due to inconsistent results in multiple studies, we found inconclusive evidence for a relationship between trunk muscle strength, or mobility of the lumbar spine and the risk of low back pain. Finally, due to a limited number of studies, we found inconclusive evidence for a relationship between physical capacity measures and the risk of neck/shoulder pain. Due to heterogeneity, the results of this systematic review have to be interpreted with caution.

INTRODUCTION

Musculoskeletal disorders are a major problem in the working population. In systematic reviews, evidence was found that exposure to physical and psychosocial work-related factors may contribute to the development of these disorders.¹⁻¹⁰ In addition, the capacity of mechanical and physiological responses of the body to the exposure to work-related physical factors might contribute to the development of musculoskeletal disorders.¹¹ More specifically, an imbalance between physical capacity and exposure to work-related physical factors might be a risk factor for musculoskeletal disorders, or physical capacity could be an effect modifier or an intermediate variable of the relation between exposure to work-related physical factors and the risk of low back pain.

Irrespective of exposure, physical capacity might also be a risk factor for musculoskeletal disorders. Muscle strength, muscle endurance, and joint mobility are examples of proxy measures of physical capacity, which can be measured by different physical tests. There is lack of information about reliability and validity of physical tests for the low back¹² and the neck.¹³ Exercises to increase physical capacity have been found as an effective preventive intervention for back and neck problems,^{14;15} but there is insufficient evidence to recommend for or against any specific type or intensity of exercise.¹⁴

Several longitudinal studies reported on the relation between performance in tests of muscle strength, muscle endurance, or joint mobility and the risk of low back or neck/shoulder pain, but, to our knowledge, the results of these studies have never been reviewed in a systematically way.

The objective of this systematic review is to investigate if there is evidence that low muscle strength, low muscle endurance, or reduced spinal mobility are predictors of work-related low back or neck/shoulder pain.

METHODS

Selection of studies

The medical electronic databases MEDLINE and EMBASE have been checked up to December 2005, as well as databases containing literature on occupational safety and health, i.e. CISDOC, HSELINE, MHIDAS, NIOSHTIC2, and RILOSH, with the following MeSH terms and text words: work (truncated), employ (truncated), job, occupation (truncated), physical, functional, capacity, tolerance, work capacity evaluation, lifting, strength, endurance,

pliability, mobility, flexibility, spinal, joint, flexion, rotation, extension, lateral bending, low back pain, neck pain, shoulder pain. Appendix 3.A shows the exact search string.

Abstracts were checked on the following criteria: 1) The study was a full report published in a peer reviewed journal in English, German, or Dutch; 2) The study design was longitudinal: either a prospective cohort study (PC), or a retrospective cohort study (RC), or a case-control study (CC); 3) The study population included a healthy working population or a general healthy adult population; 4) One or more tests of muscle strength, muscle endurance or spinal mobility were carried out; 5) The outcome measure was low back, neck or shoulder pain. If no abstract was present, or based on title and abstract it was not clear whether an article should be in- or excluded, the whole article was checked. Articles were included if they met all these five inclusion criteria. One reviewer (HH) has read all the abstracts, and a second reviewer (GA) separately has read a random sample of the abstracts. A consensus meeting was arranged to sort out differences between both reviewers. Finally, a snowball search was done, in which reference lists of the selected articles were checked for titles including risk factors and musculoskeletal disorders.

Quality assessment and best evidence synthesis

The quality of the selected studies was scored using a quality assessment list for prospective cohort studies, based on a list, which was used in earlier systematic reviews of studies on risk factors for musculoskeletal disorders.^{1;2;4;5;16} The list included eleven items on design, population, and adjustment for bias or confounding. The items on the list were rated as "1" (positive), "0" (negative) or "?" (unclear) (see Table 3.1). For all studies, a total quality score was calculated by counting up the number of positive items (a total score between 0 and 11). Studies were defined as high quality if they had a total score of six or higher. A total score between three and five was defined as low quality. Two reviewers (HH and GA) separately evaluated the quality of the studies. A consensus meeting was arranged to sort out differences between both reviewers.

Based on earlier research,¹⁷ three levels of evidence were constructed: 1) Strong evidence: consistent results found in multiple high-quality studies; 2) Moderate evidence: consistent results found in one high-quality study and in at least one low-quality study, or consistent results found in multiple low-quality studies; 3) Inconclusive evidence: inconsistent results found in multiple studies, or results based on one study. Results were regarded as consistent if at least 75% of the studies was in the same direction. We excluded studies with a total quality score of less than three from the data-extraction.

Table 3.1 Quality assessment list for prospective cohort studies.

Item	Score
Was the selection of the population non-selective with respect to physical capacity?	0 = no 1 = yes ? = unclear
Was the response rate at baseline sufficient?	0 = no: <70% 1 = yes: ≥70% ? = unclear
Was the response during follow-up non-selective with respect to physical capacity?	0 = no: selective loss-to-follow-up 1 = yes: non-selective loss-to-follow-up ? = unclear
Was the collection of low back, neck or shoulder pain clearly described?	0 = no 1 = yes ? = unclear
Was low back, neck or shoulder pain described in terms of frequency and/or duration?	0 = no 1 = yes ? = unclear
Was the time between the measurement of performance in tests of physical capacity and the measurement of low back, neck or shoulder pain sufficient?	0 = no: <3 months or >5 years 1 = yes: ≥3 months or ≤5 years ? = unclear
Were incident cases selected or was corrected for low back, neck or shoulder pain at baseline?	0 = no 1 = yes ? = unclear
Were the results adjusted for confounders?	0 = no 1 = yes ? = unclear
Was the number of cases in the multivariate analyses at least 10 times the number of independent variables?	0 = no 1 = yes ? = unclear n.a. = not applicable
Were effect sizes given or was information given to calculate these?	0 = no 1 = yes ? = unclear
Were standard errors and/or confidence intervals given for the estimates or was information given to calculate these?	0 = no 1 = yes ? = unclear

Data extraction

From all studies, information on design, population, response rates, tests, outcome and risk estimates was extracted. When effect sizes, standard errors, confidence intervals, or p-values were not presented, but enough data were given to calculate them, this was done.

Data extraction was separated for low back and neck/shoulder pain. We regarded results with a p-value of 0.10 or less as statistically significant.

RESULTS

Selection of studies

We found 4047 articles from the databases. After exclusion of doubles, the first reviewer (HH) has read 2980 abstracts and the second reviewer (GA) has read a random sample. The percentage agreement between the two reviewers was 93%. Disagreement was resolved in a consensus meeting. The inclusion criteria were met by 24 articles.¹⁸⁻⁴¹ The most important reasons for exclusion were a cross-sectional design, absence of tests of muscle strength, muscle endurance or spinal mobility, or absence of low back, or neck/shoulder pain as outcome measure. Another four articles were selected based on the snowball search.⁴²⁻⁴⁵

Finally, 26 studies were included, which had all a prospective cohort design (see Figure 3.1). Of these studies, twenty studies dealt with trunk muscle strength, 12 dealt with trunk muscle endurance, and nine dealt with mobility of the lumbar spine. Only three studies reported on the relation between physical capacity of the neck/shoulder region and the risk of neck/shoulder pain, of which one dealt with strength of the neck/shoulder muscles, one dealt with endurance of the neck/shoulder muscles, and two dealt with mobility of the cervical spine.

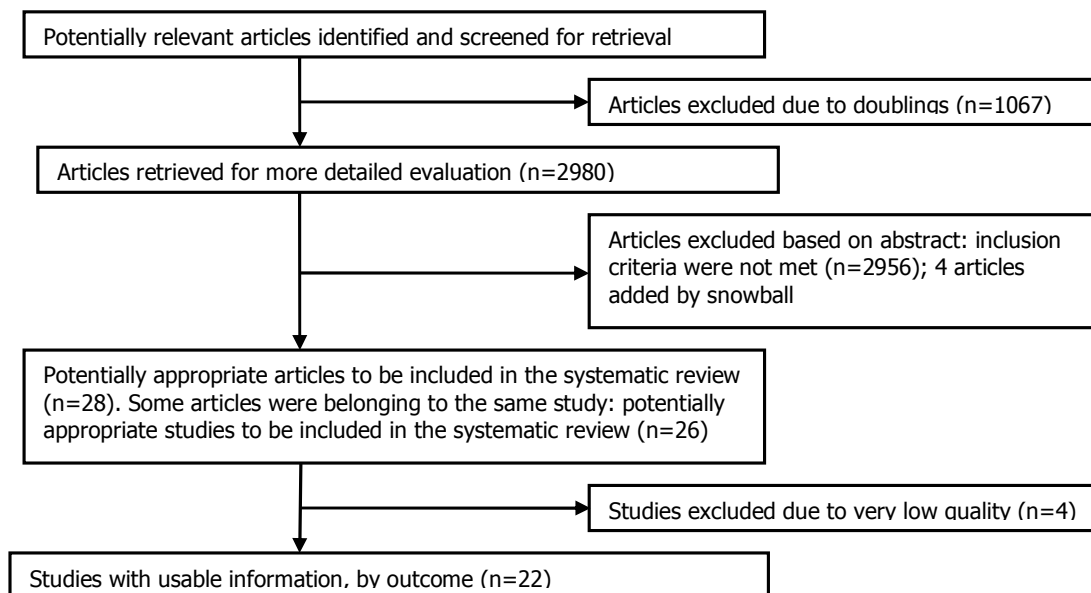


Figure 3.1. Flow chart of selection process.

Quality assessment and best evidence synthesis

Table 3.2 shows the quality scores of the selected studies. The overall agreement between the two reviewers was 90% (Kappa 0.74). Disagreement was resolved in a consensus meeting. We defined 15 studies as high quality and seven studies as low quality. We excluded four studies from the data-extraction due to a total quality score lower than three.

Physical capacity measures and the risk of low back pain

Table 3.3 shows the results of the data-extraction of the studies reporting on physical capacity measures and the risk of low back pain. Results with a p-value of 0.10 or less, which were considered as statistically significant, are bold. Some studies, which reported on more than one type of strength test, and/or reported on different gender groups, found for one group a positive (or negative) effect, whereas for another group no effect. We counted these studies twice.

Trunk muscle strength and the risk of low back pain

Thirteen high-quality studies^{19;20;25;29-32;37;39-42;45-50} and four low-quality^{18;24;36;44;51} studies reported on the relation between trunk muscle strength and the risk of low back pain.

All studies reported on no association between trunk muscle strength and the risk of future low back pain. Of the high-quality studies, the risk ratios for low back pain varied between 0.6 (non-significant)³⁷ and 1.24 (non-significant)³² for low compared to high isometric strength. In some studies, no difference ($p > 0.10$) in trunk muscle strength was found between those developing low back pain and those not developing pain.^{22;25;29;40-42;46;49;50}

Furthermore, some studies only reported that there was no relation between trunk muscle strength and the risk of low back pain.^{22;31;39;40;42;45;47;49} Of the low-quality studies, Dueker et al.²⁴ and Lee et al.⁴⁴ found no statistically significant differences in trunk muscle strength among those developing low back pain, compared to those without low back pain. Other studies^{18;36;51} only reported that there was no relation.

In five high-quality studies,^{19;32;40-42;48-50} poor trunk muscle strength was found as a significant risk factor for low back pain. In contrast, Masset et al.³² and Leino et al.³⁰ found high strength as a risk factor.

In conclusion, there is inconclusive evidence for a relation between trunk muscle strength and the risk of low back pain, because the results were not consistent.

Trunk muscle endurance and the risk of low back pain

Eight high-quality studies and four low-quality studies reported on the relation between trunk muscle endurance and the risk of low back pain.

Seven high-quality studies^{25;28-31;39;40;46;47;49} and four low-quality studies^{18;27;36;38;51} did not find any relation between trunk muscle endurance and the risk of low back pain. Gibbons et al. / Latikka et al.^{25;46} and Kujala et al.²⁹ found no differences in trunk muscle endurance between subjects developing low back pain and those staying free of pain ($p>0.10$). The other five high-quality studies^{28;30;31;39;40;47;49} only reported that there was no relation between trunk muscle endurance and the risk of low back pain. Of the low-quality studies, risk ratios between 0.93 (non-significant)³⁸ and 1.2 (non-significant)²⁷ were found among subjects with poor performance in a static endurance test for trunk extensors compared to those with high performance. Other low-quality studies^{18;36;51} only reported that there was no relation between trunk muscle endurance and the risk of low back pain.

Three studies reported poor trunk muscle endurance as a risk factor for low back pain,^{22;31;38;42;47} of which one was of low quality.³⁸ Biering-Sørensen et al.^{22;42} found that lower trunk muscle endurance was a predictor of first-time occurrence of low back pain. Luoto et al. / Alaranta et al.^{31;47} found an odds ratio of 3 among workers with poor trunk muscle endurance compared to those with good performance.

In conclusion, there is strong evidence that there is no relation between trunk muscle endurance and the risk of low back pain, because more than 75% of the high-quality studies reported on an absence of a relation. The results of the low-quality studies were consistent with the results of the high-quality studies.

Mobility of the lumbar spine and the risk of low back pain

Seven high-quality studies^{21;22;31;32;39-42;47;49;52} and two low-quality studies^{18;36;51} reported on the relation between mobility of the lumbar spine and the risk of low back pain. All studies reported on no relationship between mobility of the lumbar spine and the risk of low back pain. Some of these studies found no differences in lumbar spine mobility between subjects developing low back pain and those staying free of pain.^{21;22;40-42;49;52} Furthermore, some of these studies only reported that there was no relation.^{18;22;31;36;39;40;42;47;49;51} One high-quality study⁴² reported on larger lumbar flexion as a predictor of first-time low back pain in males. Troup et al. / Griffin et al.^{41;50} found a larger flexion–extension range in subjects developing low back pain compared to those not developing low back pain. On the other hand, two studies^{18;40;49} found reduced lumbar flexion among subjects developing low back pain.

In conclusion, due to inconsistent results in multiple high-quality and low-quality studies, there is inconclusive evidence for a relation between mobility of the lumbar spine and the risk of low back pain.

Table 3.2. Quality scores of the included studies.

Quality item*	1	2	3	4	5	6	7	8	9	10	11	
Study	Selection	Response base-line	Response follow-up	Description outcome	Duration outcome	Follow-up	Inclusion cases	Adjustment	No. of cases multi-variate	Effect sizes	SE or CI	Total score
High quality												
Riihimäki et al. (1989)	1	1	1	1	0	1	1	1	1	1	1	10
Battié et al. (1989, 1990)	1	1	1	1	0	?	1	1	1	1	1	9
Biering-Sørensen et al. (1984, 1989)	1	1	1	1	0	1	1	1	0	1	0	8
Kujala et al. (1996)	1	0	?	1	1	1	1	1	1	1	0	8
Leino et al. (1987)	1	?	?	1	1	0	1	1	1	1	1	8
Masset et al. (1998)	1	?	1	1	0	1	1	1	0	1	1	8
Barnekow-Bergkvist et al. (1996, 1998)	1	?	1	1	1	0	?	1	0	1	1	7
Gibbons et al. (1997) and Latikka et al. (1995)	1	?	1	1	1	1	1	?	n.a.	1	0	7
Luoto et al. (1995) and Alaranta et al. (1994)	1	?	1	0	0	1	1	1	0	1	1	7
Stevenson et al. (2001)	1	1	?	1	0	1	0	1	1	1	0	7
Troup et al. (1987) and Griffin et al. (1984)	1	?	?	1	1	1	1	1	1	0	0	7
Hämäläinen et al. (1994)	1	?	1	1	?	1	1	0	n.a.	1	0	6
Klaber Moffett et al. (1993)	1	?	?	1	1	1	1	1	?	0	0	6
Newton et al. (1993)	1	?	1	1	0	1	1	0	n.a.	1	0	6
Takala et al. (2000) and Mayer et al. (1984)	1	0	?	1	1	1	1	?	n.a.	1	0	6
Low quality												
Adams et al. (1999)	1	?	?	1	0	1	0	?	n.a.	1	1	5
Lee et al. (1999)	1	?	1	0	0	1	1	0	n.a.	1	0	5
Norlander et al. (1997)	1	?	?	1	1	?	?	0	n.a.	1	1	5
Rissanen et al. (2002)	1	0	1	0	0	0	?	1	0	1	1	5
Dueker et al. (1994)	1	?	?	1	0	0	1	0	n.a.	1	0	4
Josephson et al. (1996)	?	?	?	1	0	1	0	?	n.a.	1	1	4
Ready et al. (1993) and Chaffin et al. (1978)	1	0	?	1	0	?	0	1	0	0	0	3
Very low quality												
Mostardi et al. (1992)	1	?	?	0	0	?	1	0	n.a.	0	0	2
Mooney et al. (1996)	0	?	?	0	0	?	1	0	n.a.	0	0	1
Chaffin et al. (1973, 1974)	1	?	?	?	0	?	?	0	n.a.	0	0	1
Howell et al. (1984)	0	?	?	1	0	?	?	0	n.a.	0	0	1

* Eleven quality items as described in Table 3.1; n.a.: not applicable.

Table 3.3. Data-extraction of the prospective cohort studies on trunk muscle strength, endurance, or mobility of the lumbar spine and the risk of low back pain.

Study; QS	Pop; follow-up*	Physical capacity measure	Outcome measure	Results (adjusted for confounders)
Adams et al. (1999); QS=5	Health care workers and students (N=403) without serious LBP; 3 years	1. Isometric muscle strength 2. Static endurance extensors: Biering-Sørensen test (sec) 3. Mobility: a. Extension: measured with EMG (degrees) b. Flexion measured with EMG (degrees) c. Flexion measured by modified Schöber test (cm) d. Lateral bending: measured with EMG (degrees)	Self-reported incidence of serious LBP (required medical attention or time off work) or any LBP during the past 6 months	1, 2, 3a,d. $P>0.05$ (no effect size shown) 3b. Reduced range predicted serious LBP in all subjects, in ♀, in students, and in subjects without any LBP; $p<0.05$ c. Reduced range predicted serious LBP in students; $p<0.05$ d. Per decrease of 2 SD: OR 2.5 (95% CI 1.4-4.5); $p=0.002†$
Barnekow-Bergkvist et al. (1996, 1998); QS=7	Employees (N=238); 18 years	Max isometric lifting strength (N)	Self-reported LBP during the past 12 months	$\geq$ median vs < median: ♂: OR 0.66 (0.18-2.44); $p=0.53†$; ♀: OR 0.11 (0.02-0.58); $p=0.009†$
Battié et al. (1989, 1990); QS=9	Air craft manufacturing employees (N=2178); 4 years	1. Isometric lifting strength (lbs) 2. Mobility (cm): a. Flexion measured by modified Schöber test (cm) b. Flexion measured by sit-and-reach test c. Lateral bending	Report to the company medical department or filing of insurance claims due to back problems	1. Per increase of 20 lbs: RR 0.99 (0.76-1.29) $†$; $p=0.94$ 2a. Mean (SD) N-LBP vs I-LBP: ♂: 22.1 (1.2) vs 22.1 (1.1); $p=0.73$; ♀: 21.2 (1.3) vs 21.5 (1.2); $p=0.46$ b. Mean (SD) N-LBP vs I-LBP: ♂: -1.0 (9.6) vs -0.2 (9.7); $p=0.43$; ♀: 2.6 (8.0) vs 3.8 (8.8); $p=0.49$ c. Mean (SD) N-LBP vs I-LBP: ♂: 21.5 (4.2) vs 21.8 (4.5); $p=0.45$; ♀: 21.3 (3.9) vs 20.6 (3.2); $p=0.48$
Biering-Sørensen et al. (1984, 1989); QS=8	General population (N=351); 1 year	1. Max isometric strength (N): a. Extensors b. Flexors 2. Dynamic strength: a. Flexors: curled-trunk sit-up (grade) b. Abdominal muscles: leg-lowering test (angle between legs and couch) 3. Static endurance extensors: Biering-Sørensen test (sec) 4. Mobility: a. Flexion measured by modified Schöber test (mm) b. Flexion measured by fingertip-floor distance (cm)	Self-reported incidence of LBP in the past 12 months	1a. ♂: no discrimination between N-LBP and I-LBP; ♀: lower performance predicted I-LBP; $p=0.002$ b. Mean (SD) N-LBP vs I-LBP: ♂: 895 (190) vs 936 (166); ♀: 461 (129) vs 434 (144); $p>0.18$ 2a. N-LBP vs I-LBP: ♂: $p=0.093$; ♀: $p=0.90$ b. N-LBP vs I-LBP: ♂: $p=0.73$; ♀: $p=0.51$ 3. Lower performance indicated I-LBP; $p\leq 0.05$ 4a. ♂: larger value predicted I-LBP; $p<0.001$; ♀: no discrimination between N-LBP and I-LBP b. Mean: N-LBP vs I-LBP: ♂: 3.6 vs 4.1; $p=0.83$; ♀: 1.6 vs 3.1; $p=0.12$

Table 3.3. Continued.

Study; QS	Pop; follow-up*	Physical capacity measure	Outcome measure	Results (adjusted for confounders)
Dueker et al. (1994); QS=4	Consecutive applicants for work in a steel mill (N=205); 62 to 70 months	Isokinetic max peak torque and work per repetition at velocities of 60°/sec, 120°/sec and 180°/sec (ft-lbs): a. Extensors b. Flexors	Monitor of low back injuries by the safety department at the participating facility	a. Mean (SD) non-injured vs injured: ♂: peak torque at 60°/sec: 224 (60) vs 226 (54); p=0.59; work per repetition: 281 (72) vs 288 (56); p=0.73; ♀: power too low to analyse b. Mean (SD) non-injured vs injured: ♂: peak torque at 60°/sec: 158 (42) vs 157 (34); p=0.94; work per repetition: 207 (56) vs 194 (46); p=0.30; ♀: power too low to analyse
Gibbons et al. (1997) and Latikka et al. (1995); QS=7	Men from the Finnish Twin Cohort (N=43); 1 year	1. Max isokinetic lifting strength (N) with a velocity of 0.5 m/sec 2. Psychophysical lifting strength (N) 3. Static endurance extensors: Biering-Sørensen test (sec)	Self-reported incidence of LBP during the past 12 months (by interview)	1. Mean (SD) N-LBP vs I-LBP: 1029 (224) vs 1034 (325); p=0.95 2. Mean (SD) N-LBP vs I-LBP: 357 (160) vs 410 (168); p=0.33 3. Mean (SD) N-LBP vs I-LBP: 84 (45) vs 80 (46); p=0.83
Josephson et al. (1995); QS=4	Female nursing aides (N=91); 6 months	Static endurance extensors: Biering-Sørensen test (sec)	Self-reported incidence of LBP: ≥11 on a VAS score 0-100	≤110 sec compared to >110 sec: RR 1.2 (0.6-2.6); p=0.64†
Klüber	Student nurses	1. Static endurance (sec): a. Extensors: Biering-Sørensen test b. Abdominal muscles	Self-reported incidence of LBP: A: during ≥3 consecutive days; B: during ≥21 days and/ or 1 day sick	No statistically significant relations (p>0.05) (data not shown)
Moffett et al. (1993); QS=6	(N=181) 5 years			
Kujala et al. (1996); QS=8	General population (N=262); 5 years	1. Relative max isometric torque by body mass (Nm/kg): a. Extensors b. Flexors 2. Dynamic endurance test: sit ups (no. of repetitions in 30 sec): a. Extensors b. Flexors	Self-reported incidence of mild LBP (intensity ≤30 on a scale of 0-100) or severe LBP (>30)	1a. Mean N-LBP vs M-LBP vs S-LBP: 318 vs 317 vs 315; p=0.96 b. Mean N-LBP vs M-LBP vs S-LBP: 270 vs 263 vs 268; p=0.72 2a. Mean N-LBP vs M-LBP vs S-LBP: 20.2 vs 20.8 vs 20.0; p=0.33 b. Mean N-LBP vs M-LBP vs S-LBP: 14.8 vs 14.8 vs 14.3; p=0.66

Table 3.3. Continued.

Study; QS	Pop; follow-up*	Physical capacity measure	Outcome measure	Results (adjusted for confounders)
Lee et al. (1999); QS=5	Students (N=67); 5 years	Max isokinetic peak torque with a velocity of 60 °/sec (Nm): a. Extensors b. Flexors c. Left rotators d. Right rotators	Incidence of LBP leading to work absence and/or requiring medical attention	a. Mean (SD) N-LBP vs I-LBP ♂: 239.6 (63.3) vs 204.2 (36.5); n.s.; ♀: 118.7 (29.1) vs 98.2 (30.6); n.s. b. Mean (SD) N-LBP vs I-LBP ♂: 197.3 (42.8) vs 221.0 (53.0); n.s.; ♀: 119.4 (24.2) vs 127.3 (27.0); n.s. c. Mean (SD) N-LBP vs I-LBP ♂: 126.8 (26.9) vs 125.1 (21.8); n.s.; ♀: 57.6 (19.0) vs 60.5 (20.6); n.s. d. Mean (SD) N-LBP vs I-LBP ♂: 128.8 (29.8) vs 128.1 (23.9); n.s.; ♀: 57.8 (16.4) vs 65.8 (24.6); n.s.
Leino et al. (1987); QS=8	Employees in the metal industry (N=654); 10 years	1. Max isometric strength (N): a. Extensors b. Flexors 2. Dynamic endurance (no. of repetitions in 30 sec): a. Extensors b. Flexors; sit ups	Self-reported chronic lumbo-sacral disease checked by a physiotherapist	1a. Low vs high: ♂: RR 0.91 (0.53-1.54); p=0.73†; ♀: RR 0.71 (0.40-1.27); p=0.25† b. Low vs high: ♂: RR 1.12 (0.65-1.91); p=0.68†; ♀: RR 0.55 (0.29-1.04); p=0.066† 2. No statistically significant relation (data not shown)
Luoto et al. (1995) and Alaranta et al. (1994); QS=7	Workers City Council (N=126); 1 year	1. Isometric lifting strength trunk muscles 2. Static endurance extensors: Biering-Sørensen test (sec) 3. Dynamic endurance: a. Extensors; arch-ups b. Flexors; repetitive sit-ups 4. Mobility: a. Extension (degrees) b. Flexion (degrees) c. Mean left and right rotation (cm) d. Mean left and right side bending (cm)	Self-reported incidence of LBP during the past 12 months	1,3,4. No relation (data not shown) 2. Moderate tertile vs highest tertile: OR 1.4 (0.4-4.2); p=0.55†; lowest tertile vs highest tertile: OR 3.4 (1.2-10.0); p=0.026†

Table 3.3. Continued.

