Assessment of postural load on the back in occupational epidemiology

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Assessment of postural load on the back in occupational epidemiology

Het schatten van fysieke belasting van de rug door houding in de arbeidsepidemiologie

Proefschrift

ter verkrijging van de graad van doctor
aan de Erasmus Universiteit
op gezag van de rector magnificus
Prof.Dr C.J. Rijnvos
en volgens besluit van het College van Dekanen.

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Alex Burdorf

geboren te Heerlen

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Promotores:	Prof. Dr P.J. van der Maas
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	Dr H.J. Stam

Dedicated to my mother

Manifold is the harvest of diseases reaped by certain workers from the crafts and trades that they pursue. All the profit they get is injury to their health, that stems mostly, I think, from two causes. The first and most potent is the harmful character of the materials that they handle, noxious vapors and very fine particles, inimical to human beings, inducing specific diseases. As a second cause I assign certain violent and irregular motions and unnatural postures of the body, by reason of which the natural structure of the living machine is so impaired that serious diseases gradually develop therefrom.

— Ramazzini, *De Morbis Artificum,* 1700

(translation W.C. Wright, *About Diseases of Workers.*
Hafner, New York 1964)

Preface

Low-back pain is a common symptom among workers, nearly everyone will be affected by low-back pain at some point in life. This opening line may sound deceptive since low-back pain is usually a self-limiting condition, where recovery without a physician's consultation can be demonstrated in the vast majority of all episodes. Yet, there is ample evidence that the symptom of back pain is recurrent, with one-year recurrence rates reported of more than 60%.

In many industrial populations low-back pain is an important cause of sick leave and permanent work disability. This observation has certainly increased awareness of the low-back pain problem in industry. The considerable economic costs of low-back pain in the past decade has proved to be a main motive behind studies on occurrence and recurrence of low-back pain, causative factors in working conditions and methods of prevention. To institute primary prevention measures at the workplace risk factors in working conditions have to be identified from which workers should be protected. However, the efficacy of preventive solutions for low-back pain have not been described very often. The complex problem of characterization of exposure to risk factors will partly account for this situation. Risk factors are often simultaneously present, have complex interrelationships and vary considerably by subject and time. It is believed that research on measurement of risk factors in postural load on the back will contribute to better understanding and control of the occupational low-back pain problem. This belief runs through the studies described in this thesis like a continuous thread.

This rationale is well-considered but - it must be admitted - retrospectively developed. Earlier research projects were focused on description of occurrence and nature of low-back pain in occupational groups. Based on vast experience in occupational hygiene, the attention in the research was soon drawn towards recognition and evaluation of causative factors in working conditions for the development of low-back pain among workers. A thorough review of epidemiologic literature revealed that techniques for measurement of exposure are still in their infancy. It must be concluded that the concept of exposure is hardly developed in epidemiologic studies on back disorders. As a consequence, dose-response and dose-effect relationships are barely available. Approaches of measurement strategies in occupational hygiene proved to be applicable to so-called ergonomic exposures. This thesis explores the possibilities and difficulties of the assessment of postural load on the back in several occupational situations.

It will become clear that the problem of measurement of postural load on the back is complex and often not easily manageable; the challenge to develop valid and practical techniques for assessing exposure to postural load is still open. Although ready-made solutions cannot be presented, this book will hopefully guide researchers in epidemiologic studies on occupational low-back pain towards better quantification and understanding of exposure to postural load. The reader may judge if this objective has been achieved. Since research is a life-time learning process comments and critical remarks will be warmly welcomed.

Lex Burdorf

Contents

Low-back pain

The prevalence of low-back pain usually is high in occupational groups. The large number of workers who regularly experience low-back pain and its consequences of sick leave and disability urge for reduction of the epidemic incidence if low-back pain. Primary prevention will have to focus on exposure at work. Among others, postural load on the back is considered an important occupational risk factor.

1 Introduction

Low-back pain in occupational groups

In the past decades the opinion has echoed several times that health and quality of life are greatly reduced for many workers because of acute and chronic low-back pain. In 1954 in his classic study Hult estimated the lifetime prevalence of occupational low-back pain in Sweden to be about 60%, based on a survey of more than 1000 male workers in different occupations. The dramatic impact of low-back pain on disability was clearly demonstrated since 4% of the workers had been absent at some time because of their low-back pain for more than six months and another 11% had been absent between three weeks and six months. Heavy industrial labour was shown to be an important risk factor of (severe) low-back pain and, subsequently, sick leave.[1]

Automation and mechanization of the workplace in the 1960s and early 1970s has markedly reduced the number of jobs involving heavy physical work.[2] Despite this development, Hult's results have been repeatedly confirmed by many studies in following years. In spite of varying conditions among (industrial) populations and large socioeconomic differences among countries, there is a surprising number of similarities in descriptive morbidity data on low-back pain in Western countries. Taking into account the age groups studied, surveys of general populations can be useful in estimating the magnitude of the low-back pain problem among workers in general. Often cited large cross-sectional surveys among male subjects in Sweden, Finland, the United States and England have shown lifetime incidence rates of low-back pain of 69%, 78%, 70% and 65%, respectively.[3-6] Surveys among female populations in Sweden and Finland, consisting predominantly of working women, have shown lifetime incidence rates of low-back pain of 67%, 66% and 75%.[3,7,4]

Numerous reports have focused particularly on the prevalence of low-back pain among specific occupational populations. Interpretation of these data on frequency of low-back pain is often hampered by methodologic problems in definition, classification and diagnosis of low-back pain. Moreover, comparibility among surveys is impeded by differences in work environments, occupational populations and study designs. Nevertheless, the presentation of some well-known studies illustrates the magnitude of the low-back pain problem encountered in occupational health. In a cross-sectional study among 2891 civil servants in various occupations a lifetime incidence of low-back pain of 60% was reported. No difference was observed between male and female workers. The recurrence rate of low-back pain in the 12-month follow-up was 62% for male workers and 68% for female workers.[8] This latter result is close to the reported recurrence rates of low-back pain of 56% and 58% respectively in the study of Biering-Sørensen.[3] A large survey among workers of an American aircraft company showed a lifetime incidence of 60% for male workers and 55% for female workers.[9] In a cross-sectional survey among 2222 male workers in Finnish companies lifetime incidence rates of low-back trouble (defined as sciatica, lumbago or nonspecific low-back pain) of 90% for machine operators and carpenters and 75% for sedentary workers were found, which are among the highest in the literature.[10]

Few surveys have presented the consequences of low-back pain for the work-force. A 12-month follow-up of the Swedish population revealed that 6% of the workers had been absent from work because of low-back pain. About 1% of the workers were off work more than one month due to low-back pain. No differences were observed between male and female workers who had a steady job at the time of the investigation.[11] Svensson and colleagues reported that in the three years preceding the cross-sectional investigation, 18% of the participating women had been sick-listed because of low-back pain, and 3.4% for three months or longer.[12] An episode of low-back pain has predictive value for recurrence of symptoms leading to further treatment or absence from work during the following years because of low-back pain.[13]

In The Netherlands there is also ample evidence to indicate that low-back pain is a prevalent symptom in many occupational groups. In the past few years several surveys on the occurrence of low-back pain in the 12 months preceding the investigations have been published. In these studies the same standardized questionnaire has been used. These studies have shown a low-back pain prevalence of 61% among crane operators and 27% among maintenance workers,[14] of 44% among fork-lift truck and freight-container tractor drivers,[15] of 59% among concrete workers,[16] and of 64% among riveters.[17]

The prognostic value of episodes of low-back pain for sickness absence or disability has not been studied in The Netherlands. The impact of the occurrence of low-back pain in occupational populations on health impairment of workers has to be derived from official health registers. Unfortunately, the official registry on sickness leave is not a reliable source of information since the diagnosis of sickness is too often limited to cases with sickness leave duration more than two weeks.[18] The information obtained from the official health register on disability clearly demonstrates the impact on society of low-back pain. In The Netherlands musculoskeletal disorders are the leading course of permanent disability among workers, accounting for about 25% of the incidence every year. Low-back pain roughly accounts for

60% of those disorders.[19] A considerable proportion of all low-back pain cases may be attributed to occupational sources.[18]

The large number of workers who regularly experience attacks of low-back pain and the associated consequences of sick leave, permanent disability and medical treatment strongly urge for reduction of the epidemic incidence of low-back pain.[20] To institute programmes aimed at preventing low-back pain before it occurs, risk factors in working conditions have to be identified from which workers should be protected. At present, primary prevention is handicapped by a lack of knowledge on the relations between low-back pain and risk factors at work.[21]

Objective of this thesis

Epidemiology can offer insights critical to the process of unravelling the multifactorial etiology of low-back pain. Epidemiologic studies are needed to determine associations between the presence of low-back pain and individual and external risk factors. Occupational epidemiology as a distinct subdiscipline within the general fields of epidemiology and occupational medicine will focus on the effects of workplace exposures on the frequency and distribution of low-back pain in occupational populations. The result of occupational epidemiologic studies can be used to specify exposure-response relationships and to provide adequate occupational exposure guidelines so as to reduce the risk of the development of low-back pain in occupational environments.

Ideally, the amount, specificity, and precision of exposure data in an occupational epidemiologic survey should be of comparable quality as the measurent of disease frequency in relation to quantitatively determined levels of exposure.[22] In practice, however, exposure measurement data in most epidemiologic studies on low-back pain are either not available or restricted to job title.[23,24] Using job titles as a proxy of measurement of work load is extremely problematic. Poor assessment of exposure to physical load may partly explain the considerable uncertainty as to the etiological role of physical load in the development of back disorders.[25] There is a clear need to develop valid methods and techniques for characterizing occupational exposures to risk factors for low-back pain.

Mechanical load on the lumbar spine is believed to be a primary cause of low-back pain.[26] Since in many work situations mechanical load is restricted to postural load on the back, most emphasis is placed on postural load on the back in occupational situations. The origin of postural load on the low-back is posture, simply defined as the position of the trunk. Although load moments due to external forces like push, pull and carry can substantially increase the mechanical load, this thesis is mainly focused on aspects of postural load on the back experienced more or less continuously over the workday. Other important risk factors for low-back pain, such as impact forces on the back due to occupational accidents, are also not taken into account.

The principal objectives of this thesis are:

1 To explore the possibilities and difficulties of assessment of exposure to postural load on the back in occupational epidemiology;

2 To review existing measurement techniques and evaluate their application in occupational epidemiology;

3 To present recommendations for future strategies to assess postural load on the back in occupational groups.

Therefore, types and sources of exposure data of postural load used in occupational epidemiology are discussed. A detailed analysis was conducted to study the effect of variability of exposure to postural load on bias in the classification of workers with respect to exposure status. Two studies were conducted to estimate the validity of measurement techniques often applied in occupational epidemiologic surveys. In order to investigate the necessity and usefulness of an extensive measurement programme of postural load on the back two cross-sectional studies were performed in two work environments. The main aim of the studies presented in this thesis is to improve the assessment of postural load on the back in occupational epidemiology.

Reading guidance

This thesis is divided into 5 parts. Part I (Chapters 1-2) presents the foundation for the methodological issues addressed in part II and III and provides an overview of basic knowledge necessary to understand the epidemiologic studies described in part IV. Chapters in this section outline the nature and extent of the problem of occupational low-back pain and its main risk factors.

Part II (Chapters 3-6) concentrates on methodological considerations and difficulties experienced when quantifying aspects of postural load on the back in occupational work situations. Chapter 3 summarizes general methods and techniques which can be applied to measure aspects of postural load. Chapter 4 reviews the state of the art of measurement of postural load in the occupational epidemiology of low-back pain. The last chapters of this section is devoted to the problem of variability in exposure to postural load on the back in occupational groups and its implication for the assessment of the risk estimates in epidemiologic surveys.

Part III (Chapters 7-8) deals with studies conducted to evaluate the validity of measurement methods often used. Since a 'golden standard' is not available aspects of validity are investigated by comparing the performance of different methods and techniques in the same work situation.

Part IV (Chapters 9-10) contains two examples of epidemiologic studies on low-back pain with emphasis on measurement of aspects of postural load on the back. These surveys were initially designed to assess the contribution of specific risk factors to the occurrence of low-back pain in occupational groups. The emphasis on measurement of exposure to these risk factors will also guide towards evaluation of the workplace with regard to strenuous work postures.

Part V (Chapter 11) presents the main conclusions of the previous chapters and discusses the strength and weakness of the surveys presented. Recommendations are given on measurement procedures of postural load on the back in working conditions and consequent strategies for its assessment in epidemiologic studies are discussed.

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2 Occupational risk factors of low-back pain

Introduction

The etiology of low-back pain and associated disorders largely remains unclear.[1-3] Several reasons account for the lack of knowledge of the underlying process of the development of low-back pain. Firstly, the etiological ambiguity is a reflection of the anatomical complexity of the spine - an intersection of many bones, joints, ligaments, muscles and nerves.[1] Many influences, ranging from mechanical pressure on ligaments to improper disc nutrition metabolism, can play an active role in the etiological process.[4,5] Secondly, low-back pain is a symptom, a reflection of a number of different disease states. A large number of diseases have been linked with low-back pain, such as sciatica, lumbago, spondylosis, spondylolysis, osteoarthrosis, and degenerative disc disease. It is very likely that there is no common etiological background for all cases of low-back pain.[1,4,5] Thirdly, a wide spectrum of work- and individual-related factors have been found to be associated with low-back pain. The many contributing factors may interact in the development of low-back pain, thereby creating much uncertainty in the understanding of the causative mechanisms in the multifactorial etiology.[5,6]

With these problems in mind, it is no surprise that occupational epidemiology on disorders of the back is quite a novel field of research. In 1970 with his article on design and disease in industry Van Wely was one of the first to draw attention to the apparent association between diseases of the musculoskeletal system and bad working conditions due to inappropriate workplace design and consequent work methods used.[7] It was not until the past decade that epidemiological techniques have been broadly applied to study basic measures of frequency and duration of exposure at work and their impact on related disorders of the back in occupational groups.[8] There is still little known about the extent to which work-related factors are etiologic and the extent to which they are symptom-precipitating or symptom-aggravating.[5] However, there is a growing evidence that postural load on the back (ie mechanical stress) is one of the key elements in the etiology of work-related low-back pain.[9,10] Describing the effects of postural load on the back two different types of injury mechanisms can be distinguished.[11] Firstly, low-back pain injuries can be caused by an impact of force on the back applied over a very short period. Such sudden force can occur when a worker slips and falls or is struck by moving equipment. Secondly, low-back pain can be caused by overexertion trauma. Continuous manual exertions, such as when bending forward frequently, may result in gradual deterioration of trunk tissues over weeks and years.[11]

In the present chapter the epidemiologic data on work-related risk factors of low-back pain accumulated over the past 10 years have been reviewed. The analysis is restricted to the second type of exposure; the mechanical load on the back experienced more or less continuously over the workday. The aim of this chapter is to describe the main work-related risk factors of low-back pain. Studies on back pain and associated disorders are also reviewed. The next chapter will summarize methods which could be applied to measure exposure to these risk factors. Chapter 4 will review the methods and techniques which have actually been used in occupational epidemiologic studies on low-back pain and associated disorders.

Selection of references

A search of available literature was made for epidemiologic studies on (low-) back pain in occupational populations, published between 1982 and 1991. This period slightly differs from the review on exposure assessment presented in chapter 4. The entire procedure to select relevant articles has been described previously.[12]

Retrieved articles were regarded appropriate if three criteria were met. The first criterion was that only original studies in occupational populations were taken into account. The second criterion was that the articles should contain some quantitative data on exposure to risk factors of low-back pain and should allow calculation of a risk measure. Methods and techniques used to assess exposure to these risk factors are described in chapter 4. The third criterion for inclusion comprised of methodological aspects covering the design of the study, the selection of occupational populations and reference groups, and the accuracy of exposure parameters.

Several reports of original studies were excluded for the following reasons:

1 Insufficient description of exposure conditions or lack of adequate data on the distribution of exposure measures within the exposure group and the reference group.

In three articles the work load was characterized by rating physical demand on a three or five-item scale, thereby discriminating between subjective categories like "heavy physical work" and "light physical work".[13-15] The information presented in these articles was too much condensed to interpret. One publication did not describe differences in exposure between exposed workers and reference group,[16] another publication only mentioned exposure data for the workers with low-back pain.[17]

2 Lack of an appropriate reference group in order to provide an estimation of the proportion of the reported prevalence of back disorders which could be attributed to the risk factor studied.

In two articles neither external nor internal reference groups have been used.[18,19]

3 Lack of information on the health outcome or presentation of results not suitable to calculate the association between risk factor and health outcome.

Three studies of the same research group were excluded since the described data and analyses performed made it impossible to derive a measure of risk.[20-22] For the same reason two comprehensive studies on working conditions during professional fishing[23] and musculo-skeletal disorders among fisherman[24] could not be analyzed in this review.

4 Presence of clear bias in the design of the study.

Two case-control studies among hospitalized subjects were regarded as not suitable because of selection bias known as Berkson's fallacy.[25,26] For the same reason two studies among subjects derived from a family-practice facility were not taken into account.[27,28]

In total, 18 articles were used to evaluate associations between work-related factors increasing the mechanical load on the back and the occurrence of back disorders among occupational populations.

Findings from epidemiologic studies

Table 2-1 summarizes the epidemiologic studies with significant associations between work-related factors and back disorders among occupational populations.[29-44] Design, health outcome, risk factor and other characteristics of these studies are presented. In one cross-sectional study among nurses none of the work-related factors were associated with low-back pain.[45] Another cross-sectional study among welders and office workers showed some relationship between frequent awkward postures and low-back pain, but the small sample size is likely to have attributed to the absence of any significant difference.[46]

The investigations covered a broad range of occupational groups. In 12 out of 16 studies a cross-sectional design had been used and, as a consequence, odds ratios have been derived as quantitative risk estimate. The health outcome used most frequently was the occurrence of back pain. Definitions of back pain were found to vary widely, ranging from the rather undefined description of "regularly experienced back pain"[31] to the detailed description of "low-back pain occurring at least once a week, for as long as

Table 2-1 Significant associations between work-related factors and back disorders in epidemiologic studies among occupational populations

Author	Study design[1]	Study-population[2]	Health outcome	Risk factor	Risk estimate[3]	Control for confounding
Arad 1986[29]	CS	831 nurses F	Low-back pain within the previous month (42%)	Lifting	OR = 2.4	Age
Bongers 1988[30]	R	743 crane operators M 662 floor workers M	Disability due to intervertebral disc disorders ICD 722.0-722.9 (27 vs 8)	Whole-body vibration	IDR = 2.0	Age
			Disability due to degeneration of intervertebral disc ICD 722.6 (14 vs 3)		IDR = 3.0	Age
Bongers 1990[31]	CS	133 helicopter pilots M 228 non-flying officers M	Pain or stiffness in the back regularly experienced (68% vs 17%)	Whole-body vibration	OR = 8.0	Age, height, weight, bending forward, twisted posture
			Pain of stiffness in the lower back regularly experienced (55% vs 11%)		OR = 9.0	Age, height, weight, bending forward, twisted posture
Boshuizen 1990[32]	R	577 agricultural workers M	Pain or stiffness in the back regularly experienced (29%)	Whole-body vibration	OR = 3.6	Age, height, twisted posture, lifting
Burdorf 1991[33]	CS	114 concrete workers M 52 maintenance workers M	Back pain within the previous 12 months (59% vs 31%)	Trunk flexion and rotation	OR = 2.8	Age, lifting, heavy physical work in previous jobs
Estryn-Behar 1990[34]	CS	1505 nurses F	Back pain within the previous 12 months (47%)	Postural load on back Lifting	OR = 2.8 OR = 2.6	Age, years of occupation Age, years of occupation
Gaudemaris 1986[35]	CS	299 nurses F	Back pain within the previous 12 months (62%, 61% vs 34%)	Awkward posture, lifting & standing	OR = 2.2	Age, height, weight
		314 industrial workers M 591 office workers F/M		Awkward posture, lifting & standing	OR = 1.5	Age, height, weight
Gilad 1986[36]	CS	250 workers F/M	Back pain in the past (59%)	Lifting	OR = 3.1	No

Author	Study design[1]	Study-population[2]	Health outcome	Risk factor	Risk estimate[3]	Control for confounding
Johanning 1991[37]	CS	492 subway train operators F/M 92 switch board operators F/M	Sciatica within the previous 12 months (22% vs 8%)	Whole-body vibration	OR = 3.9	Age, gender, job title, duration of employment
Mandel 1987[38]	CS	428 nurses F	Low-back pain within the previous 12 months (42%)	Lifting	OR = 1.4	Age, gender, height, weight, job title, shift, physical work load
Punnett 1991[39]	CC	219 automobile assembly workers M	Low-back pain within the previous 12 months (95 cases, 124 referents)	Trunk flexion	OR = 5.1	Age, gender, duration of employment, lifting
				Trunk flexion and rotation	OR = 5.9	Age, gender, duration of employment, lifting
Riihimäki 1985[40]	CS	217 concrete workers M 202 house painters M	Back pain within the previous 12 months (73% vs 59%)	Trunk flexion and rotation & accidents	OR = 1.8	No
			Sciatica within the previous 12 months (37% vs 27%)	Trunk flexion and rotation & accidents	OR = 1.6	No
Riihimäki 1989[41]	CS	852 machine operators M 696 carpenters M 674 office workers M	Sciatica within the previous 12 months (34%, 29% vs 19%)	Trunk flexion and rotation	OR = 1.5	Age, occupation, back accidents, annual car driving
Ryan 1989[42]	CS	513 supermarket workers F/M	Low-back pain within the previous 12 months (21%)	Standing (>80% of worktime)	OR = 2.5	No
Shugars 1984[43]	CS	487 dentists ?	Low-back pain (54%)	Sitting (>80% of worktime)	OR = 1.7	No
Videman 1989[44]	P	199 nurses F	Back pain within the previous 12 months (56%)	Work load	RR = 2.4	No effect in multivariate analysis

[1] CS=cross-sectional; R=retrospective follow-up; CC=case-control; P=prospective follow-up
[2] F=female; M=male
[3] OR=odds ratio; IDR=incidence density ratio

two months in the past year".[42] The risk factor of primary interest was postural load, typically characterized by trunk flexion and rotation.

The occurrence of back disorders among nurses have been extensively studied. Four surveys on occupational risk factors showed a similar approach; in a cross-sectional study-design questionnaires were used to gather information on (low-) back pain and strenuous working conditions.[29,34,35,38] Arad *et al.* demonstrated a clear trend in one-month prevalence rates of low-back pain which rose with increasing numbers of lifts per shift. The odds ratio for lifting was 2.4, when comparing nurses who regularly lifted loads greater than 20 kg more than six times a shift with nurses who lifted less.[29] Corresponding odds ratios were documented by Estryn-Behar[34] for lifting activities (OR=2.6) and postural load (OR=2.8) and by Gaudemaris[35] for jobs involving awkward postures and frequent lifting (OR=2.2). In Mandel's survey a lower odds ratio for lifting of 1.4 was found, maybe due to controlling for physical work load.[38] The study of Videman *et al.*[44] is noteworthy because of its approach to evaluate the effect of patient-handling skill on subsequent back pain among nurses. A risk ratio of 2.4 was observed for self-assessed work load, based on lifting and/or rotated and bent posture more than three hours a shift. In the multivariate analysis the work load also explained to some extent the occurrence of back pain, but was not statistically significant. Patient-handling skill was independent of the 12-month prevalence of back pain.[44]

Several surveys have focused on the association between back symptoms and postural load due to frequent bending and twisting. Odds ratios for back pain due to elevated postural load ranged from 1.8 to 2.8.[33,34,40] Odds ratios for low-back pain radiating to the leg, often referred to as sciatica, showed slightly lower values of 1.5 to 1.6.[40,41] An interesting approach has been described by Punnett and associates. In their case-referent study they observed a strong relationship between nonneutral trunk postures and the prevalence of low-back pain within the past 12 months, expressed by odds ratios of 5.1 to 5.9.[39] These associations were adjusted for lifting activities. In Riihimäki's well-known study on low-back pain and sciatica among 2222 male workers, the relationship between sciatic pain and working in twisted or bent trunk postures has been confirmed among office workers whose work rarely involved lifting of heavy loads.[5]

The importance of changes in work postures has been stressed by two investigators. Ryan and colleagues have indicated that low-back pain among supermarket workers is related to prolonged standing,[42] whereas Shugars has demonstrated that prolonged static sitting postures increased the prevalence of back pain among dentists.[43]

The reviewed studies on whole-body vibration demonstrated the highest risk estimates. In three cross-sectional studies, workers with daily exposure to whole-body vibration have been compared with reference groups without vibration exposure. Significant odds ratios for back complaints were found of 8.0 among helicopter pilots,[31] of 3.6 among tractor drivers,[32] and of 3.9 among subway train operators.[37] In a retrospective follow-up study in the steel industry permanent disability caused by intervertebral disc disorders, especially degeneration of intervertebral disc, was 3.4 to 4.7 times higher among crane operators than floor workers.[30] In none of these studies the results presented were adjusted for postural load on the back.

Discussion

Study design

A strong preference was observed for conducting cross-sectional surveys. This type of study is extremely sensitive to one of the key-problems in epidemiology: the question of an appropriate comparison between exposed and reference group. Comparisons are seldomly performed satisfactorily. To improve the comparibility of occupational groups one has to take into account selection processes that may influence health status, for example changes in job as a consequence of back pain. Since such information will be hardly available in cross-sectional studies, some authors have selected an internal reference group of subjects who are least exposed. This approach has particularly been favoured in studies among nurses.[29,34,35,38,44] Although such study design may be desirable when a strong selection process during employment is expected, considerable differences in health selection may still occur. Moreover, entry into a profession may be vulnerable to health status too. An important drawback of most studies is the lack of controlling for occupational exposures in previous jobs.

Measurement of health outcome

In the reviewed studies health outcome was determined by several methods, including disease registries,[30] occupational health examinations,[33] self-administered questionnaires,[34] and self-reports.[39] It is obvious that the interpretation of the results is hindered by the substantial differences in parameters of health outcome and diagnostic criteria applied. This is clearly demonstrated in the five studies among nurses, which showed prevalences of (low-) back pain from 42% to 62%.

Self-administered questionnaires have been applied most common.[29,31-38,41-43] The use of a standardized questionnaire for musculo-skeletal symptoms, including low-back pain, has recently been proposed.[47] The validity of the questions concerning the occurrence of low-back pain have been studied thoroughly.[48] The absence of physical examinations in most epidemiologic studies can be explained by reasons of feasibility.[49]

Measurement of exposure

The quality of exposure data in the reviewed studies is poor. Few studies have applied measurement techniques that permit accurate and precise characterization of aspects of postural load.[33,39,40,42] Questionnaires have been used frequently, but the validity of derived exposure variables has not been addressed.[29,31,32,34-38,43-44] The studies on whole-body vibration have conducted quantitative measurements of vibration exposure, but other risk factors have been described qualitatively.[30-32,37]

Exposure assessment was predominantly used to characterize the mean exposure of the occupational groups under investigation. Few studies have quantified the intensity of exposure in order to determine no-effect levels or dose-response relationships.[33,39,42] None of the studies presented information on temporal aspects of exposure and variability within job titles. A detailed analysis of the methods and techniques used to quantify exposure to risk factors in occupational epidemiology on back disorders will be presented in chapter 4.

Plausibility of association

It is inherent to cross-sectional studies that the observed associations between work-related factors and the occurrence of (low-) back pain cannot straightforward be interpreted as being causal. The evaluation of the epidemiologic studies on (low-) back pain among occupational groups have consistently shown relationships with frequent bending and twisting, lifting and whole-body vibration. These findings are consistent with the results emerged from surveys among workers in the general population. Several population-based surveys have demonstrated that frequent bending and twisting of the trunk,[26,27] lifting activities,[26,50,51] and exposure to whole-body vibration[52] are well-known occupational risk factors for low-back pain. These studies also indicated that heavy physical work and prolonged static work posture may be regarded as occupational risk factors.[50,51]

The term 'occupational risk factor' has to be interpreted with caution. The cross-sectional studies cannot prove whether the risk factors per sé are a sufficient cause for chronic low-back pain of whether these factors introduce the necessary co-condition to develop low-back pain. The problem gets even more complicated since risk factors may aggravate attacks of back pain on the one hand and relieve them on the other. Biering-Sørensen has described that sitting, standing, walking, and stooping were all deemed to bring about aggravation for some and relief for others depending on which patient was being questioned.[53]

Ideally, one should attempt to gather information on all known (work-related) risk factors and to adjust for them in the analysis. However, surprisingly few studies have applied multivariate statistical methods to do so. Most studies failed to control for confounding variables, especially other work-related factors. In the discussion as presented by the authors this was seldom even mentioned as an important problem. The vast majority of the studies was focused on one single risk factor. This may be the wrong approach for several reasons. Flor has made the interesting remark that "it is probably wrong to look for a single cause. Chronic low-back pain should more appropriately be viewed as multiple determined with specific factors achieving etiological significance only by their interaction".[54]

Conclusion

Numerous reports have been published on the occurrence of back pain in different occupational populations and working conditions. The quality and quantity of available exposure data constituted a weak part of many studies. Epidemiologic studies with sufficient information on exposure to work-related factors and without apparent methodologic shortcomings have been reviewed and evaluated. Although of sheer methodologic necessity conclusive evidence is limited, the epidemiologic studies on (low-) back pain among occupational groups have shown clear relationships with frequent bending and twisting, lifting and whole-body vibration. Taking into account also the surveys among workers in the general population, the mainstream of epidemiologic research on occupational risk factors for low-back pain seems to be adequately summarized by Andersson's six primary vocational risk factors: heavy physical work, static work posture, frequent bending and twisting, lifting and forceful movements, repetitive work, and vibrations.[55]

The isolated effects of these risk factors are difficult to evaluate since many of the risk factors are interrelated. The problems are often further confounded by the reliance on subjective estimates of exposure variables and health outcome with little or no opportunity for validation.[56] Moreover, many studies have only taken a limited number of risk factors into consideration. Few studies have demonstrated associations between work-related factors and (low-) back pain which have been adequately controlled for potential confounding by other work-related factors.

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Postural load on the back

Principally, one can choose several methods to assess exposure to postural load at work. Epidemiologic studies among working populations show a great variety of measures of exposure to risk factors for disorders of the back. Aspects of postural load are addressed in many surveys. Despite the fact that exposure at work can vary considerably, measurement strategies which account for the variability of exposure to postural load have hardly been used.

3 Methods for the assessment of postural load on the back

Introduction

Quantification of postural load on the back is difficult since no direct means exists that measures loads upon the lumbar spine in occupational work situations.[1] Indirect measurement methods have to be used to allow to estimate the postural load on the back. Several methods have been developed which are based on parameters that are believed to be related to the loads upon the spine. These methods range from a simple questionnaire about strenuous working conditions to intra-discal pressure measurement.

In figure 3-1 a general exposure-response model for low-back pain due to mechanical load of occupational origin is outlined. The underlying idea is that the design of the workplace and the subsequent worker's tasks introduce nonneutral postures (eg bending), movements of the trunk, and external loads due to hand tools or other external forces like push, pull and carry. This exposure is external to the worker and compounds the well-known risk factors for occupational low-back pain, such as static work posture, frequent bending and twisting, and lifting objects.[2] The risk factors for low-back pain can be quantified by different monitoring techniques, designed to reflect the exposure to these risk factors that a worker may encounter in the course of

Figure 3-1 Outline of a general exposure-response model for low-back pain due to mechanical load

	Workplace factors →	**Risk factors** (external exposure) →	**Mechanical load** (internal dose) →	**Low-back pain** (response)
Parameters	weights and measures (of design) of workplace and tasks	posture movement burden	force moment	
Effect modifiers		working methods personal behaviour	individual capacity personal behaviour working methods exposure pattern	individual susceptibility
Monitoring				
technique	check list observation direct measurement	questionnaire observation direct measurement	electromyography muscle strength intra-discal pressure blood tests	
principle	measurement at the source	personal sampling	biological monitoring	

a work shift. The measurement strategy is based necessarily on personal sampling.

The three basic elements of the external exposure are posture, movement and burden. These basic elements determine the mechanical load on the spine, which can be considered as a measure of dose. Biomechanical models can be used to estimate forces and moments acting on the lumbar spine resulting from body segment weights, movements of the trunk and extremities, and any external load being handled or applied.[3] Using these models the external exposure (ie exposure to risk factors) provides an assessment of the dose (i.e. mechanical load). When mechanical load is restricted to postural load on the back, the load primarily depends on the orientation of the trunk in the gravitational field.

Complementary methods based on *in vivo* measurements may provide measures of dose. Several studies have shown a clear association between the myoelectric activity of a muscle and the force developed by the muscle or by the load moment across a joint.[4] There have been attempts to use concentrations of serum creatine kinase and myoglobin in blood as a dose measure and suggestions have been made to use the perceived exertion by the worker as load measure.[5] Measurement of dose is equivalent to the concept of biological monitoring in occupational hygiene.

Whatever indicator of exposure will be chosen to assess postural load on the back, the exposure characterization has to take into account indices of exposure such as time-weighted averages, frequency, duration and sequence of peaks, and cumulative exposure measures.

The aims of this chapter are to review briefly existing methods for the assessment of postural load on the back and to study their applicability and usefulness for exposure evaluation in epidemiologic surveys on low-back pain. The principal distinction has been made between the measures of external exposure and the measures of dose.

Assessment of external exposure

Since any deviation from upright standing posture, such as forward bent or twisted position, produces a higher load on the lumbar spine, recording of the angular position of the trunk may offer a suitable approach to assess postural load on the back during normal work.[6] This approach has led to the development of several methods for measurement of trunk postures and movements, varying from simple questionnaires to observational methods and direct measurement techniques.

Often, in epidemiologic surveys the exposure is assessed by questionnaire.[7] Questions are constructed to obtain information about frequency and duration of non-neutral trunk postures. These questions predominantly focus on the risk factor frequent bending and twisting of the trunk. Questions are formulated to collect data on the frequency of bending and twisting per hour[8] or duration of work with bent and twisted trunk in hours per week.[9] Sometimes the evaluation of the exposure to frequent bending and twisting is restricted to an ordinal scale with subjective categories like "moderate" and "rather much"[10] or to an dichotomous variable.[11] Unfortunately, most studies have failed to report any validation of the questionnaires used.[5,7]

In the past decade several methods for systematic observations have been developed. Methods for measuring aspects of postural load on the back vary from simple observations by an observer to highly sophisticated systems for three-dimensional automated tracking of posture and movement of the trunk.[4] In table 3-1 the main characteristics of frequently used methods have been summarized.[12-19] One can differentiate between the methods based on rating procedures[12-16] and the methods derived from objective measurement techniques.[17-19] The OWAS method is one of the simpler observational methods for postural analysis.[14] The recording procedure is based upon repeated observations of the worker at specific time intervals throughout either a number of representative work cycles or a specified period. When the aim is to analyze durations of postures as well as frequencies, a continuous method has to be used. Most real-time observational methods record work activities on videotape which is later analyzed in the laboratory by a trained technician using special computer facilities. Advanced systems have been developed which record postures and movements three-dimensionally.[17-19] There are limitations in the scope of the methods described: direct observational methods[13-15] are ruled out in work situations which require that movements take place at a very high speed, and techniques with videocameras[17-19] are limited to work situations in clearly defined areas or to simulations of work routine in laboratory experiments.

An alternative approach to observational methods is the application of instruments that can be attached to the person to measure postures and motions. Estimates of postural load are performed by measuring the angular position of the trunk. Inclinometers and pendulum potentiometers have been used to register bending of the back.[20,21] Postural angle measurements can be extended by angular velocity measurements, thereby improving the assessment of the postural load on the back.[22] This type of instruments offers an objective, real-time method for measuring motion of the trunk. Exposure characteristics like frequency, duration, level and sequence of specific trunk postures and movements during normal work activities can be easily studied.

Table 3-1 Main characteristics of observational methods applicable for assessing postural load on the back

Author	Method	Target	Principle	Equipment	Restrictions
Rohmert 1985[12]	AET Ergonomic job analysis	Tasks, work equipment, environment, job demands (e.g. standing bent)	Real-time sampling; duration	Pencil and paper	Subjective, non-specific method
Corlett 1979[13]	Posture targetting	Posture of trunk, head, lower and upper arms, lower and upper legs	Instant interval sampling; duration	Pencil and paper Adaptable for video-analysis and entry in computer	Less repeatable in dynamic work situations
Karhu 1977[14]	OWAS	Posture of back, head, arms, legs	Instant interval sampling; duration	Pencil and paper Adaptable for computerized registration	Broad categories, lack of precision
Foreman 1988[15]	Posture and activity classification system	Posture of back, legs	Real-time sampling; duration, frequency	Computerized registration	Broad categories, lack of precision
Holzmann 1982[16]	ARBAN	Posture of head, shoulder, elbow, hand, back, thigh, knee, foot	Real-time sampling; duration, frequency	Video-analysis and entry in computer	Trend analysis rather than absolute measurement of work situation
Keyserling 1988[17]	Posture classification	Posture of back	Real-time sampling; duration, frequency	Video-analysis and entry in computer	Focused on repetitive work
Wangenheim 1987[18]	Auto-EWA	Posture and movements of body segments	Real-time sampling; duration, frequency	Video-analysis (3D) and entry in computer	Work situations in defined area
Pearcy 1987[19]	CODA	Posture and movements of body segments	Real-time sampling; duration, frequency, velocity, acceleration	Video-analysis (3D) and entry in computer	Simulations of work routine in laboratory
Pearcy 1987[19]	VICON	Posture and movements of body segments	Real-time sampling; duration, frequency, velocity, acceleration	Video-analysis (3D) and entry in computer	Simulations of work routine in laboratory

Assessment of dose

Several measurement methods to assess loads upon the spine have been developed, mostly focusing on mechanical load rather than postural load.

The recording of electromyographic activity of the trunk muscles may provide an important measure of dose. Often the myoelectric signals are normalized by using the maximum value of the myoelectric signal as the normalization constant; obtained values are expressed as percentage of the maximum voluntary contraction. The determination of the maximum voluntary contraction needs a careful calibration procedure for each muscle to be measured. Different studies have shown that the myoelectric activity of the trunk muscles is associated with trunk moment and posture.[23-25] High correlations were found between the measured myoelectric activities at eight locations over the back muscles and the predicted muscle contraction forces by a biomechanical model.[26] However, the applicability of EMG recordings is limited since clear difficulties arise in estimating muscle force. A localized recording of the electromyographic activity from a large trunk muscle, for instance the lumbar erector spinae, may not be representative of the total force developed by the same muscle, in that different sections of the muscle may be differentially activated.[4] Even more problematic is that trunk movements are performed by several synergistic flexor and extensor muscles which may share the total postural load differently, depending on subtle changes in posture and movement of the trunk.

Recently a number of devices have become available to measure directly trunk muscle strength under isometric or isodynamic conditions.[27] Measurements can be performed to evaluate movements and actions similar to those during normal working activities. An essential disadvantage is that measurements of trunk muscle strength of subjects requires skilled personnel and expensive heavy equipment, to which the subjects must be connected. Measurement during working activities at the workplace is not possible. The important question can be raised whether trunk muscle strength should be regarded as a measure of dose or as a reflection of health status. The vast majority of applications of trunk strength measurements is aimed at evaluating worker's capability or diagnosing disorders of the back at early stages.[27,28] An example of the latter approach has been included in appendix B of this thesis.

An original approach was chosen by Eklund and Corlett who used shrinkage as a measure of the effect of load on the spine.[29] This method is based on the principle that changes in body height can reflect disc compression. The rate and magnitude of disc compression are caused by the loading and its temporal pattern; disc compression measurement offers a direct method of assessing spinal load. Their experiments demonstrated that measurements of shrinkage when sitting in different chairs were in agreement with disc compression measurements, available from the literature.[29] The results of a survey among nurses showed significant correlations between loss of stature and both the total duration of stooped postures and the total duration of lifting during the eight-hour working shift.[30]

Intra-discal pressure measurement is considered a semi-direct method of evaluating spinal loads.[1] During manual material handling operations linear relationships have been demonstrated between the trunk moment and intra-discal pressure in static trunk positions.[1, 23]

Another indirect measurement of load upon the lumbar spine is that of intra-abdominal pressure. Andersson and colleagues found a linear relationship between intra-abdominal pressure and the trunk load and angle in their studies on back loads in lifting.[24] However, theoretical considerations indicate that during bending of the trunk the bending moment capability of the pressurized abdominal cavity can considerably reduce the bending moment on the lumbar spine.[25] This implies that the intra-abdominal pressure and the postural load on the back will show an opposite effect, depending on the lifting technique applied.

Entirely different variables for the assessment of postural load are specific enzymes, proteins, and metabolites in blood samples of workers.[5] Among assemblers and welders an increase of serum creatine kinase during a week was found, possibly indicating exposure to high muscular load.[32] However, it can be expected that such parameters will reflect physical work load in general rather than postural load on the back.

Approach in epidemiologic research

Methods for recording postures in occupational situations have been developed by several researchers in the field of ergonomics. Ergonomists are interested in detailed work analysis to study the characteristics of man-machine relationships in order to optimize the design of the job to match the worker. The ergonomic approach in assessment of postural load on the back will not necessarily be appropriate for epidemiologic research. The ergonomist seeks precision to measure detailed factors at the level of individual postures and movements in specific working conditions. The epidemiologist would like a simple, non-interfering method which easily records a wide range of risk factors present in a specific job.

Methods for the assessment of postural load in occupational epidemiology command for particular requirements. In their article on the design of an equipment for continuous measurement of postural angles during work, Aarås and Stranden presented some useful criteria:[20]

- the method has to be cheap, easy applicable, and suitable for continuous use;
- the equipment should record accurately the movements undertaken by the subjects during work;
- the measurements has to be repeatable under predescribed conditions, ie within the range of movements normally occurring in the actual work situation;
- the recording equipment should not interfere with the movements being recorded.

Apart from these necessary features, it is essential in epidemiologic surveys that data on working postures are readily codable for computer storage and analysis.[25]

Ideally, one would like to measure directly postural load. Since this is not possible, measurement of derived aspects of dose can be regarded as best practicable means. There are few methods to measure aspects of dose. Electromyographic investigation of trunk muscle activity requires skilled personnel and expensive equipment, to which the subjects must be connected. It is not a simple method to use and it is not advocated for large epidemiologic studies.[3] Sometimes vocational electromyography is performed by a selected group of workers in prescribed work situations simulated in laboratory experiments.[33] The deficiency of methods such as measurement of intra-abdominal pressure and intra-discal pressure is that they have been applied only in well-controlled experiments on evaluation of load upon the spine during lifting activities. An important disadvantage of intra-discal pressure measurement is that this is an invasive procedure and has the potential for injury to the subjects.[1] The specificity of other in vivo measurements, such as shrinkage and different blood parameters, is too low for a sound assessment of postural load.

At present, methods based on measurement of exposure to risk factors of postural load are best applicable in epidemiologic surveys. The real-time recording of trunk postures by direct measurement techniques offers a promising method for assessment of postural load. Also, this method is suitable to study the variability of exposure within the work shift. Since these instruments are expensive and time-consuming their application in epidemiologic surveys is still hampered. The validity of highly automated observational methods is good but these complicated systems have been proved to be not easily applicable at the workplace. To avoid measurement error in many work situations three-dimensional film techniques will be required instead of two-dimensional film images. This implicates the use of stereo cameras and viewing equipment which will increase the time and labour costs of job analysis even further.[34] Reported research in the literature in predominantly conducted under laboratory conditions. It can be seriously doubted whether simulations of work routines in a laboratory will reflect actual working procedures at the workplace. Moreover, their application is limited to highly static work activities. Simple observational methods like the OWAS method are increasingly being used. Although they lack precision they are easily learned and seem to be useful in static and dynamic working situations.

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4 Exposure assessment of risk factors for disorders of the back in occupational epidemiology*

Abstract

This review describes methods for assessing exposure to postural load of the back in occupational epidemiologic studies. Eighty-one original articles were selected that presented information on the prevalence of back disorders in occupational groups. In 47 (58%) of these studies no information on exposure to risk factors was given. In the remaining 34 (42%) studies exposure assessment was performed by questionnaire (33%), observation (9%), and direct measurement (5%). Measures of exposure were predominantly presented at the nominal and ordinal levels. It is argued that in most epidemiologic studies on disorders of the back in occupational groups the quality of exposure data is poor. Quantitative measurement methods need to be developed for application in occupational epidemiology.

Introduction

Disorders of the back have been recognised as one of the most important occupational health problems. In many occupational populations disorders of the back, especially low-back pain, are the main reason for sick leave and for permanent disability.[1] However, for the vast majority of workers with symptoms of the back, the underlying cause of these symptoms is unknown; the role of many contributing factors in the etiology of disorders of the back is generally unclear.[2] In working environments mechanical load on the spine is considered to be of causative importance to disorders of the back.[3-5]

In the process of unraveling the multifactorial etiology of disorders of the back, epidemiologic studies are needed to investigate possible associations between exposure to specific working conditions and the development of disorders of the back. Considerable effort has been given to establish standardized classifications and diagnoses of disorders of the back, for example low-back pain[6,7] and low-back injuries.[8] Less attention has been paid to the characterizing biologically relevant measures of exposure in

* Burdorf A. *Scand J Work Environ Health* 1992;18:1-9

epidemiologic studies on disorders of the back. In many of these studies the measurement of exposure has been restricted to job titles or job categorization.[9,10] It can be expected that a proxy such as job title has a limited correlation with the actual exposure.[11] Thus, the assignment of subjects to exposure categories in a study based upon job titles is easily subject to exposure misclassification. As a consequence, real associations between exposure to risk factors and specific disorders of the back can remain undetected and the strength of the relationships can be underestimated.[12]

Inappropriate modes of measurement may partly explain the lack of knowledge of risk factors for occupational disorders of the back. Therefore, a review study was performed to gain insight into the measurement methods used in occupational epidemiology to identify workplace factors which can increase the mechanical load on the spine. In accordance with Andersson[13] six primary vocational risk factors can be distinguished. They are heavy physical work, static work posture, frequent bending and twisting, lifting and forceful movements, repetitive work, and vibrations. Although physiological and psychosocial factors as well as safety aspects[14-16] can be of causative importance to the development of disorders of the back, this review is restricted to occupational risk factors of chronic strain over long periods of time.

The purpose of the present article is twofold, (i) to evaluate methods employed to assess exposure to specific risk factors for disorders of the back in occupational epidemiology and (ii) to evaluate measures and procedures to quantify exposure assessments of these risk factors.

Selection of references

An extensive search of the available literature was made for studies published in 1981-1990. Data bases such as Medline were used to select relevant articles. Ten scientific journals which regularly pay attention to the epidemiology of musculoskeletal disorders were manually searched. The primary key words used were back, backache, work, and risk factor. The secondary key words were back pain, back disorders, musculoskeletal system, musculoskeletal complaints, postural load, and occupation. The initial selection consisted of 104 articles in which any attempt had been made to describe the prevalence or incidence of disorders of the back in specific occupational groups or to relate the occurrence of back disorders to specific work conditions. Reports on occupational risk factors associated with accidents causing back injuries were not taken into account. Studies focusing on individual risk factors (eg, psychological, social, and anthropometric factors) were not examined. Neither were articles describing risk factors of back

Table 4-1 Selection of epidemiologic studies which present measures of exposure to risk factors for disorders of the back in occupational situations

	Included studies		Excluded studies	
	N	%	N	%
Initial examination	104	100		
Selection criterion 1				
review			15	14
secondary analysis			8	8
Original works	81	78		
Selection criterion 2				
occupation or job title			38	37
measures of exposure at dichotomous level			9	9
Original works with useful measures of exposure	34	33		

disorders in populations without clear reference to occupations or work conditions.