Study; QS	Pop; follow-up*	Physical capacity measure	Outcome measure	Results (adjusted for confounders)
Masset et al. (1998); QS=8	Male blue-collar workers in the steel industry (N=215); 2 years	1. Max, 50% of max, and 25% of max isometric torque (Nm): a. Extensors b. Flexors c. Right and left rotators d. Right and left lateral flexors 2. Mobility: a. Extension (degrees) b. Flexion (degrees) c. Flexion: measured by modified Schöber test (mm) d. Right and left rotation (degrees) e. Right and left lateral bending (degrees)	Self-reported incidence of LBP (by interview)	1a. Per increase of 1 SD: max OR 1.14 (0.81-1.61); p=0.46†; 50%: OR 1.69 (1.04-2.76); p=0.036†; 25% 1.08 (0.66-1.78); p=0.76† b. Per increase of 1 SD: max OR 1.60 (1.01-2.55); p=0.048†; 50%: OR 1.71 (1.04-2.82); p=0.036†; 25% 1.24 (0.76-2.02); p=0.39† c. Per increase of 1 SD: max OR 0.84 (0.55-1.28); p=0.42†; 50%: OR 0.89 (0.60-1.33); P=0.57†; 25% 0.69 (0.46-1.05); P=0.076† d. Per increase of 1 SD: max OR 1.00 (0.64-1.55); p=1.00†; 50%: OR 1.19 (0.81-1.75); p=0.38†; 25% 1.06 (0.69-1.61); p=0.78† 2a. Mean (SD) N-LBP vs I-LBP: 50%: 25 (12) vs 24 (10) p>0.05; 25% 28 (12) vs 27 (12) p>0.05 b. Mean (SD) N-LBP vs I-LBP: 50%: 49 (22) vs 47 (20) p>0.05; 25% 51 (20) vs 50 (14) p>0.05 c. Mean (SD) N-LBP vs I-LBP: 22.3 (0.9) vs 22.2 (0.8); n.s. d. Mean (SD) N-LBP vs I-LBP: 50%: 37 (14) vs 39 (14) p>0.05; 25% 44 (10) vs 43 (10) p>0.05 e. Mean (SD) N-LBP vs I-LBP: 27%: 37 (10) vs 26 (8) p>0.05; 25% 30 (10) vs 29 (10) p>0.05 No statistically significant relation (data not shown)
Newton et al. (1993); QS=6	General population (N=66); 26-32 months	1. Isokinetic peak torque at velocities of 60, 90, 120 and 150°/sec (ft-lb): a. Extensors b. Flexors c. Rotators 2. Isokinetic lifting peak force at 18 and 36°/sec (lb) 3. Isometric lifting strength (lb) 4. Psychophysical lifting strength (kg)	Self-reported incidence of LBP	

Table 3.3. Continued.

Study; QS	Pop; follow-up*	Physical capacity measure	Outcome measure	Results (adjusted for confounders)
Ready et al. (1993) and Chaffin et al. (1978); QS=3	Female nurses (N=119); 18 months	1. Isometric lifting strength (kg) 2. Dynamic endurance (no. of repetitions): a. Extensors: push-ups b. Flexors: partial curl ups 3. Mobility: extension (cm)b. Flexion (cm) c. Rotation (degrees) Max isometric strength (N): a. Back muscles b. Abdominal muscles	Self-diagnosed (severe) back injuries	P≥0.05 (no effect sizes shown)
Riihimäki et al. (1989); QS=10	Male reinforcement workers (N=67)/house painters (N=96); 5 years		Self-reported incidence of sciatic pain	a. Lowest vs highest quartile: RR 0.6 (0.3-1.2); p=0.15† b. RR 0.9 (0.4-1.9); p=0.78†
Rissanen et al. (2002); QS=5	General population (N=535); 12 years	Dynamic endurance (no. of repetitions in 30 sec): a. Extensors: arch-up test b. Flexors: sit-up test	Collection of work disability due to back disorders	a. Per increase of 1 SD: RR 0.43 (0.26-0.70); p=0.00† b. Highest three quartiles compared to the lowest: RR 0.93 (0.43-2.00); p=0.85†
Stevenson et al. (2001); QS=7	Industrial spinning operators (N=137); 2 years	1. Dynamic lifting strength extensors (N) 2. Static endurance extensors: Biering-Sørensen test (sec) 3. Dynamic endurance abdominal muscles: curl-ups (no. of repetitions in 1 min) 4. Mobility (degrees): a. Extension b. Flexion	Self-reported incidence of LBP	No statistically significant relation (data not shown)

Table 3.3. Continued.

Study; QS	Pop; follow-up*	Physical capacity measure	Outcome measure	Results (adjusted for confounders)
Takala and Viikari-Juntura (2000) and Mayer et al. (1984); QS=6	Forest industry workers (N=307); 2 years	1. Max isokinetic strength (N), work (J) and power (W) with velocities of 30°/sec and 90°/sec: a. Extensors b. Flexors 2. Max isokinetic lifting strength with velocities of 0.5m/sec and 1.0m/sec (N) 3. Static endurance extensors; Biering-Sørensen test (sec) 4. Mobility (degrees): a. Flexion measured by lumbar movement b. Flexion measured by pelvic movement c. Flexion measured by total movement	A. Self-reported incidence of LBP: >30 days in the preceding 12 months B. Registration of medical consultation or sick-leave due to LBP at the occupational health service	1a,2,3,4a,e. No statistically significant relation (data not shown) 1b. B: ♂ lower performance at a speed of 90°/sec predicted a shorter time until the first consultation (p=0.001); ♀: no statistically significant relation (data not shown) 2. A: mean (SD) N-LBP vs I-LBP ♂: 947 (186) vs 870 (186); p=0.09 4a. A: mean (SD) N-LBP vs I-LBP ♂: 65 (13) vs 60 (13); p=0.08; B: ♂: 49 (9) vs 46 (9); p=0.08 b. B: mean (SD) N-LBP vs I-LBP ♀: 73 (16) vs 82 (11); p=0.04 c. B: mean (SD) N-LBP vs I-LBP ♀:119 (18) vs 122 (11); p=0.09
Troup et al. (1987) and Griffin et al. (1987); QS=7	General population (N=988); 1 year	1. Max isometric lifting strength (kg) 2. Psychophysical lifting strength (kg) 3. Dynamic muscle strength trunk flexors (no. of repetitions): sit-up test 4. Mobility (degrees): a. Extension b. Flexion - extension range	Self-reported incidence of mild LBP (≤once a month) or chronic LBP (≥once a week)	1. Mean (SD) N-LBP vs I-LBP ♂: 100.94 (27.89) vs 96.87 (27.05); p>0.10†; ♀: 50.25 (17.45) vs 50.12 (17.83); p>0.10† 2. Mean (SD) N-LBP vs I-LBP ♂: 50.65 (22.11) vs 47.48 (18.68); p>0.10; ♀: 23.50 (14.78) vs 23.56 (11.59); p>0.10† 3. Mean (SD) N-LBP vs I-LBP ♂: 1.98 (0.15) vs 1.98 (0.15); p>0.10; ♀: 1.92 (0.28) vs 1.82 (0.39); p≤0.10† 4a. Mean (SD) N-LBP vs I-LBP ♂: 50.57 (9.13) vs 49.82 (9.75); p>0.10; ♀: 59.34 (9.44) vs 57.49 (10.87); p>0.10† b. Mean (SD) N-LBP vs I-LBP ♂: 79.90 (12.30) vs 80.22 (12.31); p>0.10; ♀: 83.86 (12.83) vs 80.96 (11.29); p≤0.10†

* Number of subjects used for the analyses and time between measurement of physical capacity and measurement of low back pain.

† Calculated.

QS: quality score.

♂: men; ♀: women.

OR: odds ratio; RR: relative risk; CI: confidence interval; SD: standard deviation.

LBP: low back pain; N-LBP: no low back pain during follow-up; I-LBP: incidence of low back pain during follow-up; M-LBP: incidence of mild low back pain during follow-up; S-LBP: incidence of severe low back pain during follow-up.

n.s.: not significant.

Table 3.4. Data-extraction of the prospective cohort studies reporting on muscle strength or endurance of the neck/shoulder muscles or mobility of the cervical spine and the risk of neck/shoulder pain.

Study/QS	Pop./follow-up*	Physical capacity measure	Outcome measure	Results (adjusted for confounders)
Barnekow-Bergkvist et al. (1996, 1998); QS=7	Employees (ex-students) (N=238) 18 years	Dynamic endurance (no. of lifts at 25 per minute): bench press	Self-reported neck/shoulder pain during the past 12 months	≥median vs <median ♂: OR 0.30 (95% CI 0.09-0.85); p=0.024; ♀: OR 2.47 (0.58-10.51); p=0.22†
Hämäläinen et al. (1994); QS=6	Male student fighter pilots (N=66); 1 to 3 years	1. Isometric strength (kg): a. Extensors b. Lateral flexors c. Lateral flexors 2. Mobility (degrees): a. Passive extension b. Passive flexion	Self-reported incidence of acute in-flight neck pain	1a. Mean (SD) N-NP vs I-NP: 24.6 (4.5) vs 24.0 (3.9); n.s. b. Mean (SD) N-NP vs I-NP: 20.0 (3.5) vs 19.3 (2.6); n.s. c. Mean (SD) N-NP vs I-NP: 19.9 (3.3) vs 18.6 (2.5); n.s. 2a. Mean (SD) N-NP vs I-NP: 80.6 (7.2) vs 80.6 (7.2); n.s. b. Mean (SD) N-NP vs I-NP: 84.2 (9.7) vs 87.8 (11.6); n.s.
Norlander et al. (1997); QS=5	Female laundry workers (N=161); 2 years	Flexion mobility: inverse if equal or less mobility in segment C7-T1 compared to segment T1-T2	Self-reported neck/shoulder pain: more than 7 days during the past 12 months	Inverse ≥3 of 5 times during follow-up compared to inverse ≤2 times; RR 3.1 (1.2-8.3); p=0.024†

* Number of subjects used for the analyses and time between measurement of physical capacity and measurement of low back pain.

† Calculated.

QS: quality score.

♂: men; ♀: women.

OR: odds ratio; RR: relative risk; CI: confidence interval; SD: standard deviation.

N-NP: no neck pain during follow-up; I-NP: incidence of neck pain during follow-up.

n.s.: not significant.

Physical capacity measures and the risk of neck/shoulder pain

Table 3.4 shows the results of the data-extraction of the studies reporting on physical capacity measures and the risk of neck/shoulder pain. Results with a p-value of 0.10 or less, which were considered as statistically significant, are bold.

Very few studies reported on the relation between physical capacity measures and the risk of neck/shoulder pain. One high-quality study reported on muscle strength of the neck/shoulder muscles,²⁶ one high-quality study reported on endurance of the neck/shoulder muscles,^{19;48} and both a high-quality²⁶ and a low-quality study reported on mobility of the cervical spine.³⁵

In conclusion, there is inconclusive evidence for a relation between muscle strength or endurance of the neck/shoulder muscles and the risk of neck/shoulder pain, due to a limited number of studies reporting on these relations. There is also inconclusive evidence for a relation between mobility of the cervical spine, due to inconsistent results in two studies.

DISCUSSION

To our knowledge, the present systematic review is the first that reported on the evidence of performance in tests of muscle strength, muscle endurance, or spinal mobility as predictors of future low back or neck/shoulder pain.

The results of this systematic review showed strong evidence that there is no relation between trunk muscle endurance and the risk of low back pain. Furthermore, it showed inconclusive evidence for a relation between trunk muscle strength, or mobility of the lumbar spine and the risk of low back pain. Finally, it showed inconclusive evidence for a relation between physical capacity measures and the risk of neck/shoulder pain.

Some comments can be made on the selection criteria regarding the types of tests of physical capacity and the outcome measures. First, we decided to limit this systematic review to muscle strength, muscle endurance and mobility as proxy measures of (local) physical capacity. However, physical capacity can be measured by performance in other tests as well,⁵³ such as tests on proprioceptive control mechanisms,⁵⁴ balance,⁵⁵ or tests used in a functional capacity evaluation.⁵⁶ Furthermore, cardiovascular fitness can be considered as a measure of physical capacity. Second, we decided to limit the search string to studies reporting on pain, or similar terms (see appendix 3.A), but we excluded studies reporting on disability or absence from work due to musculoskeletal pain. The use of a wider search string on physical capacity measures or outcome measures could have led to different results, but probably also to more heterogeneity of the results.

Heterogeneity

The results of this systematic review have to be interpreted with caution, due to heterogeneity. This was mainly due to differences in physical tests, outcome measures, follow-up, and adjustment for confounders. Therefore, it was not possible to perform a statistical pooling of the effect.

Physical tests

In the studies reporting on trunk muscle endurance, both static and dynamic endurance tests were used. If we carried out a best evidence synthesis on low back pain separated for type of physical test, there would be strong evidence for an absence of a relation with dynamic endurance of the back extensors, but there would be inconclusive evidence for a relation with static endurance of the back extensors.

Furthermore, in the studies reporting on muscle strength, isometric, isokinetic, dynamic, and psychophysical muscle strength tests were used. If we carried out a best evidence synthesis separated for type of test, for most type of tests there would be inconclusive evidence for a relation with low back pain. However, there would be strong evidence for an absence of a relation with isometric, isokinetic or psychophysical strength of the back extensors, and there would be moderate evidence for an absence of a relation with isokinetic strength of the rotators.

Finally, mobility of the lumbar spine was measured as extension, flexion, rotation or lateral bending. If we carried out a separated best evidence synthesis, there would be inconclusive evidence for a relation with flexion of the lumbar spine. However, there would be strong evidence for an absence of a relation with extension, rotation, and lateral bending.

Outcome measures

Most studies used self-reported low back pain as outcome measure. They reported incidence rates between 16% and 34%. In some studies, registrations of back injuries were used,^{20;24;40;49} or back injuries were self-diagnosed.^{36;51} The incidence rates found in these studies were lower than the self-reports: between 8% and 15%. Furthermore, various definitions of pain were used with respect to frequency, intensity, or localization of pain.

If we restricted the best evidence synthesis to the studies with self-reported low back pain, this would not lead to different results.

Follow-up

The follow-up time of two high-quality studies was longer than five years.^{19;30;48} Because it is plausible that physical capacity and musculoskeletal disorders change in time, the results of these studies have to be interpreted with caution.

If we ignored the results of these two studies, this would not lead to different results of the best evidence synthesis.

Adjustment for confounders

In most studies, adjustments for multiple confounders were done, while four studies did not adjust for confounding factors.^{24;41;44;45;50} Three studies did not adjust for all potential confounding factors, but only for age and/or gender.^{20;29;37} Lack of adjustment for confounding factors could lead to an under- or overestimation of the effect. Therefore, the results of these studies have to be interpreted with caution.

If we restricted the best evidence synthesis to the studies with satisfactory correction for confounders, this would not lead to different results of the best evidence synthesis.

Best evidence synthesis

Ideally, we would have based the best evidence synthesis on effect sizes, but this was not possible due to heterogeneity in effect measures. For instance, some studies reported on risk ratios, others reported on mean differences in physical capacity between subjects developing pain and those remaining free of pain, others reported on prediction of pain with a p-value, and finally some studies only reported "no relation". Furthermore, different cut-off points of "high" and "low" physical capacity were used. Due to these problems, we decided to base the best evidence synthesis on statistical significance. To include borderline significant effects, we used a p-value of 0.10 or less as cut-off point, instead of the commonly used cut-off point of 0.05.

If we had only selected studies reporting on risk ratios or odds ratios, this would have led to an adaptation of the conclusion for endurance. Then, we would have found inconclusive evidence for a relationship between strength, endurance or mobility and the risk of low back pain. However, if we had used a p-value of 0.05 or less to interpret whether there is an effect or not, this would not lead to different results of the best evidence synthesis.

Quality assessment

To investigate the influence of the assumptions and cut-off points we have used in the best evidence synthesis, we carried out sensitivity analyses on low back pain varying those assumptions. We did not carry out sensitivity analyses on neck/shoulder pain, due to the limited number of studies.

First, we calculated the total quality score by summing up all positively scored items with the same weight. However, some items could be considered as more important for the

quality assessment than others. We assumed that the quality items on response during follow-up, the time between the measurement of physical capacity and the measurement of the outcome measures, adjustment for confounders, effect sizes, and standard errors and/or confidence intervals have more impact on the level of evidence. We gave these items a double weight leading to a maximum total score of 16. We defined studies as high quality, if they had a total score of eight or higher, and we defined as low quality, if the total score was between four and seven. In contrast to the initial quality assessment, this would lead to an addition of Adams et al.,¹⁸ Lee et al.,⁴⁴ and Rissanen et al.³⁸ to the high-quality studies. However, this would not lead to an adaptation of the conclusions of trunk muscle strength, trunk muscle endurance, or mobility of the lumbar spine and the risk of low back pain.

Second, when the cut-off points regarding the qualification of studies as high or low quality were shifted, the number of high-quality studies would change. Shifting the cut-off point regarding a study as high-quality from a score of six to seven would lead to an adaptation of the conclusions for trunk muscle endurance, and mobility of the lumbar spine. The strong evidence for an absence of a relation between trunk muscle endurance and the risk of low back pain would change into inconclusive evidence and for mobility *vis versa*. Including the studies with very low quality, which we excluded from the data-extraction, would not lead to an adaptation of the conclusions.

Finally, if we had counted the studies reporting both a positive (or negative) effect, and no effect for different types of tests and/or different gender groups, only one time for the positive effect, instead of twice, this would not lead to different results. However, if we had counted all effects that were reported in the different studies (some studies reported more than 10 effects), this would lead to an adaptation of the conclusions for trunk muscle strength and mobility of the spine into strong evidence for no relationship.

Overall, the results of the best evidence synthesis were not very sensitive to the assumptions and cut-off points we used, and can therefore be considered to be quite robust.

Appendix 3.A. Search string; rows represent "AND", and columns represent "OR".

Work-related	Physical capacity	Outcome measure
Work*	Physical	Capacity
Job	Functional	Tolerance
Jobs	Work capacity evaluation	Lowback
Occupation*	Lifting	Lumbar vertebrae
	Strength	Neck
	Endurance	Cervical vertebrae
	Pliability	Shoulder
	Mobility	Spine
	Flexibility	Spinal
		Joint
		Joints
		Flexion
		Rotation
		Extension
		Lateral bending

* Truncated

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CHAPTER 4

PHYSICAL CAPACITY IN RELATION TO LOW BACK, NECK, OR SHOULDER PAIN IN A WORKING POPULATION



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Abstract

Objective: To investigate the longitudinal relation between physical capacity (isokinetic lifting strength, static endurance of the back, neck, and shoulder muscles, and mobility of the spine) and low back, neck, and shoulder pain.

Methods: In this prospective cohort study, 1789 Dutch workers participated. At baseline, isokinetic lifting strength, static endurance of the back, neck, and shoulder muscles, and mobility of the spine were measured in the pain free workers, as well as potential confounders, including physical workload. Low back, neck, and shoulder pain were self-reported annually at baseline and three times during follow-up.

Results: After adjustment for confounders, Poisson Generalised Estimation Equations showed an increased risk of low back pain among workers in the lowest sex-specific tertile of performance in the static back endurance tests compared to workers in the reference category (risk ratio (RR) 1.42; 95% confidence interval (95% CI) 1.19 to 1.71), but this was not found for isokinetic trunk lifting strength, or mobility of the spine. An increased risk of neck pain was shown for workers with low performance in tests of isokinetic neck/shoulder lifting strength (RR = 1.31; 95% CI 1.03 to 1.67) and static neck endurance (RR = 1.22; 95% CI 1.00 to 1.49). Among workers in the lowest tertiles of isokinetic neck/shoulder lifting strength or endurance of the shoulder muscles, no increased risk of shoulder pain was found.

Conclusion: The findings of this study suggest that low back or neck endurance were independent predictors of low back or neck pain, respectively, and that low lifting neck/shoulder strength was an independent predictor of neck pain. Neither an association was found between lifting trunk strength, or mobility of the spine and the risk of low back pain, nor between lifting neck/shoulder strength or endurance of the shoulder muscles and the risk of shoulder pain.

INTRODUCTION

Low back, neck, and shoulder pain are of multi-factorial origin. Both physical and psychosocial factors can contribute to its development, as well as individual factors such as gender, age, and anthropometry.^{1;2} The biomechanical load-tolerance model assumes that musculoskeletal disorders can be explained by an imbalance between load and tolerance, which may become manifest as musculoskeletal symptoms and disorders. The term “load” describes physical stresses acting on the body or on anatomical structures within the body. These stresses include kinetic (motion), kinematic (force), oscillatory (vibration), and thermal energy sources, which can originate from the external environment (such as vibrating tools), or from actions of the individual (such as lifting objects). The term “tolerance” is used to describe the capacity of physical and physiological responses of the body to the load.¹

The association between physical capacity and musculoskeletal disorders has been studied in the laboratory using in vitro and cadaver studies.^{3;4} In epidemiological studies, only proxy measures of physical capacity can be used, e.g. isokinetic lifting strength, endurance time of sub-maximal static muscle contraction, or joint mobility. Several longitudinal studies reported on the relation between physical capacity and the risk of low back pain. Low performance in tests of muscle strength,⁵⁻⁸ endurance,⁹⁻¹¹ and mobility^{7;12} were reported as risk factors for low back pain, although many other studies did not find these results.^{7;9;12-24} Furthermore, very few longitudinal studies have examined the association between physical capacity and the risk of neck or shoulder pain.^{5;25} Barnekow-Bergkvist et al. reported on a decreased risk of neck/shoulder problems in males with high performance in a test of dynamic endurance,⁵ but no association was found between muscle strength and the risk of neck or shoulder pain.²⁵

The main objective of this prospective cohort study among a working population is to investigate if isokinetic lifting strength and static endurance of the back and neck/shoulder muscles, and mobility of the spine are predictors of low back, neck, or shoulder pain, independent of the physical workload.

METHODS

Design

The present study is part of the longitudinal study on musculoskeletal disorders, sickness absenteeism, stress, and health (SMASH),²⁶⁻²⁸ a large prospective cohort study among a working population with a follow-up time of three years. Almost 1800 blue-collar and white-collar workers participated in this study. They were working in 34 companies

located throughout the Netherlands. Data were collected on physical capacity, musculoskeletal disorders, and many potential confounding factors. The baseline measurements were carried out between January 1994 and May 1995 consisting of a comprehensive self-administered postal questionnaire, measurements of physical capacity, and assessment of physical load at the workplace. During follow-up, three questionnaires were filled out about once every year with a range of 9 to 15 months at maximum due to differences in response time.

Study population

At baseline, 1789 (87%) of the 2064 workers who were invited to participate in SMASH completed the self-administered questionnaire. We excluded workers from the analyses if they had worked less than one year in their current job, worked less than 20 hours per week, or received sickness benefit or permanent disability pension at baseline (211 workers were excluded). Furthermore, we excluded workers from the analyses when data on outcome measures were missing in three or four questionnaires (107, 105, and 108 workers were excluded for low back, neck, and shoulder pain, respectively).

Just before testing physical capacity at baseline, we asked the workers for contraindications that might involve a health risk, or that might have an effect on the results of the tests. We excluded workers from the tests if they had cardiovascular diseases, or fever, or were pregnant (143, 204, and 211 workers were excluded, respectively). In addition, current Localised Musculoskeletal Discomfort (LMD) was asked. The LMD-score was used to obtain a rating of the perceived feelings of discomfort (pain, muscle fatigue, tremor, etc.) in any part of the body (ranging from no discomfort (zero) to worst imaginable discomfort (10)).²⁹ We excluded workers from the tests for the low back, neck, or shoulder if they reported an LMD-score of at least four points in the matching body region. Finally, we included 1328, 1269, and 1259 workers in the analyses on low back, neck, and shoulder pain, respectively.

Assessment of outcome measures

Outcome measures were self-reported low back, neck, and shoulder pain. Data on musculoskeletal disorders were measured by an adapted Dutch version of the Nordic Questionnaire.³⁰ In the baseline and the three follow-up questionnaires, low back, neck, and shoulder pain were asked ("Did you have pain in the past 12 months?") on a four-point scale ("no", "sometimes", "regular", or "prolonged"). We dichotomised these variables by combining "no" with "sometimes" ("no pain"), and "regular" with "prolonged" ("pain"). If a pain-free episode was followed by an episode with low back, neck, or shoulder pain, we

defined this as occurrence of an event. We did not consider pain at baseline as an event. However, if workers with pain at baseline recovered during follow-up and experienced recurrence at a later follow-up moment, we defined this as occurrence of an event. In addition, for some workers events occurred twice at follow-up, if they reported pain in both the first and third follow-up questionnaire, but were free of pain at baseline and at the second follow-up moment. Furthermore, for workers with at random missing data on low back, neck or shoulder pain in one or two questionnaires, potential transitions from “no pain” to “pain” were analysed in the same way as for workers without missing data, but transitions from a missing value to a non-missing value and vice versa were ignored.

Assessment of physical capacity

At baseline, physiotherapists performed the different tests of isokinetic lifting power strength, sub-maximal endurance time of static contraction of the back, neck, and shoulder muscles, and mobility of the spine. Isokinetic lifting strength was measured with the Aristokin dynamometer (Lode BV Medical Technology, Groningen, the Netherlands), both from floor to hip level for the trunk muscles, and from hip to shoulder level for the neck/shoulder muscles. After practicing, in order to get familiar with the Aristokin, workers had to lift the box three times with maximum effort with a velocity of 40 cm/sec and a rest period of 30 seconds in between. Isokinetic lifting strength (in Newtons) was defined as the average outcome of the second and third lifts.

We defined static endurance as the number of seconds during which the workers could keep a position, while carrying a load. To test the static endurance of the back extensors, the Biering-Sørensen test⁸ was used. Workers were lying prone on a table and had to keep their unsupported upper part of the body in a horizontal position with fixation of the buttocks and legs. We asked the LMD-score at intervals of 15 seconds. The test was finished when the workers reached an LMD-score of five in the back region, or a score of seven in another part of the body, or after 4 minutes at maximum. For the measurement of the static endurance of the neck extensors, the workers had to keep their head flexed at 45 degrees in a sitting position, while carrying a helmet of 5 kilograms for males, or 2.5 kilograms for females. For the measurement of the static endurance of the shoulder elevators, workers had to keep their arms elevated at 90 degrees in a sitting position, while carrying a load of 2.5 kilograms for males, or 1.5 kilograms for females. We obtained LMD at intervals of 30 seconds. The tests were finished at an LMD-score of five in the neck/shoulder region, or a score of seven in another part of the body, or after 7 minutes at maximum.

Lumbar flexion was measured by the Schöber test, that is the difference in the distance between 5 cm below and 10 cm above S1/S2 in a position of maximum flexion and

in the neutral position.³¹ Rotation of the spine was measured by the difference in the distance (in cm) between the incisura jugularis and L5 in a position of maximum rotation and in the neutral position. Both flexion and rotation were measured twice. In this study, we averaged the outcomes of those two measurements. Furthermore, we averaged left and right rotation, because of high correlation (Pearson correlation coefficient 0.74 ($p=0.000$)).

Assessment of potential confounders

Potential confounding factors related to low back, neck, or shoulder pain were measured at baseline including age, length, Body Mass Index, years of employment, number of working hours per week, education, physical workload, psychosocial workload,³² physical load during leisure time,³³ coping style,³⁴ and exposure to one or more life events.³⁵ Furthermore, we considered previous low back, neck or shoulder pain, self-reported general health status, self-reported physical condition, and measures of physical capacity, apart from the independent variable, as potential confounders. Finally, co-morbidity regarding other musculoskeletal disorders at baseline and during follow-up was a potential confounder.

Physical load at work was assessed using video-recordings and was self-reported. Four 10 or 14 minutes video-recordings were taken randomly during a day of about half of the workers. They were assigned to groups with similar tasks. In each of these groups, about half of the videotapes was observed by trained research assistants and was analysed for posture, movement and force exertion. Data on psychosocial workload were collected by means of the Job Content Questionnaire, which measured all dimensions of the Demand-Control Support Model. Various items on the questionnaire were combined into dimensions as proposed by Karasek et al.³² Physical load during leisure time included the average number of hours of sports participation per week during the past year, the number of years of sports participation in the past,³⁶ and the frequency of sports or heavy physical activities which causes sweating during the past four months.