Each of the 104 articles selected was thoroughly checked according to a scheme of criteria for exclusion in order to select studies pertinent to the subject of this overview (see table 4-1). The first reason for exclusion was that only original studies were to be taken into account. Fifteen references were excluded because they only reviewed studies on back disorders without paying attention to the quantification of exposure to risk factors.[2,13,17-29] Another eight papers were not selected since they simply reported in a slightly different way on a previously published study.[30-37]

The second criterion applied was that the articles should contain more or less quantitative data on exposure to one or more risk factors. Among the 81 remaining references, only 34 studies were eligible for this review since they provided some numerical information on exposure variables, measured at least at the ordinal level. Thirty-eight publications were excluded because they only mentioned occupations or job titles and did not contain any meaningful exposure data.[38-75] An additional nine studies were not retrieved since measures of exposure were restricted to information on presence or absence of certain risk factors.[5,76-83]

The remaining 34 articles were used to evaluate the methods of measurement of exposure to specific workplace factors.[84-120] Two articles of the same research group were treated as one publication since the first article[120] presented the exposure data in the populations under study whereas the second article[106] described the prevalence of disorders of the back in both occupational populations. The same procedure was applied to studies of postural load and back pain among nurses[95-96] and postural load and back pain among fishermen.[115-116]

Methods of measurement

Thirty-four original works with useful measures of exposure were selected. The methods of measurement used in these studies can be divided in the following three broad groups: (i) questionnaires (N=27), (ii) observational methods (N=7), and (iii) direct measurement techniques (N=6). The application of questionnaires can be split into 19 studies in which the questionnaire was self-administered and eight studies in which workers were interviewed by means of a structured questionnaire.

Table 4-2 shows the great variety of measures used in the questionnaire surveys to quantify exposure at the workplace to specific risk factors for disorders of the back. Forty-six measures of exposure were found, mainly focused on lifting and forceful movements (17 measures in 17 studies) and static work posture (9 measures in 13 studies). The responses in the questionnaires can be classified according to three basic types: (i) nine yes/no-responses used to ascertain the presence or absence of specific characteristics such as static work postures and lifting activities, (ii) twenty-two responses assessing specific characteristics of exposure on a scale ranging from 3-points to 5-points, such as physical work load and frequency of lifting activities, and (iii) fifteen responses concerning measurable attributes on at least an interval scale, such as the number of hours sitting per shift and the average weight per lift.

The majority of the variables were measured at either the nominal (dichotomous) or ordinal level. Only 15 variables (33%) present not only an ordering of separate categories but also a meaningful measure of the distance between different categories.

Heavy physical work was measured by questionnaire in 10 studies. In three papers subjects were asked to evaluate their work load by rating physical demands on a three- or five item-scale and thereby discriminate between subjective categories like "heavy physical work" and "light physical work".[93,97,112] In three more publications job titles or trades groups were used to classify subjects according to physical work.[85,103,114] In two studies of the same research group the assessment of physical work load was based on the distribution of hours per day spent lifting, bending or rotating, standing, walking, and sitting.[118-119] In a survey among school lunch workers an interesting proxy of work load was that of the total number of lunches prepared during a normal shift.[105]

The importance of static work postures has been recognized by 13 investigators. The nine measures used mainly concentrate on duration of sitting per shift and prolonged strenuous postures. None of the studies presented a definition of strenuousness of specific postures in the questionnaire.

Table 4-2 Variables used in 27 questionnaire surveys to measure exposure to risk factors for disorders of the back in occupational groups

Occupational risk factor	Dichotomous variable (yes/no)	Ordinal variable (3 grades or more)	Interval variable
Heavy physical work	Perspiration[109*]	Worker's assessment; 3 grades[93], 4 grades[112], 5 grades[97] Author's assignment; by job title in 3 grades[85,103,114], by other risk factors in 3 grades[118-119]	Number of lunches prepared per shift[105]
Static work posture	Feet flat on floor[90] Maintaining uncomfortable posture[91]	Maintaining fixed posture; 3 grades[113,117] Hours of sitting per shift; 3 grades[113,117], 4 grades[112] Awkward postures; 4 grades[89]	Hours of sitting per shift[84,87,88,92,110] Hours of standing per shift[84,87,88,96,117] Hours per shift with constrained posture[92,98]
Frequent bending and twisting	Bending more than 10 times per hour[91]	Twisted or bent posture; 3 grades[113,117], 4 grades[107], 5 grades[104]	Hours of bent posture per shift[84,90,100] Number of bends per hour[90] Hours of twisted or bent posture per shift[87,88,118,119]
Lifting and forceful movements	Lifting weights of more than 15 kg[91] Lifting patients more than 5 times per shift[91] Pushing beds more than 10 minutes per shift[91]	Frequency of lifting; 3 grades[93,112,113,117], 5 grades[109] Average weight per lift; 3 grades[100], 4 grades[93] Average weight of load carried; 3 grades[96,100] Frequency of patient lifting; 4 grades[118,119], 5 grades[111] Frequency of forceful movements; 3 grades[117]	Number of lifts per shift[84,90,96,100] Average weight per lift[90] Hours of lifting per shift[87,88,92,118,119] Number of patients lifting per shift[96,102] Number of pulls per shift[90,96] Number of loads carried per shift[96,100]
Repetitive movements	Monotonous and/or repetitive movement[109]	High repetition; 4 grades[89]	Number of repetitive actions per minute[98]
Whole-body vibration	Vibration[92,109]	Annual amount of driving in km; 3 grades[107]	Hours of driving per week[90,105]

* Numerals in superscript represent reference numbers

Frequent bending and twisting of the trunk was evaluated in 12 studies in which seven different measures were used. These measures included both the duration and the frequency of this risk factor. A clear description of a bent and twisted posture of the trunk was not provided in any of the 12 publications.

Lifting and associated activities were evaluated as a possible risk factor for disorders of the back in 17 surveys. The characterization of exposure differed very much. In some questionnaires measurement was restricted to nonspecified categories like "sometimes" and "occasionally",[109] whereas in other investigations the category 'sometimes' was exactly defined as lifting a load of more than 5 kg regularly but less than 10 times per hour.[112-113] The variables for interval scales concentrated on the frequency of lifting loads (four measures), the duration of lifting activities (one measure) and the average weight of the load (one measure).

The relation of repetitive work and whole-body vibration to disorders of the back did not receive much attention. These risk factors were only taken into account in seven investigations.

Although the parameters of exposure described were collected at the individual level in all of the questionnaire surveys, most studies used this information to assign the respondents to a limited number of exposure groups. Few studies applied multivariate statistical techniques to investigate relationships between exposure data at the individual level and their effects on the back.[90,95,111,119] The questionnaire approach was predominantly used in cross-sectional studies to assess exposure during current work conditions. This actual exposure was regarded a suitable proxy for retrospective exposure assessment. In one study the workers' ratings of physical work load in the baseline examination were used to investigate the influence of work load on the incidence of sciatica during an 11-year follow-up.[97] In none of the 27 studies with questionnaires were repeated measurements conducted.

Observational methods and direct measurement techniques were applied in 11 studies. In three studies observations were made at regular intervals by observers.[96,108,120] In four studies the acquisition and analysis of data on trunk posture was simplified with the use of video systems.[89,98,101,116] The methods of measurement and associated measures of exposure are presented in table 4-3. Twenty-six different measures of exposure were used, of which 14 variables (54%) were related to bending and twisting of the trunk. The observed motions of the trunk were bending forward (flexion), bending sideways (lateral flexion), and twisting (rotation). The correspondence with respect to the classification of nonneutral trunk postures was low, although a difference of more than 20 degrees from a straight, neutral position was regarded as significant by several authors.[101,108,116]

The presence of lifting activities and forceful movements was quantified differently in five studies. In one study, a method of the United States National Institute for Occupational Safety and Health was used to evaluate manual lifting tasks.[98] Exposure to whole-body vibration was directly measured in three studies of the same research group,[86-88] according to the requirements of the International Standard ISO 2631.[121]

Table 4-3 Variables used in seven observational techniques and four direct measurement methods to measure exposure to risk factors for disorders of the back in occupational groups

Occupational risk	Method	Variable at interval-scale
Heavy physical work	-	-
Static work posture	Observation	Number of static postures (at least 30 seconds during patient handling) per shift[96] * Percentage of work time without movement[120] Number of postural changes per minute[101]
	Electromyography	Static load (N) of right lumbar erector[94]
Frequent bending and twisting	Observation	Percentage of static actions with trunk in asymmetric position[96,98] Percentage of work time with bent trunk; forward ($20^\circ < \alpha < 45^\circ$) [101] forward ($\alpha > 45^\circ$) [101] forward ($15^\circ < \alpha < 90^\circ$) [120] forward ($\alpha > 90^\circ$) [120] forward ($\alpha > 20^\circ$) [116] forward ($\alpha > 45^\circ$) [108] sideways ($\alpha > 20^\circ$) [101] sideways ($\alpha > 30^\circ$) [116] Percentage of work time with trunk; rotated[120] rotated ($\alpha > 20^\circ$) [101,108] rotated ($\alpha > 30^\circ$) [116]
	Direct measurement	Flexion of the back; mean angle[89] angular velocity[89]
Lifting and forceful movements	Observation	Number of patient handling per shift[96] Number of activities per shift involved lifting, pushing or otherwise manupulating objects > 60 lb (27 kg)[96] Number of lifts per shift (weight of the load 5-20 kg, over 20 kg)[120] Number of handled weight/force or pulls (< 10 kg, 10-20 kg, over 20 kg)[116] Percentage of work time; lifting[108] pulling and pushing[108]
	Direct measurement by NIOSH-method	Weight, frequency of lifts, vertical location and vertical travel distance[98]
Repetitive movements	-	-
Whole-body vibration	Direct measurement	Frequency-weighted root-mean-square acceleration (m/s^2) [86-88]

* Numerals in superscript represent reference numbers

The observational methods and direct measurement techniques were applied in 10 cross-sectional studies[87-89,94,96,98,101,108,116,120] and one retrospective follow-up study.[86] In the latter, measurements of exposure to whole-body vibration were available from several periods which allowed the researchers to describe historical developments in exposure.[86] The 10 cross-sectional studies focused on current exposure to risk factors. The common approach was based upon characterizing measures of exposure within distinguished occupational title groups. In two studies observations of frequent bending and twisting of the trunk were conducted for each subject.[89,101] In one study among helicopter pilots measurement of vibration levels of the current helicopters provided accurate estimates since the design of these helicopters had changed little over the last decade. The total cumulative vibration dose of each pilot could be calculated since their hours of flight were registered in a personal flight log.[87] In contrast, the other studies had to rely on length of employment as an estimate of duration of exposure.

Discussion

In the past 10 years numerous reports have been published on the frequency of the occurrence of disorders of the back in different occupational populations under different work conditions. In this literature review 104 publications were examined, of which 81 (78%) were considered to be original work. It was surprising to find that 38 studies (37%) only focused on incidence, prevalence, and/or severity of back disorders in occupational groups without presenting any information on exposure to risk factors in these occupations. In nine more studies a crude classification into presence or absence of a specific risk factor had been used to investigate the influence of this risk factor on the occurrence of disorders of the back. Only in 34 out of 81 (42%) original studies had an attempt been made to characterize exposure to risk factors at the workplace in a (semi) quantitative way.

The (self-administered) questionnaire technique was used the most frequently to collect information on exposure to risk factors in the workplace. Questions about working conditions were phrased in such a way that answers were predominantly scaled at a nominal or ordinal level. Moreover, most questions consisted of qualitative descriptions, lacking a clear definition of categories of exposure. Such characterization of exposure will substantially limit accuracy and preciseness of measures of exposure.[122]

Since the questionnaire surveys derived measures of exposure from subjective responses, the validity of such measures must be considered before they can be regarded as unbiased estimators of true exposure to risk factors. However, the number of publications which addressed the issue of precision and validity was limited.[87,97,100] Heliövaara[97] argued that the validity of the classification of self-assessed physical work load used in her study was questionable because no fixed criteria for strenuousness were given in the questionnaire. Another author mentioned that, despite the inevitable lack of precision of reported lifting and carrying activities, differences in exposure to this risk factor among workers could be ascertained.[100] Two publications mentioned the application a validated questionnaire[109,118] but further details were not given.

The restricted attention to random and systematic error in measurement of exposure to postural load in the questionnaire surveys is remarkable because several studies have cast doubt on the determination of exposure to risk factors through questionnaire assessment.[9,123-125] Comparisons of questionnaire assessments and observational data has shown that reports on the time spent in specific activities like walking, standing, and kneeling were not very reliable.[123,124] Two studies have reported that the agreement between self-administered questionnaires by employees and direct observation by investigators was poor for bending and twisting of the trunk.[124,125] Hagberg and co-authors found that questionnaire information and observational data on lifting activities were consistent for only 10% of the workers studied in regard to both the weight and frequency of the material handled.[9] In a study on steel workers complementary results have been reported.[124]

Observational techniques were applied in seven studies. The basis of such techniques is to show how a specific body segment derives from a given standard position and to calculate total postural load over worktime. Three research projects used a 'pencil-and-paper' technique that required observers to register working postures and movements during a specified period at the workplace.[96,108,120] Each publication made reference to training procedures of observers to ascertain repeatable results and to minimize inter-observer variability. Four studies applied a video-computerized technique for recording postures and movements.[89,98,101,116] The continuous video recording of selected tasks enabled them to perform a real-time analysis. The reliability of exposure data can be improved in this manner since the videotape can be reviewed several times by different observers in laboratory. These computerized systems essentially provided the same measures of exposure for postural activity as observational techniques based upon observers at the workplace.

Application of observational methods will certainly increase the quality of exposure assessment. Several methods for systematically evaluating postures and movements during work have been described.[126-131] Observational techniques are extensively being used in ergonomic studies to identify particularly strenuous tasks and awkward postures and to evaluate workplace improvements. It is apparent from this literature review that such observational techniques have hardly been employed in occupational epidemiology. The same conclusion can be drawn with regard to direct measurement methods, although some promising techniques for continuous measurement of trunk movement during work have been developed.[132,133]

In epidemiologic studies on disorders of the back valid quantification of exposure to risk factors will be difficult for various reasons. Exposure characterization has to take into account relevant strenuous postures and movements, their frequency and duration within and between shifts, and intra- and interindividual variability during work activities. Therefore, the application of observational methods or direct measurement techniques implicates assessment of exposure of many workers for several days. This is certainly a time-consuming, labour-intensive and expensive activity,[101] and therefore the applicability of these methods in (large) epidemiologic studies is limited. Thus, feasibility considerations may well explain the common preference to (self-administered) questionnaires as a tool to assess exposure to risk factors for back disorders at the workplace.

Whenever objective measurement of exposure is not possible in an epidemiologic study, the validity of the questionnaire developed should be studied prior to this epidemiologic study, for example, by comparing the questionnaire with objective, direct measurement techniques. Special attention should be given to between-group and within-group variances to investigate whether it is possible to distinguish homogeneous exposure groups in the population under study. If the within-group variance is large compared to the between-group variance, the ranking of exposure groups is severely hampered. Retrospective epidemiologic studies advocate the use of questionnaires. Again there is a clear need for validation of the questionnaire applied. Attention should not only be given to exposure variability at the group level, but also to between-worker and within-worker variance. Repeated measurements in time may be useful to distinguish between a worker's personal distribution of day-to-day exposures and a change in exposure over time. If the within-worker variance is large compared to the between-worker variance, the application of questionnaires for estimating past exposures is limited. This exposure assessment strategy may also be an important feature of a prospective measurement strategy.

Concluding remarks

Epidemiologic research is needed to evaluate the possible associations between workplace exposures and adverse human health outcomes, such as disorders of the back. This extensive literature review revealed that an important drawback of many epidemiologic studies on disorders of the back is the poor quality of available exposure data. In 58% of the original studies examined (N=47), no information on exposure to specific risk factors was given. In the remaining 42% surveys (N=34) exposure data were collected with a questionnaire in 27 studies. The validity of questionnaires applied was evaluated in only a few studies. Measures of exposure were predominantly presented at a nominal and ordinal scale. This procedure limits the precision of measures of exposure and, consequently, increases the misclassification of exposure. Preferable measurement of exposure, based upon quantitative measures of exposure in observational methods or direct measurement techniques, has only been applied in 11 original studies (14%).

The characterization of exposure to workplace factors is frequently made difficult by the simultaneous action of several factors whose interrelationships and relative importance are not well understood.[134] Although a major problem is the fact that still little is known about which exposure variables are risk factors for occupational disorders of the back, there is a clear need for the development of better objective measures of exposure to occupational risk factors.[9,10,134] Valid quantitative measures of exposure are necessary in prospective epidemiologic studies to identify the role of various risk factors in the development of disorders of the back and, consequently, to establish dose-response and time-response relationships. Valid questionnaires for exposure assessment are needed in retrospective epidemiologic studies.

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5 Sources of variance in exposure to postural load on the back in occupational groups*

Abstract

Among five occupational groups, the variability of exposure to postural load on the back has been studied. A random sample of workers in each occupational group was observed for two periods of 30 minutes (min) during a shift, while classifying their posture every 20 seconds (s). The estimated percentage of time spent in trunk flexion and trunk rotation were the principal measures of exposure. The partitioning of the total variability of exposure showed that the occupational group status was the principal source of variance. The between-group variance accounted for 47% and 72% of the total variability of exposure to trunk flexion and rotation. The corresponding percentages for the within-worker variance of trunk flexion and rotation were 29% and 16%, and for the between-worker variance 24% and 12%, respectively. This type of analysis of the sources of exposure variability may guide towards appropriate measurement strategies for exposure to postural load on the back in epidemiologic studies on low-back pain.

Introduction

Postural load has been recognized as an important occupational risk factor for low-back pain.[1-3] Biomechanical modelling has demonstrated that any deviation from anatomically neutral trunk postures incraeses the load on the lumbar spine.[4] Some epidemiologic studies have shown that nonneutral postures of the trunk, for example bending and twisting, are significantly related to the risk of low-back pain.[5-7] However, the epidemiologic evidence is limited since other studies have failed to find any association between frequently bending or rotation of the trunk during work and low-back pain.[8,9] Associations between specific aspects of postural load and the development of disorders of the back may remain undetected because of misclassification of exposure.[10]

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It has been argued that in many epidemiologic studies on disorders of the back in occupational groups the quality of exposure data is poor.[11] Often the measurement of exposure has been restricted to surrogates as occupational title or job categorization. In a limited number of studies quantitative measurement methods have been applied to assess exposure to nonneutral trunk postures during work.[11]

Basically, two approaches of exposure assessment can be considered.[12] In the first approach each worker of the population under study is monitored. Since measurement of nonneutral trunk postures is time-consuming and labour intensive this measurement strategy has been applied in a few studies only.[5,6,13] In the second approach, more common in epidemiologic surveys, a random sample of workers in each occupational group under study is monitored. Subsequently, the average values of the parameters measured are being used to characterize the postural load of the workers within each occupational group. An underlying assumption of this measurement strategy is that the mean exposure of the workers sampled is supposed to be equal to the average of the whole occupational group.

In epidemiologic studies based on a comparison of occupations with clearly distinguishable levels of exposure this second approach warrants that differences in exposure among occupations are substantially larger than differences among workers within the occupation; that is that the exposure variability within occupational groups is small compared to differences between occupational groups. This usually implies exposure groups with workers more or less uniformly exposed, often referred to as homogeneous exposure groups. Because not only workers of groups are sampled but also specific parts of worker's exposure experience, the magnitude of exposure variability at individual level is important. Since it is largely unknown whether an individual's distribution of nonneutral trunk postures within a shift and between different shifts varies considerably, repeated mesurements of the same individuals have to be performed. To obtain an unbiased estimator of the true exposure, the measurement strategy has to take into account all relevant sources of variability of exposure. Therefore, evaluation of the components of exposure variability is necessary, partitioning the variability into the between-group variance, the between-worker variance and the within-worker variance.[14] Ultimately, assessment of these components of exposure variability may enable the investigator to evaluate the attenuation of associations between exposure and health outcome.

The goal of the current study was (i) to identify the components of exposure variability of nonneutral trunk postures in different occupational groups and (ii) to investigate consequences of exposure variability for the assessment of exposure to postural load on the back in occupational epidemiology. Since bending and rotation of the trunk are frequently observed postures in many work situations, the choice was made to assess postural load due to postures of the trunk in flexion or rotation.

Subjects and methods

Subjects

Five occupational title groups were selected in three different companies. The first occupational title group was obtained by taking a random sample of 21 out of 95 straddle-carrier drivers at a terminal in the Port of Rotterdam. Their tasks involved the transport of freight containers from the quay to the stack. On average 30 to 40 containers are handled every hour. This work is performed in a sedentary posture. The second occupational title group was selected in the same company and consisted of 20 crane operators who were randomly selected from 94 subjects in the same job. The task of the operators of overhead travelling cranes was to load and unload freight containers from a ship to the quay. In normal conditions 40 to 60 containers are handled every hour. This work is also performed in a sedentary posture. The third occupational title group comprised 10 out of 86 office workers in this transport company. Their activities involved normal clerical tasks, mainly performed in sedentary posture at a desk.

The fourth occupational title group was obtained by sampling 14 out of 24 sawyers and woodworking machinists in a woodworking company. These workers operated various woodcutting machines. Their task was either to feed wooden shelfs into a machine or to remove wooden shelfs from a machine. These tasks are machine-paced and of repetitive nature with work cycles often less than one minute. Their work was predominantly performed in standing posture, mainly in close vicinity of the woodcutting machine. The fifth occupational title group consisted of 12 out of 50 packers in a large auction of flowers. Their activities encompassed a number of different tasks, such as the assembly of prefabricated boxes and the collection and delivery of boxes to the various departments of the auction. A work cycle can vary from 20 s to 10 min, according to the task performed. Their work is mainly performed in standing posture, not necessarily restricted to one place.

Method for assessing postural load

The assessment of the postural load on the back was focused on nonneutral postures of the trunk in the sagittal plane (flexion) and the transversal plane (axial rotation). Deviations from straight upright posture of the trunk were classified as forward flexion (>20° bent forward) or axial rotation (>20°

twisted). The method of measurement used was the Ovako working posture analysing system (OWAS) which was slightly modified to separate flexion and rotation during the observations.[15] Observations were made at the workplace every 20 s during two periods of 30 min, thus collecting 90 observations of each worker during each measurement. To decrease inter-observer variability all measurements in a specific company were performed by one person. The exposure measure presented is the percentage of the total working time spent with the trunk in flexion or rotation.

The duration of measurement was 30 min. In most occupational groups this will cover at least 15 complete work cycles. If the work cycle is the most important source of variance, the characterization of trunk postures during a number of subsequent work cycles is assumed to assess adequately the postural load on the back to which a worker was exposed during a typical workday. The first measurement was conducted in the first hours of the shift, the second measurement in the latest hours of the same shift. This procedure of repeated measurement provided information concerning the personal distribution of exposure to postural load within a shift. The assumption was made that the variance of exposure to postural load within a shift markedly exceeded the shift-to-shift variance of exposure. Therefore, the worker's distribution of exposure to postural load within a shift (the within-shift variance) was used as a proxy of the 'within-worker distribution' of postural load.