Appendix 4.A lists all potential confounding factors for the analyses on low back, neck and shoulder pain separately, which were associated with low back, neck, or shoulder pain with a p-value of 0.25 or less. Mutually dependent confounding factors (Spearman correlation coefficients of ≥ 0.5 or ≤ -0.5) were excluded.

Statistical analyses

We have used Poisson Generalised Estimation Equations (GEE) to analyse the association between isokinetic lifting strength, static endurance, and mobility of the spine at baseline as fixed variables and self-reported low back, neck, or shoulder pain at every follow-

up moment as dichotomous time-variables.³⁷ For each of the three follow-up moments, the transitions from a pain free episode to an episode with pain were measured. We performed the analyses with the statistical package Stata version 7.0 (Stata Corp, College Station, TX, USA).

In order to adjust for differences in performance in tests of physical capacity between men and women, we calculated sex-specific tertiles, which were combined categories of both tertiles for men and women. We estimated univariate and multivariate risk ratios (RRs) and 95% confidence intervals (95% CIs) with the highest tertile as reference category. These RRs can be interpreted as the risk of occurrence of pain during follow-up in workers with low or medium performance in tests of physical capacity compared to those with high performance, taking into account the dependency of the observations within one worker.³⁸

We included follow-up time both in univariate and multivariate analyses to adjust for the fact that the association between physical capacity at baseline and the risk of musculoskeletal disorders during follow-up could be stronger after one year than after two or three years. Furthermore, we selected age as a confounder a priori. All other potential confounders were included in the univariate GEE models together with the dependent and independent variables. If the crude beta coefficients changed at least 10 percent, these confounders were included in the final multivariate models. All confounders were added as fixed variables to the models, except co-morbidity regarding other musculoskeletal disorders during follow-up, which was added as a time-variable.

RESULTS

Characteristics of the study population

Tables 4.1 and 4.2 present descriptive statistics of the study population and performance in tests of physical capacity, both among males and females. Almost 70% of the workers were male and the mean age was 36 years. Employees worked 38 hours per week on average. Almost 70% of the workers had a blue-collar or caring profession and more than 30% had a white-collar job. During follow-up, between 7% and 11% of the workers had a low back pain episode following a pain-free episode, between 4% and 7% of the workers had neck pain, and between 6% and 7% of the workers had shoulder pain.

For some measures, performance in tests of physical capacity was not distributed normally. Many workers were able to reach the maximum endurance time in the static neck and shoulder endurance tests. Therefore, Table 4.2 shows median (minimum-maximum) performance. Median static endurance of the back and neck

Table 4.1. Characteristics of the study population, SMASH, 1994-1997 (N=1357).

Characteristics*	Total population†
Men	69.5
Age (mean (SD))‡	35.4 (8.8)
Working hours per week (mean (SD))‡	38.1 (5.1)
Years of employment in current job (mean (SD))‡	9.4 (7.6)
Type of occupation	
Blue-collar occupations	61.3
White-collar occupations	31.0
Caring occupations	7.7
Occurrence of low back pain during follow-up§	
Follow-up 1	8.9
Follow-up 2	10.6
Follow-up 3	6.9
Occurrence of neck pain during follow-up§	
Follow-up 1	5.8
Follow-up 2	6.9
Follow-up 3	3.7
Occurrence of shoulder pain during follow-up§	
Follow-up 1	7.2
Follow-up 2	6.4
Follow-up 3	5.8

* Unless otherwise indicated, baseline characteristics are given.

† Unless otherwise indicated, values are percentages (%).

‡ SD, standard deviation.

§ Regular or prolonged pain in the past 12 months and no or sometimes pain in the past 12 months was reported in the previous questionnaire.

Table 4.2. Characteristics of the study population, SMASH, 1994-1997 (N=1357).

	Men	Women	Total
	median	median	median
	(min-max)	(min-max)	(min-max)
Isokinetic lifting strength back muscles (N)	551 (52 to 1358)	338 (39 to 724)	475 (39 to 1358)
Isokinetic lifting strength neck/shoulder muscles (N)	257 (38 to 563)	129 (15 to 272)	210 (15 to 563)
Static endurance back extensors (sec)*	90 (5 to 240)	90 (6 to 240)	90 (5 to 240)
Static endurance neck flexors (sec)*	278 (7 to 420)	284 (30 to 420)	280 (7 to 420)
Static endurance shoulder elevators (sec)*	270 (48 to 420)	210 (27 to 420)	257 (27 to 420)
Flexion of the spine (cm)	7.0 (2.0 to 10.0)	6.5 (0.5 to 10.01)	7.0 (0.5 to 10.0)
Rotation of the spine (cm)	5.8 (1.5 to 12.8)	5.1 (1.4 to 11.5)	5.5 (1.4 to 12.8)

* Loads were different for men and women.

muscles and mobility of the spine were comparable in men and women, but median isokinetic lifting strength and median static endurance of the shoulder muscles were higher in men than in women.

Low back pain

Table 4.3 shows the results of the univariate and multivariate GEE analyses of the association between performance in tests of physical capacity of the low back and the risk of low back pain. Adjusted for age and follow-up time, the risk ratio of low back pain was 1.42 (95% CI 1.19 to 1.71) among workers in the lowest tertile of static endurance of the back muscles compared to the reference. No increased risk of low back pain was found among workers with low isokinetic lifting strength or decreased mobility of the spine.

Table 4.3. Univariate and multivariate risk ratios (95% confidence intervals) of the association between sex-specific tertiles of physical capacity and low back pain, SMASH, 1994-1997 (N=1328).

Physical capacity	Total events/total number at risk*	Crude RR (95% CI)†	Adjusted RR (95% CI)
Isokinetic lifting strength back muscles	High (86 / 1060)	1.00	1.00‡
	Moderate (98 / 1056)	0.99 (0.83 to 1.19)	1.01 (0.84 to 1.21)
	Low (96 / 1055)	1.06 (0.89 to 1.27)	1.09 (0.91 to 1.31)
Static endurance back extensors	High (87 / 1003)	1.00	1.00‡
	Moderate (85 / 991)	1.14 (0.93 to 1.39)	1.13 (0.93 to 1.38)
	Low (94 / 1010)	1.43 (1.19 to 1.71)	1.42 (1.19 to 1.71)
Flexion of the spine	High (94 / 1160)	1.00	1.00‡
	Moderate (99 / 1015)	1.08 (0.91 to 1.29)	1.09 (0.91 to 1.30)
	Low (129 / 1469)	1.10 (0.94 to 1.30)	1.12 (0.95 to 1.31)
Rotation of the spine	High (92 / 1179)	1.00	1.00§
	Moderate (119 / 1194)	1.09 (0.92 to 1.30)	0.99 (0.82 to 1.19)
	Low (111 / 1268)	1.18 (1.00 to 1.39)	1.10 (0.92 to 1.32)

* Summarisation of occurrence annually during follow-up divided by a summarisation of all workers at risk annually during follow-up.

† RR, risk ratio; CI, confidence interval. Including the covariate duration of follow-up.

‡ Adjusted for duration of follow-up, and age.

§ Adjusted for duration of follow-up, age, and isokinetic lifting strength.

Neck pain

An increased risk of neck pain was shown among workers with low performance in the tests of isokinetic neck/shoulder lifting strength (adjusted RR = 1.31; 95% CI: 1.03 to 1.67) and static endurance of the neck muscles (adjusted RR = 1.22; 95% CI 1.00 to 1.49) (see Table 4.4).

Shoulder pain

Univariate analyses showed an increased risk of shoulder pain among workers in the lowest tertile of isokinetic lifting strength (crude RR 1.34; 95% CI 1.06 to 1.70). After adjustment for confounders, no relationships remained. No association was found between static endurance of the shoulder elevators and the risk of shoulder pain (see Table 4.5).

Table 4.4. Univariate and multivariate risk ratios (95% confidence intervals) of the association between sex-specific tertiles of physical capacity and neck pain, SMASH, 1994-1997 (N=1269).

Physical capacity	Total events/total number at risk*	Crude RR (95% CI)†	Adjusted RR (95% CI)
Isokinetic lifting strength	High (59 / 1030)	1.00	1.00‡
neck/shoulder muscles	Moderate (60 / 1084)	1.27 (0.99 to 1.64)	1.21 (0.94 to 1.55)
	Low (59 / 1039)	1.45 (1.14 to 1.84)	1.31 (1.03 to 1.67)
Static endurance neck flexors	High (47 / 1099)	1.00	1.00§
	Moderate (76 / 1174)	1.24 (0.97 to 1.59)	1.15 (0.94 to 1.40)
	Low (64 / 1152)	1.70 (1.34 to 2.14)	1.22 (1.00 to 1.49)

* Summarisation of occurrence annually during follow-up divided by a summarisation of all workers at risk annually during follow-up.

† RR, risk ratio; CI, confidence interval. Including the covariate duration of follow-up.

‡ Adjusted for duration of follow-up, age, and length.

§ Adjusted for duration of follow-up, age, co-morbidity of low back or shoulder pain, and previous neck pain.

Table 4.5. Univariate and multivariate risk ratios (95% confidence intervals) of the association between sex-specific tertiles of physical capacity and shoulder pain, SMASH, 1994-1997 (N=1259).

Physical capacity	Total events/total number at risk*	Crude RR (95% CI)†	Adjusted RR (95% CI)
Isokinetic lifting strength	High (62 / 1030)	1.00	1.00‡
neck/shoulder muscles	Moderate (73 / 1070)	1.25 (0.98 to 1.59)	1.16 (0.91 to 1.46)
	Low (71 / 1028)	1.34 (1.06 to 1.70)	1.16 (0.92 to 1.46)
Static endurance shoulder elevators	High (77 / 1091)	1.00	1.00§
	Moderate (73 / 1097)	1.05 (0.83 to 1.32)	0.86 (0.69 to 1.07)
	Low (63 / 1091)	1.17 (0.93 to 1.46)	0.88 (0.71 to 1.11)

* Summarisation of occurrence annually during follow-up divided by a summarisation of all workers at risk annually during follow-up.

† RR, risk ratio; CI, confidence interval. Including the covariate duration of follow-up.

‡ Adjusted for duration of follow-up, age, and length.

§ Adjusted for duration of follow-up, age, co-morbidity of low back or neck pain, previous shoulder pain, and the number of sports participation in the past.

DISCUSSION

Interpretation of the results

In the present study, we reported on the longitudinal association between physical capacity, measured by isokinetic lifting strength, static endurance, and mobility of the spine, and the risk of low back, neck, or shoulder pain.

Workers with low performance in the static back endurance test at baseline had an increased risk of low back pain during three years of follow-up. We found no increased risks of low back pain among workers with decreased levels of isokinetic trunk lifting strength and mobility of the spine. Furthermore, workers with low performance in static endurance tests of the neck muscles or the isokinetic neck/shoulder lifting test at baseline had an increased risk of neck pain during follow-up. Finally, we found no relationships between isokinetic neck/shoulder lifting strength and static endurance of the shoulder muscles and the risk of shoulder pain.

The associations found in this study cannot automatically be interpreted as direct causal relationships, because intermediate factors could have played a role. For example, physical capacity at baseline could have been decreased by musculoskeletal disorders in the past and /or could have been influenced by physical load at work and during leisure time in the past. It is plausible that higher physical load in the past would have led to higher physical capacity at baseline, due to training. Because in this study, several potential confounding factors were taken into account, such as previous musculoskeletal disorders, anthropometry, physical and psychosocial load at work, and physical load during leisure time, it can be concluded that low back or neck muscle endurance are independent predictors of low back or neck pain, respectively, and that low lifting neck/shoulder strength is an independent predictor of neck pain.

Comparisons with former research

In line with our results, three studies in the general population reported on low endurance as a risk factor for low back pain.⁹⁻¹¹ In two of these studies, the Biering-Sørensen test was used, as we used in our study.^{9;11} Rissanen et al.¹⁰ reported on dynamic trunk extensor endurance using standardize arch-up tests and is therefore not comparable with the results of our study. On the other hand, the results of the present study for the static back endurance tests were contradictory to several studies that did not find a relation.^{7;12;15-18;20;23} These differences can be explained by many factors. In contrast to our study, some of these studies reported on the relationship between dynamic endurance and low back pain.^{18;20} In

other studies, which used the Biering-Sørensen test, the study population was quite specific,^{7;12;15-17;20;23} like (female) nurses^{16;17} or spinning operators,²³ in contrast to our diverse study population.

Furthermore, in line with our results, several studies did not find any association between lifting strength and the risk of future low back pain.^{3;9;13;15;18-22;24} However, the results of many of these studies are not comparable with our results, because isometric strength was measured, in contrast to our isokinetic strength test.^{3;9;13;18;20;22;24} Four studies found low trunk strength as a significant risk factor for low back pain,⁵⁻⁸ but these studies are not comparable with our results. Three of these studies used an isometric strength test,^{5;6;8} and Takala et al.⁷ used a specific study population of forest industry workers.

About half of the studies reporting on the association between trunk mobility and low back pain found no association,^{9;14;24} which is in line with our results, while half of the studies found decreased mobility of the spine as a risk factor for low back pain.^{7;12} On the other hand, Biering-Sørensen et al.⁸ reported on a larger Schöber value as a predictor of first-time low back pain in males.

Very few studies reported on the longitudinal relationship between physical capacity and the risk of neck or shoulder pain.^{5;25} Our finding that low isokinetic lifting strength predicts neck pain is contradictory to the study of Hämäläinen et al.,²⁵ in which no relation was found. It is difficult to compare these results directly with our results, because Hämäläinen et al. used an isometric strength test instead of our isokinetic strength test and their study population of student fighter pilots was more specific. Our finding of low static endurance as a predictor of neck pain is in line with the study of Barnekow-Bergkvist et al.,⁵ although this study reported on dynamic endurance measured by a bench press.

Methodological considerations

Some methodological considerations can be made regarding this study. First, we assumed that the association between physical capacity at baseline and the risk of low back, neck, or shoulder pain would be stronger after one year than after two or three years. Therefore, we included follow-up time in the analyses as a potential confounder of this relationship. In addition, to examine if our assumption was correctly, we performed univariate analyses with inclusion of the interaction term physical capacity*follow-up time, but found no interaction (data not shown). This means that it is plausible that the relation between performance in tests of physical capacity and the risk of low back or neck pain did not change substantially during follow-up. In addition, because pain was asked for a relatively long period of 12 months, we assumed that the on average small differences in

response time did not influence the outcome measure. Therefore, we did not adjust for these differences and used equal time points for all workers.

Second, the interpretation of performance in tests of physical capacity depends on several factors. One of these factors is the test-retest reliability and inter-rater reliability. These were investigated in four different pilot studies among healthy subjects (15 students and 18 workers). Two physiotherapists carried out the tests of physical capacity at two moments with one week in between. The average results of these pilot studies showed high test-retest reliability (Pearson correlation coefficient of more than 0.75 and a p-value of the paired t-test of more than 0.40), but moderate inter-rater reliability (Pearson correlation coefficient between 0.50 and 0.75 and a p-value of the paired t-test between 0.10 and 0.40) for the isokinetic neck/shoulder lifting test and the back endurance test. Test-retest reliability and inter-rater reliability were moderate for the other tests of physical capacity. This means that misclassification could not completely be excluded from our study. Furthermore, performance in tests of physical capacity might have been influenced by motivation, pain during testing, or kinesiophobia, leading to non-differential misclassification, resulting in an attenuation of the effects. To investigate the influence of motivation and pain on the performance in the isokinetic lifting tests and endurance tests in this study, we carried out analyses for a selection of workers who were evaluated by the physiotherapist as well motivated for the tests (on a three-point scale) and did not report or show pain (N=1151). Univariate risk ratios were comparable with those for the whole study population, which means that motivation or pain during testing did not play an important role in the performance of the tests and misclassification was not likely.

A third factor that could have influenced the results of the study was our choice to divide performance in tests of physical capacity into tertiles, because we did not have any physiological cut off point. Some measures were normally distributed while others were skewed. For example, many workers were able to reach the maximum endurance time in the static endurance tests, which means that no distinction could be made between workers with good performance and workers with very good performance. To investigate if underestimation of effects might be at hand among the normally distributed measures, due to inclusion of individuals with a "normal" physical capacity in the high and low tertiles, we calculated quartiles and combined the second and third one as the moderate category, but we found comparable results with those of tertiles. Furthermore, in general, physical capacity of men is higher than that of women. On average, men have larger body sizes, higher muscle forces, and higher aerobic capacity than women.³⁹ In the present study, the isokinetic lifting tests and the mobility tests of the spine were identical for men and women, whereas the loads used in the static endurance tests of the neck and shoulder muscles were heavier

for men than for women. When calculating tertiles of the isokinetic lifting tests of the whole study population, as expected, most of the men were categorised into the highest tertile, while most of the women were categorised into the lowest tertile. Despite the fact that the static shoulder endurance test was specified by gender, most of the men were still categorised into the highest tertile, while most of the women were categorised into the lowest tertile. In this study, we have chosen to calculate sex-specific tertiles for all measures of physical capacity, in order to adjust for the unequal distribution of men and women. A comment can be made on this choice, because in many occupations workload is comparable for men and women, which means that the capacity of a women in the highest tertile could still be too low to give an appropriate response on the workload, while the capacity of a men in the lowest tertile (with a higher physical capacity than the women) could be high enough to give an appropriate response on the same workload.

Finally, results for neck and shoulder pain might have been different when we had combined neck and shoulder pain as one outcome measure. Reasons to combine neck/shoulder pain are the facts that the trapezius muscles act on both the neck and the shoulder region, and that respondents find it difficult to discriminate between neck and shoulder pain. A reason to separate neck and shoulder pain is to get more insight in the difference in effect on either neck or shoulder pain. Despite lower statistical power, we separated neck and shoulder pain, because univariate results were different (RR were 1.31 and 1.16, respectively).

CONCLUSIONS

The results of the present study suggest that low back or neck muscle endurance were independent predictors of low back or neck pain, respectively, and that low lifting neck/shoulder strength was an independent predictor of neck pain. Isokinetic lifting trunk strength and mobility of the spine were not found as predictors of low back pain, nor were lifting neck/shoulder strength and endurance of the shoulder muscles found as predictors of shoulder pain.

Appendix 4.A. Potential confounding factors, which were associated with low back, neck, or shoulder pain with a p-value of 0.25 or less and with exclusion of mutually dependent confounding factors, SMASH, 1994-1997 (N=1357).

Low back pain	Neck pain	Shoulder pain
General		
Age	Age	Age
Years of employment	Years of employment	Years of employment
Working hours per week	Working hours per week	Working hours per week
	Education*	Education*
General health†	General health†	General health†
Physical condition†	Physical condition†	Physical condition†
Length	Length	Length
Body Mass Index	Body Mass Index	Body Mass Index
Co-morbidity: neck or shoulder pain‡	Co-morbidity: low back or shoulder pain‡	Co-morbidity: low back or neck pain‡
Previous low back pain§	Previous neck pain§	Previous shoulder pain§
Observed physical workload		
The number of lifts of 25 kg during an 8-hour working day	The working time with repeated movements at least 4 times per minute	The working time with repeated movements at least 4 times per minute
The number of lifts of 10 kg during an 8-hour working day	The working time with the neck in flexion of at least 45 degrees	The number of lifts of 10 kg during an 8-hour working day
The working time with the trunk in flexion of at least 30 degrees	The working time with the neck in rotation of at least 45 degrees	The working time with the neck in rotation of at least 45 degrees
The working time with the trunk in flexion of at least 90 degrees	The working time with the neck in flexion of at least 20 degrees	The working time with the neck in flexion of at least 20 degrees
The working time with the trunk in rotation of at least 30 degrees	The working time with the upper arm elevation of at least 60 degrees	The working time with the upper arm elevation of at least 30 degrees
	The working time sitting	
Self-reported physical workload		
Driving a vehicle¶	Driving a vehicle¶	Driving a vehicle¶
Frequent flexion or rotation of the upper part of the body¶	Frequent flexion or rotation of the upper part of the body¶	Frequent flexion or rotation of the upper part of the body¶
Working with vibrating tools¶	Working with vibrating tools¶	Working with vibrating tools¶
Activities in the same posture for a long time¶	Activities in the same posture for a long time¶	
Moving loads of at least 5 kg¶		Working with the arms above shoulder level¶
Moving loads of at least 25 kg¶		Pinching with hands¶
		Sitting§
Self-reported psychosocial workload		
Quantitative job demands	Quantitative job demands	Quantitative job demands
Supervisor support	Supervisor support	Supervisor support
Co-worker support	Co-worker support	Co-worker support
Decision authority	Decision authority	Decision authority
Conflicting demands**	Conflicting demands**	Conflicting demands**
Job security**	Job security**	Job security**
Job satisfaction¶	Job satisfaction¶	

Appendix 4.A. Continued.

Low back pain	Neck pain	Shoulder pain
Self-reported physical load during leisure time		
Frequent flexion or rotation of the upper part of the body¶	Frequent flexion or rotation of the upper part of the body¶	Repeated movements with hands and/or arms¶
Lifting loads of at least 5 kg¶	Video display terminal work¶	Video display terminal work¶
Lifting loads of at least 25 kg¶	Working with vibrating tools¶	Working with vibrating tools¶
Driving a vehicle¶	Driving a vehicle¶	
Activities in the same posture for a long time¶	Activities in the same posture for a long time¶	
	Force exertion with hand and/or arms¶	Force exertion with hand and/or arms¶
	Working with the arms above shoulder level¶	Working with the arms above shoulder level¶
Frequency of heavy physical activities during the past 4 months*††	Reaching¶	Frequency of heavy physical activities during the past 4 months*††
Average number of hours of sports participation per week during the past year	Average number of hours of sports participation per week during the past year	Average number of hours of sports participation per week during the past year
Number of years of sports participation in the past	Number of years of sports participation in the past	Number of years of sports participation in the past
Coping style and exposure to life events		
Active problem-solving	Active problem-solving	Active problem-solving
Avoidance behaviour	Avoidance behaviour	Avoidance behaviour
Social support seeking	Social support seeking	Social support seeking
Number of life events during the past year‡‡	Number of life events during the past year‡‡	Number of life events during the past year‡‡

* No education or primary school, lower secondary or vocational school, intermediate secondary or vocational school, higher secondary or vocational school, or university.

† Good, fairly, moderate, poor.

‡ Regular or prolonged pain in the past 12 months during follow-up.

§ Ever, or never.

¶ Seldom/never, sometimes, quite often, or very often.

** Agree, or disagree.

†† More than 3 times per week, 1-2 times per week, 1-3 times per month, or less than once per month.

‡‡ No, one, or more than one.

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CHAPTER 5

IS AN IMBALANCE BETWEEN PHYSICAL CAPACITY AND EXPOSURE TO WORK-RELATED PHYSICAL FACTORS ASSOCIATED WITH LOW BACK, NECK, OR SHOULDER PAIN?



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Abstract

Objectives: This study investigates whether an imbalance between physical capacity and exposure to work-related physical factors is associated with low back, neck, or shoulder pain.

Methods: Data of the longitudinal study on musculoskeletal disorders, absenteeism, stress, and health (SMASH), with a follow-up of 3 years (N=1789), were used. At baseline, exposure to work-related physical factors and physical capacity (isokinetic lifting strength, static muscle endurance and mobility of the spine) were assessed. During the follow-up, low back, neck, and shoulder pain were self-reported annually. "Imbalance" was defined as lower than median capacity combined with higher than median exposure, "high balance" was high capacity and high exposure and "low balance" was low capacity and low exposure.

Results: For both the low back and neck, imbalance between static endurance and working with flexed postures was a risk factor for pain (relative risk (RR) 1.35, 95% confidence interval (95% CI) 1.08-1.68, and RR 1.36, 95% CI 0.96-1.91, respectively). Low balance was also a risk factor for low back pain (RR 1.29, 95% CI 1.04-1.68). Furthermore, low balance between isokinetic lifting strength and lifting exposure was a risk factor for low back and neck pain (RR between 1.22 (95% CI 0.99-1.49) and 1.35 (95% CI 1.03-1.79)). No associations were found with shoulder pain.

Conclusion: Some relationships between low back and neck pain and combined measures of physical capacity with exposure to work-related factors seem to exist, but an imbalance between physical capacity and exposure was not found to yield higher risks than high balance or low balance.

INTRODUCTION

Musculoskeletal symptoms are common in the working population and may be caused by high exposure to work-related physical factors.¹⁻⁵ Next to high exposure, the low capacity of mechanical and physiological responses of the body to the exposure may contribute to the development of musculoskeletal symptoms. Muscle strength, muscle endurance, and joint mobility are examples of proxy measures of physical capacity, which can be measured by different physical tests. The relationship between physical capacity and the risk of musculoskeletal symptoms has been investigated in several longitudinal studies with contradictory results.⁶⁻¹⁹ However, it may play a role in the risk of musculoskeletal symptoms in combination with high exposure. The biomechanical load-tolerance model defines “load” as physical stresses acting on the body or on anatomical structures within the body and “tolerance” as the capacity of physiological responses of the body to counteract the load.²⁰

Previously, data of the longitudinal study on musculoskeletal disorders, absenteeism, stress, and health (SMASH) have been used for analyses on the association between exposure to work-related physical factors and low back or neck pain^{21;22} and on the association between physical capacity and low back, neck, or shoulder pain.¹² In these studies, some physical work-related measures, as well as some physical capacity measures, were found to be risk factors. In a study of Harbin and Olson,²³ the incidence of low back injuries was much higher in workers who did not have the lifting strength to perform their job than among workers who had the needed physical capabilities.

We hypothesized that an imbalance between physical capacity and exposure to work-related physical factors is an even more important risk factor for musculoskeletal symptoms than each of these factors on its own. For either high capacity combined with high exposure or low capacity combined with low exposure, we hypothesize only a small increased risk compared to that of high capacity and low exposure. The main objective of the current study was to determine whether an imbalance between physical capacity (isokinetic muscle strength, static muscle endurance, and mobility of the spine) and exposure to work-related physical factors is associated with low back, neck, or shoulder pain.

STUDY POPULATION AND METHODS

Design

Data from the longitudinal study on musculoskeletal disorders, absenteeism, stress, and health (SMASH),^{21;22} a large prospective cohort study among a working population, were used. Data from about 1800 blue-collar and white-collar workers were collected between

March 1994 and March 1997. At baseline, a questionnaire on individual factors, musculoskeletal symptoms, and physical and psychosocial load at work and during leisure time had to be filled out.²⁴⁻²⁸ Physical load at the workplace was observed using video-recordings. Physical capacity was measured using different tests of isokinetic lifting strength, static endurance of the back, neck, and shoulder muscles, and mobility of the lumbar spine. Follow-up questionnaires were sent out three times annually.