Exposure characteristics of occupational groups

The measurements of the average percentages of time spent in trunk flexion and in trunk rotation were the principal measures of exposure to postural load on the back. The distribution of exposure measurements in each occupational group was evaluated and six out of ten distributions differed significantly from the normal distribution. Therefore, simple log-transformations were performed which markedly reduced the skewness of the distributions of exposure variables within each occupational group. Eight out of ten distributions of log-transformed data could be adequatly described by a normal distribution. For reason of comparability, log-transformations were performed on all measurements. This procedure allowed the normal distribution to be used in the statistical methods. For each occupational group the following descriptive statistics of measures of postural load are presented: the arithmetic mean (AM), the geometric mean (GM), the geometric standard deviation (GSD) and the range.

To study whether classification into groups by occupational title is justified, the homogeneity of exposure to postural load in each group was assessed. The first approach was to calculate the geometric standard deviation of the distribution of worker's mean exposure within each occupational group. The GSD of the between-worker variance was derived directly from the analysis of variance of the log-transformed exposure data by the equation $GSD = \exp(SD_{L,w})$.[16] Since this parameter is somewhat difficult to interpret, the between-worker variance was also expressed by the ratio of the 97.5th percentile to the 2.5th percentile of the distribution of worker's mean exposure, denoted by the range ratio $R_{0.95}$. The range ratio can be calculated by the equation $R_{0.95} = \exp(3.92 * SD_{L,w})$. The second approach was to calculate the between-worker and within-worker variance in each occupational title group. If the between-worker variance is large compared with the within-worker variance the workers are not uniformly exposed. A useful parameter is the variance ratio λ, the ratio of the within-worker and the between-worker variance.[12] The third approach was to calculate the different components of the exposure variability and to evaluate the contribution of each source of variance to the total variance in the population under study. An analysis of variance was performed to calculate the proportion of variance due to the occupational groups, to the workers within the groups and to the individual workers within a shift.

Statistical methods

In order to test whether measurements within each occupational group were normally distributed the Shapiro and Wilks statistics were calculated.[17]

An analysis of variance technique was used to separate the total variance of the measurements into its various components. A one-way analysis of variance with repeated measurements was used to estimate the magnitude of the variance between workers and the variance within workers for each occupational group under study. A hierarchic classification was regarded as most appropriate, in which a population (the occupational group) is sampled a number of times (the workers) and repeated measurements are carried out on each worker. The hierarchic classification is alternatively called a nested classification.[18,19] A random-effect model was used since the two periods of observation of each worker are assumed to be drawn at random from the total distribution of parts of shifts. Similarly, the selected workers are regarded as random elements from the total population of workers in their occupational group. The analysis of variance for *n* repeated measurements on *q* workers is summarized in table 5-1. The mean squares (MS) are estimates of the expected variances E(MS) which can be used to partitioning of the total variance into the between-worker and within-worker variance.[18,19]

To determine the influence of the occupational title group, the individual worker and the parts of the shift on the exposure to postural load on the back a two-way analysis of variance with repeated measurements was performed.

Table 5-1 One-way analysis of variance with repeated measurements on the same worker

Sources of Variance	Sum of Squares	Degrees of Freedom	Mean Square	Expected Mean Square
Between groups	$SS_{b,w}$	q-1	$SS_{b,w}$ / (q-1)	$\sigma_s^2 + n\,\sigma_w^2$
Between parts of shift within workers	$SS_{b,s}$	q(n-1)	$SS_{b,s}$ / q(n-1)	σ_s^2

σ_s^2 between parts-of-shift variance = within-worker variance
σ_w^2 between-worker variance
q number of workers
n number of repeated measurements per worker

Again, a hierarchic classification was used with a random effect model. The first underlying assumption of this design was that the group factor is random; since no *a priori* assumption was made on the level of exposure in each group the groups can be regarded as a random sample from an almost infinite population of occupational groups. In this design the workers are nested within the levels of the group factor. The idea of nesting is that the different levels of the group factor contain different workers. The second underlying assumption was that the group of workers consisted of a random sample of all possible workers in each occupational group. The third assumption was that the measurements of exposure to postural load within a worker were independent and normally distributed. For the general two-way analysis of variance with *p* levels of the factor A (group), *q* levels of the nested factor B (worker) and *n* repeated measurements at each level of factor B, the analysis of variance is summarized in table 5-2.[18,19] The mean squares were used to estimate the between-group variance and the between-worker and within-worker variance. Since the number of workers in each occupational group were not equal a so-called unbalanced design was used. Unbiased estimates for the variance components can be computed similarly

Table 5-2 Two-way analysis of variance with repeated measurements on the same worker, who is nested within the group factor

Sources of Variance	Sum of Squares	Degrees of Freedom	Mean Square	Expected Mean Square
Between groups	$SS_{b,g}$	p-1	$SS_{b,g}$ / (p-1)	$\sigma_s^2 + n\,\sigma_w^2 + n\,q\,\sigma_g^2$
Between workers within groups	$SS_{b,w}$	p(n-1)	$SS_{b,w}$ / p(n-1)	$\sigma_s^2 + n\,\sigma_w^2$
Between parts of shift within workers	$SS_{b,s}$	pq(n-1)	$SS_{b,s}$ / pq(n-1)	σ_s^2

σ_s^2 between parts-of-shift variance = within-worker variance
σ_w^2 between-worker variance
σ_g^2 between-group variance
p number of groups
q number of workers per group
n number of repeated measurements per worker

to a balanced design. The degrees of freedom associated with the between-group variance will be calculated as a kind of average of the numbers of measurements per group.[18]

The data analyses were performed with SAS statistical software. The analysis of variance was carried out by using the procedure Proc Nested which conveniently computes the different compenents of variance. The data used in the analysis of variance are the log-transformed estimates of the percentage of worktime spent with the trunk in flexion or rotation.

Results

The results of the measurements of percentage of worktime with trunk flexion are presented in table 5-3. The differences in mean exposure to trunk flexion among the occupational groups were large. Crane operators had, on average, a nearly sevenfold level of exposure compared with straddle-carrier drivers. Within each occupational group large differences were observed between the measurements of worker's exposure to trunk flexion. These large differences are reflected in the values of the GSDs, ranging from 1.6 to 3.9.

The measurements of percentage of worktime with trunk rotation are summarized in table 5-4. Again, the differences in mean exposure to trunk rotation among the occupational groups were considerable. Crane operators showed the lowest mean exposure with an average of 3% of the worktime with trunk rotation. Among straddle-carrier drivers a thirteenfold level of exposure was found. Within each occupational group the measurements of worker's exposure to trunk rotation showed a large variation. The values of the GSDs ranged from 1.5 to 3.0. A notable finding was that the occupational groups were inversely ordered with respect to their mean exposures to trunk flexion and trunk rotation.

Table 5-3 Results of measurements of percentage of worktime with trunk flexion by occupational title group

Occupational title group	Number of measurements	AM %	GM %	GSD	Range %
Straddle-carrier drivers	42	5.2	3.0	3.9	0.1 - 18.0
Crane operators	40	33.3	26.8	2.2	4.0 - 60.0
Office workers	20	25.1	22.0	1.7	10.0 - 52.0
Woodworking machinists	28	13.4	8.0	3.0	1.0 - 49.0
Packers	24	11.7	10.6	1.6	4.0 - 28.0

AM Arithmetic Mean
GM Geometric Mean
GSD Geometric Standard Deviation

Table 5-4 Results of measurements of percentage of worktime with trunk rotation by occupational title group

Occupational title group	Number of measurements	AM %	GM %	GSD	Range %
Straddle-carrier drivers	42	39.0	35.9	1.6	12.7 - 58.0
Crane operators	40	3.0	1.8	3.0	0.1 - 18.0
Office workers	20	6.2	4.7	2.4	0.7 - 14.3
Woodworking machinists	28	8.6	6.6	2.7	0.1 - 19.0
Packers	24	27.4	25.3	1.5	9.0 - 51.0

AM Arithmetic Mean
GM Geometric Mean
GSD Geometric Standard Deviation

Table 5-5 presents the results of the one-way analysis of variance with repeated measurements. The analysis of variance for the total population, regardless of the worker's membership of different occupational groups, showed that the overall variance ratio was smaller than 1. This expresses that the between-worker variance is greater than the within-worker variance. A similar analysis of variance for each occupational group demonstrated variance ratios which varied from 0.2 to 7.1. Among the packers the within-worker variance was markedly larger than the between-worker variance for both trunk flexion and trunk rotation. Moreover, the GSDs of the between-worker variances in this group were small, which implicates that all packers have experienced a similar postural load on the back. The small between-worker variances in the group of packers are also expressed in the modest values of the associated range ratios. Among the other occupational groups large values of the GSD and the $R_{0.95}$ were found. Workers within these group are exposed to different levels of postural load due to trunk flexion and rotation. In every occupational group the GSD appeared to be smaller than the GSD for the total population. This demonstrates that the

Table 5-5 The between-worker variance $GSD_{b,w}$, range ratio $R_{0.95}$ and variance ratio λ for log-transformed distribution of trunk flexion and trunk rotation by occupational title group

Occupational title group	Number of measurements	Trunk flexion			Trunk rotation		
		$GSD_{b,w}$	$R_{0.95}$	λ	$GSD_{b,w}$	$R_{0.95}$	λ
Straddle-carrier drivers	42	2.0	14.7	3.0	1.5	5.1	0.2
Crane operators	40	2.1	16.9	0.3	1.7	7.4	3.6
Office workers	20	1.5	4.6	1.0	2.1	17.7	0.5
Woodworking machinists	28	2.5	35.9	0.5	2.1	18.8	0.8
Packers	24	1.3	2.5	2.8	1.2	1.8	7.1
Total	154	2.9	66.8	0.5	3.7	168.2	0.2

$GSD_{b,w}$ Geometric Standard Deviation of the between-worker variance ($\exp SD_{L,w}$)
λ variance ratio (σ_S^2/σ_W^2)
$R_{0.95}$ ratio of 97.5th percentile to the 2.5 percentile ($\exp(3.92 \cdot SD_{L,w})$)

Table 5-6 Estimated contribution of different sources of variance to the total variability of exposure to postural load due to trunk flexion and trunk rotation in five occupational groups

Source of variance	Estimated variance component	Contribution to the total variability	
		Trunk flexion	Trunk rotation
Between groups	σ_g^2	47.4%	72.2%
Between workers within groups	σ_w^2	24.1%	11.7%
Between parts of shifts within workers	σ_s^2	28.5%	16.1%
Total		100.0%	100.0%

differences between workers within an occupational group were smaller than the differences between workers in the total population. Therefore, this finding indicates differences in exposure experience among the occupational groups.

In table 5-6 the total variability of exposure to postural load is partitioned into its different components. Both for trunk flexion and trunk rotation the estimated contribution of the variance between occupational groups was the largest source of variance. In case of trunk flexion the between-group variance almost equalled the within-group variance, whereas for trunk rotation the between-group variance was considerably larger than the within-group variance. This analysis showed that the breakdown in occupational groups was more succesful for the exposure to trunk rotation than applied to the exposure to trunk flexion. Differences between parts of the shift within workers resulted in the second source of variance. When accounting for occupational group status, the within-worker variance is larger than the between-worker variance.

Discussion

Exposure assessment in occupational epidemiology on back pain needs more attention.[11,20] Characterization of exposure to postural load on the back has to take into account frequency and duration of strenuous work postures and movements, their variability during work activities within a shift and between different shifts, and the differences between workers performing the same tasks. This study was conducted to investigate sources of variability in exposure to postural load on the back and to evaluate homogeneity of the exposure within occupational groups. The concept of postural load was restricted to nonneutral postures of the trunk in flexion and rotation. The measure of exposure was the percentage of worktime spent with the trunk in flexion or rotation. A measurement strategy with repeated measurements was applied to estimate variability in exposure due to differences between groups, between workers and within workers.

In this study the distributions of measurements within each occupational group were better characterized by the log-normal distribution than by the normal distribution. While adopting the log-normal model for the exposure to postural load on the back it was possible to draw inferences about this exposure and apply the well-developed theory of exposure assessment to toxic substances in air.[14]

An issue not addressed explicitly in this study is the contribution of the random measurement error to the variability of exposure, i.e. to the within-worker variance. Exposure measurement with an observational method is sensitive to intra- and interobserver variability. One study on the observers' agreement of direct observations showed a coefficient of reliability of 81% for bending of the trunk. However, in the same study rotation of the trunk was difficult to observe and a reliability coefficient was found of 20%.[21] Prior to this study, a limited survey was conducted with two observers who simultaneously observed seven workers for a 60 min period each. The percentage of agreement was 83% (SD 4) for trunk flexion and 78% (SD 11) for trunk rotation. Intra-observer variability cannot be assessed when applying a direct observation method. Under the assumption of random inter-observer variability the percentage of agreement between the two observers can be regarded as the measurement error of the observational technique. The variability due to random errors in the measurement technique can be represented by the coefficient of variation (CV). The observed variability of exposure, expressed by the GSD of the lognormally distributed measurements, can be adjusted for the variability of measurement technique, represented by the CV of the normally distributed measurement errors.[22] The relative contribution of a coefficient of variation of 20% to an observed variability of exposure of GSD = 1.50 will be about 6%. With larger values of GSDs, the contribution of the measurement error will be negligibly small. Therefore, it is a reasonable assumption that the measurement error of the observation method used does not contribute significantly to the variability in exposure due to workplace conditions and individual characteristics of workers. This finding indicates that improvement of the reliability of the measurement method is of lesser importance than improvement of the measurement strategy.

Three approaches have been used to study the classification of workers into groups with distinguishable levels of exposure. The first approach strongly focused on the homogeneity of occupational groups exposed to postural load on the back. Rappaport has advocated the use of a range ratio as quantitative measure of the uniformity of exposure across an occupational group.[14] According to his strict definition of a homogeneous exposure group, characterized by a range ratio $R_{0.95}$ of two or less, only the packers could be considered as such. The range ratios in other groups were significantly larger, showing that workers within the same job can be differently exposed. The interindividual variability in postural load may be explained by variations in the tasks performed and the subjects' anthropometry and work methods.[6] The consequence for misclassification of exposure of substantial between-worker variance in epidemiologic surveys depends on the relative magnitude of the other sources of variability.

The second approach is based on the ratio of the between-worker variance and the within-worker variance. The variance ratio in some occupational groups showed that the contribution of the within-worker variance to the total exposure variability can surpass the influence of the between-worker variance. The poor agreement between the variance ratio and the range ratio points out that a large variance ratio can still imply large differences in exposure to postural load among workers of the same occupational group. The within-worker variance may be partly explained by differences in the tasks performed. The averaging time of the measurements and the number of repeated measurements can also account for the observed variability of exposure to postural load within one shift. In this study the within-shift variance is based on the short averaging time of 30 minutes and two repeated measurements only. Analogous to chemicals in the air at the workplace,[23] it can be expected that the variance of a worker's distribution of exposure to postural load decreases with increasing averaging time of measurement or increasing number of repeated measurements. This will dampen the within-shift variation and will improve precision of the estimated mean exposure of individuals.

Heederik and colleagues have argued that inhomogeneous groups are acceptable in epidemiologic studies unless they have overlapping exposure distributions.[16] The third approach of partitioning the total exposure variability can reveal the ratio of the between-group and within-group variance. In this study the use of occupational groups could explain the variability of exposure to postural load due to trunk flexion and rotation for 47% and 72%, respectively. The between-group variance was the most important source of variability of exposure in this survey. This is a desirable feature in an epidemiologic study based on comparison of different exposure groups. The within-group variance can be reduced by the appropriate selection of occupational groups with maximal contrast in exposure. For example, in this study the woodworking machinists appeared to have an intermediate exposure to postural load with a large within-group variance. Excluding this occupational group from the analysis of variance increased the contribution of the group component in the variability of trunk flexion and rotation to 56% and 79%, respectively.

An important topic in epidemiologic studies is misclassification, either of exposure or health endpoint. This study focused on possible sources of non-differential misclassification of exposure to postural load on the back which will bias the relationship between postural load and (low-)back pain towards the null hypothesis.[10] The analysis of the components of variability of exposure to postural load on the back may guide towards appropriate measurement strategies for exposure in epidemiologic studies on low-back pain. Often, a random sample of workers of the occupational groups under study is monitored. Such approach warrants that the between-group variance is the principal source of variability of exposure. Unfortunately, one cannot rely on traditional methods for grouping strategies such as occupation or job title. The assumption of distinguishable exposure groups has to be evaluated; the between-group variance has to exceed the within-group variance. In absence of distinguishable subgroups in the population under study, often characterized by a small between-worker variance, an external reference group has to be selected with maximal contrast in exposure. When confronted with a large within-worker variance, the workers of the population under study have to be monitored repeatedly, or alternatively, be monitored with increased averaging time of measurement. In case of individuals as most important source of differences in exposure to postural load the most appropriate approach would be to monitor each subject under study in order to estimate postural at individual level.

It is obvious that the choice of measurement strategy has important implications for the applicability of measurement techniques for postural load on the back. Repeated measurement of many workers during several days will limit the feasibility of most observational techniques. Personal monitoring with direct measurement techniques may be required.[24] Some study designs will require extensive measurement programmes.

Before starting large epidemiologic studies on low-back pain, information on important sources of the exposure variability is required. It has been recommended to conduct an exposure-oriented survey prior to the start of the epidemiologic study. In such survey multiple measurements are collected from representative workers.[14] Subsequently, the partitioning of the variability of exposure into its various components provides the basis for assigning groups and the development of an adequate exposure assessment strategy.[12]

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6 Bias in risk estimates arising from variability of exposure to postural load on the back in occupational groups*

Abstract

Variability of exposure can be a source of information bias which may occur in studies with exposure assessment based on a sample of workers in each occupational group under study. This paper presents a simple method to assess the rate of exposure misclassification by the magnitude of overlap of exposure distributions and, consequently, to evaluate the bias to risk estimates in cross-sectional and prospective studies. The percentage of work-time with trunk flexion and rotation in five occupational groups was studied. The rate of misclassification of exposure to trunk flexion and rotation varied from 0.03 to 0.35. Misclassification below 0.10 was found only by occupational groups with at least a fourteenfold difference in mean exposure. Higher rates of misclassification may easily bias the risk estimates up to 50%. In the cross-sectional design the odds ratio was more sensitive to bias than the prevalence rate ratio. The estimate of the relative risk in a prospective study design was least biased.

Introduction

Epidemiologic research is needed to study the effects of workplace exposures on the occurrence of diseases in the working population. Investigations of low-back pain due to workplace exposures are often conducted with a cross-sectional design. In a cross-sectional study the prevalence of low-back pain is compared between groups of workers with respect to exposure status.[1] In many surveys concerning low-back pain the information on exposure status is obtained by self-administered questionnaires.[2] If exposure to postural load is determined by reports provided by the workers considerable misclassification of exposure is almost inevitable. Studies on the reliability of questionnaires have consistently shown that self-reported aspects of postural load are in poor agreement with more objective measurements.[3-5] This source of misclassification of exposure, when inde-

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pendent of disease status, will generally bias the effect estimate towards the null value.[1,6] In order to reduce the measurement error several methods for objective measurement of postural load in working conditions have been advocated.[7-9] Application of these measurement techniques in occupational studies will markedly reduce the measurement error and, as a consequence, reduce the potential bias due to nondifferential misclassification of exposure.

However, information bias can also occur as a result of the measurement strategy applied. The common approach in cross-sectional studies on low-back pain is to monitor a sample of workers in each occupational group under study. When exposure assessment of each individual is not possible the measurements of postural load are used to assign exposure categories to the occupational groups, often based on the worker's mean exposure.[2] Subsequently, the prevalence of low-back pain is compared among groups with different exposure status. In this grouping strategy, inherent misclassification of exposure will occur if the occupational groups show overlapping distributions of worker's mean exposures in each occupational group. A similar problem may arise in prospective studies on incident cases of low-back pain in occupational groups when a random sample of workers in each occupational group is being monitored.

Therefore, variability of exposure among workers within an occupational group can be described in terms of nondifferential misclassification of exposure. Hence, it is important to know the magnitude of overlap of exposure distributions. In this paper, the rate of nondifferential misclassification of exposure due to variability of exposure among workers will be derived from the magnitude of the overlap in exposure experience of two occupational groups. Its impact on the estimate of the association between postural load and low-back pain will be investigated. The purpose of the present analysis is to assess the potential magnitude of bias to the risk estimate in cross-sectional and prospective studies due to exposure assessment based on grouping strategies.

Methods

In cross-sectional studies, the prevalence odds ratio is frequently being used to derive a measure of association between exposure and disease. Some authors give preference to the prevalence rate ratio when the prevalence of disease is rather high.[10] Since this condition is often true while studying low-back disorders, for the purpose of the discussion the effect of exposure misclassification on both measures of risk will be presented.

Exposure misclassification is expressed in table 6-1 by a two by two table of conditional probabilities.[11] Assuming nondifferential misclassification with

Table 6-1 Distribution of subjects by true and observed exposure status

		True exposure Yes (1)	True exposure No (0)
Observed exposure	Yes (1)	P_{11}	P_{10}
	No (0)	P_{01}	P_{00}

regard to exposure status, the probability of being classified correctly as exposed (P_{11}) should be equal to the probability of being classified correctly as unexposed (P_{00}). P_{11} is often referred to as exposure sensitivity and P_{00} as exposure specificity.[11] Under the assumption that the correct classification rate of exposed and nonexposed will be equal (that is $P_{11}=P_{00}$), the magnitude of nondifferential misclassification due to exposure variability can be derived from the overlap of exposure distributions of the two occupational groups compared. The probability of a measurement among the unexposed subjects to exceed or equal a specific value is supposed to be the same as the probability of a measurement among the exposed subjects to fall below this value. Essential for estimating this probability is the inference about the underlying distributions. The distribution of measurements of aspects of postural load on the back is described best by the log-normal distribution, characterized by the Geometric Mean (GM) and the Geometric Standard Deviation (GSD).[12]

Thus, the probability can be obtained by the following equation:

$$\ln GM_0 + (\ln GSD_0)(t_\alpha) = \ln GM_1 + (\ln GSD_1)*(t_\alpha) \qquad (1)$$

The value of t_α corresponds to the percentile of the distribution of the one-sided Student's t-statistic.[13,14] The corresponding probability of a measurement exceeding or equalling this percentile presents the estimate of the misclassification rate γ. Note that the misclassification rate γ is equal to $1 - P_{11}$.

As a simple illustration of the effect of exposure misclassification, consider the hypothetical data of a cross-sectional study in table 6-2. An occupational group of 200 (n_1) subjects with high exposure to postural load on the back is compared with an occupational group of 200 (n_0) subjects with low exposure to postural load on the back. The measure of disease is the 12-month prevalence of low-back pain. In this example the overall pre-

Table 6-2 True distribution of subjects with low-back pain and subjects without by exposure status of postural load in a cross-sectional design

		Subjects with low-back pain		Subjects without low-back pain		Total	
Exposure status	High (1)	100	(a)	100	(b)	200	(n_1)
	Low (0)	60	(c)	140	(d)	200	(n_0)

valence of low-back pain is 40% among the total population. The prevalence of low-back pain among subjects with high exposure is a/n_1, among subjects with low exposure c/n_0. By definition, when the exposure misclassification is nondifferential with regard to health status, subjects with low-back pain and subjects without low-back pain have the same exposure sensitivity and specificity. Moreover, in this approach the exposure sensitivity and specificity are assumed to be equal, and can be derived directly from the obtained rate of misclassification. Given the true distribution of cases and controls by exposure status, and the common value S for exposure sensitivity and specificity, the observed values of the cell frequencies can be calculated by the following equations:

$$A = aS + c(1\text{-}S) \quad (2)$$

$$B = n_1 - A \quad (3)$$

$$C = cS + a(1\text{-}S) \quad (4)$$

$$D = n_0 - C \quad (5)$$

In these equations the rate of misclassification is estimated by 1-S. The observed values of cell frequencies can be used to obtain the observed risk estimates. The biased odds ratio is estimated by

$$OR_b = [A/(n_1\text{-}A)] / [C/(n_0\text{-}C)] \quad (6)$$

The biased prevalence rate ratio is estimated by

$$PRR_b = (A/n_1) / (C/n_0) \quad (7)$$

A similar approach can be described for a hypothetical prospective study, as presented in table 6-3. A group of workers with high exposure to postural load on the back is compared with an occupational group of workers with low exposure to postural load. Suppose the true incidence rates of low-back pain are 70 per 1,000 person-years in the high exposure group and 30 per 1,000 person-years in the low exposure group. The true distribution of cases and person-years are presented in table 6-3. Given this figures and the common value S for exposure sensitivity and specificity, the observed number of cases and subsequent person-years of exposure can be calculated by the following equations:

$$A = aS + b(1\text{-}S) \quad (8)$$

$$B = bS + a(1\text{-}s) \quad (9)$$

$$N_1 = n_1S + n_0(1\text{-}S) \quad (10)$$

$$N_0 = n_0S + n_1(1\text{-}S) \quad (11)$$

Table 6-3 True distribution of incident cases of low-back pain and exposure to postural load in a prospective design

		Incident cases of low-back pain		Person-years	
Exposure status	High (1)	350	(a)	5000	(n_1)
	Low (0)	180	(b)	6000	(n_0)

The biased relative risk is estimated by

$$RR_b = (A/N_1) / (B/N_0) \tag{12}$$

Empirical data of a survey on worker's distributions of exposure to postural load in five different occupational groups have been used to estimate different rates of misclassification. The principle measure of exposure was the percentage of worktime with trunk flexion or trunk rotation.[12] Straddle-carrier drivers were found to be the occupational group with lowest exposure to trunk flexion, and crane operators the occupational group with lowest exposure to trunk rotation. The magnitude of the overlap of worker's exposure distributions has been calculated for each occupational title group, using the group with the lowest exposure as reference.

To investigate the effect of exposure misclassification on the risk estimates in a cross-sectional study an overall prevalence of low-back pain of 40% among the 200 subjects in the high exposure group and 200 subjects in the low exposure group was used. Different distributions of workers with low-back pain by exposure status were evaluated, which yielded values of true odds ratios close to 1.50, 2.25, and 3.00, and associated true prevalence rate ratios. For three rates of misclassification the biased odds ratios and prevalence rate ratios were calculated. An analogous analysis was made for a prospective design using hypothetical data according to the format of table 6-3. The true relative risk were 1.50, 2.33 and 3.00, and the same three rates of misclassification were evaluated.

Results

In table 6-4 the workers' distributions of exposure to trunk flexion and trunk rotation are presented, characterized by their geometric mean and geometric standard deviation. With regard to exposure to trunk flexion the group of straddle-carrier drivers was used as reference. When comparing the four occupational title groups with this reference group, application of equation 1 yielded rates of misclassification varying from 0.15 to 0.35. For exposure to trunk rotation the rates of misclassification varied from 0.03 to 0.31, when comparing the four occupational title groups with the group of crane oper-

Table 6-4 Misclassification of exposure to postural load due to overlap of distributions of percentage of worktime with trunk flexion and trunk rotation among occupational title groups

Occupational title group	Exposure to trunk flexion					Exposure to trunk rotation				
	GM	GSD	df	t_α	γ	GM	GSD	df	t_α	γ
Straddle-carrier drivers	3.0	3.9	-	-	-	35.9	1.6	80	1.91	0.03
Crane operators	26.8	2.2	80	1.02	0.16	1.8	3.0	-	-	-
Office workers	22.0	1.7	60	1.05	0.15	4.7	2.4	58	0.49	0.31
Woodworking machinists	8.0	3.0	68	0.40	0.35	6.6	2.7	66	0.62	0.27
Packers	10.6	1.6	64	0.69	0.25	25.3	1.5	64	1.76	0.04

GM Geometric Mean
GSD Geometric Standard Deviation
df degrees of freedom
t_α value of t distribution
γ misclassification rate

ators. It can also be noted that considerable rates of misclassification can occur, although the occupational title groups can have clearly different values of workers' mean exposure to trunk flexion or trunk rotation.

In table 6-5 hypothetical data, similar to the data given in table 6-2, have been used to illustrate the extent of bias due to nondifferential misclassification of exposure in a cross-sectional study. The true odds ratio for low-back pain due to aspects of postural load is obtained simply from the marginal totals of a two by two table. When accounting for nondifferential misclassification of exposure the true odds ratio will markedly decrease. For example, the true odds ratio is 2.23, whereas the observed odds ratio under conditions of 10% misclassification of exposure is only 1.89. Two points are noteworthy. First, when the true odds ratio increases, the bias introduced by misclassification of exposure also increases. Second, higher rates of misclassification will bias more strongly the odds ratio towards unity. With regard to the true prevalence rate ratio, the magnitude of the bias to the prevalence rate ratio also depends on the actual prevalence of the health outcome. The degree to which the prevalence rate ratio is underestimated is smaller than the bias in the odds ratio.

Table 6-5 Bias to the true odds ratio (OR) and the true prevalence rate ratio (PRR) due to nondifferential misclassification of exposure in a cross-sectional design

True Odds Ratio OR	Biased odds ratio OR_b			True prevalence rate ratio PRR	Biased prevalence rate ratio PRR_b		
	γ=0.1	γ=0.2	γ=0.3		γ=0.1	γ=0.2	γ=0.3
3.05	2.42	1.93	1.55	1.96	1.70	1.48	1.30
2.23	1.89	1.61	1.37	1.62	1.47	1.33	1.21
1.52	1.40	1.28	1.18	1.29	1.22	1.16	1.11

γ misclassification rate

Table 6-6 Bias to the true relative risk (RR) due to nondifferential misclassification of exposure in a prospective design

True Relative Risk RR	Biased Relative Risk RR_b		
	γ=0.1	γ=0.2	γ=0.3
3.00	2.45	2.03	1.70
2.33	2.03	1.77	1.55
1.50	1.43	1.37	1.31

γ misclassification rate

In table 6-6 the bias to the relative risk in a prospective study design is illustrated. Again, the observed relative risk decreases with a higher rate of misclassification. The magnitude of the bias in the estimated relative risk in the prospective design is slightly less than the bias in the estimated prevalence rate ratio in the cross-sectional design.

Discussion

Frequently, in occupational epidemiology on low-back disorders the prevalence of these disorders is compared between occupational title groups. Whenever objective measurement techniques for postural load have been used, often a random sample of workers in each occupational group is monitored. The average values of the parameters measured are being used to characterize the exposure to postural load in the occupational title groups.[2] In fact, workers who have not been monitored are assigned the mean exposure of their occupational group.

Two occupational groups can have significantly different values of their mean exposure, thereby suggesting a clear difference in exposure status. However, large variability of exposure within each group can result in overlapping exposure distributions and thus into misclassification of exposure. The variability of exposure within each occupational group is due to within-worker and between-worker variance. Information on the underlying distributions is essential for estimating the magnitude of the overlap. An extensive measurement programme of the percentage worktime spent with trunk flexion and trunk rotation in five different occupational groups revealed that these aspects of exposure to postural load were best described by log-normal distributions.[12] Hence, it was possible to drawn inferences about the magnitude of overlap between two exposure distributions. The area of overlap will present a fruitful estimate of the rate of misclassification of exposure that is nondifferential to both exposure status and disease status. In this approach the nondifferential misclassification is solely due to the variability in exposure within an occupational group.

In this study the rates of misclassification of exposure to trunk flexion and rotation varied from 0.03 to 0.35. Misclassification below 10% was found only by comparing occupational groups with at least a fourteenfold level of exposure, compared with the low exposure group. The high rates of misclassification reflect the considerable variance in exposure between workers in the same group and between parts of shift within workers.[12] Under the assumption that the exposure variability and the concomitant concept of a log-normal distribution can be generalized to other occupational groups and working situations, misclassification of postural load due to nonneutral postures will be easily obtained.

Attenuation of the risk estimate caused by exposure misclassification is demonstrated in tables 6-5 and 6-6. In the cross-sectional approach the odds ratio was more sensitive to bias than the prevalence rate ratio. The relative risk in the prospective approach showed the least bias. In case of a dichotomous exposure categorization nondifferential misclassification of exposure always bias a true effect toward the null value. The foregoing approach to estimate the amount of bias can be extended to the more general case of more than two exposure categories. In specific cases it can be demonstrated that the bias due to nondifferential misclassification of exposure is not necessarily downward when a polychotomous exposure measure is used.[6]

In this study the misclassification of exposure has been limited to a main measure of exposure to postural load and its effect on the risk estimate for this exposure. In many occupational situations workers are exposed to several risk factors of postural load, such as rotation of the trunk, lifting and forceful movements. There are no reasons to believe that misclassification of exposure to these confounding factors will not occur. An assessment of the possible effect of confounder misclassification can be achieved by using a similar approach for evaluating the nondifferential misclassification of the main exposure variable. Recently, Ahlbom and Steineck pointed out that misclassification of the confounding (exposure) factor can be of particular importance. In their example control for a confounding variable, subject to a considerable amount of misclassification, led to a strong overestimate of the true exposure-disease association measured by the incidence rate ratio.[15] This observation clearly shows that the influence of variability of exposure on misclassification must not be restricted to the main exposure variable of interest, but should also include the confounding exposure variables.

This paper has attempted to demonstrate a practical approach for assessing the possible bias in cross-sectional and prospective studies based on comparison of two occupational groups with overlapping exposure distributions. The approach is only valid when the exposure sensitivity and specificity are assumed to be equal. If this assumption is being met, the presented method allows a direct estimation of the extent of misclassification of exposure and its effect on attenuation of the risk estimate. This approach only requires empirical data on the distributions of exposure in the occupational groups under study. The primary importance of the procedure outlined in this article is that the assessment of exposure misclassification may guide researchers towards improvement of measurement strategies to decrease the estimated rate of misclassification. In some studies the conclusion could be inevitable that the grouping strategy by job title is inadequate. In other studies it may be necessary to collect exposure data on individual level. Of less importance is the application of this procedure to adjust or 'correct' the observed effect estimate for the amount of exposure misclassification due to exposure variability. Simultaneous presentation of the observed risk estimates and the adjusted 'true' risk estimates will offer the reader insight in the bias associated with the sources of variability.

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Validity of measurement methods

The challenge to develop valid and practicle techniques for assessing exposure to postural load at work is still open. Simultaneous application of different measurement techniques in strenuous working situations is a useful approach to study the reliability of such methods

7 Comparison of three methods for the assessment of postural load on the back*

Abstract

A questionnaire, a self-administered log, and an observational method were simultaneously applied in the workplace of 35 mechanical repair man to assess exposure to strenuous postures and movements for the back. The average duration of time spent in a standing position was considerably underrated by workers, while the duration of sitting was strongly overrated when compared with the ratings obtained with the observational method. The workers' ratings of duration of time with a bent or rotated trunk was found to be two to four times lower than the observed duration. The estimate of the average number of lifts performed per hour was more than four times higher in the questionnaire than in the log. The same striking difference was found for the frequency of bending or rotating of the trunk. These results suggest that the reliability of questionnaire methods for the assessment of postural load in epidemiologic studies is probably not very high.

Introduction

Musculoskeletal disorders are a major source of morbidity in many industrial populations. Back pain is one of the most common reasons for time-loss through sick leave.[1,2] In many occupational work situations studies are undertaken to provide a basis for risk assessment of the development of back pain. Although a variety of pathogenetic mechanisms may affect different spinal structures, it is widely accepted that mechanical loads on the spine, in particular as a result of occupational activities, may cause low-back pain.[3,4] The impact of mechanical loads on the spine is difficult to assess in occupational (epidemiologic) studies. A quantitative description of exposure to mechanical loads in occupational situations has many methodological difficulties and limitations.[5] Therefore, alternative approaches based upon simplified methods to document ergonomic exposures are required.

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* Burdorf A, Laan J. *Scand J Work Environ Health* 1991;17:425-9

However, most studies in occupational populations lack any model for the quantification of postural load on the back. In many of these studies the assessment of exposure to risk factors for back pain was restricted to broad occupational titles or job categories.[6] In some studies the presence or absence of specific risk factors, such as lifting, bending, twisting and prolonged standing and sitting, was evaluated by dichotomous responses, while in others exposures to risk factors were measured by scaled parameters rating subjective responses from, for example, "never" to "always". A more quantitative description of ergonomic exposures, based on detailed information on the frequency and duration of specific postures and movements, is relatively sparse. Quantitative objective measures of exposure to postural load have rarely been employed in occupational studies.[5,7]

Regarding the limited scope of most measures of exposure to postural load on the back, it can be expected that their validity and reliability in epidemiologic studies is rather poor and subsequently easily lead to a misclassification of exposure. For this reason, a pilot study was conducted to explore the differences in some commonly used techniques for the assessment of postural load on the back. The study compared two methods of workers' ratings of postural load with a more quantitative observational method. The aims of this study were (i) to evaluate the agreement between the three methods for assessing postural load on the back and (ii) to determine the extent to which disagreement is likely to be influenced by individual characteristics of subjects in the study population and their working conditions.

Subjects and methods

Subjects

The study was carried out in a maintenance and repair department of a steel factory. The study population originally consisted of 41 workers who participated in the questionnaire part of this study. It was not possible to perform observations on three workers (because of holidays) and another three workers kept a log with insufficient data. The remaining 35 workers performed several tasks. The following task groups could be distinguished: (i) seven pipe-fitters, (ii) seven mechanical repair man, (iii) six constructional fitters and (iv) 15 benchmen.

The subjects ranged in age between 22 and 57 (mean 44, SD 10) years. The mean height and weight were 179 (SD 8) cm and 79 (SD 11) kg, respectively. The subjects' mean work experience was 17 (SD 9) years in the present job.

Methods for assessing exposure

Three different methods for assessing exposure to postural load on the back were selected. Each procedure aimed at collecting information on the frequency and duration of specific movements and postures during normal work.

The first method was based on a questionnaire about the subjective workload of the present job. The work load was evaluated by questions regarding the duration and frequency of basic work postures and movements, lifting activities and specific movements of the lower back during activities on an average workday of the past week. The questions concerning standing, walking, sitting and kneeling were phrased as: "How many hours do you have to stand on an average workday?". Lifting activities were evaluated by questions regarding how much of the workday the individual lifted or carried loads, how many times per hour these activities were performed, and how much the average load weighed. Information on trunk posture was elicited by the question: "How many hours do you have to work with a bent or twisted trunk on an average workday?". The frequency of trunk bends and twists was obtained with a question similar to the question on the frequency of lifting activities. Questions were also included on personal characteristics such as age, height and weight, and work experience. This approach has recently been used, for example, in studies among nurses.[8, 9] A second questionnaire was used to obtain information on complaints of back, neck, or shoulder pain within the past 12 months.[10] Both questionnaires were administered by a physician at the on-site medical service.

The second method was based on a log including the same questions as the questionnaire on duration and frequency of postures and movements during work activities. Each worker had to keep this log for one workday and had to answer the questions every hour regarding his postural load during the preceding hour. This method was selected to avoid recall-bias with respect to the subjects' judgments of their postural loads.

The third method was the Ovako working posture analysing system (OWAS) for identifying and evaluating poor working postures.[11] The positions of the lower back and the lower limbs were observed and recorded according to the 84 different postures distinguished by this method. Trunk postures with flexion or rotation of more than 20 degrees from a straight, neutral position were classified as bending of the trunk. The position and movement of the lower limbs was used to distinguish between standing, walking, sitting and kneeling/squatting. After the specific work tasks were identified for each separate job, the workers were observed during two periods of 10 min covering all the important work tasks. The recording procedure consisted of 60 observations of every worker, at intervals of 20 s.

This sampling method was sufficient to include all the relevant activities. All of the observations were performed on the same day that the worker had to keep a log so that confounding by day-to-day fluctuations in the subjects' work conditions could be avoided when the OWAS-method was compared with the subjects' ratings in the log. The observations were made by the same observer. The observation data can be used to calculate the average percentage of time spent in defined work postures and movements during a workday. Recent examples of similar approaches have been published by several research groups.[12-14]

The study took place over a period of three weeks. The investigation started with the recruitment of workers. Each worker was interviewed for information on specific aspects of their postural load during work (method 1). During the following two weeks they were asked to keep the log for one workday (method 2). On the same day the observational method was performed (method 3). The measures of exposure in the three selected methods for the assessment of postural load on the lower back are summarized in table 7-1. For reasons of comparability parameters on the duration of time recorded in the questionnaire and the log-book have been

Table 7-1 Results of the assessment of exposure of postural load on the back

Parameter	Questionnaire (N=35)		Log (N=35)		OWAS method (N=35)	
	Mean	SD	Mean	SD	Mean	SD
Basic postures and movements						
Standing (% of daily worktime)	38	17%*	37	15%*	58	18%
Walking (% of daily worktime)	29	10%*	24	10%	24	14%
Sitting (% of daily worktime)	16	9%*	28	16%*	4	9%
Kneeling/squatting (% of daily worktime)	13	10%	10	8%	14	12%
Lifting						
Duration of lifting and/or carrying (% of daily worktime)	4	3%*	-	-	37	25%
Frequency of lifting and/or carrying (average number per hour)	11.3	10.9*1	2.7	2.4	-	-
Load weight (average load weight in kg)	12.1	8.9	12.8	9.1	-	-
Trunk bending						
Duration of time of postures with forward inclination and/or rotation of the trunk (% of daily worktime)	22	14%*	11	8%*	40	18%
Frequency of bending and/or rotating of the trunk (average number per hour)	24.1	27.4*1	4.8	5.6	-	-

* $P<0.05$; two-tailed paired *t*-test with the OWAS method as reference

*1 $P<0.05$; two-tailed paired *t*-test with the log as reference converted from hours per workday to percentage of daily worktime. Since there were some minor differences among the parameters of postural load in each method, some parameters were only be measured by two methods.

Statistical methods

The null hypothesis that the mean of the differences between pairs of continuously distributed parameters does not significantly differ from zero, is tested with the two-tailed paired *t*-test. An analysis of variance was used to determine the influence of categorical variables (eg, task group and presence of musculoskeletal complaints) on the workers' ratings and the observations. Since the parameters of exposure were measured at intervals, measures of agreement for qualitative data such as Cohen's kappa were not applicable. Therefore, a multiple regression analysis was performed to describe extent, direction, and strength of the correlation between parameters derived from two different methods. The workers' assessments were used as independent variables and the measurements of the observational method were considered the dependent variables. The rationale behind this choice was that we were interested in whether the workers' subjective assessments could predict the more objective observations. A significant regression coefficient indicates that two parameters are associated linearly. A significant intercept indicates the existence of a systematic difference between two parameters, whose absolute value depends on the value of the independent variable. The strength of the linear relationship between two parameters, expressed by the proportion of variance explained, can be regarded as a measure of agreement between workers' ratings and the observations carried out.

Results

The questionnaire on health complaints revealed that the 12-month prevalences of pain of the back, the neck, and the shoulder among these workers were 46%, 34% and 34%, respectively.

The overall results of the workers' assessments and of the observations on duration and frequency of working postures and movements are summarized in table 7-1. For most of the postures and movements significant differences were observed. The average duration of time spent in a standing position was underrated by the workers while the duration of sitting was overrated. The most striking difference appeared in the estimated duration of lifting and/or carrying loads during a workday. As shown in this table, the estimates of the average number of lifting activities were much higher in the questionnaires than in the logs. The same result was found for the frequency of bending and/or rotating of the trunk. Large standard deviations were found for all postures and movements, regardless of the method of assessment.

In the analysis of variance dichotomous variables for the four different task groups were far from significant. The variance in the workers' ratings in the questionnaire and the log, as well as the variance of the observed aspects of postural load, could not be explained by differences in work conditions among the four task groups. Therefore the study population of 35 workers can be regarded as a uniform sample of workers, performing different activities as part of their job.

Multiple regression analyses were conducted to investigate whether the workers' ratings could be used as a suitable predictor for the observed postures and movements. The results of the (age-adjusted) regression analyses, presented in table 7-2, demonstrate that the proportion of variance explained by the questionnaire method was low for each parameter. The workers' ratings in the log resulted in a much better fit for observed period of time in standing and sitting position. For kneeling/squatting and trunk bending significant regression coefficients were found although the proportions of variances explained were not very high. In each regression model the role of potential confounders was investigated. Neither personal characteristics like age, height and weight nor duration of employment in the job

Table 7-2 Linear regression with observed postures and movements as dependent variable and workers' assessments of these postures and movements as independent variables

Parameter	Questionnaire			Log		
	Intercept β_0	Posture β_1	Explained Variance R^2	Intercept β_0	Posture β_1	Explained Variance R^2
Basic postures and movements						
Standing (% of daily worktime)	43.9**	0.37*	11%	32.5**	0.68**	33%
Walking (% of daily worktime)	13.5	0.35	6%	18.5**	0.24	2%
Sitting (% of daily worktime)	-1.6	0.36*	14%	-4.9*	0.33**	40%
Kneeling/squatting (% of daily worktime)	10.2**	0.30	5%	8.0*	0.61*	15%
Lifting						
Duration of lifting and/or carrying (% of daily worktime)	24.8**	3.33*	12%	-	-	-
Trunk bending						
Duration of time of postures with forward inclination and/or rotation of the trunk (% of daily worktime)	32.1**	0.34	7%	29.6**	0.93*	18%

* $P<0.05$
** $P<0.01$

showed any significant influence on the relationships between workers' ratings and observed postures and movements.

In general, the health status of the workers did not influence their ratings of postural load. Workers with low-back pain and workers with shoulder pain usually reported the same distribution of strenuous working postures and movements as workers without these complaints. However, in the regression analysis on the predictive power of workers' ratings in the log for the observed duration of time with a bent trunk, significant contributions were observed for dichotomous variables of low-back pain ($\beta=-10.8$, $P<0.05$) and shoulder pain ($\beta=14.6$, $P<0.05$). Workers with low-back pain judged their duration of trunk bending postures during an average workday to be lower than workers without low-back pain, whereas for workers with shoulder pain the opposite result was found. When both complaints were taken into account in the regression model, the proportion of variance explained raised from 18 to 37%.

Discussion

The workers' estimates of duration and frequency of specific working postures and movements showed considerable variations. The variance in the ratings of the workers in the questionnaire and the log could not be explained by differences between the four task groups among the personnel of the maintenance and repair department. The between-task variability mainly accounted for less than 10% of the exposure variance, which indicates that the within-task variability was much greater than the between-task variability. The same results were found for the assessments based on the observation technique. Therefore, it is not likely that differences in work conditions among the four task groups account for the considerable variations in the exposure assessments.

The question then arises how the exposure variance might be explained. Personal characteristics like age and height and the work history in total years of employment did not influence the workers' ratings or the observed postures and movements. It has been postulated that workers' assessment of exposure could be influenced by the existence of musculoskeletal pain either because workers with pain might learn their jobs in a way that minimizes biomechanical load in order to alleviate their symptoms or to avoid their aggravation[7] or that subjects with back pain are more sensitive to tasks which entail heavy lifting and frequently bending and rotating of the trunk.[3] In this study the three methods showed no significant differences in working postures and movements between workers with musculoskeletal pain and those without, except for workers' ratings in the log of daily worktime with a bent or twisted trunk. This association could not be reproduced for workers' ratings of the same parameter in the questionnaire or for any other parameter in the questionnaire, the log or the observation. The presence of response bias due to complaints of the back, neck or shoulder could not be proved.