Study population

Of the workers who were invited to participate in SMASH, 1789 (87%) filled out the baseline questionnaire. For the analyses of this study, employees were excluded if they had worked less than 1 year in their current job (N=40), worked less than 20 hours per week (N=37), were receiving sickness benefit or permanent disability pension (N=36), or had a second job (N=98). Furthermore, employees without longitudinal data on low back, neck, or shoulder pain were excluded (N=107, N=105 and N=108, respectively). Finally, employees with missing data on the physical capacity measures in combination with the physical work-related measures were excluded (N=38, N=12, and N=13 for low back, neck, and shoulder pain, respectively). The result was a dataset of 1291, 1233, and 1226 for the analyses of workers on low back, neck, and shoulder pain, respectively.

Almost 70% of the workers was male; the mean age was 35 years. Employees worked 38 hours a week on the average and worked 9 years on the average in their current job. Almost 70% of the workers had a blue-collar or caring profession, and around 30% had a white-collar job.

Low back, neck, and shoulder pain

Low back, neck, and shoulder pain were self-reported, using an adapted Dutch version of the Nordic Questionnaire.²⁴ In the baseline and the three follow-up questionnaires, which were sent out once every year, workers were asked if they had low back, neck, or shoulder pain in the past 12 months. We defined the occurrence of low back, neck, or shoulder pain if a pain-free episode ("no" or "sometimes" pain) was followed by an episode with pain ("regular" or "prolonged" pain).

Assessment of exposure to work-related physical factors

Exposure to work-related physical factors was assessed using video-recordings, as well as self-reports. For about half of the workers, four video-recordings of 10 or 14 minutes were taken randomly during a day. The workers were subdivided into groups with similar tasks. In each of these groups, about half of the videotapes was observed by trained

research assistants. These videotapes were analyzed for posture, movement and force exertion. The exposure to work-related physical factors in the analyzed group was assigned to all of the workers with similar tasks.

Assessment of physical capacity

Physical capacity was measured at baseline. Before the tests of physical capacity, the employees were asked for contraindications that might involve a health risk, or that might affect the results of the tests. Localized musculoskeletal discomfort (LMD) was assessed for a rating of the perceived feelings of discomfort (pain, muscle fatigue, tremor, etc.) in any part of the body, ranging from no discomfort (zero) to worst imaginable discomfort (ten).²⁹ The workers who reported an LMD-score of four points or higher in the matching body region were excluded from the tests. In addition, those who reported cardiovascular diseases, fever, or pregnancy were excluded.

Isokinetic lifting strength of the back muscles and the neck/shoulder muscles was measured using an Aristokin dynamometer (Lode BV Medical Technology, Groningen, Netherlands). The workers were asked to lift a box isokinetically from the floor to hip level for the trunk muscles, and from the hip to shoulder level for the neck/shoulder muscles. Static endurance of the back extensors was measured using the Biering-Sørensen test.⁹ The test was terminated when the workers reached an LMD-score of five for the back region, a score of seven for another part of the body, or when 4 minutes were completed. Static endurance of the neck extensors was measured using a helmet of 5 kilograms for the men and 2.5 kilograms for the women. The workers had to keep their head flexed at 45 degrees in a sitting posture. For the measurement of the static endurance of the shoulder elevators, the workers had to keep their arms elevated at 90 degrees in a sitting posture, while carrying a load of 2.5 kilograms for the men, and 1.5 kilograms for the women. The tests for the neck and shoulders were terminated at an LMD-score of five for the neck/shoulder region or a score of seven for another part of the body or after seven minutes. Lumbar flexion was measured by the Schöber test.³⁰ Rotation of the spine was measured by the difference in the distance between the incisura jugularis and the L5 disc in a posture of maximum rotation and in the neutral posture.¹²

Imbalance between physical capacity and exposure to work-related physical factors

The work-related physical capacity measures and exposure variables were combined to define the balance and imbalance groups. Isokinetic lifting strength was combined with

the number of lifts during an 8-hour workday. Furthermore, either static endurance or mobility of the spine was combined with the work time in a specific posture. Due to the absence of a biological cut-off point, "imbalance" was defined as lower than the median score of physical capacity and a higher than the median score of physical exposure. "High balance" was defined as both high capacity and high exposure, and "low balance" was defined as both low capacity and low exposure. The workers with high capacity and low exposure were considered to be the reference group.

Data analyses

We estimated univariate and multivariate relative risks (RR) and 95% confidence intervals (95% CI) for both balance groups and the imbalance group with respect to the reference group. Data were analyzed using Poisson Generalized Estimation Equations (GEE) (Stata version 7.0, Stata Corporation, College Station, TX, USA).

In the multivariate analyses, gender and age were selected as confounders related to low back, neck, or shoulder pain a priori. Furthermore, the follow-up time was selected beforehand to adjust for the fact that the association between imbalance at baseline and musculoskeletal symptoms during follow-up could be stronger after 1 year than after 2 or 3 years. All other potential confounding factors were analyzed separately. Potential confounders were measured at baseline including body height, body mass index, years of employment, number of work hours per week, education, previous low back, neck, or shoulder pain, co-morbidity regarding other musculoskeletal symptoms at baseline and during follow-up, self-reported general health status, self-reported physical fitness, exposure to work-related psychosocial risk factors,²⁷ physical load during leisure time,^{25;31} coping style,²⁸ and exposure to life events.

All of the potential confounding factors were added as time-independent variables to the models, except co-morbidity regarding other musculoskeletal symptoms, which was added as a time-dependent variable. If the crude beta coefficients changed at least 10 percent by adding, the confounder was included in the final multivariate models. However, some of these confounders were excluded because of mutual dependency (Spearman correlation coefficients ≥ 0.5 or ≤ -0.5). Finally, interaction terms with age and gender were added to the GEE models to investigate to which the relationships were modified by these variables.

RESULTS

Characteristics of the study population

The 12-month baseline prevalence rates for regular or prolonged low back, neck, and shoulder pain were 31%, 22%, 9%, respectively. The occurrences of an episode of regular or prolonged musculoskeletal pain during the follow-up, after no or sometimes pain in the previous year, varied between 7% and 11% for low back pain, between 4% and 7% for neck pain, and between 6% and 7% for shoulder pain (see Table 5.1).

Table 5.1. Characteristics of the study population in 1994-1997.

Characteristics	Low back pain (N=1291)	Neck pain (N=1233)	Shoulder pain (N=1227)
Occurrence of musculoskeletal symptoms during follow-up *			
Follow-up 1 (%)	8.9	5.8	7.1
Follow-up 2 (%)	10.7	6.8	6.6
Follow-up 3 (%)	6.8	3.7	5.7
Baseline exposure to work-related physical factors (median (range))			
≥25 kg lifts during an 8-hour workday	0 (0-172)		
≥10 kg lifts during an 8-hour workday	8 (0-1401)	8 (0-1401)	8 (0-1401)
Work time with the trunk in ≥30 degree flexion (%)	5 (0-60)		
Work time with the trunk in ≥90 degree flexion (%)	0 (0-15)		
Work time with the trunk in ≥30 degree rotation (%)	3 (0-32)		
Work time with the neck in ≥20 degree flexion (%)		35 (0-79)	
Work time with ≥30 degree upper arm elevation (%)			36 (8-87)
Work time with ≥90 degree upper arm elevation (%)			0 (0-43)
Work time carrying out repeated movements (%)			0 (0-92)
Baseline physical capacity (median (range))			
Isokinetic lifting strength back muscles (N)	474 (39-1358)		
Isokinetic lifting strength neck/shoulder muscles (N)		208 (15-563)	208 (15-563)
Static endurance of the back muscles (sec)	90 (5-240)		
Static endurance of the neck muscles (sec)		280 (7-420)	
Static endurance of the shoulder muscles (sec)			253 (27-420)
Flexion of the spine (cm)	7 (0.5-10)		
Rotation of the spine (cm)	5.5 (1.4-12.8)		

* A pain-free episode ("no" or "sometimes" pain in the past 12 months) was followed by an episode with pain ("regular" or "prolonged" pain in the past 12 months).

Table 5.1 also presents median and range of physical capacity and the exposure to work-related physical factors for the study population. For the number of lifts of ≥25 kilograms during an 8-hour workday, the work time with the trunk in ≥90 degree flexion or ≥90 degree upper-arm elevation, and the work time carrying out repeated movements, the

median was zero, which means that fewer than half of the workers were exposed to these work-related factors.

Low back pain

Table 5.2 shows the results of the univariate and multivariate GEE analyses of the association between combined measures of physical capacity and exposure to work-related physical factors and the risk of low back pain. Low balance between isokinetic lifting strength and exposure to lifting at work was borderline significantly associated with low back pain (RR 1.22). Furthermore, imbalance or low balance between static endurance of the back muscles and flexion at work was associated with low back pain (RR 1.29 and 1.35, respectively). For the other imbalance or low balance combinations, no associations were found with low back pain, or for any of the high balance combinations.

Neck pain

Table 5.3 shows the results of two combined measures for neck pain. The workers who had low isokinetic lifting strength and did not often have to lift at work had an increased risk of neck pain (RR 1.35). Imbalance between static endurance of the neck muscles and flexion of the neck at work was associated with a borderline significantly increased risk of neck pain (RR 1.36).

Shoulder pain

The results of the univariate analyses showed increased risks of shoulder pain for most of the combined measures, but, after adjustment for confounders, no association remained (see Table 5.4).

Interaction with gender and age

We included interaction terms with age and gender to the multivariate GEE models to investigate the extent to which the relationships were modified by these variables. Statistically significant interaction effects ($p\text{-value} \leq 0.10$) with gender were found for some of the variables, but only one interaction effect with age was found.

For low back pain, interaction effects were found for low balance and imbalance between isokinetic lifting strength and lifting at work, with an increased risk among men (adjusted RR varying between 1.25 (95% CI 0.97-1.62) and 1.41 (95% CI 1.04-1.91)), but no effect among women (adjusted RR varying between 0.80 (95% CI 0.55-1.18) and 0.89 (95% CI 0.64-1.24)). Furthermore, an interaction effect was found for high balance or

Table 5.2. Univariate and multivariate relative risks (RR) and 95% confidence intervals (95% CI) of the association between measures of physical capacity and exposure to work-related physical factors and low back pain in 1994-1997 in the longitudinal study on musculoskeletal disorders, absenteeism, stress, and health (SMASH) (N=1291).

Combined measures of physical capacity and exposure to work-related physical factors	Cut-off at median physical capacity and median physical exposure*		
	Group	Crude RR (95% CI) [†]	Adjusted RR (95% CI)
Isokinetic lifting strength (N) & lifting ≥25 kg at work	Reference	1.00	1.00 [‡]
	High balance	1.19 (0.94-1.52)	1.17 (0.92-1.49)
	Low balance	1.21 (1.01-1.44)	1.22 (0.99-1.49)
	Imbalance	1.15 (0.92-1.44)	1.16 (0.92-1.45)
Isokinetic lifting strength (N) & lifting ≥10 kg at work	Reference	1.00	1.00 [‡]
	High balance	1.06 (0.85-1.32)	1.04 (0.83-1.30)
	Low balance	1.20 (0.97-1.49)	1.22 (0.96-1.54)
	Imbalance	1.14 (0.92-1.41)	1.14 (0.92-1.42)
Static endurance & trunk flexion ≥30 degrees at work	Reference	1.00	1.00 [‡]
	High balance	0.98 (0.78-1.23)	0.99 (0.78-1.24)
	Low balance	1.30 (1.05-1.61)	1.29 (1.04-1.59)
	Imbalance	1.32 (1.06-1.64)	1.35 (1.08-1.68)
Maximum flexion of the spine & trunk flexion ≥90 degrees at work	Reference	1.00	1.00 [‡]
	High balance	0.96 (0.78-1.17)	0.95 (0.77-1.16)
	Low balance	1.01 (0.84-1.22)	1.01 (0.83-1.21)
	Imbalance	1.09 (0.91-1.31)	1.09 (0.91-1.31)
Maximum rotation of the spine & trunk rotation ≥30 degrees at work	Reference	1.00	1.00 [§]
	High balance	1.00 (0.82-1.22)	0.97 (0.76-1.26)
	Low balance	1.11 (0.91-1.35)	0.93 (0.71-1.23)
	Imbalance	1.25 (1.03-1.51)	1.19 (0.93-1.52)

* High balance was defined as higher than median physical capacity combined with higher than median physical exposure; low balance was defined as lower than median physical capacity combined with lower than median physical exposure; imbalance was defined as lower than median physical capacity combined with higher than median physical exposure; and the reference was defined as higher than median physical capacity combined with lower than median physical exposure.

[†] Adjusted for follow-up time.

[‡] Adjusted for follow-up time, gender, and age.

[§] Adjusted for follow-up time, gender, age, isokinetic lifting strength, and the number of years of sports participation in the past.

imbalance between static endurance and flexion at work with a borderline significantly increased risk for imbalance among the men (RR 1.22 (95% CI 0.98-1.53)), and no effect among the women (RR 0.84 (95% CI 0.61-1.16)).

Table 5.3. Univariate and multivariate relative risks (RR) and 95% confidence intervals (95% CI) of the association between measures of physical capacity and exposure to work-related physical factors and neck pain in 1994-1997 in the longitudinal study on musculoskeletal disorders, absenteeism, stress, and health (SMASH) (N=1233).

Combined measures of physical capacity and exposure to work-related physical factors	Cut-off at median physical capacity and median physical exposure*		
	Group	Crude RR (95% CI) [†]	Adjusted RR (95% CI)
Isokinetic lifting strength (N) & lifting ≥10 kg at work	Reference	1.00	1.00 [‡]
	High balance	0.76 (0.54-1.08)	1.00 (0.72-1.40)
	Low balance	1.99 (1.51-2.62)	1.35 (1.03-1.79)
	Imbalance	1.31 (0.96-1.78)	1.20 (0.88-1.62)
Static endurance & neck flexion ≥20 degrees at work	Reference	1.00	1.00 [§]
	High balance	1.38 (1.00-1.89)	1.11 (0.78-1.57)
	Low balance	1.32 (0.94-1.85)	0.96 (0.65-1.42)
	Imbalance	2.07 (1.53-2.79)	1.36 (0.96-1.91)

* High balance was defined as higher than median physical capacity combined with higher than median physical exposure; low balance was defined as lower than median physical capacity combined with lower than median physical exposure; imbalance was defined as lower than median physical capacity combined with higher than median physical exposure; and the reference was defined as higher than median physical capacity combined with lower than median physical exposure.

[†] Adjusted for follow-up time.

[‡] Adjusted for follow-up time, gender, age, length, education, and previous neck pain.

[§] Adjusted for follow-up time, gender, age, co-morbidity of low back or shoulder pain, previous neck pain, isokinetic lifting strength of the neck/shoulder muscles, and the number of years of sports participation in the past.

Table 5.4. Univariate and multivariate relative risks (RR) and 95% confidence intervals (95% CI) of the association between combined measures of physical capacity and exposure to work-related physical factors and shoulder pain in 1994-1997 in the longitudinal study on musculoskeletal disorders, absenteeism, stress, and health (SMASH) (N=1227).

Combined measures of physical capacity and exposure to work-related physical factors	Cut-off at median physical capacity and median physical exposure*		
	Group	Crude RR (95% CI) [†]	Adjusted RR (95% CI)
Isokinetic lifting strength (N) & lifting ≥10 kg at work	Reference	1.00	1.00 [‡]
	High balance	0.86 (0.63-1.17)	0.71 (0.48-1.06)
	Low balance	1.73 (1.31-2.27)	1.09 (0.71-1.65)
	Imbalance	1.38 (1.04-1.84)	0.76 (0.51-1.13)
Isokinetic lifting strength (N) & upper arm elevation ≥30 degrees at work	Reference	1.00	1.00 [§]
	High balance	0.93 (0.68-1.27)	0.80 (0.60-1.07)
	Low balance	1.53 (1.16-2.02)	0.90 (0.67-1.22)
	Imbalance	1.75 (1.34-2.30)	1.08 (0.82-1.43)

Table 5.4. Continued.

Combined measures of physical capacity and exposure to work-related physical factors	Cut-off at median physical capacity and median physical exposure*		
	Group	Crude RR (95% CI) [†]	Adjusted RR (95% CI)
Isokinetic lifting strength (N) & upper arm elevation ≥90 degrees at work	Reference	1.00	1.00 [¶]
	High balance	0.84 (0.62-1.15)	0.71 (0.49-1.02)
	Low balance	1.65 (1.25-2.17)	1.02 (0.71-1.46)
	Imbalance	1.48 (1.12-1.94)	0.94 (0.66-1.34)
Static endurance & upper arm elevation ≥30 degrees at work	Reference	1.00	1.00**
	High balance	1.06 (0.79-1.40)	1.00 (0.78-1.29)
	Low balance	1.38 (1.05-1.80)	1.08 (0.85-1.37)
	Imbalance	1.29 (0.99-1.69)	1.06 (0.84-1.34)
Static endurance & upper arm elevation ≥90 degrees at work	Reference	1.00	1.00 ^{††}
	High balance	0.86 (0.51-0.91)	0.75 (0.52-1.08)
	Low balance	1.14 (0.88-1.48)	0.91 (0.66-1.23)
	Imbalance	1.08 (0.84-1.39)	0.93 (0.68-1.25)
Static endurance & repeated movements at work	Reference	1.00	1.00 ^{‡‡}
	High balance	1.02 (0.75-1.38)	0.93 (0.65-1.32)
	Low balance	1.27 (1.01-1.60)	0.98 (0.73-1.33)
	Imbalance	1.38 (1.03-1.84)	0.94 (0.67-1.31)

* High balance was defined as higher than median physical capacity combined with higher than median physical exposure; low balance was defined as lower than median physical capacity combined with lower than median physical exposure; imbalance was defined as lower than median physical capacity combined with higher than median physical exposure; and the reference was defined as higher than median physical capacity combined with lower than median physical exposure.

[†] Adjusted for follow-up time.

[‡] Adjusted for follow-up time, gender, age, length, working with the arms above shoulder level, the work hours per week, the number of years of sports participation in the past, and decision authority.

[§] Adjusted for follow-up time, gender, age, length, and co-morbidity of low back or neck pain.

[¶] Adjusted for follow-up time, gender, age, length, the work hours per week, co-morbidity of low back or neck pain, and the number of years of sports participation in the past.

** Adjusted for follow-up time, gender, age, and co-morbidity of low back or neck pain.

^{††} Adjusted for follow-up time, gender, age, co-morbidity of low back or neck pain, isokinetic lifting strength, and the number of years of sports participation in the past.

^{‡‡} Adjusted for follow-up time, gender, age, length, co-morbidity of low back or neck pain, isokinetic lifting strength, the number of years of sports participation in the past, and decision authority.

For neck pain, an interaction effect was found for high balance between isokinetic lifting strength and lifting at work with a non-statistically significant effect among the women (RR 4.03 (95% CI 0.83-19.49)), but no effect among the men (RR 0.92 (95% CI 0.66-1.29)). For this combined measure, no effect was found for the whole population.

For shoulder pain, an interaction effect was found for low balance between static endurance and repeated movements at work with a non-statistically significant effect among the women (RR 1.46 (95% CI 0.60-3.57)), but no effect among the men (RR 0.67 (95% CI 0.41-1.10)). Furthermore, a negative interaction effect was found for age, and, therefore, the effect was weaker for the workers with a higher age. For this combined measure, no effect was found for the whole population.

DISCUSSION

Main results

Our study reports on the risk of low back, neck, or shoulder pain for workers who are in balance or imbalance with regard to physical capacity and exposure to work-related physical factors. For low back and neck pain, the results of our study partly supported our hypothesis that an imbalance between physical capacity and exposure to work-related physical factors would lead to an increased risk. However, our hypothesis that imbalance would yield a higher risk than low or high balance was not supported, because we found that the risks of musculoskeletal symptoms for the low balance combinations (i.e. low capacity in combination with low exposure) were often higher than those for the imbalance combinations. Finally, our results suggested that a low balance may be a more important risk factor for musculoskeletal symptoms than high balance (i.e. high capacity in combination with high exposure).

More specifically, for both the neck and the low back, imbalance between static endurance and exposure to flexion was a risk factor for pain, and low balance was a risk factor for low back pain. Low balance between isokinetic lifting strength and exposure to lifting at work was a risk factor for low back and neck pain. For all other balance and imbalance combinations, no associations with musculoskeletal symptoms were found. The analyses stratified for gender yielded inconsistent results.

Comparison with former research

As far as we know, no previous study combined physical capacity measures with exposure to work-related physical factors as risk factors of future musculoskeletal symptoms among healthy workers. However, in studies with functional capacity evaluations, physical capacity was found to be related to specific job demands.^{23;32} Harbin and Olson²³ found that job lifting requirements in association with lifting ability correlates with work injury incidence (i.e. any musculoskeletal work-related incident that resulted in absence).

The results of the present study can be compared to the results of previous studies on exposure to work-related physical factors^{21;22} and those on physical capacity¹² using SMASH data. However, different statistical analyzing techniques, different cut-off points, and different selections of the study population were used. In our present study, we found that, for both the low back and the neck, imbalance between static endurance and exposure to flexion was a risk factor for pain. This finding was consistent with those of previous studies, in which both working in flexion^{21;22} and with low static endurance¹² have been found to be risk factors on their own. Furthermore, our results regarding low balance between isokinetic lifting strength and lifting at work as a risk factor for low back and neck pain were partly consistent with previous results. Low isokinetic lifting strength was not found to be a risk factor for low back pain.¹² Overall, these findings support our hypothesis that an imbalance between physical capacity and exposure to physical factors may be a more important predictor of low back or neck pain, than the effects of each of these variables on its own.

Methodological considerations

The strengths of our study were the large study population and the prospective cohort study design with a follow-up time of 3 years. Furthermore, both physical capacity and exposure to work-related physical factors were assessed in an appropriate way. For exposure to physical factors, we only used data obtained from observations from video-recordings. Physical capacity was measured using physical tests with satisfactory clinimetric characteristics. Self-reports of musculoskeletal symptoms were assessed three times during follow-up.

However, some limitations can be mentioned with regard to this study. First, we decided to use median physical capacity and median physical exposure as cut-off points to define imbalance, because biological cut-off points were not available, except for the Schöber test.³³ This was an arbitrary choice. To investigate the effect of the cut-off points, we performed additional analyses for more extreme groups. Imbalance was defined as the lowest 30% of capacity combined with the highest 30% of exposure, high balance as the highest 30% of capacity and the highest 30% of exposure and low balance as the lowest 30% of capacity and the lowest 30% of exposure. For neck pain, this division generally led to a slight increase in strength of effects, especially for the imbalance and low balance groups. However, for low back and shoulder pain, no differences were found.

Second, we assumed that the association between imbalance at baseline and the risk of low back, neck or shoulder pain would be stronger after 1 year than after 2 or 3 years of follow-up. Therefore, follow-up time was included in the analyses as a potential confounder. In addition, to examine whether our assumption was correct, we carried out univariate

analyses and included the interaction term with follow-up time. A statistically significant negative interaction effect was found only for two combined measures. Therefore, it could be concluded that the relation between imbalance and the risk of musculoskeletal symptoms did not change substantially during the follow-up of 3 years.

Third, the effects could have been influenced by measurement errors of the physical tests. Test-retest reliability and inter-rater reliability were investigated in four pilot studies among healthy people (15 students and 18 workers). Two physiotherapists carried out the tests of physical capacity twice with an interval of 1 week between the two. The average results of these pilot studies showed high test-retest reliability (Pearson correlation coefficient of more than 0.75 and a p-value of the paired t-test of more than 0.40), but moderate inter-rater reliability (Pearson correlation coefficient between 0.50 and 0.75, and a p-value of the paired t-test between 0.10 and 0.40) for the isokinetic neck/shoulder lifting test and the back endurance test. The test-retest reliability and inter-rater reliability were moderate for the other tests of physical capacity. Therefore, non-differential misclassification could not completely be excluded from our study in that it might have led to an underestimation of the real effect.

Finally, it should be kept in mind that, within workers, the degree of imbalance or balance between physical capacity and physical exposure can be considered to be dynamic³⁴ (i.e. high physical exposure could lead to an increase of physical capacity) due to a training effect. It is plausible that there will be an optimum in this relationship, because prolonged exposure to physical factors could lead to tissue damage, which could result in decreased physical capacity.³⁵

CONCLUDING REMARKS

In general, the results of this study suggest that imbalance between static endurance of the back or neck muscles and exposure to flexed postures of these body parts is a risk factor for low back and neck pain, respectively. Furthermore, low balance between isokinetic lifting strength and lifting at work was found to be a risk factor for low back and neck pain. No other balance and imbalance combinations were found to be risk factors of musculoskeletal symptoms.

For several combined measures, imbalance and low balance were found to be a risk factor for musculoskeletal symptoms, but high balance was not found to be a risk factor. The results need to be confirmed by other studies focusing on the imbalance between physical capacity and physical exposure.

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CHAPTER 6

DOES MUSCULOSKELETAL DISCOMFORT AT WORK PREDICT FUTURE MUSCULOSKELETAL PAIN?



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Abstract

Objective: The objective of this prospective cohort study was to evaluate if peak or cumulative musculoskeletal discomfort may predict future low back, neck or shoulder pain among symptom-free workers.

Methods: At baseline, discomfort per body region was rated on a 10-point scale six times during a working day. Questionnaires on pain were sent out three times during follow-up. Peak discomfort was defined as a discomfort level of 2 at least once during a day; cumulative discomfort was defined as the sum of discomfort during the day. Reference workers reported a rating of zero at each measurement.

Results: Peak discomfort was a predictor of low back pain (relative risk (RR) 1.79), neck pain (RR 2.56), right, and left shoulder pain (RRs 1.91 and 1.90). Cumulative discomfort predicted neck pain (RR 2.35), right or left shoulder pain (RRs 2.45 and 1.64).

Conclusion: These results suggest that both peak and cumulative discomfort could predict future musculoskeletal pain.

INTRODUCTION

Musculoskeletal pain is common among the working population. Both the demands at work and the capacity of the worker to perform work-related activities may play a role in the development of this pain, which has been stated in the load-tolerance model.¹ In previous studies, high exposure to work-related physical factors,^{2;3} low physical capacity,⁴ and an imbalance between those two factors⁵ were found to be associated with musculoskeletal pain at long-term. However, these associations were not consistently found for all work-related factors and physical capacity parameters. In the short-term, an imbalance between physical capacity and work-related physical factors may lead to musculoskeletal discomfort in and around active and passive structures (i.e. muscles, tendons and joints). Musculoskeletal discomfort can become manifest as tension, muscle fatigue, soreness, heat, tremor, et cetera.⁶ Perceived musculoskeletal discomfort is generally used as a subjective indicator of short-term effects. In the case of insufficient recovery, short-term effects may end as more permanent effects, that is musculoskeletal pain.^{7;8}

In many studies reporting on short-term musculoskeletal discomfort as an indication of the effect of an ergonomic intervention, the authors assume that musculoskeletal discomfort can predict musculoskeletal pain at long-term.⁹⁻¹⁴ However, to the authors' knowledge, this relationship has only been investigated in one longitudinal study,^{15;16} in which a relationship was found between baseline neck or shoulder discomfort and future upper extremity tendonitis.

In the present study, it was hypothesised that musculoskeletal discomfort may predict future musculoskeletal pain, with two potential aetiological mechanisms on the basis of that relationship. The first hypothesis was that at least one moment of discomfort during a working day, as an indicator of peak exposure to work-related physical factors, is a risk factor for future musculoskeletal pain. The second hypothesis was that cumulative discomfort during a working day, as an indicator of cumulative exposure to work-related physical factors, is a risk factor for future musculoskeletal pain. The objective of this prospective cohort study was to evaluate the two hypotheses, that peak levels of musculoskeletal discomfort and/or cumulative discomfort may predict future musculoskeletal pain among symptom-free workers.