Another source of variability in the measures of exposure may have been a lack of precision (ie, reliability). Since repeated measurements were not performed, this hypothesis cannot be tested. However, the results in table 7-2 suggest that reliability of the questionnaire and log methods for measuring specific aspects of postural load will probably not be very high. When the OWAS observation method is regarded as an instrument capable of measuring true exposure, both questionnaire instruments lacked validity for assessing exposure. Although there were significant associations between workers' ratings and observations, the proportions of variances explained were low. The calculated values of the intercepts in the regression models expressed large systematic differences in data obtained by the self-administered methods and direct observation method.

The workers severely underestimated the average time spent in a posture with bent or twisted trunk. Rossignol and co-authors[15] also found that agreement between self-administered questionnaires by employees and direct observation by investigators was poor for the perception of bending and twisting of the trunk. These results indicate that workers cannot be expected to evaluate accurately nonneutral postures when defined in terms of degrees of deviation. Thus, poor agreement between the questionnaire and the observation method on this parameter may be the result of incomparability of both methods.

Other parameters may be expressed more accurately in questionnaires, for example duration of lifting and/or carrying loads. In this study a striking difference appeared in the average duration of lifting or carrying objects during a workday. In one study a complementary observation has been reported.[6] The authors stated that only for 10% of the workers were the questionnaire and observation method consistent regarding both the weight and frequency of the material handled. Although basic postures like standing, walking and kneeling are easily defined, significant underestimation by workers was also present for these parameters in our study. This finding suggests that accurate measurement of basic postures in questionnaires may be difficult. In a study among nurses some contradictory results have been described. Workers' estimates of the average time spent sitting versus standing or walking during a workday closely agreed with those of the observers, whereas reports on the time spent in other activities (eg, kneeling) were less reliable.[16]

Since the OWAS method was applied as a multimoment technique, no comparisons can be made for parameters of frequency. The comparison of workers' ratings in the questionnaire and the log showed significant differences for the frequency of lifting activities and of trunk bending. Workers recalled these risk factors more thoroughly in the questionnaire, which demonstrates that the assessment of exposure depends on the method of administration.

One might question the appropriateness of the observation technique as reference. The observations were only two 10-min samples of much longer work periods in which tasks could vary with unknown frequency. Since this technique is time-consuming and costly for observing and analyzing a large number of jobs, the sampling period was an economic and practical choice. Observation during a period of 8 h would have enhanced the agreement between the observational method and the log on an individual level. Consequently, the proportion of variance explained would have been higher. However, on a group level, the significant large differences in mean values of certain risk factors would not have disappeared with a longer sampling period. The mean score of the OWAS method for a specific risk factor is based upon 2100 observations (nearly 12 h) during a period of two weeks, which is likely to be sufficient for estimating the true exposure to the risk factor in the uniform sample of workers. Even though this method only provided limited information on specific aspects of postural load on an individual level, it was regarded as adequate for the purpose of the study.

Although the small number of workers limits interpretation, the results of this study suggest that the use of exposure information based on self-reported aspects of postural load on the back is probably not very reliable. In this study the consistency of workers' ratings with an observational technique was rather poor. Therefore, it can be argued that questionnaires for assessing postural load are not viable tools with which to classify postural load of workers. Considerable misclassification is inevitable when questionnaire data are used to assign exposure categories for the subjects in epidemiologic studies. Since the misclassification of exposure always is in the direction of the zero value,[17] relationships between postural load and musculoskeletal disorders will systematically be underestimated. It is obvious that inconclusive dose-related risk estimates on musculoskeletal disorders must be interpreted with great care.

This study underlines the statement made by several authors that the challenge to develop valid and practical techniques for assessing exposure to postural load is still open.[5-7]

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8 Measurement of trunk bending during work by direct observation and continuous measurement*

Abstract

An observational method and a continuous measurement technique were simultaneously applied to record bending of the trunk during work. In a group of 16 workers performing dynamic tasks a significant correlation (r=0.57) was found between the two methods. A similar result was observed among 14 sedentary workers (r=0.62). Although significant correlations between direct observation and continuous measurement were present, large differences were found between data obtained from individual subjects. The results cast doubt on the validity of assessments of percentage of worktime with bent trunk at an absolute level using only one measurement method. It is suggested that greater consideration has to be given in future studies to the reliability of measurement of postural load due to trunk bending.

Introduction

Low-back pain and associated disorders are the main reason for sick leave and permanent disability in many occupational populations.[1,2] Laboratory studies and biomechanical simulations have demonstrated that any deviation from upright standing posture produces higher loads on the lumbar spine.[3] Epidemiologic studies have shown that non-neutral postures and movements, eg frequent bending and twisting, are significantly related to the risk of low-back pain.[4-7] Measurement of nature and magnitude of trunk load is difficult.[8] Exposure characterization has to take into account relevant awkward trunk postures, their frequencies and durations within a shift and intra- and interindividual variability during work activities.

A number of techniques have been developed for the collection of information on exposure to risk factors of low-back pain.[9] Observational techniques specially developed for evaluation of occupational activities, have become popular since they are widely applicable and often rather easy to use.[10-13] Most of these recording procedures are based upon repeated

* Burdorf A, Derksen J, Naaktgeboren B, Van Riel M. *Appl Erg* 1992;23:263-7

observations of the worker at specific time intervals throughout either a number of representative work cycles or a specified period of time. Defined postures and movements are observed and recorded, taking into account forces and loads acting on the back.

Application of observational techniques has considerable drawbacks. Most techniques are very time-consuming and subject to intra- and interobserver variability. The posture categories used sometimes are too broad and result in a lack of precision.[9,13] Recording of trunk posture and movement is complicated by frequent changes of the trunk during certain work activities. The validity of observational techniques in a highly dynamic work setting strongly depends on the sampling and recording procedures used.[14]

Hence, there is a clear need for an objective, real-time method for measuring motion of the trunk. Recently, equipment has been developed for objective, continuous measurement of angles and angle changes in a defined plane, eg to record trunk flexion in the sagittal plane.[15,16] The advantages of these instruments are clear: movements can be examined in great detail, movements can be recorded without the presence of an observer and thus observer bias is avoided, recording over eight hours or more is possible and no alterations in normal work routine is prompted by measurement procedure or observer's presence. However, these systems are more expensive than observational techniques and are often restricted to evaluation of a small number of movements.

In studying many different jobs and tasks, feasibility considerations may demand the application of observational techniques in identification of strenuous work situations[18,19] and in evaluation of control measures in working environments.[19-21] The reliability of such methods has to be considered to make sure that observations are appropriate to achieve unbiased and precise estimates of daily exposure to awkward postures. For this reason a study was conducted in two occupational populations to compare results of a direct observational technique with results of a real-time method with continuous measurement. Since bending of the trunk is a frequently observed movement in many working situations, the choice was made to measure trunk movements in the sagittal plane.

Subjects and Methods

Subjects

Two types of work were studied in order to select two clearly distinguished levels of activity: that is, dynamic workload in which the worker's whole body is involved in performing the job, and static workload in which the worker is predominantly sitting during his job. The study was carried out in two different companies. The first group of male subjects was obtained by taking a random sample of 16 employees of a maintenance shop in a steel company. These workers performed several activities as part of their job, for example welding, pipe-fitting, repairing and assembling. Their work could be characterized as dynamic since standing and walking were necessary during most of their shift. The second group of male workers consisted of 14 employees in a transport company. These subjects performed sedentary work as crane drivers, carrier drivers or administrators. Therefore, their work could be characterized as very static.

Measurement of trunk bending

The observations were made using the Ovako working posture analysing system (OWAS) for identifying and evaluating poor working postures.[11] In each company, characteristics of work activities were analyzed in detail. After identification of specific work tasks for each job, workers were observed during 60 min covering all important work tasks. The observations were focused on movements of the trunk with bends forwards or backwards at an angle of more than 20°. The angle of inclination is defined as the angle between the straight line through the pelvis and shoulders and the vertical.[11] Observations were made at the workplace every 20 s, thus collecting 180 observations for each worker.

Together with direct observation, movements of the trunk in the sagittal plane were continuously measured with a special device, the Portable Posture Registration Set, described in detail by Snijders and colleagues.[16] This device consists of an inclinometer, based upon a pendulum potentiometer, and a portable miniature recorder. The position of the trunk is measured by the inclinometer, which is placed on a small area of the skin of the lumbar spine at the level of L2-L3. The inclination of this part of the spine is assumed to be representative of the position of the trunk as a whole in relation to the vertical[16] since the ranges of forward bending motion are largest in the lumbar spine.[22] The measurement device can be worn under the subject's clothing without causing discomfort or hindrance in carrying out usual activities. The electrical signal of the inclinometer is recorded and afterwards converted by a computer programme into the angle of the trunk in the sagittal plane. The measurement error of this device is below 1°. Each measurement session lasted for at least 60 min. An observer simultaneously recorded stooped postures of the trunk with more than 20° inclination.

Data analysis

Direct observations and real-time registration were both used to calculate the average percentage of time spent with the trunk in bent position during a normal workday. Since this parameter was measured on an interval scale, measures of agreement for qualitative data were not applicable without transformation of the data collected. Therefore, results of both methods were used to classify all subjects into workers with a high percentage of time spent in bent posture and workers with a low percentage of time spent in bent posture. The borderline for classification was set to 30% of the worktime with a bent trunk, since this level has been used by the OWAS method to distinguish between work situations which do not need any special attention and work situations which prompt for action in the near future to decrease the percentage of time working with a bent trunk.[23] The proportion of agreement between these categorical data was analyzed by Cohen's kappa, taking into account that interjudge agreement is dependent on both the number of agreements about the categories and the number of disagreements about these categories.[24]

A second analysis was conducted to test the linear association between the results of both methods. Spearman rank correlation coefficients (r_S) for matched pairs were calculated. Statistical significance ($P<0.05$) meant that the association was not due to chance alone.[24]

Results

In table 8-1 the results of the direct observations and the continuous measurements in both occupational groups are presented. The figures are expressed as proportions of the workday spent with the trunk bent at an angle greater than 20°. Although large differences were found at individual level, there is a clear similarity between the two measures of trunk bending. The Spearman rank correlation coefficient was 0.62 ($P=0.02$) for sedentary workers and 0.57 ($P=0.02$) for dynamic workers. From figure 8-1 it is clear that there are considerable differences between direct observation and continuous measurement. The relationship between both methods can be expressed in linear form of the type $Y = \beta_0 + \beta_1 X$ where Y is the percentage of worktime with a bent trunk measured by the continuous measurement and X is the percentage of worktime with a bent trunk assessed by the direct observation. The regression equation obtained for dynamic workers is $Y = 3.7 + 0.86X$. The regression equation obtained for sedentary workers is $Y = -3.6 + 0.47X$.

In order to assess the extent of agreement between the methods, data were broken down into two categories with the borderline set to 30% of the

Table 8-1 Comparison of percentage worktime with bent trunk at an angle more than 20° assessed by direct observation and continuous measurement

Subject	Sedentary workers (n=14)		Dynamic workers (n=16)	
	Direct observation (%)	Continuous measurement (%)	Direct observation (%)	Continuous measurement (%)
A	66	31	9	9
B	38	2	35	40
C	73	42	32	10
D	33	16	26	19
E	33	19	29	26
F	8	1	13	22
G	1	4	24	31
H	3	0.1	36	54
I	7	0.1	43	14
J	9	0.1	39	52
K	8	1	42	63
L	21	1	14	19
M	8	0.1	15	14
N	46	0.1	25	23
O	-	-	43	27
P	-	-	10	8

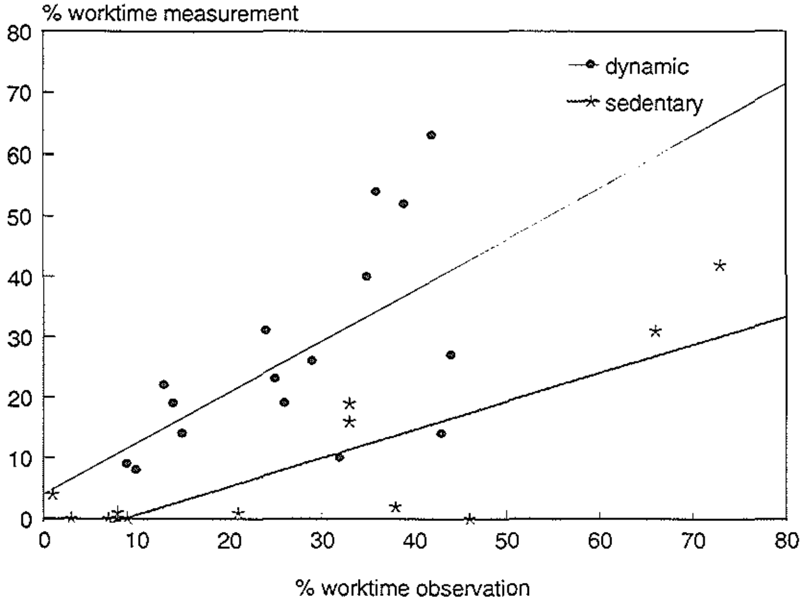

Figure 8-1 Relationship between direct observations and continuous measurements for the assessment of the percentage of worktime with a bent trunk of sedentary workers (n=14) and dynamic workers (n=16)

Table 8-2 Agreement of direct observation and continuous measurement on classification of 30 subjects according to percentage worktime with bent trunk at an angle more than 20°

	Direct observation	
Continuous measurement	≤ 30% worktime with bent trunk	> 30% worktime with bent trunk
≤ 30% worktime with bent trunk	16	7
> 30% worktime with bent trunk	1	6

worktime with a bent trunk. Table 8-2 presents the classification results for all subjects. Over 73% of the subjects were equally classified by the two methods. Cohen's kappa was 0.43 for all subjects, 0.36 for the sedentary workers and 0.51 for the dynamic workers.

Table 8-3 shows the average percentage of time spent with the trunk in a bent position for both occupational groups. Within each group, apparent differences among individuals were demonstrated, illustrated by the large standard deviation of the mean. For dynamic workers the assessments of mean proportion of worktime with bent trunk were equal for the direct observations and the continuous measurements. In the group of the sedentary workers the method of direct observation gave a significantly higher estimate of the average percentage of worktime with the back in a bent posture (paired *t*-test, $P<0.001$). This striking difference between both occupational groups could not be explained by the actual distribution of trunk postures. No significant differences were noticed for the mean angle of bent posture and the trunk posture experienced most frequently.

Discussion

In this study two methods for recording bending of the trunk have been applied simultaneously in two occupational groups. Although significant

Table 8-3 Measures of trunk bending of sedentary workers and dynamic workers

	Sedentary workers (n=14)		Dynamic workers (n=16)	
	Mean	SD	Mean	SD
Direct observation				
Bends > 20° (% worktime)	25.3	23.6	27.2	12.1
Continuous measurement				
Bends > 20° (% worktime)	8.4*	13.6	27.0	17.1
Mean posture of the trunk in the sagittal plane (°)	7.7	5.5	12.3	8.4
Most frequently adopted posture of the trunk in the sagittal plane (°)	7.3	5.6	10.6	10.2

SD Standard Deviation

* *t*-test, $P<0.001$, comparison of direct observation and continuous measurement for sedentary workers

correlations between direct observation and continuous measurement were present (r_{s1}=0.62 and r_{s2}=0.57), large differences were found between data obtained of individual subjects. Differences of more than 20% between assessments of percentage worktime with bent trunk were not exceptional. In a previous study of Baty and colleagues similar results have been reported. They compared observation of bends greater than 15° to measurement of inclination in a small group of 7 workers.[25] They found a reasonable correlation of 0.63 between both methods but they also reported the presence of important differences at individual level. Nordin *et al*[15] followed 10 subjects for 1 h and noticed that the correlation between inclinometer results and observer's recording of deep forward flexion (greater than 72°) was 0.99. This remarkable result suggests that a movement of deep forward bending is easier to observe than trunk bends with moderate flexion and, as a consequence, that validity of observational methods for recording trunk bending will depend on the definition of the non-neutral trunk posture.

At an individual level the results obtained by direct observations differ from those found by continuous measurements. The existence of large differences is difficult to explain. It could be argued that direct observation will lack precision if movements of the trunk are concentrated in the critical range around the borderline of 20° flexion/extension. However, the figures in table 8-3 on average posture (mean) and most frequently adopted posture (modus) do not support this hypothesis.

A second possible explanation for the marked difference between both methods is that the definitions of the angles of trunk bending applied are different. Trunk flexion observed by the OWAS method is defined by an angle of 20° between the straight line through the pelvis and shoulders and the vertical. Using this method, flexion of both the thoracic and the lumbar spine contribute to the observed angle. The contribution of the thoracic spine to total flexion of the spine can be of considerable importance.[26] Measurements of inclination of the trunk at T12 and L4 of subjects standing or sitting have shown in general more trunk flexion at T12 than at L4.[27] The method of continuous measurement is focused on the position of the lumbar section of the trunk, with positioning of the inclinometer at L2/L3, thereby assuming to be representative of the position of the trunk as a whole. Using this method, the angle of trunk bending depends only on lumbar motion. Therefore, the difference in the two definitions applied suggests that the continuous measurement will systematically underrate the angle of trunk bending and, thus, presents lower estimates of the proportion of the worktime with a bent trunk as compared with the direct observation. Since such underrating was not observed for the average worktime with a bent trunk among dynamic workers, this explanation cannot account for the large differences among individual within this group. Among the sedentary workers, the continuous measurements showed systematically lower values of trunk bending as compared with the direct observations. This could be due to an apparent influence of the thoracic spine on total flexion of the trunk of sedentary workers. Experiments with chair and table adjustment for seated work have shown that the thoracic curve can exceed the lumbar curve.[28] An accompanying reason for the poor agreement among sedentary workers may be that the observer's visibility is restricted to the thoracic spine and the position of the shoulders of sedentary subjects and, consequently, will lack precision. Agreement between both methods among sedentary workers could be improved if the continuous measurements were be focused on the section of the spine with the largest contribution to trunk flexion.

While the method of continuous measurement is regarded as being capable of supplying objective measures of trunk bending, the findings of our study tend to cast doubt on the validity of assessments of the risk factor trunk bending at an absolute level following an observational method. Such approach has been used in several epidemiologic and ergonomic surveys.[17,19,21,29]

In occupational epidemiology stratification procedures are regularly applied in case of an internal reference group with low exposure.[30] In this study subjects were classified into two exposure categories. Agreement between both methods, expressed by Cohen's kappa, was found to be reasonable. Eight out of thirty subjects were wrongly classified. This provides evidence that some misclassification will be present when observational data are used to assign exposure categories for subjects under study.

This study has been limited by the number of subjects and occupational groups involved and the risk factor for postural load measured. The results may not be generalizable to workers of other occupational groups and to different working conditions. However, the poor agreement at individual level of direct observations and continuous measurements illustrates the importance of assessing validity of methods for evaluating working postures. This prompts to introduction of pilot studies to validate subjective methods for assessment of postural load prior to the studies which will apply these methods. Since a measurement technique that can be applied as 'golden standard' does not exist, only comparison of the results of simultaneously applied measurement techniques can guide towards the assessment of validity and feasibility of the methods.

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Postural load on the back and low-back pain

In absence of a valid, unequivocal measurement method repeated observations of work posture can be regarded as a suitable alternative. Associations between the occurrence of low-back pain in occupational groups and measures of their exposure to postural load on the back are difficult to derive. Within each job, workers will experience to some extent exposure to postural load on the back.

9 Postural load and back pain of workers in the manufacturing of prefabricated concrete elements*

Abstract

In a population of male workers in a concrete manufacturing plant (n=114) the occurrence of back pain was studied in relation to a reference group of maintenance engineers (n=52). The prevalence of back pain in the past 12 months preceding the investigation was 59% among the concrete workers, and 31% among the controls. After excluding persons with existing back pain before starting their work in the present factory, a comparison between concrete workers and maintenance engineers showed an age-adjusted odds ratio for back pain of 2.80 (1.31-6.01). Postural load of workers in both plants were measured using the Ovako working posture analysis system. During 4009 observations working postures concerning the back, lower limbs and lifting activities were recorded. The average time spent working with a bent and/or twisted position of the back was found to contribute to the prevalence of back pain. The results of this study also suggest that exposure to whole-body vibration, due to operating vibrotables, is a second risk factor for back pain.

Introduction

Musculoskeletal disorders are a major source of morbidity in many industrial populations. Diseases of the musculoskeletal system are ranked first in causes of disability in the Netherlands and account for about 27% of the incidence every year.[1] The manufacturing of stone and concrete products is one of the sectors of industry with a high annual rate of permanent work disability due to musculoskeletal disorders. The number of disabling musculoskeletal disorders, mainly back pain and associated diagnoses, per 100 workers per year in the past few years was on average 1.5.[2]

The production of prefabricated concrete parts and elements is well known for its ergonomic problems.[3] Workers in this industry are exposed to several important risk factors for the occurrence of low-back pain, eg heavy

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* Burdorf A, Govaert G, Elders L. *Ergonomics* 1991;34:909-18

physical work, monotonous work, stooped work postures, sudden maximal physical effort and whole-body vibration.[4] Although the construction industry and associated activities are often mentioned as a branche of industry with a high prevalence of back disorders[5] there have been only a few studies conducted on back pain of workers in this branche of industry.

Studies among concrete reinforcement workers have demonstrated a relationship between their working activities and increased risks of sciatic pain,[6-8] back pain[9] and early retirement because of musculoskeletal diseases.[4] Wickström[9] compared concrete reinforcement workers with maintenance house painters and stated that no factor other than the considerable difference in physical work and strain on the back could sensibly explain the reinforcement workers' higher prevalence of back symptoms and degenerative changes of the back when compared with painters.

Since there is very little information available regarding the existence of musculoskeletal symptoms in employees working in the manufacturing of prefabricated concrete parts and elements, a cross-sectional study was undertaken to assess the prevalence of back pain among these workers and to identify factors in postural load associated with the occurrence of back pain.

Materials and methods

Subjects

Male workers were selected from the production departments of a factory producing prefabricated concrete elements. The working population in this factory, 120 people, was devided into the following occupational groups: (i) steel benders, responsible for the preparation of a skeleton of steel rods, (ii) operators, mainly occupied with concrete pouring and finishing of the concrete elements, (iii) model makers, who construct patterns and models made of wood, (iv) fitters, working as maintenance engineers and (v) a miscellaneous group which consisted of several occupations like foremen, planning engineers, controllers, stock managers and forklift truck drivers.

The reference group was made up of 52 male workers from a large department of an engineering factory. Their work included the production and repair of engines, dynamos, and switchboxes. This job was regarded as comparable to the job of a fitter in the concrete factory.

Postural load

In order to determine the amount of time spent in different working postures during work activities the Ovako working posture analysis system (OWAS) was used for identifying and evaluating poor working postures. The OWAS

Table 9-1 Classification of working postures as definied by the OWAS-method

Target organ	OWAS-Code	Definition of the posture
Back	1	straight
	2	bent, forward inclination more than 20°
	3	straight and twisted, rotation of the back more than 20°
	4	bent and twisted, combination of posture 2 and 3
Lower limbs	1	standing, loading on both limbs, straight
	2	standing, loading on one limb, straight
	3	squatting, loading on both limbs, bent
	4	squatting, loading on one limb, bent
	5	kneeling, loading on one limb on the floor
	6	walking, body is moved by the limb
	7	sitting, both limbs hanging free
Lifting load	0	no load to lift or carry
	1	load less than 10 kg
	2	load more than 10 kg and less than 20 kg
	3	load more than 20 kg

observation method is extensively described by Karhu *et al.*.[10] This method records 84 different postures based on general features like sitting, standing, and walking and the position of the back and the arms. In this study only the postures of importance for the occupational strain on the back were taken into account (table 9-1).