METHODS

Design

The longitudinal Study on Musculoskeletal disorders, Absenteeism, Stress and Health (SMASH) was a prospective cohort study among almost 1800 workers from 34 different companies with a follow-up of 3 years. SMASH investigated work-related risk factors for low back, neck and shoulder pain. At baseline, localised musculoskeletal discomfort (LMD) in each body region was rated once before work and six more times during a working day. Questionnaires were sent out at baseline and three times annually during follow-up. In these questionnaires, workers were asked whether they had had low back, neck or shoulder pain in the past 12 months, using an adapted Dutch version of the Nordic Questionnaire.¹⁷ An incident case of low back, neck or shoulder pain was defined if a pain-free episode (no or sometimes pain in the past 12 months) was followed by an episode with pain (regular or prolonged pain in the past 12 months).

Subjects

A study population was selected based on the following inclusion criteria. First, workers had to complete the baseline questionnaire; 1789 (87%) of the 2064 workers who were invited to participate in SMASH did so. Furthermore, workers had to work at least 1 year in their current job for more than 20 hours per week and should not receive a sickness benefit or a permanent disability pension (N=1578). Furthermore, data on LMD of the low back, neck or shoulder region should be available (N=1420). Finally, workers had to report no or sometimes pain in the 12 months previous to the baseline measurement (N=913, N=1055, N=1146, N=1181 for low back, neck, right and left shoulder pain, respectively), and the question on musculoskeletal pain had to be answered in at least one follow-up questionnaire. This resulted in a dataset of 865, 1001 and 1083 and 1119 workers in the analyses of low back, neck, right and left shoulder pain, respectively.

Localized musculoskeletal discomfort

The LMD-method⁶ was based on the Borg Category Ratio (CR-10) scale,¹⁸ as shown in Appendix 6.A The LMD method used both numbers and verbal intensity descriptors to rate the level of discomfort. The scale ranged from 0 (no discomfort at all) to 10 (extreme discomfort, almost maximum). Except for the rating of 0.5 (extremely little discomfort), only round numbers were presented. However, workers were free to choose any intermediate number using decimals. Workers were asked to indicate their LMD-ratings in 13 parts of the

body using an adapted body map of the back of the body (see Figure 6.A.1), the focus being on the low back, the neck and the right and left shoulders.

During the introduction, the method was explained to and briefly tried out by the workers. At baseline, LMD was measured six times during one particular working day: 90, 50 and 10 min before lunch; just after lunch; and 40 and 80 min after lunch. In addition, one measurement was assessed before the start of the working day to have an indication of the discomfort caused by factors other than work on the measurement day. This first measurement was excluded from the analyses, because the focus of interest was discomfort caused by the activities at work.

A discomfort level of 2 (little discomfort) was defined as the cut-off point for the peak discomfort measure. This level was put forward as an evaluation criterion in the International Standards Organization guideline ISO/FDIS 11226 for static working postures,¹⁹ which states that a holding time-recovery scheme during work should be chosen so that discomfort would not exceed 20% of the maximal holding time during static working postures. The guideline considers that a rating of 2 on the Borg CR-10 scale is the equivalent of 20% of the maximal holding time. In the present study, workers reporting a rating of zero at each of the measurements during a working day (except for the measurement before work, which was discarded) were considered to be the reference group. The other workers were divided into a group reporting LMD-ratings of 2 or lower at each of the six measurements (but at least one LMD-rating higher than zero) and a group reporting LMD-ratings higher than 2 for at least one of the six measurements (exceeding the guideline).

With regard to cumulative discomfort measure, again the reference group consisted of the workers reporting a rating of zero at each of the six measurements during the working day. For the other workers, the sum of the six LMD-ratings during the working day was calculated. To be able to find a potential dose-response relation these workers were divided into two groups. With the lack of a recognised physiological cut-off point, the median value of the summed ratings was used to divide these workers into two equal groups.

Data analyses

To investigate the relationship between LMD at baseline and the risk of future low back, neck or shoulder pain among symptom-free workers at each of the three follow-up times, data were analysed using Poisson generalised estimation equations (GEE). This longitudinal regression analysis technique corrects for dependency between the repeated measures of pain.^{20;21} Univariate and multivariate relative risks (RRs) and 95% CI were estimated. In the multivariate analyses, gender and age were selected a priori as confounders, as well as follow-up time to adjust for a potential time effect. Other potential

confounding factors (self-reports) were analysed separately, including years of employment, number of work hours per week, BMI, co-morbidity regarding other musculoskeletal pain at baseline and during follow-up, physical load during leisure time,^{22;23} general health status, physical activity, psychosocial factors (dimensions of the Demand-Control Support Model) of Karasek et al.²⁴ and coping style.²⁵ If the crude beta coefficients changed by at least 10 percent, the confounder was included in the final multivariate models.

RESULTS

Descriptive statistics

The mean age in the study population was 35 (SD 8.7) years and 71% were men. On average, they had worked for 9 years (SD 7.6) in their current job for 38 (SD 5.1) hours per week; 63% had a blue-collar profession. During the 3 years of follow-up, 9.8% of the workers experienced an incident episode of low back pain, 5.8% of neck pain, 5.4% of shoulder pain at the right side and 5.8% of shoulder pain at the left side.

Figure 6.1 presents the mean LMD-ratings before work and at the six measurements during the working day for the low back and neck regions (taking the mean of left and right body sides) and for the right and left shoulders. The ratings increased during the morning, decreased after the lunch break and increased again during the afternoon until the end of the

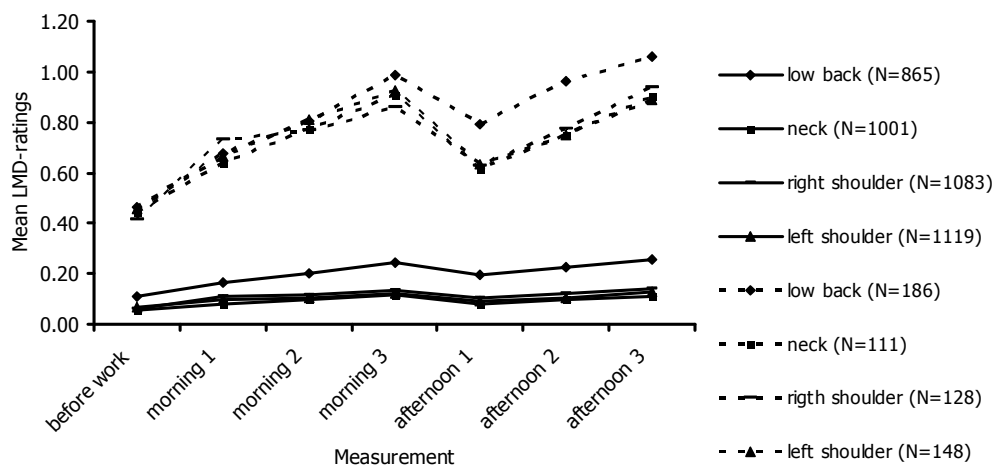


Figure 6.1. Mean localised musculoskeletal discomfort LMD in the low back, neck and shoulder regions over the course of the working day. Solid lines represent the whole study sample; dashed lines represent the group of workers who reported LMD-ratings higher than zero at least once in the day.

Table 6.1. Univariate and multivariate relative risks (RR) and 95% confidence intervals (95% CI) of the association between peak localized musculoskeletal discomfort (LMD) and low back pain, neck or shoulder pain.

Body region	LMD group	Total incident cases/total number at risk*	Crude RR (95% CI)†	Adjusted RR (95% CI)‡
Low back (N=865)	0 at each measurement	152 / 1738	1.00	1.00§
	0 - 2 at each measurement	58 / 452	1.41 (1.05-1.89)	1.24 (0.86-1.79)
	> 2 at least one measurement	17 / 106	1.63 (1.01-2.65)	1.79 (0.97-3.27)
Neck (N=1001)	0 at each measurement	122 / 2342	1.00	1.00¶
	0 - 2 at each measurement	24 / 258	1.61 (1.03-2.53)	1.43 (0.80-2.56)
	> 2 at least one measurement	13 / 78	3.47 (2.03-5.92)	2.56 (1.36-4.81)
Right shoulder (N=1083)	0 at each measurement	115 / 2469	1.00	1.00**
	0 - 2 at each measurement	17 / 193	1.77 (1.15-2.75)	1.61 (0.94-2.75)
	> 2 at least one measurement	26 / 196	3.28 (2.10-5.13)	1.91 (1.02-3.57)
Left shoulder (N=1119)	0 at each measurement	144 / 2603	1.00	1.00††
	0 - 2 at each measurement	18 / 269	1.38 (0.87-2.20)	1.02 (0.54-1.93)
	> 2 at least one measurement	12 / 74	3.87 (2.42-6.19)	1.90 (0.81-4.46)

* Summation of 12 months incident cases during follow-up divided by summation of workers at risk during follow-up.

† Including duration of follow-up.

‡ Adjusted for duration of follow-up, gender and age (included a priori).

§ Additional adjustment for the number of years of sports participation in the past.

¶ Additional adjustment for co-morbidity of low back or shoulder pain, and the number of years of sports participation in the past.

** Additional adjustment for co-morbidity of low back or neck pain, general health, and the number of years of sports participation in the past.

†† Additional adjustment for co-morbidity of low back or neck pain, general health, the number of years of sports participation in the past, coping: active problem-solving, coping: avoidance behaviour, and coping: social support seeking.

working day. The mean LMD-ratings were low, due to the large percentage of the workers who reported a rating of zero at all measurements (76% for the low back, 88% for the neck and left shoulder and 86% for the right shoulder). The standard deviations of LMD were between 0.51 and 0.78 for the low back region, between 0.37 and 0.53 for the neck region and between 0.35 and 0.56 for the shoulder regions, respectively.

Peak LMD as a predictor of future low back, neck or shoulder pain

Table 6.1 shows the results of the univariate and multivariate GEE analyses for peak discomfort, in which the group exceeding the discomfort level of LMD-rating 2 and the group with at least one LMD-rating higher than zero but none exceeding 2, were compared with the

Table 6.2. Univariate and multivariate relative risks (RR) and 95% confidence intervals (95% CI) of the association between cumulative localized musculoskeletal discomfort (LMD) and low back pain, neck or shoulder pain.

Body region	LMD group	Total incident cases/total number at risk*	Crude RR (95% CI)†	Adjusted RR (95% CI)‡
Low back (N=865)	0 at each measurement	152 / 1738	1.00	1.00§
	Sum 0 - 3.5	40 / 286	1.57 (1.12-2.19)	1.33 (0.88-2.02)
	Sum > 3.5	35 / 272	1.34 (0.93-1.93)	1.32 (0.83-2.12)
Neck (N=1001)	0 at each measurement	122 / 2342	1.00	1.00¶
	Sum 0 - 3.0	12 / 154	1.49 (0.81-2.76)	1.07 (0.53-2.17)
	Sum > 3.0	25 / 177	2.52 (1.65-3.85)	2.35 (1.55-3.58)
Right shoulder (N=1083)	0 at each measurement	115 / 2469	1.00	1.00**
	Sum 0 - 3.0	17 / 193	1.56 (0.93-2.62)	1.45 (0.80-2.62)
	Sum > 3.0	26 / 196	2.77 (1.85-4.15)	2.45 (1.64-3.64)
Left shoulder (N=1119)	0 at each measurement	144 / 2603	1.00	1.00††
	Sum 0 - 3.3	12 / 170	1.37 (0.79-2.39)	0.92 (0.43-1.99)
	Sum > 3.3	18 / 173	2.42 (1.56-3.76)	1.63 (0.78-3.40)

* Summation of 12 months incident cases during follow-up divided by summation of workers at risk during follow-up.

† Including duration of follow-up.

‡ Adjusted for duration of follow-up, gender and age (included a priori).

§ Additional adjustment for the number of years of sports participation in the past.

¶ Additional adjustment for BMI, and coping: social support seeking.

** Additional adjustment for co-morbidity of low back or neck pain.

†† Additional adjustment for the number of years of sports participation in the past, coping: avoidance behaviour, and coping: social support seeking.

reference group of those who reported a LMD-rating of zero at each of the six measurements during the day.

Working exceeding the discomfort limit of 2 was found to be a predictor of future low back pain (RR 1.79, borderline significant), neck pain (RR 2.56) and right shoulder pain (RR 1.91) but not for left shoulder pain (RR 1.90, NS). Except for right shoulder pain (RR 1.61, borderline significant), working at less than the discomfort limit of 2 did not predict pain compared to the reference group.

Cumulative LMD as a predictor of future low back, neck or shoulder pain

Table 6.2 presents the results related to cumulative discomfort. Compared to the reference group, the group of workers reporting the highest LMD-ratings (sum > 3.0) had an increased risk of neck and right shoulder pain (RR 2.35 for neck pain and RR 2.45 for right

shoulder pain), but not of low back pain or left shoulder pain (RR 1.32 and 1.63, NS). No relationship was found for the group of workers who reported low LMD-ratings.

DISCUSSION

Main results

The aim of this study was to investigate whether high levels of musculoskeletal discomfort and/or cumulative discomfort were predictors of future low back, neck or shoulder pain among symptom-free workers. The discomfort limit in the ISO/FDIS 11226 guideline was used to determine a cut-off of peak discomfort. In this study, it was found that peak discomfort was a predictor of future low back, neck and shoulder pain and that cumulative discomfort was a predictor of future neck and shoulder pain.

Comparisons with former research

To the authors' knowledge, the relationship between musculoskeletal discomfort and future musculoskeletal pain among symptom-free subjects has been studied previously in only one longitudinal study,^{15;16} which found that, in a cohort of 501 industrial or clerical workers, baseline neck or shoulder discomfort significantly increased the risk of becoming an incident case of upper extremity tendonitis during 5.4 years of follow-up on average (odds ratio (OR) 1.84 (95% CI 1.03–3.29)). Furthermore, for the worst regional discomfort rating (on a 0–10 rating scale) from any upper extremity region at baseline, the risk of future tendonitis significantly increased for every 1 point increase (OR 1.21 (95% CI 1.06–2.38)).

These results cannot be compared directly with the results of the present study, due to different outcome measures, but there seem to be similarities between the results for neck and shoulder pain and those of Werner et al.¹⁵ regarding upper extremity tendonitis.

Since it was hypothesised that peak and cumulative discomfort are indicators of biomechanical peak or cumulative exposure, respectively, the biomechanical literature reporting on peak or cumulative workload in relation to musculoskeletal pain can be used as a background. From biomechanical studies, there is evidence that both peak spinal loading²⁶⁻²⁸ and cumulative spinal loading²⁶⁻³⁰ can contribute to the development of low back pain. The present study found an association with low back pain only for peak discomfort and not for cumulative discomfort.

Furthermore, it is well known that some psychosocial factors at work are assumed to be risk factors for musculoskeletal pain.³¹ Referring to the hypothesis that musculoskeletal discomfort is a predictor for musculoskeletal pain, it is convincing that musculoskeletal

discomfort could be an indicator of psychosocial exposure as well. However, only one study could be found reporting on this relationship.³² In this study, physical discomfort (on a scale between 0 and 6) was found to be a mediating factor in the relationship between psychological workload and musculoskeletal pain.

Strengths and weaknesses

Strengths of the present study were the large study population and the prospective cohort study design with a follow-up time of 3 years. Self-reports of musculoskeletal pain were assessed three times annually during follow-up. The test-retest reliability of the LMD method was acceptable, both for static workloads (correlation coefficient: back-neck region 0.73; shoulder-arm region 0.74)³³ and in more dynamic types of work (correlation coefficient: back-neck region 0.71; shoulder-arm region 0.78). The study contained data on fluctuations of musculoskeletal discomfort during a working day, because it was recorded three times in the morning and three times in the afternoon.

However, this study had some weaknesses as well. First, it is debatable to what extent the concept of discomfort differs from the concept of musculoskeletal pain, resulting in the question as to what extent discomfort can predict pain. However, it is thought that the concepts differ, because discomfort is measured as a short-term effect of an imbalance between physical capacity and exposure to work-related physical factors (i.e. the amount of discomfort on one particular working day) and pain is measured as a long-term effect (i.e. regular or prolonged pain in the past 12 months). Furthermore, a pain-free population at baseline was chosen to avoid any distortion of the measurements of discomfort due to pain. However, the risk of misclassification cannot be totally excluded. Therefore, the conclusions have to be interpreted with caution.

Second, for peak discomfort, the cut-off based on the ISO/FDIS 11226 guideline¹⁹ was considered appropriate, since work exceeding the discomfort limit of 2 is a risk factor for low back, neck and shoulder pain. However, the guideline states that musculoskeletal discomfort may exceed the rating of 2 only if it will be followed by a recovery time, such that the remaining endurance capacity is not below 80%. From that perspective, the chosen cut-off in this study can be seen as too strict, which could have led to an underestimation of effects.

Third, for cumulative discomfort, it was difficult to indicate a cut-off of the sum of LMD-ratings, above which the risk of future musculoskeletal pain would increase considerably, because the distribution of LMD-ratings was skewed to the right in this dataset. A large proportion of workers reported a rating of zero at each measurement and, for the other workers, the sum of the six LMD-ratings was also low. This led to a median sum of

LMD-rating around 3. In additional analyses using different cut-offs ranging between sum scores of 0.5 and 18, a dose–response relationship was found for shoulder pain, with an increase in effect for higher cut-offs. However, this was not found for low back and neck pain.

Finally, in spite of the selection of workers who reported no or sometimes low back, neck or shoulder pain in the past 12 months, the results could have been influenced by the workers who reported sometimes pain. In additional analyses, it was found that reporting sometimes pain was a confounder in the relationships studied, leading to lower risk ratios. Furthermore, since musculoskeletal pain recurs frequently, these workers could have had pain earlier in the past. In this dataset, 37% of the population had experienced previous low back or neck pain and 60% of the population had experienced previous shoulder pain in the past. In studies reported in the literature, a previous episode with pain has been found to be an important risk factor of experiencing pain again in the future.^{34;35} In additional analyses, it was found that reporting previous low back, neck or shoulder pain in the past (“yes” or “no”) was a confounder, leading to lower risk ratios. Nevertheless, it was decided not to adjust for these two confounders in the presented analyses because this would have led to an over-correction of the results, due to the recurrent character of musculoskeletal pain.³⁵ It was assumed that correction for sometimes pain in the past 12 months or correction for previous pain would lead to results for a very healthy working population. The workers in this dataset were considered to be “normal” workers.

Ergonomic implications of LMD

Measurements of musculoskeletal discomfort are often used to indicate short-term effects of ergonomic interventions.⁹⁻¹³ From the results of the present study, it can be concluded that peak or cumulative discomfort, measured at several times during a working day, can also be used as a predictor of future pain among healthy workers. Even relatively low ratings can yield an increased risk of future low back, neck and shoulder pain compared to reporting a rating of zero at each of the measurements. However, in the mixed working population of the SMASH study, only the low region of the Borg CR-10 scale was used. When stratified for the type of work, the sums of LMD-ratings of the low back and shoulder regions appeared to be only a little higher among blue-collar workers compared to white-collar workers. For the neck region, the sum of LMD-ratings was only a little higher among white-collar workers compared to blue-collar workers. If the LMD method is to be used as a predictive screening instrument, many workers should be tested to find only a few with an increased risk of developing musculoskeletal pain.

It is questionable if a 10-point scale is appropriate to measure musculoskeletal discomfort among healthy workers in ergonomically well-designed workplaces. Perhaps, a smaller detectable scale should be used to obtain more sensitive measures of discomfort or it might be better to apply the LMD method selectively among high-risk-workers.³⁶ More research is necessary to investigate this.

CONCLUSION

The results of this study verified the hypothesis that high levels of musculoskeletal discomfort and/or cumulative discomfort among symptom-free workers may develop into musculoskeletal pain in the long term. The results of the study suggest that both peak and cumulative discomfort could predict future musculoskeletal pain.

Appendix 6.A. Measurement of localised musculoskeletal discomfort (LMD)

A short explanation of LMD method during the field studies gave the following explanation:

- LMD includes:
 - tension
 - fatigue
 - soreness
 - heat
 - tremor
 - pressure in muscles
 - feelings of effort
- Discomfort refers to the tissue loaded (muscles or non-muscular tissue).
- Discomfort can be experienced locally (e.g. discomfort in the neck but not in the wrist).
- Discomfort can be experienced after a short period, after a long period or not at all.
- Discomfort can increase, decrease or remain the same during the day.
- The amount of discomfort differs between subjects. What we are interested in is the amount of discomfort you personally experience during the working day.
- A rating scale is used to measure the amount of discomfort:
 - The rating scale goes from zero (no discomfort at all) to 10 (almost maximum).
 - A rating of zero means that you do not experience any discomfort at all.
 - A rating of 10 can be seen as when you are holding two buckets of water with your arms stretched forwards. When you have to lower your arm because you cannot hold it any longer, this is a score of 10.
 - A score of 5 is the half of a score of 10.
- Furthermore, verbal intensity descriptors are used to measure the amount of discomfort.
- Finally, a body map is used to localise the discomfort:
 - The body map represents the rear view of the human body (Figure 6.A.1). This means that any feeling of discomfort at the front of the body can be indicated on the body map by looking 'through' the figure.
 - C and V belong to the back region, Z and X belong to the shoulder regions and T and Y belong to the neck region.
- How to rate the amount and localisation of discomfort:
 - Concentrate on your body and try to perceive discomfort in each of the 13 body regions.
 - For each, choose a word that represents the amount of discomfort at best per body region.
 - Choose the rating of discomfort that belongs with the chosen word representing the amount of discomfort.

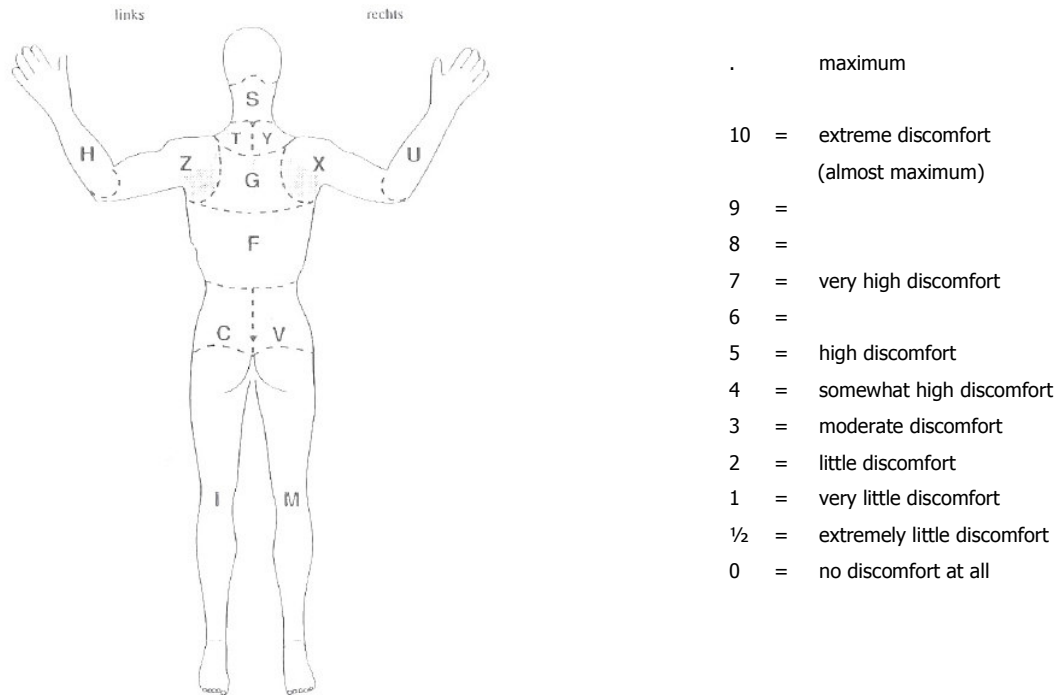


Figure 6.A.1. Adapted body map used to measure localized musculoskeletal discomfort

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CHAPTER 7

THE EFFECT OF A RESISTANCE-TRAINING PROGRAM ON MUSCLE STRENGTH, PHYSICAL WORKLOAD, MUSCLE FATIGUE AND MUSCULOSKELETAL DISCOMFORT



Submitted as:

Hamberg-van Reenen HH, Visser B, van der Beek AJ, Blatter BM, van Dieën JH, van Mechelen W. The effect of a resistance-training program on muscle strength, physical workload, muscle fatigue and musculoskeletal discomfort.

Abstract

Objective: To investigate the effectiveness of a resistance-training program on muscle strength of the back and neck/shoulder muscles, relative physical workload, muscle fatigue and musculoskeletal discomfort during a simulated assembly and lifting task.

Methods: Twenty-two workers were randomized over an 8-week resistance-training group, and a control group. Isokinetic muscle strength was assessed using the Cybex dynamometer, muscle fatigue was measured using EMG, and perceived discomfort was measured using a ten-point scale.

Results / conclusion: We found no effects of the resistance-training program on isokinetic muscle strength of the back and shoulder muscles. Furthermore, we did not find any effect on EMG data as indicator for muscle fatigue, nor on musculoskeletal discomfort during the simulated work tasks. However, at the follow-up measurement, trained workers performed the lifting tasks for a longer time than those in the control group, until they reported considerable discomfort.

INTRODUCTION

Several work-related physical factors have been identified that can increase the risk of musculoskeletal discomfort or pain among workers.¹⁻⁶ Especially in professions with heavy physical demands, muscle fatigue or musculoskeletal discomfort may be perceived during work tasks. It has been suggested that in case of insufficient recovery, such muscle fatigue or musculoskeletal discomfort may end as musculoskeletal pain.⁷⁻⁹ Muscle fatigue is defined as a decrease in force producing capacity of muscles.¹⁰ It is associated with changes in the amplitude as well as the spectral parameters of the electromyogram (EMG) over time. A decline of the Mean Power Frequency (MPF) and an increase in amplitude can be observed when constant submaximal isometric force levels are produced.^{11;12} Musculoskeletal discomfort can become manifest as tension, muscle fatigue, soreness, et cetera in and around active and passive structures, i.e. muscles, tendons and joints.¹³ Perceived musculoskeletal discomfort as subjective indicator for short-term effects, can be measured by self-reports using a discomfort rating scale with a body map.^{13;14}

It is generally assumed that workers with high muscle strength can better deal with high exposure to physical factors than workers with low muscle strength. In a previous prospective study, we found that an imbalance between physical capacity and exposure to work-related physical factors was a risk factor for future low back or neck pain, although this was not consistently found for all parameters.¹⁵ It is well-known that physical training programs can have a positive effect on physical capacity of workers.^{16;17} Strong evidence was reported for physical exercises in the primary prevention of low back pain,¹⁸⁻²³ and neck pain.^{20;21} However, there is insufficient evidence to recommend for or against any specific type or intensity of exercise in the prevention of low back pain.¹⁸

Next to a positive effect of training on future muscle pain at long-term, we hypothesized that a resistance-training program can reduce relative physical workload and consequently reduce muscle fatigue or musculoskeletal discomfort during work tasks at short-term. As far as we know, only one previous experiment reported on the relationship between muscle strength training and muscle fatigue or musculoskeletal discomfort during work tasks. In this study, Pedersen et al.²⁴ reported a positive effect of resistance-training of the neck/shoulder muscles on perceived muscle fatigue in static and dynamic endurance tests.