The sampling strategy started with a task analysis of the specific work tasks in each job in both plants. After identification of those work tasks for each seperate job, observations were made covering all the important work tasks. For each task two or three workers were selected at random. During the execution of their task six periods of five minutes were sampled on the same workday. The working posture and activity of each subject were recorded at intervals of 20 s, using a three-number code (table 9-1). This sampling period was short enough to include all relevant activities. All observations were made by the same observer. After all postures had been recorded, they were classified into the four distinguished categories of the OWAS method, reflecting the expected influence of each working posture on the risk of back pain. Action category 1 implies normal postures, action category 2 slightly harmful postures, action category 3 distinctly harmful postures and action category 4 extremely harmful postures.

Musculoskeletal symptoms

A questionnaire was used to collect personal data, details of the respondent's job and employment history, and the presence or absence of symptoms of back pain. The questionnaire was administered by the occupational physician in the period January-February 1990. The questionnaire was derived from the standardized Nordic questionnaire which has been designed to collect reproducible and repeatable information on the nature of the symptoms, their duration (days) and their frequency (occurrences per month).[11] Back pain was defined as pain which had continued for at least a few hours during the past twelve months. In the questionnaire a few questions were included about earlier employment history and present risk factors in the occupational environment in present in previous jobs, like exposure to whole-body vibration and heavy physical work.

Statistical analysis
Differences between frequencies were tested with the χ^2-test, the differences between the means of continuous variables were tested with the unpaired Student's *t*-test. Crude associations between occupational risk factors and back pain were analysed in two-way tables using the Mantel-Haenszel χ^2 statistics. The Spearman rank correlation coefficient (θ) was used as measure of association. Unconditional logistic regression analysis was performed to study the respective weights of occupational and personal risk factors for back pain.[12] Significance levels below 0.10 are presented in the tables, but only p-levels below 0.05 were regarded as significant. Since age appears to influence strongly the probability of symptoms like back pain, it was included in each model, regardless of its level of significance.

Results

Population characteristics
The selected study population comprised 120 workers of the concrete factory and 57 workers of the engineering factory. In both factories a high response rate was achieved, respectively 95% (n=114) and 91% (n=52).

Table 9-2 shows the main characteristics and work experience for both groups. The concrete workers were significantly older and smaller than the controls. Within the departments of the concrete factory the age distribution slightly varied but the differences were not statistically significant.

Marked differences were found in occupational history between the concrete workers and the controls. The majority of the concrete workers (68%) have had different jobs in other factories, which was significantly more than the 12% among the controls. Both the concrete workers and the controls have worked in different jobs in their present factory, respectivily 32% and 23%. This difference was not statistically significant. The small differences

Table 9-2 Comparison of individual characteristics and working experience for concrete workers and a reference group of maintenance engineers

	Concrete workers (n=114)			Reference group (n=52)		
Individual characteristics						
Age (yr)*	43.5	±	11.5	39.7	±	9.6
Height (cm)*	176.3	±	8.5	179.3	±	6.9
Weight (kg)	78.9	±	12.3	78.5	±	9.6
Work history						
Total working experience (yr)	23.9	±	12.4	20.2	±	10.1
Work in the present factory (yr)	17.6	±	12.3	19.4	±	10.0
Work in the present job (yr)	13.9	±	11.6	16.9	±	9.7

* *t*-test, $P<0.05$

in working experience (in years) of both groups merely is a reflection of the difference in mean age.

Postural load

A total of 4009 observations were collected during seven workdays. These data were used to calculate the average percentage of time spent in the defined working postures for each occupational group. The results of the OWAS analysis are shown in table 9-3. The distribution of working postures presented can be considered as an average of the postural load during a workday. The most important poor working postures of all workers under study were the back in a bent position (an average of 33%) and the legs in a kneeling or squatting position (an average of 6%). These postures are classified by the OWAS as action category 2, which means that they are regarded as slightly harmful, and action to change the working posture should be taken in the near future.

The average percentage of time working in harmful postures, ie action category 2 or higher, was 37% for the concrete workers, calculated as a weighted average for the number of workers in each occupational group. This is significantly higher compared to the engineering workers who worked in harmful postures for about 27% of their total working time. Within the concrete factory there were great differences among the main occupational groups. The observations revealed that steel bending was done primarily with the back in a bent posture (53% of the working time) whereas workers in the miscellaneous group mostly worked with their back in a straight posture (86% of the working time).

A specific factor in the postural load of concrete workers was exposure to whole-body vibration. Twenty-seven concrete workers were exposed to whole-body vibration including 25 operators of concrete vibrotables.

Table 9-3 Distribution of time spent in different working postures for each occupational group in the concrete factory and the engineering factory

Working posture	Occupational groups in the concrete factory					Engineering factory
	steel benders	operators	model makers	fitters	miscellaneous	
	(n=14)	(n=39)	(n=14)	(n=19)	(n=28)	(n=52)
Back						
straight	46%	52%	62%	63%	86%	73%
bent	47%	41%	34%	37%	12%	24%
straight and twisted	1%	5%	1%	0%	0%	2%
bent and twisted	6%	2%	3%	0%	2%	1%
Lower limbs						
standing	65%	56%	80%	58%	76%	77%
squatting or kneeling	6%	14%	3%	6%	3%	5%
walking	12%	7%	1%	16%	1%	1%
sitting	17%	23%	16%	20%	21%	18%
Lifting loads						
no load	94%	97%	92%	94%	97%	98%
load less than 10 kg	2%	2%	8%	5%	2%	2%
load between 10-20 kg	2%	0%	0%	0%	1%	0%
load more than 20 kg	2%	1%	0%	1%	0%	0%
Total percentage of time working in harmful posture (action category > 1)	54%	48%	38%	37%	14%	27%

Reported symptoms

Table 9-4 shows the prevalence of complaints of back pain during the 12 months preceding the medical investigation. The crude comparison of reported symptoms of back pain between concrete workers and controls showed an age-adjusted odds ratio of 3.90 (confidence intervals of 1.89 and 8.08). Strong differences were present among the occupational groups

Table 9-4 12-months prevalence of back pain among concrete workers and a reference group of maintenance engineers

		Subjects with back pain		Subjects with onset of back pain after starting work in present factory	
Concrete workers	(n=114)	67	(59%)	50	(44%)
steel benders	(n=14)	8	(57%)	6	(43%)
operators	(n=39)	29	(74%)	21	(51%)
model makers	(n=14)	8	(57%)	5	(36%)
fitters	(n=19)	6	(32%)	5	(26%)
miscellaneous	(n=28)	16	(57%)	13	(46%)
Maintenance engineers	(n=52)	16	(31%)	16	(31%)

within the concrete factory. The onset of back pain started for 17 persons of the concrete factory during previous jobs in other factories. After controlling for this confounder the concrete workers still have an increased risk of back pain compared to the controls (age-adjusted odds ratio of 2.80 with confidence intervals of 1.31 and 6.01).

The history of recurrent back pain was the same for concrete workers and controls. An average worker has back pain for 7.4 years which started at the age of 34.7 years. No significant differences were observed in the frequency and duration of back pain episodes. Among all workers with back pain in this study 42%[35] had had these complaints only once or twice during the preceding year of the investigation. The distribution of the mean duration of back pain episodes was as follows: 50% had back pain less than 8 days, 20% had pain lasting 8-30 days and 30% reported pain episodes of more than 30 days.

Among the workers with back pain 37%[31] had had at least one period of sick leave due to back pain in the past 12 months. The duration of these sick leave periods was equally distributed among these concrete workers and controls: 10% reported a sick leave period lasting 1-7 days, 35% a period of 8-30 days, and 55% a sick leave period of more than 30 days.

The proportion of workers with back pain who sought medical care by visiting a general practitioner, an occupational physician, or a physiotherapist was 46%.[38] Medical care was more frequently used by workers with increasing duration of a back pain episode ($\theta = 0.55$, $P<0.001$), the occurrence of at least one period of sick leave due to back pain in the past 12 month ($\theta = 0.62$, $P<0.001$), increasing frequency of sick leave periods due to back pain ($\theta = 0.57$, $P<0.001$) and increasing duration of sick leave due to back pain ($\theta = 0.64$, $P<0.001$).

Relations between postural load and symptoms

The study concerned relations between risk factors in previous and present jobs, especially postural load, and the present complaints of back pain. Most risk factors were measured as dichotomous variables. The postural load was summarized in a posture index, ranking the occupational groups according to the proportion of postures classified as action category 2 or higher. The group steel benders were given rank 6, the group operators rank 5, and so on. Since the posture index is entirely based on the time spent in a working posture with the back in a bent and/or twisted position, a seperate lifting index was constructed. The ranking of occupational groups was derived from the percentage of time lifting loads.

The analysis started with examining univariate associations between risk factors and present complaints of back pain. The 17 concrete workers who

Table 9-5 Univariate associations between risk factors in present and previous working conditions and present complaints of back pain among the workers in the study population (n=149)

Risk factor	Measure of association rho coefficient (θ)	Significance level P
Present working conditions		
posture index	0.17	0.04
exposure to whole-body vibration	0.21	0.01
Previous working conditions		
heavy physical work in previous jobs	0.17	0.04

reported to have experienced back pain before starting their work in the present factory were excluded from the analysis. Table 9-5 summarizes the significant crude associations, presenting the rho coefficient as measure of association. Significant relations were found for the posture index, exposure to whole-body vibration and heavy physical work in previous jobs. In the univariate analyses the lifting index as well as individual characteristics like age, height and weight were not found to be a significant indicator.

The respective weights of occupational and individual risk factors for back pain were studied in multivariate unconditional logistic regression analysis. The regression coefficients (β) of the logistic models are presented in table 9-6 and show that only the posture index (model I) and exposure to whole-body vibration (model II) have a significant effect. Since the posture index and the presence of vibration were strongly correlated ($\theta = 0.48$, $P<0.001$) it was not possible to include both risk factors in one logistic model. In a seperate logistic regression analysis only including workers without exposure to whole-body vibration the regression coefficient of posture index had almost exactly the same magnitude as the regression coefficient in model I. This result suggest that postural load as well as whole-body vibration are important risk factors for the prevalence of back pain.

In both models the univariate association between heavy physical work in previous jobs and back pain disappeared. None of the other possible risk factors like individual characteristics and the lifting index contributed to the occurrence of back pain. In order to analyse the possible role of other factors

Table 9-6 Coefficients and significance levels of estimates for the logistic models with present complaints of back pain as dependent variable

Variables in equation	Model I (n=149)		Model II (n=149)	
	β	P	β	P
Intercept	-1.15	0.14	-0.62	0.37
Posture index (6 levels)	0.21	0.04		
Whole-body vibration (2 levels)			1.12	0.01
Age (continuous)	0.01	0.67	0.004	0.78

associated with the two factories under study, like general working conditions and attitude to health and safety problems, a dummy variable was introduced with value 1 for the concrete factory and value 0 for the engineering factory. This dummy variable was far from significant in both logistic models.

Discussion

This study has shown that 59% of the workers in the concrete manufacturing plant reported complaints of back pain in the past 12 months preceding the investigation. This one-year prevalence of back pain is high compared to the life-time prevalence of 51% in a male Dutch population with the same age distribution.[13] Among the persons with back pain in this general population, 20% had visited a physisican for reasons of back pain. The proportion of concrete workers with back pain who sought medical care during the previous 12 months was 46%. This remarkable higher percentage suggest that for many concrete workers their complaints of back pain caused a considerable problem.

After adjusting for workers who entered the factory with already existing back complaints, the concrete workers had a higher prevalence of back pain than maintenance workers of an engineering factory. The estimated odds ratio was 2.80 (with confidence interval 1.31 - 6.01). An important question is whether this excess of back pain in concrete workers is (partly) due to their work conditions.

In many epidemiologic studies it has been shown that heavy physical work is an important risk factor for back pain.[14,15] Quantitative evaluation of the risk factor heavy physical work is problematic since specific components in postural load responsible for back pain have not yet been clearly defined.[16] In this study the OWAS method was used to provide a basis for the estimation of postural load of the workers involved. This observation method appeared to be quite suitable since almost every working posture could be described within the definition and classification of working postures therein. In the analysis of possible associations between postural load and the prevalence of back pain, the choice was made to use the "percentage of time working in a harmful posture" (ie OWAS action category > 1) as measure of postural load. In this particular study this measure is completely interchangeable with the 'percentage of time working with the back in a bent and/or twisted position'.

A comparison of the distribution of postures during an average workday revealed that the time spent working with a bent and/or twisted position of the back, was significantly higher among the concrete workers than the controls. The importance of the position of the back as a risk factor for the prevalence of back pain was strengthened by the results of the logistic regression analysis. An index for postural load was constructed, using an ordinal scale for rating the average proportion of poor postures of the back in each occupational group. This postural index could partly explain the prevalence of back pain within each occupational group. Therefore, the time spent with a bent and/or twisted posture of the back can be regarded as a risk factor for back pain. This finding is in agreement with knowledge that prolonged static load of the back is probably the major factor in modern working life in causing work-related back disorders.[17] Other well-known risk factors in static postural load, such as prolonged standing[18] or sitting,[19] showed no positive relation with the prevalence of back pain. Exposure to whole-body vibration was another contributory factor for the elevated prevalence of back pain among concrete workers. Whole-body vibration is regarded to be one of the decisive conditions for (low) back pain.[20] No other possible risk factor was found to have a significant influence on the prevelance of back pain.

A reasonable conclusion from this study is that the excess prevalence of back pain among concrete workers can be considered to partly be the result of their work conditions, especially postural load. The OWAS method suggest that the combination of bending and/or twisting of the back during work is an important risk factor for back pain. A second risk factor for back pain among concrete workers was exposure to whole-body vibration, becuase of working with vibrotables.

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10 Occupational risk factors for low-back pain among sedentary workers*

Abstract

In a cross-sectional study the relationship of low-back pain and sedentary work was eximaned among crane operators (N=94), straddle-carrier drivers (N=95) and a reference group of office workers (N=86), aged 25-60 years. Information about history of low-back pain, individual characteristics and working conditions in past and present was obtained by a standardized interview. Assessment of postural load on the back was performed by observation of non-neutral postures of the trunk during normal work activities. Measurements of exposure to whole-body vibration in cranes and straddle-carriers were conducted. The 12-month prevalence of low-back pain among crane operators was 50%, among straddle-carrier drivers 44%, and among office workers 34%. After adjustment for age and confounders the odds ratio for low-back pain among crane operators was 3.29 (95% CI 1.52-7.12), and among straddle-carrier drivers 2.51 (95% CI 1.17-5.38). In both occupations the daily exposure to whole-body vibration was low, and therefore not considered an important risk factor for low-back pain in this study. The observations showed that non-neutral postures of the trunk were frequently adopted among all workers. The results of this study suggest that sustained sedentary work in a forced non-neutral trunk posture is a risk factor for low-back pain

Introduction

Numerous reports have been published on the occurrence of low-back pain in different occupational populations and working conditions.[1,2] Epidemiologic studies on low-back pain have shown clear relationships with heavy physical work,[3-5] frequent bending and twisting,[6-8] and lifting.[9-11] Contradictory observations have been reported on sedentary labor as risk factor for low-back pain. Some studies have indicated that workers with jobs that demand prolonged sitting have an increased risk of low-back pain.[12,13]

* Burdorf A, Naaktgeboren B, De Groot HCWM. *J Occup Med* (submitted)

Others have not been able to detect such relationship.[3,14] Although conclusive epidemiologic evidence is lacking, a relationship between sitting and low-back pain is biologically plausible. Sitting leads to an increase of disc pressure and is often associated with sustained static loading of the lumbar spine and surrounding tissues.[1,15] Both factors are considered to play a role in the causality of low-back pain.[1,16]

The limited agreement on sedentary work as risk factor for occupational low-back pain may be partly explained by the common use of job titles in epidemiologic studies as proxy for postural load on the back.[17] Sedentary work often involves conditions which can be assumed to increase the risk for low-back pain: static trunk postures such as forward flexion and rotation of the trunk and exposure to whole-body vibration.[16] Therefore, a survey was conducted in three occupational groups with sedentary labor, with special emphasis on assessment of exposure to risk factors for low-back pain associated with sedentary work.

The objectives of the cross-sectional study were to investigate the prevalence of low-back pain in three groups of sedentary workers, to clarify the physical demands of their work, and to determine the risk factors connected with increased prevalence of low-back pain.

Materials and methods

Study population

The study population consisted of male workers of a large transport company in the Port of Rotterdam. Three categories of workers performing sedentary work were selected: (1) crane operators, (2) straddle-carrier drivers, and (3) office workers. The task of the operators of overhead travelling cranes is to load and unload freight containers from the ship to the quay. In normal conditions about 40 to 60 containers are handled every hour. The main task of the straddle-carrier drivers is the transport of freight containers from the quay to the stack. About 30 to 40 containers can be handled every hour. The activities of the office workers involved normal clerical tasks, mainly performed in sedentary posture at a desk.

Company records were used to select the subjects for study, the criteria being employed for at least 12 months in the current job and being aged between 25 and 60 years. Office workers with a history of employment as crane operator or straddle-carrier driver were excluded. Of each category a sample of 100 subjects of the current workforce was randomly selected.

Data collection
Between December 1, 1990 and February 28, 1991 the selected 300 men were invited by letter to participate in the survey. Data were collected by means of a standardized interview by two physicians at the medical service on site. The questionnaire used during this interview consisted of four major sections focusing on various aspects of the work environment and complaints of low-back pain. The first section included questions about individual characteristics like age, height and weight. The second section covered occupational history in the current and previous companies. The information on occupational titles and job categories in the past was used by the authors to assign the presence or absence of risk factors to the subjects with previous jobs. The following risk factors were distinguished: prolonged sitting more than six hours per day; exposure to whole-body vibration exceeding 0.10 m s^{-2} for four hours or more; heavy physical work defined as manual labor with frequently lifting activities and other forceful movements. A third section requested information on various aspects of pain in the back. The questions in this section were derived from the standardized Nordic questionnaire for the analysis of musculoskeletal symptoms.[18] 'Low-back pain' was defined as pain located in the lumbar region which had persisted for at least a few hours during the past 12 months. Questions on the natural history of low-back pain were used to assess the time of onset of the complaints and the severity of the current complaints. The fourth section aimed at describing the occurrence at work of specific physical hazards like cold and draught, and psychological stress factors like working under severe pressure and job satisfaction. The presence of these risk factors were based on self-assessment of the subjects interviewed.

Measurements of exposure to risk factors for low-back pain were concentrated on whole-body vibration and postural load. Exposure to whole-body vibration at the workplace was measured by means of a vibration meter and a piezoelectric accelerometer. The frequency range of measurement was from 1 to 80 Hz (1/3 octave bands) and frequency-weighted accelerations (root-mean-square values) in the three separate directions were obtained by applying the weighting factors recommended by the International Organization for Standardization.[19] Measurements were performed in 20 cranes (79 measurements) and 21 straddle-carriers (112 measurements) under different working conditions. All different types of cranes and straddle-carriers were included in the measurement program. The exposure measure presented is the frequency-weighted acceleration (m s^{-2}), averaged over 5 minutes. The mean value of the measurements in the cranes and in the straddle-carriers were assigned to all vehicle operators within each occupational title group.

Exposure to postural load of the lower back was measured by means of the Ovako working posture analysing system (OWAS).[20] In this method, workers are observed while executing their specific tasks. Defined postures and movements were recorded, like sitting, standing and walking, and the position of the trunk. Deviations from straight upright posture of the trunk were broken down into three non-neutral postures: forward flexion (>20° bent forward), lateral flexion (>20° bent sideways), and axial rotation (>20° twisted). Since the application of an observational technique is a time-consuming, labor intensive and expensive activity, for feasibility reasons the choice was made to monitor a random sample of workers in each occupational title group under study. The mean exposure of the workers sampled is supposed to be equal to the average of the whole occupational title group. Twenty crane operators, 21 straddle-carrier drivers and 10 office workers were observed during their work. To avoid inter-observer variability all observations were performed by one person. Observations of each worker sampled were made every 20 s during two periods of 30 min, thus collecting 180 observations. The first period of observation was chosen in the first hours of the shift, the second period in the latest hours of the same shift. For the crane operators and straddle-carrier drivers the observational period covered 30 to 60 work cycles. The exposure measure presented is the percentage of the total working time spent in a specific working posture.

Data analysis

The measure of association used to relate occupational exposure and low-back pain was the odds ratio. The crane operators and the straddle-carrier drivers were regarded as exposure groups and the office workers as reference group. Since the influence of previous and present ergonomic exposures on the occurrence of low-back pain was of primary interest, only persons who reported that they had had no complaints of low-back pain before starting their current work were included in the statistical analysis.

Two general methods of statistical analysis were employed. Firstly, univariate associations between the occupational groups and the risk of low-back pain were studied. These analyses were performed by using the Mantel-Haenszel χ^2-statistics for association.[21,22]

Secondly, unconditional logistic regression analysis was employed to study the effect of occupation on low-back pain while simultaneously controlling for a number of possible confounders and to investigate interactions.[21,22] The covariates in the logistic analysis, initially examined one by one, included a history of heavy physical work (yes/no), a history of exposure to whole-body vibration (yes/no), a history of work requiring prolonged sitting (yes/no), cold (yes/no) and draught (yes/no) in the current job, and working under severe pressure (yes/no) and job satisfaction (yes/no) in the current job. The continuous variables age, height, weight, duration of total employment and duration of employment in the current company and the current job were categorized into three strata. This procedure was chosen to allow the information about each level of the categorized variables to be used to generate effect estimates that are not constrained to follow an exponential relation to low-back pain.[23] The logistic model was supplemented with interaction terms that involved the product of exposure (occupation) and the covariates. Only models with a two-factor interaction term were considered. Likelihood ratio tests and significance levels of variables were used to judge the importance of variables included in or removed from the model. Variables were retained if their level of significance was below 0.05. Since age may influence the occurrence of low-back pain, it was included in each model, regardless of the level of significance. The final logistic models were used to obtain adjusted odds ratios and 95 percent confidence intervals.[21,22] Confidence intervals for the adjusted odds ratios were determined by the asymptotic maximum-likelihood method.[22]

Results

Of the 300 workers invited to participate in this study, 275 completed the interview, yielding an overall response of 92 percent. Small, insignificant differences in response were present among crane operators (94%), straddle-carrier drivers (95%) and office workers (86%).

Some characteristics of the three occupational groups are shown in table 10-1. The individual characteristics examined did not differ among the groups.