The objective of the present Randomized Controlled Experiment was to investigate the effectiveness of a resistance-training program on muscle strength of the back and

neck/shoulder muscles, and on relative physical workload, muscle fatigue and musculoskeletal discomfort during simulated work tasks.

METHODS

Design and population

This study was a Randomized Controlled Experiment with a convenience sample of 22 healthy workers. The workers were recruited from the VU University in Amsterdam, the Netherlands. Twenty of them were office workers, and two had a non-sitting profession. Exclusion criteria were regular or prolonged neck/shoulder or back pain in the past 12 months, participating in muscle strengthening sports of the shoulder or back region, and cardiovascular symptoms. The included workers were matched on gender and age, and were randomized over an intervention group participating in a resistance-training program 2 times per week during 8 weeks, and a control group. After the baseline measurements, the workers received the randomization result in a closed envelope. They were asked to leave the testers be blinded for the randomization. The workers were asked not to participate in sports with a strengthening effect on the shoulder or back muscles, other than the resistance-training for the intervention group, until the follow-up measurement.

Data collection

Both at baseline and after the training-program 8 weeks later, isokinetic muscle strength of the shoulder and back muscles, and, relative physical workload, muscle fatigue, and musculoskeletal discomfort during a simulated assembly and a lifting task were measured.

First, a questionnaire containing questions on the following variables was filled in: demography, anthropometry, musculoskeletal symptoms, exposure to work-related physical factors, physical activity measures, smoking, and consumption of alcohol. During the muscle strength measurements (performed as Maximal Voluntary Contraction (MVCs)), surface EMG was used to record Maximal Voluntary Excitation (MVE) levels of the shoulder and back muscles. Furthermore, during the simulated work tasks, EMG of shoulder and back muscles was recorded and perceived discomfort was asked using the localized musculoskeletal discomfort (LMD) method.

Electromyography (EMG)

Muscular activity was measured by means of surface EMG. During the shoulder strength measurements and the assembly tasks, bilateral EMG signals were recorded from deltoid pars clavicularis and acromialis muscles, and the trapezius pars descendens muscles. During the trunk muscle strength measurements and the lifting tasks, bilateral EMG signals were recorded from the erector spinae muscles at Th10 and L3. A reference electrode was placed on the C7 spinous process.

Standard procedures were followed for the use of surface EMG.²⁵ Bipolar Ag/AgCl surface electrodes (Medicotest, Rugmarken, Denmark) were used with an inter-electrode distance of 20 mm. Signals were amplified 20 times (Porti-17TM, TMS, Enschede, The Netherlands, input impedance > 1012 Ω , CMRR > 90 dB), band pass filtered (10-400 Hz) and A-D converted (22 bits) at 1000 samples/sec.

Localized musculoskeletal discomfort (LMD)

The method of measuring localized musculoskeletal discomfort (LMD)¹³ was based on the Borg Category Ratio (CR-10) scale.¹⁴ Perceived discomfort was rated by means of both numbers and verbal intensity descriptors ranging from 0 (no discomfort at all) to 10 (extreme discomfort, almost maximum). Except for the rating of 0.5 (extremely little discomfort), only round numbers were presented. However, each intermediate half number was conceivable. A map of the back of the body was used to indicate the LMD-ratings in 13 parts of the body.

We focused on the body regions Z, X, Y, and T for the shoulder, and the regions C, V and F for the back.

Isokinetic muscle strength

Isokinetic muscle strength was measured using the Cybex Dynamometer at an angular velocity of 60 degrees/sec. Muscle strength was measured in the following movement directions with a standardized sequence: right-sided and left-sided shoulder abduction (to measure muscle strength of the m. deltoid pars acromialis in particular), left-sided and right-sided shoulder anteflexion (m. deltoid pars clavicularis in particular), and back extension (m. erector spinae in particular). Shoulder abduction was measured, while the workers were sitting on a chair with supported back and fixation of the opposite shoulder. Shoulder anteflexion was measured while lying on the back with pelvic fixation. Back extension was measured, while the workers were standing with fixation of the legs, the pelvis and the chest.

Before the measurements of muscle strength in each of these movement directions, the workers had to practice two trials in order to get familiar with the Cybex. During the measurements, the workers had to move a load five trials with maximum effort with a short rest period after the second movement. Maximal isokinetic lifting strength (in Nm) was defined as the highest peak outcome of these five trials. During the muscle strength measurements (performed as MVCs), EMG was measured to indicate the MVE.

Simulated work tasks

The workers carried out two simulated work tasks during the measurements: an assembly and a lifting task loading the shoulder and back muscles, respectively. Half of the workers started with the muscle strength measurements of the shoulder and back muscles, then carried out the lifting task, took 10 minutes of rest, and finished with the assembly task. The other half of the workers started with the muscle strength measurements of the shoulder muscles, then carried out the assembly task, took 10 minutes of rest, carried out the muscle strength measurements of the back muscles, and finished with the lifting task.

With regard to the assembly task, workers had to tighten and loosen nuts and bolts from a plastic ring with elevated arms while sitting in a chair with supported back (see Figure 7.1). After each action, the workers were asked to lay down their arms for a short moment. After 2 minutes, there was a rest period of 1 minute. The first cycle started with 45° shoulder elevation, which was raised with 5° each cycle, until 120° shoulder elevation at maximum. We measured the shoulder elevation angle using goniometry. We noted the heights at 45° and 120° shoulder elevation, and raised the plastic ring each cycle with 1/15 of the difference between the minimum and maximum height. EMG was measured during the second minute of each cycle, and LMD was rated during the minute of rest. The task was stopped when an LMD-rating of 5 was reported in the neck/shoulder region, or a rating of 7 was reported in another part of the body two times consecutively, or after one hour at maximum. For the workers who were able to perform the task for one hour, the shoulder elevation angle stayed at 120° during the last 5 cycles.

The lifting task consisted of the lifting of a box from a table at hip level to the floor and back at the table again. Before placing the box back at the table, workers had to keep the box against their body with extended arms for 5 seconds. Each lifting action took 15 seconds. This was continued for 4 minutes, after which 1-minute of rest followed. The first cycle started with a load of 1 kilogram, which was raised with 1 kilogram each cycle, until a maximum load of 12 kilograms. EMG was measured during the fourth minute of each cycle, and LMD was rated during the minute of rest. The task was stopped when an LMD-rating of

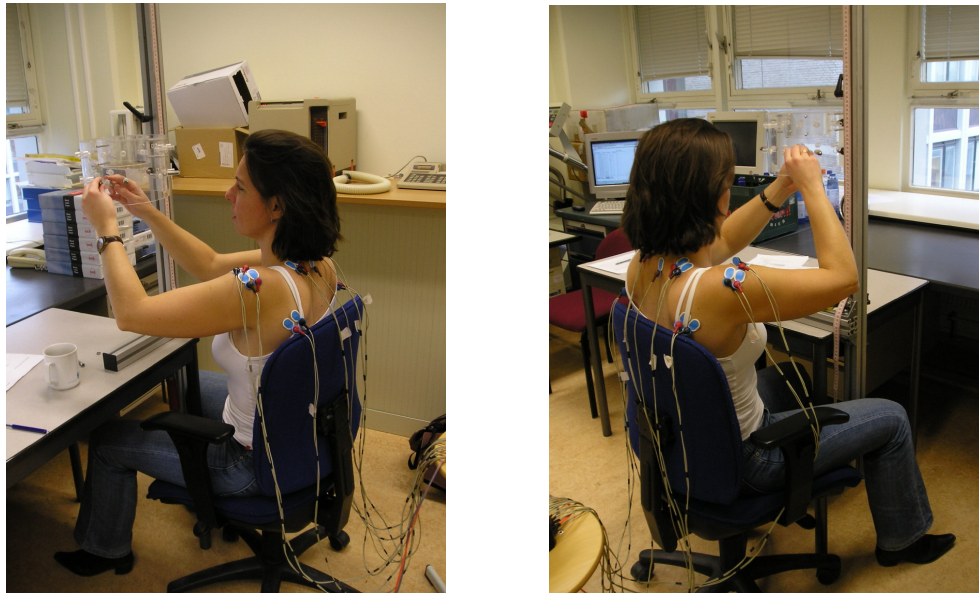


Figure 7.1. The assembly task loading the shoulder muscles

5 was reported in the back region, or a rating of 7 was reported in another part of the body two times consecutively, or after one hour at maximum.

Physical training

The resistance program for the training group consisted of a warming up of 10 minutes on a cross-trainer, exercises to increase muscle strength of the shoulder and trunk muscles during approximately 40 minutes, and a cooling down of 5 to 10 minutes on a bike. The shoulder exercises included: 1) incline shoulder presses, 2 sets of 12 repetitions, 2) front pull down, and 3) row, 3 sets of 10 repetitions, 4) dumbbell shoulder presses, and 5) dumbbell front raises, 2 sets of 12 repetitions, and 6) pectoral fly, 2 sets of 12 repetitions. The trunk exercises included: 1) oblique sit-ups, 15 repetitions each side, 2) pelvic lifts, and 3) prone opposite arm/leg reach, 12 repetitions each side, 4) back extension, and 5) rectus abdominis exercises, 2 sets of 15 repetitions. For each of these exercises, 30 to 45 seconds of rest were allowed between the sets and exercises. The loads to lift were increased during the training program, based on performance.

Data processing

The MVE for each muscle was obtained as the highest value of the digitally rectified and filtered (4th order Butterworth lowpass 5 Hz) EMG amplitude of the MVC-trials. To obtain an estimate of the overall muscular activity, the EMG data collected during the assembly and lifting tasks were digitally rectified, filtered (4th order Butterworth lowpass 5 Hz) and

normalized to MVE. Data reduction was obtained by extracting the median level (P50) from the Amplitude Probability Distribution.²⁶ The P50, which was normalized to MVE, was used as a measure of relative physical workload.

In addition, to determine muscle fatigue related changes in the frequency content of the EMG signal, the MPF over each second window was calculated using Fast Fourier Transformation. The MPF was calculated during the period the muscles were active (above a threshold of 3% MVE). The median MPF per cycle at constant workload in each task was calculated. A regression line was fitted through the MPF-values over the cycles. The slope of this regression line was used as indicator of muscle fatigue.

Statistical analyses

The results were analyzed according to the principle of intention-to-treat, i.e. we included all workers with non-missing follow-up data in the statistical analyses, independent of the training compliance in the intervention group.

First, we analyzed general differences between the training and control group with regard to baseline descriptives by means of the Students T-test (for continuous variables), and the Chi-square test (for categorical variables).

Second, with respect to the effect of the resistance-training, we analyzed the differences between the training and control group of the follow-up results corrected for the baseline results by means of Analysis of Covariance (ANCOVA) in order to correct for baseline results. We analyzed the differences on the following outcome measures: muscle strength, the time that the workers performed the tasks, musculoskeletal discomfort, and EMG indicators of relative physical workload and muscle fatigue during simulated work tasks. We carried out both univariate analyses and multivariate analyses adjusted for potential confounders. We built the smallest possible multivariate model of confounding factors that led to a change of the beta coefficients by at least 10 percent in bivariate analyses.

With respect to musculoskeletal discomfort during the simulated work tasks, we used the mean ratings of the shoulder and back LMD regions. To be able to compare baseline and follow-up results, we calculated the mean LMD-ratings of the numbers of cycles that were measured both at baseline and at follow-up. For example: a worker performed the assembly task at baseline for 10 cycles or 30 minutes and at follow-up for 15 cycles or 45 minutes. We calculated the mean LMD-ratings of the first 10 cycles.

With respect to EMG indicators of relative physical workload, the median EMG amplitude (P50), expressed as % MVE, was used to estimate the relative physical workload. For comparison, we calculated the median EMG amplitude of the number of cycles that were measured both at baseline and at follow-up (in the same way as the LMD-ratings). To

quantify muscle fatigue, we used the slope of the MPF over the cycles at constant workload in each task.

RESULTS

Descriptive statistics

Table 7.1 shows the descriptive statistics at baseline stratified for the training and control group. There were only small differences between the training and control group, but these differences were not statistically significant ($p \leq 0.05$). This means that the groups were quite comparable at baseline.

Three workers (two in the training group and one in the control group) were lost to follow-up. Furthermore, due to a measurement error, data on baseline muscle strength were missing for one female control participant. With respect to the compliance among the training group, the participants attended on average at 10.3 training sessions (min-max 2-14) of the 16 sessions provided.

Muscle strength

Table 7.2 presents mean maximal isokinetic muscle strength at baseline and at follow-up for the selection of workers without missing data on muscle strength. On average, the muscle strength increased during follow-up for all workers, but no statistically significant differences were found between the training and the control group.

Performance time of the simulated work tasks

Table 7.3 presents the mean time that the workers performed the lifting and assembly tasks, until they reported an LMD-rating of 5 in the test region or a rating of 7 in another part of the body two times consecutively, or after one hour at maximum. The performance time of the lifting task among the trained workers had increased by approximately 2 minutes, while the performance time among the untrained workers was decreased by approximately 3 minutes at follow-up. For the assembly task, the effect was in the same direction, but smaller, and not statistically significant.

LMD-ratings during the tasks

Table 7.4 shows the mean LMD-ratings, which were reported during the assembly task (LMD body regions Y, T, Z and X), and lifting task (LMD body regions V, C and F), respectively. Except for the LMD regions T and Y, the LMD-ratings at follow-up were lower

Table 7.1. Descriptive statistics at baseline for the training group (N=9) and the control group (N=10).

Variable	Training group (N=9)	Control group (N=10)
Gender (nr. of men)	3	3
Age (mean (SD))	36.6 (9.0)	37.8 (10.3)
Body weight (mean kg (SD))	69.1 (12.3)	68.7 (10.9)
Body height (mean cm (SD))	175.7 (7.7)	174.5 (6.2)
Right- or left-handed (nr. of right-handed)	8	9
Hours per week of vigorous physical activities which caused sweating during the past 4 months (mean (SD))	2.1 (4.5)	3.8 (4.1)
Exposure to physical load at work (nr. of rather or very much)		
Prolonged standing	1	0
Prolonged sitting	6	10
Prolonged working with computer	6	10
Prolonged working with arm elevation >90°	1	0
Moving or lifting loads >10 kg	1	0
Bending	3	0
Prolonged neck flexion	3	2
Prolonged back flexion	1	0
High work demands with regard to strength (nr. yes)	2	0
High work demands with regard to endurance (nr. yes)	1	0
Musculoskeletal pain in the past 7 days (nr. yes)		
Neck pain	0	0
Right shoulder pain	1	2
Left shoulder pain	0	0
Thoracic back pain	1	1
Low back pain	2	1
Smoking (nr. yes)	3	1
Alcohol consumption (mean nr. of glasses per week (SD))	4.6 (3.7)	6.5 (6.8)

Table 7.2. Maximal isokinetic muscle strength (Nm) for the training group (N=9) and the control group (N=9).

Body region	Movement direction	Training group (N=9)				Control group (N=9)			
		Baseline		Follow-up		Baseline		Follow-up	
		(Nm)		(Nm)		(Nm)		(Nm)	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Shoulder	Abduction right	23.7	10.7	26.9	14.7	29.8	12.0	29.2	13.0
	Abduction left	25.4	11.2	26.9	13.1	31.6	16.8	30.7	16.5
	Anteflexion right	38.4	16.3	40.1	19.0	38.1	14.5	40.0	12.1
	Anteflexion left	38.1	17.3	38.4	16.9	37.3	11.7	38.9	12.2
Back	Extension	156.4	83.9	176.9	84.8	156.2	50.1	176.4	60.0

Table 7.3. Performance time (minutes) of assembly and lifting tasks at baseline and follow-up for the training group (N=9) and the control group (N=10).

Body region	Task	Training group (N=9)				Control group (N=10)			
		Baseline		Follow-up		Baseline		Follow-up	
		(min)		(min)		(min)		(min)	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Shoulder	Assembly task	43.0	16.2	44.3	18.0	43.2	15.8	41.1	20.2
Back	Lifting task*	54.4	12.1	56.1	11.7	56.0	8.1	53.0	9.2

* $P=0.005$ when adjusted for alcohol consumption, sequence of the two simulated work tasks, and compliance.

Table 7.4. LMD-ratings for the body regions Y, T, X and Z, and V, C and F, respectively. Mean of the number of cycles that were measured both at baseline and at follow-up, for the training group (N=9) and the control group (N=10).

Task	LMD body region	Training group (N=9)				Control group (N=10)			
		Baseline		Follow-up		Baseline		Follow-up	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Assembly task	Y (Trap. Desc. region right)*	0.6	0.8	1.0	0.9	1.3	1.2	1.5	1.5
	T (Trap. Desc. region left)	0.4	0.6	1.0	1.0	1.1	1.3	1.4	1.5
	X (Deltoid region right)	2.1	0.7	1.9	0.9	2.3	1.0	2.3	1.4
	Z (Deltoid region left)	2.1	0.8	1.9	0.8	2.3	1.0	2.2	1.4
Lifting task	V (low back region right)	0.7	0.8	0.6	0.8	0.6	1.0	0.7	1.1
	C (low back region left)	0.7	0.7	0.4	0.7	0.6	1.0	0.6	0.8
	F (thoracic back region)	0.5	0.7	0.3	0.5	0.8	0.8	0.8	0.9

* $P=0.015$ when adjusted for working behind a computer screen, working with flexed neck, ever reported neck pain, smoking, and compliance.

among the training group, and were increased or remained about the same in the control group. However, these differences were not statistically significant. However, surprisingly, the LMD-ratings for the regions T and Y at follow-up were higher than at baseline for all workers, with higher values among the training than the control group, which was statistically significant for the region Y.

EMG indicators during the tasks

The EMG results of the different muscles included the median EMG amplitude expressed as percentage MVE (P50), and the slope of the MPF against cycles (in Hz/cycle). Table 7.5 shows that the P50 needed to carry out the tasks was lower at follow up than at baseline for all muscles in the training group, which means that the relative physical workload was decreased. In the control group, the P50 decreased for some muscles, but increased for other muscles. The differences between the training and control group were not statistically significant.

Table 7.5. Mean EMG amplitude (%MVE) for the training group (N=9) and the control group (N=10).

Task	Muscles	Training group (N=9)				Control group (N=10)			
		Baseline		Follow-up		Baseline		Follow-up	
		(%MVE)		(%MVE)		(%MVE)		(%MVE)	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Assembly task	M. Trap. Desc. right	13.3	9.4	9.4	8.5	9.6	3.8	8.5	3.0
	M. Trap. Desc. left	10.8	7.2	10.1	3.1	10.1	5.0	9.4	3.7
	M. Delt. Clav. right	9.3	4.6	8.8	4.7	11.4	6.0	11.5	6.7
	M. Delt. Clav. left	10.6	4.6	10.5	4.3	8.6	3.7	11.0	6.3
	M. Delt. Acr. right	6.3	2.8	5.7	3.4	7.3	5.1	6.0	3.5
	M. Delt. Acr. left	6.2	2.7	6.0	2.1	6.2	4.7	6.8	4.3
Lifting task	M. Er. Spinae T10 righth	10.5	5.1	9.5	6.7	13.8	9.8	14.0	10.4
	M. Er. Spinae T10 left	14.1	10.1	11.4	8.7	14.1	11.2	12.5	8.7
	M. Er. Spinae L3 righth	6.5	3.2	6.1	4.2	9.7	9.1	8.2	6.7
	M. Er. Spinae L3 left	5.1	3.0	4.8	2.4	9.8	7.6	8.8	7.9

Table 7.6. Mean slope of the Mean Power Frequency against cycles (Hz/cycle) for the training group (N=9) and the control group (N=10).

Task	Muscles	Training group (N=9)				Control group (N=10)			
		Baseline		Follow-up		Baseline		Follow-up	
		(Hz/cycle)		(Hz/cycle)		(Hz/cycle)		(Hz/cycle)	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Assembly task	M. Trap. Desc. left	0.13	0.52	0.16	0.59	0.49	0.64	0.11	0.24
	M. Trap. Desc. right	0.12	0.36	0.31	0.47	0.43	0.52	0.36	0.62
	M. Delt. Clav. right	0.20	0.47	0.01	0.49	0.37	0.38	0.27	0.39
	M. Delt. Clav. left	0.12	0.39	0.17	0.30	0.38	0.52	0.28	0.58
	M. Delt. Acr. right	0.30	0.42	0.14	0.45	0.27	0.43	0.18	0.40
	M. Delt. Acr. left	0.10	0.55	0.07	0.51	0.24	0.42	0.31	0.60
Lifting task	M. Er. Spinae T10 righth	0.17	1.98	-1.00	2.41	-0.35	0.70	-0.06	0.73
	M. Er. Spinae T10 left	-1.75	4.26	-0.24	0.39	-0.52	0.49	-0.16	0.45
	M. Er. Spinae L3 righth	-0.23	0.88	-0.39	0.60	-0.34	0.52	-0.07	0.51
	M. Er. Spinae L3 left	-0.46	0.50	-0.48	1.15	-0.46	0.62	-0.16	0.44

Table 7.6 presents generally positive slopes for the shoulder muscles and negative slopes for the back muscles, which means that the MPF increased during the assembly task for the shoulder muscles and decreased during the lifting task for the back muscles. This was found among all participants both at baseline and at follow-up. These results indicate that muscle fatigue was only present in the back muscles, but not in the shoulder muscles. Therefore, we only analyzed the differences in the back muscles for statistical significance. In the training group, a decrease in the negative slopes was only found in the left-sided

thoracic m. erector spinae. However, in the control group, the value of the negative slopes was lower at follow-up for all muscles. This means that muscle fatigue was decreased for all muscles among the control group, but for only one muscle among the training group. These differences between the training and control group were, however, not statistically significant.

DISCUSSION

Main findings

In this experiment among 22 workers, we found no effects of an 8-week resistance-training program on isokinetic muscle strength of the back and shoulder muscles. Furthermore, we did not find any statistically significant effect on EMG output as an indicator of muscle fatigue, nor on the self-reported ratings of musculoskeletal discomfort during assembly and lifting tasks. However, at the follow-up measurement, trained workers performed the lifting tasks for a longer time than the control group, until they reported considerable discomfort.

Comparisons with previous research

As far as we know, only few studies have reported on the relationship between muscle strength and muscle fatigue or musculoskeletal discomfort during work tasks. In an experiment, Pedersen et al.²⁴ found that 29 cashiers, who participated on a 15-weeks resistance-training program of the neck/shoulder muscles, perceived less muscle fatigue in static and dynamic endurance tests than 24 control cashiers, which is not in line with our results. It should be noted however, that in the present study, the training program appeared not have led to an increase in muscle strength, in contrast with a range previous studies,^{16;17;27} and in spite of the fact that the resistance-training met the generally accepted training principles with regard to frequency, intensity, and duration.^{17;27-29}

Methodological considerations

Resistance-training

The compliance among the training group was moderate with participation in on average 10 of the 16 sessions provided. This may explain the absence of a training effect on muscle strength, muscle fatigue, and musculoskeletal discomfort. To investigate the influence of compliance on the study results, we did some per protocol analyses in addition. To this end, we excluded four workers from the training group, i.e. those who participated in less

than 12 training sessions. In general, this selection of workers with better compliance had better muscle strength, reported lower LMD-ratings, but also worked at a higher percentage of the MVE both at baseline and at follow-up. However, except for a larger decrease of the percentage of MVE during follow-up, the differences between baseline and follow-up remained about the same. Moreover, the differences between this selection of trained workers and the untrained workers did also not reach statistical significance, but this may have been due to the smaller power.

Other factors that could have contributed to the absence of a training effect are the relatively short training period and the relatively low frequency of two times per week. The choice for this program was made because training periods of 6 to 7 weeks were reported to be effective in the literature.²⁷ Although longer training periods were found to be more effective, these were not used because of practical limitations.

Measurements of isokinetic muscle strength

For all workers, muscle strength had increased at follow-up. This may have been due to a learning effect, which has been found in many other studies on muscle strength.^{30;31}

A comment can be made on the differences between right-sided and left-sided shoulder muscle strength. The muscle strength results for right-sided shoulder abduction and left-sided shoulder ante flexion were on average higher than those for the other side, because these were the second-measured sides. However, because the sequence of the movement directions was standardized for all workers, we do not expect that this might have led to differences between the two groups.

The simulated work tasks

For practical reasons, we measured both isokinetic muscle strength and two different tasks in a single session. Despite 10 minutes of rest in between the tasks, this may have led to sustained muscle fatigue or discomfort of the muscle strength measurements or the preceding task. We indeed found higher LMD-ratings at the start of the second task compared to the start of the first task, but we did not find any sustained discomfort due to the muscle strength measurements. To correct for sustained discomfort, we let half of the workers start with the lifting task, and the other half with the assembly task. The sequence at follow-up was equal to the sequence at baseline. In general, the lifting task led to more sustained discomfort than the assembly task. However, for most discomfort ratings, these differences were not statistically significant. Furthermore, for most comparisons between the training and control group, the sequence of the tasks was not found to be a confounder.

However, changes in muscle fatigue or discomfort over cycles had been clearer, if the two tasks would have been measured at different days.

LMD-ratings

Musculoskeletal discomfort was measured by means of self-reported ratings. This may have led to large intra-individual variations. However, test-retest reliability of the LMD-method was found to be acceptable, both for static workloads³² and for more dynamic types of work.³³

EMG

Random errors in EMG results may have occurred, due to replacement of the electrodes between sessions. To minimize these effects, the same researcher performed the electrode placement in both sessions using standardized procedures.

In addition, the choice for a protocol with increasing workload over cycles (increasing loads to lift and increasing upper arm elevation angles) to provoke muscle fatigue more quickly is likely to have had some drawbacks. Obviously, this protocol eliminated the use of the EMG amplitude as indicator for muscle fatigue, but it may also have had some effects on the MPF. The increase in workload may have resulted in additional motor unit recruitment, partially masking the effects of muscle fatigue on the MPF. During the assembly task, this masking effect might even have been stronger, because an increase in workload was achieved by increasing upper arm elevation. This might have led to a shift of loading to other parts of the muscle or to other muscles. These facts might explain the finding that in the assembly tasks an increase in the MPF slope over cycles was observed.

CONCLUSION

In a Randomized Controlled Experiment of 22 workers, we found no effects of a resistance-training program on muscle strength, muscle fatigue, and musculoskeletal discomfort during simulated work tasks. However, at the follow-up measurement, trained workers performed the lifting tasks for a longer time period than the control group, before they reported considerable discomfort.

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CHAPTER 8

GENERAL DISCUSSION

INTRODUCTION

In the working population, muscle fatigue and musculoskeletal discomfort are common, which, in the case of insufficient recovery, may lead to musculoskeletal pain. Several factors have been found that may increase the risk of future musculoskeletal pain among workers including gender, age, previous pain, and exposure to several work-related risk factors. Low physical capacity might also be related to future musculoskeletal pain. Physical capacity includes measures of muscle strength, muscle endurance, mobility, and cardiovascular fitness.

The generally accepted conceptual model of physical capacity and exposure to physical factors states that an imbalance between physical capacity and exposure to physical factors (i.e. low capacity in combination with high exposure) is commonly used in everyday occupational health care as an explanation for musculoskeletal pain. However, there is little empirical evidence to support the plausibility of this model.

OBJECTIVE

The purpose of this thesis was to gain insight in the impact of physical capacity on future work-related musculoskeletal pain. We defined physical capacity as isokinetic muscle strength, static muscle endurance, and mobility of the lumbar spine. We focused on musculoskeletal pain of the low back, neck and shoulders. Next to physical capacity as a potential independent risk factor of musculoskeletal pain, we investigated an imbalance between physical capacity and exposure to physical factors as a potential stronger risk factor of musculoskeletal pain. We investigated the different pathways in the generally accepted conceptual model of physical capacity and exposure to physical factors as shown in Figure 1.1 of the introduction of this thesis (see page 12). The different research questions of this thesis focused on the different pathways of the model.

SUMMARY OF THE RESULTS

Below, in answering the research questions, a summary of the results is given.

1. *What are the age-related, and gender-specific differences in physical capacity in a working population, and to what extent are these dependent on sports participation?*

We found that isokinetic strength of the back and neck/shoulder muscles was highest among young men (see chapter 2). Surprisingly, we found that static muscle endurance time was longest among older workers, but no differences were found between men and women. (Moderate) sports participation seems to be effective in keeping aging workers suitable for the relatively growing work demands.

In general, isokinetic muscle strength was highest among young male workers, but static muscle endurance was highest among older workers. (Moderate) sports participation seems to be effective in keeping aging workers suitable for the relatively growing work demands.

Table 8.1. Summary of the results on the relationship between physical capacity and future musculoskeletal pain, with regard to the evidence from a review and a prospective cohort study, as well as the cohort study added to the review.

	Isokinetic muscle strength			Static muscle endurance			Mobility		
	Review	SMASH	Both	Review	SMASH	Both	Review	SMASH	Both
Low back pain	?	0	?	0	+	?	?	0	?
Neck pain	?	+	?	?	+	?	?		
Shoulder pain	?	0	?	?	0	?	?		

? Inconclusive evidence; + Positive relationship (low physical capacity is a risk factor for future musculoskeletal pain); 0 No relationship

2. *To what extent is low physical capacity an independent risk factor for future work-related musculoskeletal pain?*

Table 8.1 shows the results of the systematic review and the results of the prospective cohort study on the association between physical capacity and future musculoskeletal pain (see chapters 3 and 4, respectively). Furthermore, the results of the prospective cohort study in addition to those of the review are presented. In the review, we found strong evidence for an absence of a relationship between static endurance and future low back pain. Due to inconsistent results in multiple longitudinal studies, we found inconclusive evidence for a relationship between isokinetic muscle strength or mobility of the spine and future low back pain. Furthermore, due to a limited number of studies, we found inconclusive evidence for a relationship between physical capacity and future neck/shoulder pain. In SMASH, we found low static muscle endurance as a risk factor for future low back and neck pain, and we found low isokinetic muscle strength as a risk factor for future neck pain. When adding our SMASH- results to the results of our review, the inconclusive evidence for a relationship between physical capacity and future musculoskeletal pain remained.

Table 8.2. Summary of the results on an (im)balance between physical capacity and exposure to work-related factors in association with future musculoskeletal pain.

(Im)balance between capacity and exposure	Exposure to work-related factors	Physical capacity					
		Isokinetic muscle strength			Static muscle endurance		Mobility
		Back pain	Neck pain	Shoulder pain	Back pain	Neck pain	Back pain
Imbalance	Lifting	0	0	0			
Low balance		+	+	0			
High balance		0	0	0			
Imbalance	Working in				+	+	0
Low balance	a flexed				+	0	0
High balance	posture				0	0	0

+ Positive relationship; 0 No relationship

In SMASH, we found low static muscle endurance as a risk factor for future low back and neck pain, and low isokinetic muscle strength as a risk factor for future neck pain. However, when adding our results to the results of a systematic review, we found inconclusive evidence for a relationship between physical capacity and future musculoskeletal pain.

3. *To what extent is an imbalance between physical capacity and exposure to work-related factors a risk factor for future work-related musculoskeletal pain?*

Table 8.2 shows an imbalance between physical capacity and exposure to work-related factors (i.e. low capacity in combination with high exposure) in relationship with future musculoskeletal pain, as well as low balance (i.e. low capacity combined with low exposure) or high balance (i.e. high capacity combined with high exposure) (see chapter 5). An imbalance between static endurance and working in flexed postures was found to be a risk factor for low back and neck pain. However, the sizes of the risk ratios with respect of musculoskeletal pain were comparable to those of physical capacity alone, as shown in chapter 4, or exposure to physical factors alone as shown in previous SMASH studies.¹⁻³

An imbalance between physical capacity and exposure to physical factors was not found to be a more important predictor of future musculoskeletal pain than each of these variables on its own.

4. *To what extent is musculoskeletal discomfort predictive for future musculoskeletal pain among symptom-free workers?*

We found that peak discomfort was a predictor of future low back, neck, and shoulder pain. Cumulative discomfort was found to be a predictor of future neck, and shoulder pain, even with relatively low discomfort ratings (see chapter 6).

Musculoskeletal discomfort during work is a predictor of future musculoskeletal pain among symptom-free workers.

5. *What is the effectiveness of a resistance-training program on muscle strength, muscle fatigue, and musculoskeletal discomfort during simulated work tasks?*

In an experiment among 22 workers, we found no effect of an 8-week resistance-training program on isokinetic muscle strength of the back and shoulder muscles (see chapter 7). Furthermore, we did not find any effect on either EMG data as indicator for muscle fatigue, or on self-reported ratings of musculoskeletal discomfort during a simulated assembly and lifting work task. However, at the follow-up measurement, trained workers were able to perform the lifting task for a longer period than those in the control group.

We found no effect of a resistance-training program on muscle strength, muscle fatigue, and musculoskeletal discomfort during simulated work tasks.

THEORETICAL AND METHODOLOGICAL CONSIDERATIONS

Findings in comparison with hypotheses

The results of this thesis were for the largest part not in line with our hypotheses on the conceptual model of physical capacity and exposure to physical factors. We expected to find low physical capacity to be a risk factor for future musculoskeletal pain. Moreover, we expected to find an imbalance between physical capacity and exposure to work-related physical factors (i.e. low capacity in combination with high exposure) to be a stronger risk factor than either physical capacity or exposure to physical factors on its own. Finally, we expected to find an effect of a resistance-training program on muscle strength as well as on muscle fatigue and musculoskeletal discomfort during simulated work tasks. However, most of the expected pathways of the conceptual model were for the largest part not supported by the study results. Only the expected pathway of musculoskeletal discomfort as a short-term stage of musculoskeletal pain was proven valid by the study results.

When focussing on the different physical capacity measures (i.e. muscle strength (combined with lifting exposure), static muscle endurance (combined with flexed working posture), and mobility of the spine) as well as on the different outcome measures (i.e. low

back, neck and shoulder pain) some of the observed relations were in line with our expectations, and some were not.

With regard to the different physical capacity measures, we expected to find reduced static endurance to be a more important risk factor for future musculoskeletal pain than either muscle strength or mobility of the spine. The reason for this expectation is that reduced endurance time might be related to sub-optimal blood-flow and muscle fatigue, which have been hypothesized to be related to musculoskeletal pain.⁴ Furthermore, it can be argued that endurance time is - more than the other measures of physical capacity - not only dependent on physiological functions, but also on more subjective factors such as motivation, fear-avoidance beliefs, and pain attitude, which have also been hypothesized to be related to musculoskeletal pain.^{5,6} For static muscle endurance, we expected to find a stronger relationship with neck pain than with low back pain, because this capacity measure might counteract with long-term exposure to static muscle activity at work, which has been found to be a risk factor for future neck/shoulder pain.⁷ In SMASH, we indeed found that reduced static muscle endurance, as well as an imbalance between static muscle endurance and working in flexed postures, were related to future neck pain. However, these variables were stronger related to future low back pain. For isokinetic muscle strength, we expected to find a stronger relationship with low back pain, because this capacity measure might counteract with lifting at work, which has been found to be a risk factor for future low back pain.⁸⁻¹² In contrast to our expectations, in SMASH we did not find any relationship between reduced isokinetic muscle strength and future low back pain, but we did find a relationship with neck pain. With regard to the combination between muscle strength and lifting exposure, we could not find imbalance as a risk factor for future pain, but did find a relationship between low balance and future low back and neck pain. The results of the systematic review, regarding strong evidence for an absence of a relationship with static endurance, or inconclusive evidence for a relationship between other measures of physical capacity and future musculoskeletal pain, were contrary to our expectations.

Regarding mobility of the spine, we did not have clear expectations, but assumed no strong relationship with future low back pain. Both the results of SMASH (in which we did not find any association) and the results of the systematic review (in which we found inconclusive evidence for a relationship) were in line with this assumption.

With respect to the different outcome measures, we expected to find stronger relationships with low back and neck pain compared to shoulder pain, because of differences in morphological and physiological structure of the shoulder joint compared to the low back and neck regions. Shoulder pain is more often the result of a specific cause compared to

(non-specific) low back and neck pain. Indeed, in SMASH, we could not indicate any physical capacity or imbalance measure as a risk factor for future shoulder pain.

Theoretical considerations

In the interpretation of the findings of this thesis, different considerations have to be mentioned, which could (partly) explain the discrepancy between the expected and the observed results. Below, we describe different theoretical and methodological considerations, in comparison with previous research, which could have played a role in the absence of the hypothesized pathways of the conceptual model of physical capacity and exposure to physical factors.

This brings us to the question if the general accepted model of physical capacity and exposure to physical factors - which is also called the (biomechanical) load-tolerance model,¹⁰ the model of work capacity and workload,^{13;14} or the model of work capability and work demands¹⁵ - should be rejected. As far as we know, in this thesis, the empirical support for this model has been systematically analysed for the first time. In the previous literature, we found only a limited number of studies that were partly linked to this topic. The results of these studies are contradictory. Harbin and Olson¹⁶ found some evidence for the conceptual model of physical capacity and exposure to physical factors. In their longitudinal study on Functional Capacity Evaluations (FCEs), they found higher incidence of musculoskeletal injuries among healthy workers who did not demonstrate the lifting strength that was required for their job, compared to those who did have the physical capabilities. Furthermore, Rosenblum et al.¹⁷ found physical testing in itself as a risk factor for musculoskeletal injuries. They found that non-screened workers had a higher risk of a musculoskeletal injury than workers who did participate in pre-employment isokinetic muscle strength screening. In contrast, Kuijer et al.¹⁸ did not find any association between a mismatch between FCE activities and work demands and future sick leave among low back pain patients. It is difficult to compare these study results with our own study, because the type of physical capacity testing was different from our method, and furthermore, the outcome measures injuries and sick leave were more severe than our outcome measure musculoskeletal pain.

However, different potential explanations for not being able to confirm the pathways in the conceptual model of physical capacity and exposure to physical factors have to be taken into consideration, before the far-reaching conclusion can be drawn that the conceptual model has to be rejected.

First, the median cut-off we used to divide workers into those with physical capacity and exposure to physical factors in balance and those with those variables in imbalance might not have been suitable. More extreme cut-offs might have led to more contrast and thus to stronger study results. However, we think this would not have played an important role in the interpretation of the results, since in additional analyses using the 30% extremes as cut-off, we found only minor changes of the study results. For neck pain, this generally led to a slight increase in the strength of effects, but for low back and shoulder pain, no differences were found.

Second, the model should perhaps have been expanded with other factors to provide a more comprehensive model. One of these factors might be psychosocial factors. Moreover, the physical model should perhaps have been merged with the psychosocial demand-control(-support) model or the effort-reward imbalance model.¹⁹ However, the recent literature does not show strong relationships between psycho-social work-related risk factors and musculoskeletal pain.²⁰⁻²² Also, in this thesis, we added several psychosocial factors as potential confounders to the statistical analyses, and found only few of them to be real confounders. Reconsidering the above, we think that adding psychosocial factors as risk factors to the physical model would not have led to more pronounced effects on musculoskeletal pain.

Third, the conceptual model might be more suitable for specific groups of workers, such as workers in physically heavy professions, newly employed workers, or aging workers. One can imagine that among these groups of workers, the contrasts between physical capacity and exposure to work-related factors would be larger than among a "general" group of workers such as in SMASH. It is conceivable that the contrast between capacity and exposure has to be much larger to find a substantial effect of an imbalance on future musculoskeletal pain. In addition, it should be kept in mind that the degree of (im)balance between physical capacity and exposure to physical factors can be considered as dynamic.²³ This means that, on the one hand, high exposure to physical factors could lead to an increase of physical capacity, due to a training effect. On the other hand, prolonged high exposure to physical factors could lead to tissue damage, which could result in decreased physical capacity.²⁴ This makes it difficult to distinct balance from imbalance.

Fourth, it should be kept in mind that the conceptual model of physical capacity and exposure to physical factors is in fact a "black box". The mechanisms underlying the different pathways of the model are for the largest part unknown. Several hypotheses have been proposed for the pathogenesis of work-related musculoskeletal discomfort and pain, but detailed knowledge is still lacking.^{4;25} Intermediate factors in this so-called "black box" might have played a more pronounced role in the conceptual model of physical capacity and

exposure to physical factors than the variables that we focused on. Thus, further fundamental research is needed to get more insight in the mechanisms underlying the “black box” to reveal the pathogenesis of musculoskeletal pain. Ideally, this research should be integrated with epidemiological studies, to gain more complete insight in the pathways of the model.

Finally, in comparison to previous research, discrepancy rose between physical capacity, resistance-training, and the risk of musculoskeletal pain. In our experiment, we did not find any effect of a resistance-training program on muscle strength of the back and shoulder muscles. However, from previous studies there is evidence that resistance-training leads to increased muscle strength.^{26;27} Furthermore, physical exercises to increase physical capacity have been found as one of the few interventions with strong evidence to be primary preventive for musculoskeletal pain.²⁸⁻³³ Thus, physical training may lead to decreases in prevalence of musculoskeletal pain among workers, and thus decreases in absenteeism due to musculoskeletal pain, and decreases in costs for society and employers.

In SMASH, we found low static muscle endurance to be related to future low back and neck pain, and low isokinetic muscle strength to be related to future neck pain. However, when adding our SMASH-results to the results of our review, we concluded that there is inconclusive evidence for a relationship between physical capacity and the risk of future musculoskeletal pain.

Considering the results on physical capacity and the preventive physical training from the literature, there seems to be a discrepancy. It seems that the preventive effect is not due to the increased muscle strength. The question has risen which part of physical training then leads to the primary preventive effect of training on musculoskeletal pain. Perhaps, psychosocial factors, such as increased motivation, less fear-avoidance, or changes in pain behaviour, may play a role in the preventive effect. Furthermore, a placebo effect cannot totally be excluded from training studies, because a double blinded study design is not possible. Unless the fact that another intervention – such as an education program, or an exercise program without the use of loads - is mostly used as control group in training studies, a placebo effect can still be possible.

Methodological considerations

Next to the above-mentioned theoretical reflections, methodological strengths and limitations have to be taken into consideration in the interpretation of the study results. These are described below for the different study designs, i.e. a systematic review, SMASH and an experiment.

Systematic review

In our systematic review, the heterogeneity between the different included studies was high with regard to physical tests, and cut-off points of “high” and “low” physical capacity. Therefore, the general conclusion of inconclusive evidence for a relationship between physical capacity and future musculoskeletal pain has to be taken with caution. Grouping the physical tests in sensitivity analyses led for some types to an adaptation of the conclusions. However, the shifts of these conclusions were for the largest part in the direction of an absence of a relation. This makes the general conclusion of a potential absence of a relationship between physical capacity and future musculoskeletal pain more conceivable than the general conclusion of a potential strong relationship.

SMASH: Measurements of physical capacity

In SMASH, physical capacity was measured using tests on isokinetic muscle strength, static muscle endurance and mobility of the spine. The results of these tests could have been influenced by measurement errors.

First, with respect to the reliability of the tests, four different pilot studies among 33 healthy subjects showed moderate to high test-retest reliability and moderate inter-observer reliability. More specifically, the average results of these pilot studies showed that the test-retest reliability was high for the isokinetic neck/shoulder-lifting test and for the back endurance test, but moderate for the other tests of physical capacity.^{34;35} Furthermore, previous studies showed acceptable test-retest reliability of the isokinetic muscle strength tests,³⁶⁻³⁹ but lack of information about inter-observer reliability.³⁶ With respect to the static muscle endurance tests, the Biering-Sørensen (back) test showed acceptable inter-rater reliability,³⁷ but inconclusive evidence for test-retest reliability.³⁶ Some comments can be made on the neck and shoulder endurance tests, which were newly developed tests. First, many workers were able to reach the maximum endurance time. Therefore, these tests might have been too light. This means that no distinction could be made between workers with good performance and workers with very good performance. Considering the spinal flexion and rotation tests, the Schöber test was found to be a reliable test method, but trunk rotation measurements were found to be not reliable.³⁶ In conclusion, due to inconclusive evidence on reliability of some of the physical tests, bias due to misclassification could not completely be excluded from the results in chapters 4 and 5.

Second, other aspects that could have influenced performance in tests of physical capacity could be lack of motivation, moderate pain during testing, or kinesiophobia. However, workers suffering from cardiovascular diseases, fever, pregnancy, or considerable musculoskeletal discomfort were excluded from the tests of physical capacity for validity and

security reasons. Furthermore, in additional analyses of a selection of workers who were well motivated and did not report any pain, we found that these factors did not play an important role in the performance of the tests. Therefore, we think that misclassification for this reason was not likely.

Third, some practical choices could have influenced the study results. We decided to limit physical capacity measures to muscle strength, muscle endurance and mobility of the spine. However, physical capacity can be measured by performance in other tests as well,⁴⁰ such as tests on proprioceptive controlled balance,⁴¹ tests used in an FCE,¹⁶ and range of motion of the shoulder. Furthermore, cardiovascular fitness can be considered as an aspect of physical capacity too. Including other measures of physical capacity could have led to more pronounced study results.

SMASH: Measurements of exposure to physical risk factors

Exposure to physical risk factors was assessed using observations and self-reports by means of the standardized Dutch Musculoskeletal Questionnaire.⁴² In the analyses regarding (im)balance between physical capacity and exposure to physical factors, we used the data obtained from video observations. We clustered workers in order to minimize within-group variance and maximize between-group variance,^{43;44} but, due to individual differences, misclassification could not completely be excluded.⁴⁵

Measurements of localized musculoskeletal discomfort and musculoskeletal pain

Localized musculoskeletal discomfort (LMD) was measured using a ten-point scale from no discomfort (zero) to worst imaginable discomfort (10).⁴⁶ The test-retest reliability of the LMD-method was acceptable, both for static workloads⁴⁷ and for more dynamic types of work.⁴⁸

Low back, neck, and shoulder pain were self-reported at baseline and three times annually during follow-up using an adapted Dutch version of the Nordic Questionnaire.⁴⁹ Self-reported pain could have been influenced by different factors, such as psychological factors, or recall bias.⁵⁰ Musculoskeletal disorders, diagnosed by means of physical examination, can be seen as a more valid outcome measure, but are still not the “gold standard” in workplace studies.⁵¹ We have chosen for self-reports for practical reasons, and because we were interested in the course and the severity of the pain during a prolonged period (and not in a short-term diagnosis).

A comment can be made on the concepts of discomfort and pain. In this thesis, we assumed these two as different concepts, because discomfort was a short-term effect measure (i.e. discomfort at one particular working day) and pain was a long-term effect

measure (i.e. pain in the past 12 months). However, the difference between these two concepts did not become clear from the description in the questionnaire we used. In the Dutch adapted version of the Nordic Questionnaire, long-term pain was assessed by “problems (discomfort, pain) during the past 12 months”. For clarity, we defined this as pain.

SMASH: Statistical analyses

Some comments can be made on the statistical analysing techniques that we used in the chapters 4 to 6. First, we analysed the longitudinal relationships between the independent variables at baseline and musculoskeletal pain at follow-up using Poisson Generalized Estimation Equations (GEE). We used Poisson GEE instead of logistic GEE in order to receive relative risks instead of odds ratios. We preferred this, because relative risks are the appropriate estimates in prospective cohort studies.^{55;56}

Second, for the analyses on physical capacity or (im)balance, we did not need to select a pain-free working population at baseline (and were able to make optimal use of the available power), because in analysing each transition from a pain-free episode to an episode with pain, GEE automatically “selected” a pain-free population. We did not expect any misclassification of pain in the previous 12 months on the performance in the test of physical capacity, because we excluded workers with considerable musculoskeletal discomfort at the moment of testing. However, in the analyses with regard to musculoskeletal discomfort in relation to future pain, we expected misclassification due to the influence of pain in the previous 12 months in the ratings of discomfort. Therefore, in these analyses, we did select a pain-free population at baseline.

Randomised Controlled Field Experiment

The resistance-training met the generally accepted training principles with regard to the use of sets and repetitions and increasing loads.^{27;57-59} In spite of this, the compliance among the training group was moderate, which may explain the absence of a training effect on muscle strength, muscle fatigue and musculoskeletal discomfort. However, in additional per protocol analyses, we still did not find any training effect. Other factors that could have contributed to the absence of a training effect are the relatively short training period, the relatively low frequency of the training, and the small number of subjects.

In conclusion on these above-mentioned theoretical and methodological considerations, we think that the following two factors might have played a role in explaining the absence of confirmation at the pathways in the conceptual model of physical capacity and exposure to physical factors: 1) potential pathophysiological mechanisms that were not

included in this study ("black box") might have played a more important role than the variables we included into the model; 2) among specific groups of workers, an imbalance between capacity and exposure might have been more pronounced than among the "general" group of workers in SMASH.

From a methodological point of view, we think that the results of the systematic review and SMASH can be considered as valid, due to the strengths of these designs. However, the results of the Randomised Controlled Field Experiment have to be taken with some caution, due to the small study population and the low intensity of the training program.

FINAL CONCLUSION

In conclusion, taking the theoretical and methodological remarks into consideration, we found inconclusive evidence for a relationship between low physical capacity and future musculoskeletal pain, when adding our SMASH-results to the results of our review. Furthermore, we did not find imbalance between physical capacity and exposure to work-related physical factors as a stronger risk factor for future musculoskeletal pain than physical capacity alone. Furthermore, we did not find any effect of a resistance-training program on physical capacity nor on musculoskeletal discomfort during simulated work tasks. However, we did find musculoskeletal discomfort as a predictor of future musculoskeletal pain. As a whole, the conceptual model of physical capacity and exposure to physical factors was found to be less clear as generally accepted.

The answer to our main research question "*What is the impact of physical capacity on the development of work-related musculoskeletal pain?*" is as follows:

"There is inconclusive evidence for a causal relationship between low physical capacity and future musculoskeletal pain."

PRACTICAL IMPLICATIONS

Some practical implications can be derived from the findings of this thesis:

- It is not appropriate to recommend physical capacity testing at work with the purpose to decline the ratings of musculoskeletal pain at work.
- Although we did not find any effect of a resistance-training program on muscle strength, muscle fatigue and musculoskeletal discomfort in our experiment, due to

strong evidence from previous research, we would still promote physical training. Stimulating aging workers to participate in sports seems to be effective in keeping them fit for physical work demands.

- Discomfort rating scales can be used as a predictor of future pain among healthy workers, thus can be used by ergonomists in advising (groups of) workers on reducing exposure to physical factors.

RECOMMENDATIONS FOR FUTURE RESEARCH

This thesis contributes to insights in the impact of physical capacity on the development to work-related musculoskeletal pain. However, some questions remain unanswered and new questions have risen. Therefore, we make the following recommendations for future research:

- To get more insight in the different pathways of the conceptual model of physical capacity and exposure to work-related physical factors, fundamental research is needed on the pathogenesis of the different pathways of the model, which should be incorporated to epidemiological longitudinal studies. Future studies on physical capacity and exposure to physical factors should focus on specific groups of workers with high contrast in physical exposure.
- Intervention studies are needed on the efficacy of physical training programs for different groups of workers (i.e. newly employed workers, male or female workers, or older workers) to get more insight in the type, intensity and duration of exercises that should be recommended in the prevention of musculoskeletal pain.

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SUMMARY

In the working population, muscle fatigue and musculoskeletal discomfort are common, which, in the case of insufficient recovery, may lead to musculoskeletal pain. Musculoskeletal pain at work may lead to medical consumption, sickness absenteeism, or disability claims with high costs for society. Several factors have been found that may increase the risk of future musculoskeletal pain among workers including gender, age, previous pain, and exposure to several work-related risk factors.

Furthermore, low physical capacity might be related to future musculoskeletal pain. Physical capacity includes measures of muscle strength, muscle endurance, mobility, and cardiovascular fitness.

In this thesis, the impact of physical capacity on future work-related musculoskeletal pain was investigated. More specifically, the different pathways in the generally accepted conceptual model of physical capacity and exposure to physical factors in relation to future low back, neck and shoulder pain were investigated. We focussed this thesis on muscle strength, and muscle endurance of the back and neck/shoulder muscles and mobility of the spine.

The generally accepted conceptual model of physical capacity and exposure to physical factors states that workers with high physical capacity can better deal with high exposure to work-related physical factors, than those with low physical capacity. This model is commonly used in every day practice as an explanation for future musculoskeletal pain. However, evidence to support the plausibility of this model is lacking. We assumed that both low physical capacity and high exposure to work-related physical factors might be independent risk factors for musculoskeletal discomfort at short-term and pain at long-term. Furthermore, we assumed that an imbalance between these two risk factors (i.e. low capacity in combination with high exposure) might be a stronger risk factor than each of these variables on its own. The different chapters of this thesis focus on the different pathways of the model.

Chapters 2 to 4 of this thesis focused on physical capacity. Chapter 2 reported on the age-related and gender-specific differences in physical capacity. We used data of the longitudinal Study on Musculoskeletal disorders, Absenteeism, Stress and Health (SMASH) to analyze this. This is a prospective cohort study of almost 1800 male and female workers from 34 companies throughout the Netherlands with a follow-up of 3 years. It consisted of a mixed working population from white-collar, blue-collar and caring professions. At baseline, physical capacity, including isokinetic muscle strength of the back and neck/shoulder

muscles, static endurance of the back, neck and shoulder muscles, and mobility of the spine were assessed. Measurements of static muscle endurance were repeated at follow-up. For isokinetic muscle strength, we analyzed the relationship with age only cross-sectionally at baseline using quadratic regression analyses. For static muscle endurance, we analyzed for 5-year age-groups the age-related differences both cross-sectionally and longitudinally using the mean differences at baseline and after three years of follow-up. We stratified the results for gender and sports participation.

The results of this chapter showed that performance in tests of isokinetic muscle strength was lower at older ages than at younger ages, with optima between 19 and 33 years. Men had higher isokinetic muscle strength than women. Cross-sectionally, the mean performance for static back endurance had its optima at 29 years and 42 years among men and women, respectively. However, for the neck and shoulder muscles, performance was higher among older workers. In contrast, muscle endurance decreased longitudinally among all age-groups. Taking sports participation into account, the results suggested that younger workers who participated in sports for 3 hours per week or more had the best performance. Surprisingly, however, the results suggested that older workers who participated in sports between 0 and 3 hours per week had higher isokinetic muscle strength than those who participated in sports for 3 hours per week or more.

We concluded that there were age-related differences in isokinetic muscle strength, and static muscle endurance of the back and neck/shoulder muscles. Isokinetic muscle strength was highest among young male workers who participated in sports. Static muscle endurance was highest among older workers, but was comparable among men and women. (Moderate) sports participation seems to be effective in keeping aging workers suitable for their relatively growing work demands.

Chapters 3 and 4 reported on the independent association between physical capacity and incidence of low back, and neck/shoulder pain both with regard to the evidence in the literature, and the evidence obtained from SMASH. Chapter 3 was a systematic literature review, in which the results of 26 previous prospective cohort studies were summarized on the evidence that low muscle strength, low muscle endurance, or reduced spinal mobility were predictors of future low back or neck/shoulder pain. Abstracts found by electronic databases were checked on several inclusion criteria. Two reviewers separately evaluated the quality of the studies. Based on the quality and the consistency of the results of the included studies, three levels of evidence were constructed.

Twenty-four prospective cohort studies were included in the longitudinal relationship between physical capacity measures and the risk of future low back pain and three studies

reported on future neck/shoulder pain. We found strong evidence for an absence of a relationship between trunk muscle endurance and the risk of future low back pain. Furthermore, due to inconsistent results in multiple studies, we found inconclusive evidence for a relationship between trunk muscle strength, and also inconclusive evidence for a relationship between mobility of the lumbar spine and the risk of low back pain. Finally, due to a limited number of studies, we found inconclusive evidence for a relationship between physical capacity measures and the risk of neck/shoulder pain. In conclusion, except for strong evidence for an absence of relationship between static muscle endurance and future low back pain, we found inconclusive evidence for a relationship between physical capacity and future musculoskeletal pain. Due to heterogeneity, the results of this systematic review have to be interpreted with caution.

Chapter 4 reported on the independent relationship between isokinetic muscle strength, static muscle endurance, or mobility of the lumbar spine, and future low back, neck or shoulder pain using SMASH-data. Pain was self-reported at baseline and three times annually during follow-up using an adapted Dutch version of the Nordic Questionnaire. We defined an incident case of low back, neck, or shoulder pain if a pain-free episode (i.e. no, or sometimes pain in the past 12 months) was followed by an episode with pain (i.e. regular, or prolonged pain in the past 12 months). Poisson Generalized Estimations Equations (GEE) was used to analyse the association between baseline physical capacity and low back, neck, or shoulder pain at every follow-up moment. In order to adjust for differences in performance in tests of physical capacity between men and women, we calculated sex-specific tertiles. Both univariate and multivariate risk ratios (RRs), with adjustment for confounders, were calculated with the highest tertile as reference category.

The results of this chapter showed an increased risk of future low back pain among workers with low static trunk muscle endurance, but no association with isokinetic trunk lifting strength, or mobility of the spine. Furthermore, we found an increased risk of future neck pain among workers with low isokinetic lifting strength, or low static muscle endurance. We did not find any association between physical capacity and future shoulder pain.

We concluded that poor low back and neck muscle endurance were independent predictors of future low back and neck pain, respectively, and that low lifting neck/shoulder strength was an independent predictor of neck pain. Low physical capacity was not a predictor of future shoulder pain.

Chapter 5 dealt with an imbalance between physical capacity and exposure to work-related physical factors, in relation to incidence of low back, neck, or shoulder pain. Again,

we used data of SMASH. Exposure to work-related physical factors was assessed at baseline by means of video-observations. Imbalance was defined as lower than median capacity combined with higher than median exposure, "high balance" as high capacity with high exposure and "low balance" as low capacity with low exposure. Workers with high capacity and low exposure (i.e. "in balance") were the reference group. Again, data were analyzed by means of Poisson GEE.

We found that for both the low back and neck, imbalance between static muscle endurance and working in flexed postures was a risk factor for future pain. Low balance between these two variables was also a risk factor for future low back pain. Furthermore, low balance between isokinetic lifting strength and lifting exposure was a risk factor for future low back and neck pain, but this was not found for imbalance. No associations were found with future shoulder pain.

In conclusion, for low back and neck pain, this study partly supported our hypothesis that an imbalance between physical capacity and exposure to work-related physical factors would lead to an increased risk of future musculoskeletal pain. In general, however, an imbalance between physical capacity and exposure to physical factors was not found to be a more important predictor of future musculoskeletal pain than each of these variables on its own.

Chapter 6 reported on peak or cumulative musculoskeletal discomfort at work as predictors of future musculoskeletal pain among symptom-free workers.

Again, data of SMASH were used. Localized musculoskeletal discomfort (LMD) was assessed at baseline. The LMD-method was based on the Borg category ratio scale ranging from 0 (no discomfort at all) to 10 (extreme discomfort, almost maximum). Workers were asked to indicate their LMD-ratings six times during a working day in 13 parts of the body using an adapted map of the back site of the body. Peak discomfort was defined as a discomfort level of 2 at least one time during a day, which was derived from the ISO-guideline for static working postures. Cumulative discomfort was defined as the sum of discomfort during the day. Reference workers reported a rating of zero at each measurement. We selected a symptom-free subpopulation of workers. Again, data were analyzed by means of Poisson GEE.

We found that LMD increased during the morning, decreased after the lunch break, and increased again during the afternoon, until the end of the working day. The mean LMD-ratings were low, due to a large percentage of workers that reported a rating of zero at all measurements. Peak discomfort was found to be a predictor of future low back, and neck

pain, as well as future right- and left-sided shoulder pain. Cumulative discomfort predicted future neck pain, and right- and left-sided shoulder pain.

In conclusion, the results of this chapter suggest that both peak and cumulative discomfort could predict future musculoskeletal pain among symptom-free workers, even with relatively low ratings.

Chapter 7 reported on the effect of a resistance-training program on muscle strength, muscle fatigue, and musculoskeletal discomfort during simulated work tasks. The study design was a Randomised Controlled Field Experiment among 22 healthy workers.

The workers were matched on gender and age, and were randomized over an intervention group participating in a resistance-training program 2 times per week during 8 weeks, and a control group. Both at baseline and after the intervention period, isokinetic strength of the shoulder and back muscles, as well as muscle fatigue and musculoskeletal discomfort during a simulated assembly and lifting task were measured. Maximum isokinetic muscle strength was measured using a dynamometer (Cybex). During these muscle strength measurements, electromyography (EMG) of the shoulder and back muscles was performed in order to have an indication of the Maximal Voluntary Contraction (MVC). Furthermore, during the simulated work tasks, muscle fatigue was measured using EMG, and perceived discomfort was asked using the LMD-method. The resistance-training contained of exercises with loads to lift to increase muscle strength of the shoulder and trunk muscles. The results were analyzed according to the principle of intention-to-treat, i.e. we included all workers with non-missing follow-up data in the statistical analyses, independent of the compliance in the training group.

We analyzed the differences between the training and control group regarding the follow-up results corrected for the baseline results by means of Analysis of Covariance (ANCOVA). We focused on the following outcome measures: muscle strength, the time that the workers were able to perform the tasks, and muscle fatigue and musculoskeletal discomfort during the simulated work tasks.

We found no effects of the resistance-training program on isokinetic muscle strength of the back and shoulder muscles. Furthermore, we did not find any effect on EMG data as an indicator for muscle fatigue, or on LMD-ratings during the simulated work tasks. However, at the follow-up measurement, trained workers performed the lifting tasks for a longer time than those in the control group.

Chapter 8 contained the general discussion. In this chapter, we summarized the results by answering the research questions.

We found only few indications for each of the assumed pathways in the conceptual model of physical capacity and exposure to physical factors, and the relations were not as strong as expected. We concluded, when adding our SMASH-results to the results of our review, that there is inconclusive evidence for a relationship between low physical capacity and future musculoskeletal pain. Furthermore, the results of this thesis did not verify the hypothesis that an imbalance between physical capacity and exposure to physical factors might be a more important predictor of low back or neck pain than the effects of each of these variables on its own. Furthermore, we did not find any effect of a resistance-training program on physical capacity nor on musculoskeletal discomfort during simulated work tasks. However, we did find musculoskeletal discomfort as a predictor of future musculoskeletal pain. We concluded that the conceptual model of physical capacity and exposure to physical factors is less clear as generally accepted.

Finally, we gave some practical implications from the study results, and did recommendations for further research. The practical implications that could be derived from the findings of this thesis included that it is not appropriate to advice for physical capacity testing at work, that physical training or sports participation should be promoted for (aging) workers, and that discomfort rating scales could be used as a predictor of future pain among healthy workers. We recommended future studies on the different pathways of the conceptual model of physical capacity and exposure to work-related physical factors for specific groups of workers, in which fundamental research on the pathogenesis should be incorporated to epidemiological longitudinal studies. Furthermore, we recommended intervention studies on the efficacy of physical training programs in the prevention of musculoskeletal pain for different groups of workers (i.e. newly employed workers, male or female workers, or older workers).

SAMENVATTING

Spiervermoeidheid en lichamelijk ongemak (discomfort) komen veel voor onder de werkende bevolking. Bij onvoldoende herstel kan dit op de lange termijn tot klachten aan het bewegingsapparaat leiden. Klachten aan het bewegingsapparaat kunnen vervolgens weer leiden tot medische consumptie, werkverzuim, of arbeidsongeschiktheid, welke hoge kosten voor de maatschappij met zich meebrengen.

Er zijn meerdere risicofactoren gevonden voor het ontstaan van klachten aan het bewegingsapparaat, waaronder geslacht, leeftijd, het eerder gehad hebben van klachten aan het bewegingsapparaat en blootstelling aan hoge belasting op het werk. Verder zou lage fysieke belastbaarheid een mogelijke risicofactor kunnen zijn voor toekomstige klachten aan het bewegingsapparaat. Onder fysieke belastbaarheid worden spierkracht, spieruithoudingsvermogen, lenigheid en cardiovasculaire fitheid verstaan.

Het doel van dit proefschrift was om de impact van fysieke belastbaarheid op het ontstaan van werkgerelateerde klachten aan het bewegingsapparaat te onderzoeken. Meer specifiek was het doel de aannemelijkheid van het veelgebruikte fysieke belasting-belastbaarheidmodel te onderzoeken in relatie tot het ontstaan van lage rug-, nek- en schouderklachten. We hebben ons in dit proefschrift beperkt tot isokinetische spierkracht en statisch spieruithoudingsvermogen van de rug en nek-/schoudermusculatuur alsmede lenigheid van de lage rug.

Het algemeen geaccepteerde fysieke belasting-belastbaarheidmodel is gebaseerd op de idee dat fysiek fitte werknemers zware werkbelasting beter aankunnen dan fysiek minder fitte werknemers. Dit model wordt in de praktijk veel gebruikt als verklaringsmodel voor het ontstaan van klachten aan het bewegingsapparaat, ondanks dat het wetenschappelijke bewijs beperkt is.

In dit proefschrift zijn we uitgegaan van de hypothese dat zowel lage fysieke belastbaarheid als hoge fysieke werkbelasting onafhankelijke risicofactoren zijn voor zowel het ontstaan van fysiek discomfort op de korte termijn als klachten aan het bewegingsapparaat op de lange termijn. We zijn er verder van uitgegaan dat een disbalans tussen deze twee factoren (d.w.z. een lage belastbaarheid in combinatie met hoge werkbelasting) een sterkere risicofactor is dan elk van deze factoren apart. De hoofdstukken van dit proefschrift zijn gewijd aan de verschillende onderdelen van het fysieke belasting-belastbaarheidmodel.

De hoofdstukken 2 tot 4 gaan over fysieke belastbaarheid. In hoofdstuk 2 hebben we leeftijd- en geslachtspecifieke verschillen berekend. We hebben daarbij gebruik gemaakt van

de "longitudinal Study on Musculoskeletal disorders, Absenteeism, Stress and Health (SMASH)". Dit is een prospectieve cohortstudie met een onderzoeksduur van 3 jaar. De onderzoekspopulatie bestond uit bijna 1800 mannelijke en vrouwelijke werknemers, die werkzaam waren bij 34 verschillende bedrijven in Nederland. Onder de deelnemers bevonden zich zowel werknemers die fysiek zwaar werk verrichten, als werknemers met een kantoorbaan. Aan het begin van de studie werd fysieke belastbaarheid gemeten door middel van spierkrachtmetingen van de rug- en nek-/schouderspieren, metingen van het spieruithoudingsvermogen van de rug-, nek- en schouderspieren en lenigheid van de lage rug. De metingen van het spieruithoudingsvermogen werden aan het eind van de onderzoeksduur nogmaals gemeten. In de statische analyses hebben we spierkracht alleen cross-sectioneel geanalyseerd met behulp van kwadratische regressieanalyse en hebben we spieruithoudingsvermogen zowel cross-sectioneel als longitudinaal geanalyseerd. In de longitudinale analyses vergeleken we de gemiddelde testresultaten van de eerste met de tweede meetronde voor 5-jaars leeftijdsgroepen. We stratificeerden de resultaten naar mate van sportdeelname.

De resultaten van dit hoofdstuk laten voor oudere werknemers een lagere spierkrachtscore zien dan voor jongere werknemers, waarbij de optima tussen de 19 en 33 jaar lagen. Verder scoorden mannen in de spierkrachttesten beter dan vrouwen. Met betrekking tot spieruithoudingsvermogen van de lage rug scoorden jongeren beter dan ouderen. De optima voor mannen en vrouwen lagen op de leeftijd van 29 respectievelijk 42 jaar. Ouderen scoorden daarentegen beter in de testen van spieruithoudingsvermogen van de nek- en schouderspieren. Wanneer we spieruithoudingsvermogen longitudinaal analyseerden, waren de scores gedurende de onderzoeksduur van 3 jaar voor alle leeftijdsgroepen gedaald. Opgesplitst naar de mate van sportdeelname, suggereerden de studieresultaten dat jonge werknemers, die meer dan 3 uur in de week sportten, de beste belastbaarheidsscores hadden. Tegen onze verwachting in suggereerden de resultaten dat oudere werknemers, die 0 tot 3 uur per week sportten, beter scoorden dan oudere werknemers die vaker sportten.

Concluderend vonden we leeftijdspecifieke verschillen in spierkracht en spieruithoudingsvermogen. Spierkracht was het hoogst onder jonge, frequent sportende mannen en spieruithoudingsvermogen werd het best gescoord door oudere, af en toe sportende werknemers. Hierbij vonden we geen geslachtsverschillen. (Matig frequente) sportdeelname lijkt effectief om oudere werknemers fit te houden voor hun relatief stijgende werkbelasting.

De hoofdstukken 3 en 4 hebben betrekking op de relatie tussen fysieke belastbaarheid en de kans op toekomstige klachten aan het bewegingsapparaat. Deze relatie

werd zowel bestudeerd in de literatuur als in het SMASH-bestand. Hoofdstuk 3 heeft de vorm van een systematische review, waarin de resultaten van 26 prospectieve cohortstudies zijn samengevat. In de review wordt de mate van bewijs uitgewerkt voor lage spierkracht-, spieruithoudingsvermogen- en lenigheidscores als risicofactoren voor toekomstige klachten aan het bewegingsapparaat. We zochten samenvattingen van artikelen via elektronische databases en beoordeelden, op basis van diverse inclusiecriteria, of deze tot het onderwerp van de review behoorden. De kwaliteit van de geïnccludeerde studies werd door twee onafhankelijke reviewers bepaald. Vervolgens werden drie niveaus van bewijs gedefinieerd op basis van deze kwaliteitsscores in combinatie met de mate van consistentie tussen de verschillende studies. Van de geïnccludeerde studies hadden 24 betrekking op de lage rug en drie op de nek-/schouderregio.

We vonden sterk bewijs voor het ontbreken van een verband tussen spieruithoudingsvermogen en toekomstige lage rugklachten. Verder vonden we, op basis van inconsistentie tussen de verschillende studies, onvoldoende bewijs voor een mogelijke relatie tussen spierkracht danwel lenigheid en toekomstige lage rugklachten. Tenslotte moesten we ook concluderen dat er onvoldoende bewijs is voor een mogelijke relatie tussen fysieke belastbaarheid en toekomstige nek-/schouderklachten, als gevolg van het beperkte aantal studies dat betrekking had op deze relatie. Omdat de heterogeniteit tussen de verschillende studies groot was, is voorzichtigheid geboden bij de interpretatie van deze resultaten.

In hoofdstuk 4 is de relatie tussen spierkracht, spieruithoudingsvermogen en lenigheid en toekomstige rug-, nek- en schouderklachten onderzocht met behulp van SMASH-data. Zelfgerapporteerde klachten werden gemeten met behulp van een aangepaste versie van de "Nordic Questionnaire" aan de start van de studie en driemaal jaarlijks gedurende het onderzoek. Als een jaar waarin nooit of zelden pijn werd ervaren, werd gevolgd door een jaar waarin regelmatig of voortdurend pijn werd ervaren, werd dit beschouwd als een nieuw geval van rug-, nek- of schouderklachten. De statistische analyses werden uitgevoerd met behulp van de longitudinale regressiemethode "Poisson GEE". We berekenden zowel univariate als multivariate risicoratio's gecorrigeerd voor confounders, waarbij fysieke belastbaarheid werd gerelateerd aan de kans op een nieuwe episode met klachten. We onderscheidde lage en hoge fysieke belastbaarheid op basis van geslachtsspecifieke tertielen, waarmee we corrigeerden voor verschillen tussen mannen en vrouwen. Het hoogste tertiel diende als referentie.

Werknemers met een laag spieruithoudingsvermogen van de rugspieren hadden een verhoogd risico op lage rugklachten, maar voor spierkracht en lenigheid van de lage rug was dit niet het geval. Werknemers met een laag spieruithoudingsvermogen of een lage

spierkracht van de nekspieren hadden een verhoogd risico op nekklachten. We vonden geen relatie tussen fysieke belastbaarheid en de kans op het krijgen van schouderklachten.

Concluderend vonden we een laag spieruithoudingsvermogen als onafhankelijke voorspeller voor toekomstige lage rug- en nekklachten alsmede lage spierkracht als onafhankelijke voorspeller voor toekomstige nekklachten. Lage fysieke belastbaarheid was geen voorspeller voor toekomstige schouderklachten.

In hoofdstuk 5 hebben we onderzocht in hoeverre een disbalans tussen fysieke belastbaarheid en fysieke werkbelasting een risicofactor is voor toekomstige lage rug-, nek- of schouderklachten. We maakten hiervoor opnieuw gebruik van de SMASH-data. In SMASH is de belasting op het werk gemeten met behulp van video-observaties. We definieerden een disbalans als lagere dan mediane fysieke belastbaarheid in combinatie met een hogere dan mediane werkbelasting. "Lage balans" was een combinatie tussen lage belastbaarheid en lage werkbelasting en "hoge balans" was een combinatie tussen hoge belastbaarheid en hoge werkbelasting. De werknemers, bij wie belasting en belastbaarheid in balans waren, werden beschouwd als de referentiegroep. Voor de statistische analyses maakten we opnieuw gebruik van de longitudinale analysetechniek "Poisson GEE".

We vonden een disbalans tussen spieruithoudingsvermogen en werken in gebogen houding als risicofactor voor toekomstige rug- en nekklachten. Voor de rug werd een lage balans tussen deze twee factoren ook als risicofactor gevonden. Verder vonden we een lage balans tussen spierkracht en tillen op het werk als risicofactor voor toekomstige rug- en nekklachten, maar we vonden dit niet voor een disbalans tussen deze twee factoren. We vonden geen relatie tussen gecombineerde belasting-belastbaarheidvariabelen en toekomstige schouderklachten.

Concluderend kon op basis van deze studieresultaten de hypothese dat een disbalans tussen belasting en belastbaarheid een voorspeller zou zijn voor toekomstige klachten van het bewegingsapparaat slechts ten dele bekrachtigd worden. Een disbalans tussen belasting en belastbaarheid werd niet als een sterkere voorspeller gevonden dan elk van deze factoren apart.

In hoofdstuk 6 hebben we onderzocht in hoeverre piekdiscomfort of cumulatieve discomfort voorspellers zijn voor toekomstige klachten aan het bewegingsapparaat. We maakten hiervoor opnieuw gebruik van de SMASH-data. De meetmethode voor het meten van Lokaal Ervaren Ongemak (LEO) was gebaseerd op de Borgschaal, die loopt van 0 (geen enkel ongemak) tot 10 (maximaal ervaren ongemak). Op zes meetmomenten op een reguliere werkdag werd aan de werknemers gevraagd aan te geven in welke mate zij

ongemak ervoeren in 13 lichaamsregio's. Zij konden daarbij gebruik maken van een afbeelding van het menselijk lichaam. Als de werknemers tenminste eenmaal op een dag een score van 2 of hoger rapporteerden, werd dit als piekdiscomfort gedefinieerd. Deze grens was gebaseerd op de ISO-richtlijn Statistische Belasting. De som van alle zes LEO-scores werd als cumulatieve discomfort gedefinieerd. Werknemers die op alle zes meetmomenten een nul scoorden werden beschouwd als referentiegroep. Voor de statistische analyses selecteerden we een klachtenvrije populatie. De data werden wederom met "Poisson GEE" geanalyseerd. De resultaten lieten een stijgende lijn in LEO-scores gedurende de ochtend zien, vervolgens een daling na de lunchpauze en opnieuw een stijging gedurende de middag. De gemiddelde LEO-scores waren laag als gevolg van een hoog percentage werknemers dat op elk van de zes meetmomenten een nul scoorde. We vonden piekdiscomfort als voorspeller voor lage rug- en nekklachten en voor links- en rechtszijdige schouderklachten. We vonden cumulatieve discomfort als voorspeller voor nekklachten en voor links- en rechtszijdige schouderklachten.

Concluderend vonden we in een klachtenvrije populatie, zelfs met lage LEO-scores, zowel piek- als cumulatieve discomfort als voorspeller voor toekomstige klachten aan het bewegingsapparaat.

In hoofdstuk 7 hebben we gemeten wat het van spierkrachttraining effect is op spierkracht alsmede spierversmoeidheid en discomfort tijdens het uitvoeren van werktaken. Het betrof een gerandomiseerd gecontroleerd experiment met een populatie van 22 werknemers. De werknemers werden gepaard ten aanzien van leeftijd en geslacht en vervolgens gerandomiseerd over een trainings- en een controlegroep. De trainingsgroep nam deel aan een spierkrachttrainingsprogramma van 8 weken met een frequentie van 2 maal per week. De spierkrachttraining bestond uit spierversterkende fitnessoefeningen en was gericht op de schouder- en rugregio. Zowel aan de start van de studie als na de trainingsperiode werd spierkracht van de rug- en schouderspieren gemeten evenals spierversmoeidheid en discomfort tijdens het uitvoeren van een til- en assemblagetaak. Maximale isokinetische spierkracht werd gemeten met behulp van een dynamometer (Cybex). Tijdens deze spierkrachtmetingen werd gebruik gemaakt van electromyografie (EMG) om een indicatie te krijgen van de maximale contractie in de spieren (MVC). Ook tijdens de werktaken werden EMG-metingen verricht om een indicatie te krijgen van spierversmoeidheid. Discomfort werd gemeten met behulp van de LEO-methode. Voor de statistische analyses werd gebruik gemaakt van het "intention-to-treat" principe. Dit wil zeggen dat alle werknemers meegenomen werden in de analyses, ongeacht de mate van deelname aan het trainingsprogramma. Een uitzondering hierop vormden diegenen die voortijdig met de studie

gestopt waren. De verschillen tussen de trainings- en controlegroep in spierkracht, de tijdsduur van volhouden van de taken en spiervermoeidheid en discomfort tijdens de taken werden geanalyseerd met behulp van covariantie-analyse (ANCOVA).

We vonden geen effect van het trainingsprogramma op spierkracht van de rug- en schouderspieren. Ook vonden we geen effect op de EMG-data als indicator voor spiervermoeidheid noch op de LEO-score als indicator voor discomfort tijdens de taken. Wel konden de getrainde werknemers de tiltaak na de trainingsperiode langer volhouden dan de controlewerknemers.

Hoofdstuk 8 betreft de algemene discussie van het proefschrift. In dit hoofdstuk hebben we resultaten van het proefschrift samengevat en de antwoorden op de onderzoeksvragen gegeven. We vonden slechts ten dele indicaties voor elk van de onderdelen van het fysieke belasting-belastbaarheidmodel en de relaties waren niet zo sterk als we verwacht hadden.

Wanneer we de resultaten van SMASH toevoegden aan de resultaten van de review, kwamen we tot de conclusie dat het nog niet duidelijk is of er een verband is tussen fysieke belastbaarheid en toekomstige klachten aan het bewegingsapparaat. De hypothese dat een disbalans tussen belasting en belastbaarheid een sterkere risicofactor is dan elk van deze factoren apart (waarbij de relatie met belasting was onderzocht in vorige SMASH-studies), kon niet onderbouwd worden met de resultaten van dit proefschrift. Vervolgens hebben we theoretische en methodologische overwegingen de revue laten passeren, die een mogelijke rol gespeeld zouden kunnen hebben in de interpretatie van de onderzoeksresultaten.

We concludeerden dat het fysieke belasting-belastbaarheidmodel nog niet zo duidelijk is als algemeen wordt aangenomen.

Tenslotte hebben we enkele praktische implicaties gegeven en hebben we aanbevelingen gedaan voor toekomstig onderzoek. Op basis van de onderzoeksresultaten lijkt het niet geëigend om fysieke belastbaarheid van werknemers te testen, zou sportdeelname gepromoot moeten worden onder (oudere) werknemers en kunnen discomfortschalen gebruikt worden als voorspeller voor toekomstige klachten aan het bewegingsapparaat. We deden de aanbeveling om toekomstig onderzoek naar de verschillende onderdelen van het fysieke belasting-belastbaarheidmodel te richten op specifieke werkpopulaties, waarbij fundamenteel en epidemiologisch longitudinaal onderzoek idealiter geïntegreerd zouden moeten worden. Verder deden we de aanbeveling om interventiestudies op te zetten naar trainingprogramma's ter preventie van klachten aan het bewegingsapparaat voor verschillende groepen werknemers (zoals nieuwe werknemers, mannen of vrouwen en oudere werknemers).

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ABOUT THE AUTHOR

Heleen Hamberg-van Reenen was born in Dalfsen on July 14th 1976. She finished secondary school at the Meander College in Zwolle at 1994 and started studying Physical Therapy in Groningen. After working as a physiotherapist for one and a half year, she started her studies Biomedical Health Sciences in Nijmegen. She graduated in 2001 with a major on Epidemiology. After graduating, she worked for the Erasmus University in co-operation with the National Institute for Public Health and the Environment (RIVM) as a junior researcher on cost-effectiveness of stop-smoking-interventions. In 2003, she began as a PhD-fellow at Body@Work, VU University Medical Center, where she conducted the study as described in this thesis. During her PhD-project, she attended courses on longitudinal statistical analyzing techniques and systematic reviewing. Currently, Heleen is working as a medior researcher at the Centre for Public Health Forecasting at the RIVM on several policy related projects, i.e. the prevention of diabetes, cost-effectiveness, and the relationship between lifestyle and workers' health.