Table 10-1 Comparison of individual characteristics and working experience for crane operators, straddle-carrier drivers and office workers

	Crane operators (N=94)		Straddle-carrier drivers (N=95)		Office workers (N=86)	
	Mean	SD‡	Mean	SD	Mean	SD
Individual characteristics						
Age (years)	42.5	6.8	41.6	6.9	40.4	7.5
Height (cm)	179.5	6.4	178.9	7.0	180.6	7.7
Weight (kg)	84.3	10.3	84.6	11.6	81.3	11.8
Work history						
Total working experience (years)*†	26.0	7.8	24.7	8.7	16.6	11.0
Total working experience in current company (years)†	13.2	4.2	10.8	4.9	9.8	9.8
Employment in current job (years)	8.1	4.9	7.6	3.9	8.8	7.2

* Student *t*-test, $P<0.05$; straddle-carrier drivers compared with office workers
† Student *t*-test, $P<0.05$; crane operators compared with office workers
‡ SD, standard deviation

Table 10-2 Presence of risk factors of low-back pain in previous working conditions of crane operators, straddle-carrier drivers and office workers

Occupational risk factor	Crane operators (N=94)		Straddle-carrier drivers (N=95)		Office workers (N=86)	
	No.	%	No.	%	No.	%
Work in previous companies	90	96	91	96	59	69
Whole-body vibration*†	46	51	48	53	3	5
Prolonged sedentary posture‡	52	58	53	58	45	76
Heavy physical work*†	36	40	36	40	10	17
Work in previous jobs in the current company	89	95	84	88	48	56
Whole-body vibration*†	61	69	58	69	1	2
Prolonged sedentary posture	61	69	66	79	40	83
Heavy physical work*†	28	31	18	21	4	8

* χ^2-test, $P<0.05$; straddle-carrier drivers compared with office workers
† χ^2-test, $P<0.05$; crane operators compared with office workers
‡ χ^2-test, $P<0.05$; office workers compared with crane operators and straddle-carrier drivers

The distribution of length of employment in the current job was the same for all three groups. However, marked differences were found in work history. The vast majority of the crane operators and straddle-carrier drivers had had previous jobs in other companies, which was significantly higher than the proportion among the office workers (see table 10-2). The same difference was observed for work history in the current company. These differences in work history were also reflected in total working experience; crane operators and straddle-carrier drivers had been employed significantly longer than the office workers. When changing job, the office workers predominantly moved from one clerical job to another. The crane operators and straddle-carrier drivers mainly worked as driver, either in the current company or in previous companies. The distribution of occupational risk factors in previous working conditions is presented for each occupational group in table 10-2. As shown in this table, more crane operators and straddle-carrier drivers had previous jobs with heavy physical demands and exposure to whole-body vibration compared to the reference group of office workers.

The results of the measurements of exposure to risk factors of low-back pain in the current occupation are shown in table 10-3. A total of 217 whole-body vibration measurements was performed. The largest accelerations of cranes and straddle-carriers were measured in the *z*-axis, which is the vertical direction. Accelerations in both horizontal directions were slightly lower. The mean acceleration in each direction experienced by the straddle-carrier drivers was significantly higher than that experienced by the crane operators. Acceleration levels of different types of cranes and straddle-carrier vehicles and of various working methods and handling activities were

Table 10-3 Comparison of the measurements of exposure to risk factors of low-back pain in the working environment of crane operators, straddle-carrier drivers and office workers

Occupational risk factor	Crane operators (N=20)		Straddle-carrier drivers (N=21)		Office workers (N=10)	
	Mean	SD‡	Mean	SD	Mean	SD
Whole-body vibration						
z-axis ($m.s^{-2}$)*†	0.17	0.05	0.22	0.07	0	-
y-axis ($m.s^{-2}$)*†	0.11	0.03	0.16	0.04	0	-
x-axis ($m.s^{-2}$)*†	0.15	0.04	0.18	0.05	0	-
Non-neutral trunk postures						
Flexion (% of daily worktime)¶	52.1	30.5	8.7	9.4	44.7	26.2
Lateral flexion (% of daily worktime)¶	1.5	3.1	20.7	16.0	5.8	6.2
Axial rotation (% of daily worktime)¶	4.4	6.3	64.3	24.5	10.1	9.1
Sedentary work						
(% of daily worktime)¶	86.6	12.5	100	0	83.0	6.2

* Student *t*-test, P<0.05; straddle-carrier drivers compared with office workers
† Student *t*-test, P<0.05; crane operators compared with office workers
¶ Wilcoxon rank sum test, P<0.05; straddle-carrier drivers compared with office workers
‡ SD, standard deviation

predominantly within 25% of the mean acceleration levels presented in table 10-3.

A total of 9540 observations was collected during ten workdays, covering 53 hours of work activities of 53 workers. Non-neutral trunk postures were frequently observed among all workers. The straddle-carrier drivers, compared with the office workers, spent a significantly greater proportion of the daily worktime with the trunk in both rotation (64% versus 10%) and lateral flexion (21% versus 10%), and a significantly lower proportion with the trunk in flexion (9% versus 45%). The distribution of trunk postures during an average workday did not differ between the crane operators and the office workers. All estimates of the percentage of daily worktime in a specified non-neutral posture demonstrated large standard deviations in each occupational group. These large standard deviations reflected the great variability in work postures among the workers. During normal working activities the straddle-carrier drivers worked in sedentary posture all through their shift. This is significantly higher compared with the office workers, who worked, on average, in sedentary posture for about 83% of their total working time. Among the crane operators, 50% worked in sedentary posture all through their shift of eight hours. The remaining 50% worked half-time as crane operator and the other half of the shift as crane helpers. This latter job implied standing and, to a lesser extent, walking for two hours and sitting during another two hours. Office workers as well as crane operators showed no

Table 10-4 Prevalence of low-back pain in the past 12 months among crane operators, straddle-carrier drivers and office workers

Complaint	Crane operators (N=94)		Straddle-carrier drivers (N=95)		Office workers (N=86)	
	No.	%	No.	%	No.	%
Subjects with low-back pain	47†	50	42	44	29	34
Subjects with onset of low-back pain after starting work in the current company	38†	40	35	37	20	23
Subjects with onset of low-back pain after starting work in the current job	38†	40	29	31	17	20
Subjects with onset of severe low-back pain‡ after starting work in the current job	27†	29	21*	22	9	10

* χ^2-test, $P<0.05$; straddle-carrier drivers compared with office workers
† χ^2-test, $P<0.05$; crane operators compared with office workers
‡ severe low-back-pain; history of at least six separate episodes lasting for at least 30 days in total within the year preceding the date of interview

significant differences in frequencies of non-neutral postures while sitting and while standing/walking.

Table 10-4 shows the collected information on natural history and severity of low-back pain in the three occupational groups. The prevalence of reported complaints of low-back pain in the past 12 months was significantly higher among the crane operators than among the office workers, respectively 50% and 34%. Significant differences were also present between both groups for subjects with onset of low-back pain after starting work in the current company and in the current job. Both the straddle-carrier drivers and the crane operators complained more often than the office workers about severe low-back pain. Severe low-back pain was defined in the interview as a history of at least six separate episodes, lasting for at least 30 days in total within the year preceding the date of the interview.

The number of low-back pain episodes did not differ significantly among the three groups. Among subjects with low-back pain 52 (44%) had experienced less than 5 episodes in the past 12 months, 10 (8%) had experienced 5 to 10 episodes and the remaining 56 (48%) had experienced at least 10 episodes of low-back pain. The total duration of low-back pain episodes within the past 12 months was equally distributed among the three groups; 26% had pain for 7 days or less, 26% had pain lasting 8-30 days, 31% had pain lasting more than 30 days but not daily, and 17% reported daily low-back pain. The history of recurrent low-back pain also was the same for the three occupational groups. Subjects with low-back pain had this complaint for 8.3 (SD 7.0) years.

In the univariate analyses the odds ratio for low-back pain among straddle-carrier drivers was 1.84 (95% CI 0.91-3.71) and for crane operators

Table 10-5 Unconditional logistic regression estimates of the odds ratios for low-back pain among crane operators and straddle-carrier drivers with office workers as reference group, adjusted for age and confounders

	Crane operators		Straddle-carrier drivers	
	Odds ratio	95% CI‡	Odds ratio	95% CI
Occupation	3.29*	(1.52-7.12)	2.51*	(1.17-5.38)
Working under severe pressure	1.51	(0.69-3.29)	3.44*	(1.32-8.95)
Age				
20-35 years	1.00		1.00	
36-45 years	1.09	(0.44-2.74)	1.33	(0.53-3.35)
46-60 years	0.91	(0.34-2.47)	1.29	(0.47-3.60)

* $P<0.05$
‡ 95% CI; 95% confidence interval

2.71 (95% CI 1.37-5.36). The logistic regression models for both occupations are presented in table 10-5. These models were arrived at after fitting models to the primary exposure variable (occupation), age and important confounding covariates. Covariates studied were individual characteristics, work-related risk factors in previous jobs (as assigned by the authors), and work-related risk factors pertaining to the current job (as answered to the questionnaire). None but one of the independent variables or interaction terms significantly contributed to the logistic model or resulted in any marked change of the point estimate for the effect of occupation. The covariate working under severe pressure was included in both logistic models since it considerably influenced the estimated odds ratios. None of the age groups had a significant contribution to the occurrence of low-back pain in the past 12 months. The adjusted odds ratio for crane operators versus office workers was 3.29 (95% CI 1.52-7.12). The adjusted odds ratio for straddle-carrier drivers versus office workers was 2.51 (95% CI 1.17-5.38).

In each occupational group the relationship between low-back pain and duration of employment in the current job was studied. Duration of employment was coded as 0 (0-5 years), 1 (5-10 years), or 2 (more than 10 years). Although in each occupational group a slight trend for duration of employment in the current job and the occurrence of low-back pain first experienced in the current job was observed, none of these trends were significant.

Discussion

This cross-sectional study focused on the relationship of postural load and low-back pain. In occupational epidemiology on low-back pain measurement of postural load and health outcome both are a problem.[24,25] Low-back pain is a subjective phenomenon which is difficult to define. There is a broad range in the use of the term low-back pain in epidemiologic studies, which hinders the comparibility between published data. Therefore, the choice was made in this study to apply the standardized Nordic questionnaire for musculoskeletal symptoms, including complaints of low-back pain in the past 12 months.[18]

The 12-month prevalence of low-back pain among crane operators was 50%, among straddle-carrier drivers 44%, and among office workers 34%. Studies of comparable occupations, applying the same questionnaire, showed a 12-month prevalence of low-back pain among crane operators in a steel factory of 61%[26] and a 12-month prevalence of low-back trouble among forklift truck drivers of 65%.[27] These reported prevalences are considerable higher than the prevalences of low-back pain in the present study. Differences in distribution of age and duration of employment cannot explain this result.

Quantitative description of exposure to postural load in occupational situations has many methodological difficulties and limitations.[28] Alternative approaches are based upon simplified methods to document ergonomic exposures. A method increasingly applied are observational techniques. In this study an observational technique was chosen which has been used by several research groups.[29-32] The characterization of postural load due to non-neutral postures during the selected observation period of one hour was assumed to describe accurately the postural load of the observed subject during an average workday. However, large differences were found within subjects performing the same tasks and between subjects of the same occupational group. These differences may partly be explained by variations in the tasks performed and the subjects' anthropometry and work methods. This prompts for longer periods of observation over the workday and for observation of each subject under study in order to estimate postural load at individual level; an extensive measurement program would be the result.

For reasons of feasibility it was decided to randomly select subjects in each occupational group. Within each occupational group the distribution of postural load on the back of the observed subjects was used as proxy of the underlying distribution of postural load on the back of all subjects within each occupational group. Due to this measurement strategy the presented parameters of exposure to non-neutral trunk postures only characterize the average postural load of subjects with the same job title. It was not possible to use asessments of individual postural load in the logistic analysis. Therefore, the three occupational groups were treated as homogenous exposure groups with regard to postural load on the back.

The results of the observations clearly showed that non-neutral postures are frequently adopted among all workers. Flexion of the trunk appeared to be the main factor increasing the postural load among crane operators and office workers. Axial rotation of the trunk elevated the postural load of the straddle-carrier drivers. Crane operators and straddle-carrier drivers also experienced exposure to whole-body vibration.

Clear differences in presence of low-back pain in the 12 months preceding the investigation were observed between the crane operators and straddle-carrier drivers and the office workers. The (adjusted) odds ratio for crane operators versus office workers was 3.29, the (adjusted) odds ratio for straddle-carrier drivers was 2.51. Individual characteristics could not account for these associations, neither could working conditions in previous jobs of the workers.

The question can be raised whether the current exposure to whole-body vibration can explain the observed differences in low-back pain among the three groups of sedentary workers. The measurement of whole-body vibration indicated that crane operators and straddle-carrier drivers were exposed to a frequency-weighted acceleration over an 8 h shift of roughly 0.20 m s^{-2}. Since the variation of exposure to vibration due to different cranes and straddle-carriers and to various working conditions was small, this value may be regarded as a reliable estimate of the daily average exposure to whole-body vibration over the past years of all crane operators and straddle-carrier drivers. The acceleration level of 0.20 m s^{-2} is well below the fatigue-decreased proficiency boundary of 0.32 m s^{-2} beyond which exposure to vibration might lead to acute effects, such as muscle fatigue.[19] Although whole-body vibration can be a decisive condition for low-back pain,[16] the scarce epidemiologic data available suggest that in occupational groups with long-term exposure to whole-body vibration below 0.20 m s^{-2} other working conditions must be held responsible for elevated prevalences of low-back pain, if present.[33,34]

The occupational exposure to non-neutral trunk postures may also be looked upon as an explanatory factor for the occurrence of low-back pain. In case of postural load, unexposed subjects do not exist. In this study among three groups of sedentary workers the office workers were used as reference group. They spent, on average, a considerable proportion of the workday with the trunk in a non-neutral position, mainly due to flexion. Their postural load seems comparable to that of the crane operators who were found to maintain mainly flexion trunk postures as well. The straddle-carrier drivers showed a different distribution of trunk postures, they spent a considerable proportion of the workday with the trunk in rotated position. In general, the postural load as assessed by percentage of time with a specific non-neutral trunk posture does not indicate strong differences among the occupational groups.

However, the distribution of non-neutral postures may not accurately reflect the static loading of the lumbar spine within each occupational group. Static load on the back can by caused by maintaining a fixed posture over several hours. It is known to be deleterious to low-back pain.[35] In case of the crane operators and straddle-carrier drivers postural change was severely limited in their working conditions. Both occupations require an individual to sit for at least four hours in a confined space that prohibits standing or other efforts to changing postural position. This sustained work in a forced position is likely to result in a high static load on the trunk. In contrast, the sedentary activities of the office workers allowed them to change trunk posture whenever they wanted. Moreover, their activities required them to stand or walk during 17% of the workday. These periods of standing or walking were distributed in several short periods over the workday. This mix of sitting and standing postures will reduce low-back pain by shifting the strain on certain muscle groups.[36] Therefore, the differences in the static load on the back between the crane operators and straddle-carrier drivers and the office workers may play an important role in the elevated prevalences of low-back pain among the crane operators and the straddle-carrier drivers. In future studies this particular aspect of postural load on the back deserves greater attention.

An alternative hypothesis could be that the observed differences can be reduced to differences in education and social class. Some evidence has been presented that low-back pain is more common in the lower than in the higher social classes.[37] However, education and working conditions are difficult to disentangle since these factors may co-vary; jobs with physically heavy, monotonous and repetitive work are usually performed by lower-educated persons. For this study, a sufficiently large group of office workers belonging to the same social class as crane operators and straddle-carrier drivers could not be found. The working tasks of the office workers were more qualified and, therefore, the majority of the office workers were better educated and belonging to a higher social class. Available evidence from a large Dutch study in the general population suggests no distinct relationship between the occurrence of low-back pain and educational level and/or social class.[38] Although the possibility cannot be ruled out, it is not likely that differences in education and social class among the three occupational groups in this study account for the elevated prevalence of low-back pain in the blue-collar workers.

The possibility of differences in 'healthy worker selection' out of the three occupational groups under study should be considered. In table 10-4, the additional information on natural history of low-back pain among the subjects showed that the percentage of the workforce with low-back pain when changing company or job is equal among the three occupational groups. Therefore, a strong selection process of workers without low-back pain prior to the current job is not very likely in this study. However, to avoid this type of bias only subjects with onset of low-back pain in the current job were included in the statistical analysis. Bias is still possible since selection during the course of the current employment could differ among the three occupational groups. The odds ratios could be underestimated if the self-selection out of employment of workers with low-back pain was stronger among the crane operators and straddle-carrier drivers than among the office workers. Vice versa, associations would be overestimates if office workers with low-back pain are more eligible to change job than other workers with low-back pain. There is some evidence that such a selection effect had not occurred in the study population since the history of recurrent low-back pain did not differ among the three occupational group. Moreover, in each occupational group the occurrence of low-back pain was positively associated with duration of employment, although not significant, and the magnitude of these relationships was comparable.

In cross-sectional studies it is not possible to determine the relationship between working conditions and the development of low-back pain. However, the results of this study suggest that sedentary work in a forced non-neutral trunk posture with limited posibilities to change postural position is a risk factor for low-back pain.

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Concluding remarks

Current strategies for assessing exposure to postural load on the back during working activities still need improvement. An important feature in future measurement strategies is control of the variability of exposure

11 Concluding remarks

Conclusions

The prevalence of (low-) back pain and its consequences for sickness leave and permanent disability has been thoroughly documented in many industrial populations (chapter 2). The magnitude of this problem demonstrates that there is a significant need for preventive activities. To institute primary preventive measures work-related factors have to be identified from which workers should be protected. Present ergonomic guidelines and recommendations are based primarily on anthropometric data and short-term effects like fatigue. Their validity and usefulness as predictors for the development of low-back pain can be seriously doubted. Therefore, epidemiologic studies are needed to identify risk factors at the workplace. Due to methodologic restrictions the conclusive evidence is limited, epidemiologic studies on low-back pain have shown relationships with frequent bending and twisting, lifting and whole-body vibration (chapter 2). Therefore, primary prevention could start by controlling weight and bulk of material being handled and the posture adopted at work. This thesis focuses on the role of postural load on the back in the etiology of low-back pain (chapter 3)

Unfortunately, the results of most studies cannot guide us towards adequate control strategies. In spite of the evidence associating low-back pain with a variety of working activities and postures, dose-response relations between low-back pain and risk factors at work are far from clear. For example, there are few criteria to define what is an 'adequate' posture or how long it is safe to maintain a specific posture. Inappropriate modes of measurement of exposure to risk factors may partly explain this lack of knowledge since methods of measurement of postural load on the back are poorly developed in occupational epidemiology. In chapter 3 an overview is presented on techniques and methods which can be applied in studying the workplace. Application of these measurement instruments is sparse. The review on exposure asessment in occupational epidemiologic studies in the past ten years concluded rather pessimistically that the most frequently used exposure variable was the job title (chapter 4).

The analysis of the sources of variability of exposure to postural load on the back, as described in chapter 5, revealed that there may be a great variation in work posture between workers performing exactly the same occupational task. Although two occupational title groups can have large, significant differences in their mean exposure to trunk flexion and rotation, misclassification may be considerable. In chapter 6 examples are given which indicate that substantial bias in the risk estimate can easily occur. Variability of exposure is of particular interest when one has to assess measures of exposure that are biologically relevant to the health outcome. In general, it seems reasonable to assume that the development of low-back pain due to postural load is linked with dose based on the cumulative postural load. It is remarkable to observe that variability of exposure to postural load during the workday and between workdays has not been addressed in the literature yet.

Several authors have stated that the challenge to develop valid and practical techniques for assessing exposure to postural load on the back is still open. This challenge has not been answered by the design of the definite measurement device, the magical panacea that guarantees quick, valid and cheap measurement of postural load on the back at the workplace. Instead, in chapters 7 and 8 the performance of four different measurement instruments was evaluated. In the first study the reliability of questionnaire methods was severely questioned. In the second study a frequently used observational technique was compared with a continuous registration of trunk posture. Although significant differences were found, it was concluded that the observational method seems reliable enough to warrant its use in large epidemiologic studies.

If an occupation is suspected of involving back-loading working conditions, a cross-sectional study may be carried out to assess the exposure to possible risk factors in the occupational groups under study and to measure the prevalence of low-back pain in each occupational group. This type of study can only provide a preliminary answer to the question of work-related factors introducing and aggravating the development of low-back pain. However, if an increased prevalence of low-back pain can be related to specific risk factors, these factors can be acted upon and preventive measures can be taken. This approach has been used in surveys among concrete workers (chapter 9) and among crane operators and straddle-carrier drivers (chapter 10). It is very difficult to point out work-related factors decisive to the development of low-back pain. When differences in postural load on the back among occupational groups can be demonstrated, preventive measures are warranted even if one cannot predict its influence on occurrence and natural course of low-back pain among the workers.

Recommendations

Certainly it would be nice to present some firm recommendations in this chapter which could guide to quantification of postural load on the back in occupational epidemiology. Alas, reality is often recalcitrant and too often scientific research can at best present a poor description of reality.

This thesis has addressed the great many difficulties of exposure assessment of postural load on the back and concomitant methodologic shortcomings in epidemiologic studies. Occupational epidemiology on low-back pain is still in its infancy and the best still has to be learned. Some important recommendations for the assessment of postural load on the back in occupational epidemiology may be derived from the previous chapters. In order of appearance, not in order of importance, they are:

1 In epidemiologic surveys on occupational low-back pain and its risk factors quantitative assessment of exposure to postural load on the back is needed;

2 It is necessary to develop measurement techniques that are able to record postures quickly and reliably at the workplace to a sufficient degree of accuracy. Existing measurement methods like direct observation and continuous measurement need further improvement for widespread applicability at the workplace;

3 At present, in prospective epidemiologic studies application of observational techniques is advocated in order to assess nature, degree and extent of postural load on the back. In retrospective epidemiologic studies observational techniques may be used to assess current exposure to postural load on the back in relevant occupational groups. The best practical means is to use the current exposure as proxy of the exposure in the past. A detailed occupational history is required to assess the total cumulative exposure to postural load on the back over the years;

4 An important feature of all future strategies to assess exposure to postural load on the back should be directed at the variability of exposure. Assessment of exposure has to take into account the variability of exposure in time (frequency and duration within and between shifts) and the variability of exposure between occupational groups and between and within workers in these occupational groups. Sources of variability of exposure can also guide towards control measures.

Appendix A

Trunk muscle strength measurements and prediction of low-back pain among workers*

Abstract

A pilot study was conducted to explore the relationship between the occurrence of low-back pain and parameters of trunk muscle strength. Dynamic strength measurements were performed among 53 male workers without low-back pain and 31 male workers with low-back pain. The average torque of lateral right movement was significantly lower for workers with low-back pain compared to those without. The application of discriminant analysis pointed out that another four strength measures contributed to the discriminant function. These measures were average power of lateral right movement, mean torque and maximum velocity during flexion and isometric strength during right rotation. The results showed that it was possible to find a linear combination of these discriminating variables that successfully allocated 68% to either the group of workers with low-back pain or the group without. Although this discriminatory power is too small to be of practical significance, the discriminant analysis performed reveals some promising features for further research.

Introduction

Low-back pain and associated disorders are one of the most common causes of morbidity in many industrial populations.[10] The majority of low-back impairments are still rightly classified as idiopathic since the underlying specific cause of symptoms is generally unknown.[2,3]

Subjective impressions are used many times to describe nature and severity of low-back complaints. Diagnostic criteria would be more meaningful if they were based on objective measurements rather than on description

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* Burdorf A, Van Riel M, Snijders C. Clin Biomech 1992;7:55-8

of existing complaints. Objective measurements of low-back disorders may also provide a better insight into the etiologic background of those disorders. In some recent studies it has been argued that dynamic loads on the lumbar spine are generally of greater importance than static loads.[4,5] Consequently, it has been postulated that dynamic measures of trunk muscle strength will play an important role in determining the stress components on the back.[4,5] Recent studies have made clear that dynamic strengths, not static strengths, are more appropriate measures of a person's physical capabilities.[6]

The introduction of modern dynamic measurement devices for trunk strength[7] offers a possibility to explore the relationship between objective dynamic trunk muscle strengths and back disorders in the field of occupational health. Therefore, a pilot study was undertaken to (i) test the relationship between trunk muscle strength parameters and the occurrence of low-back pain, and (ii) estimate the discriminatory power of multiple combinations of strength measures for the presence of low-back pain among workers performing dynamic labour.

Methods

In a steel factory 53 male subjects without a history of low-back pain (LBP) and 31 male subjects with a history of LBP were asked to participate in the study. None of them refused to volunteer. The subjects without a history of LBP were obtained by using a standardized questionnaire.[8]

Medical records of the occupational health service were surveyed for subjects with a recorded history of LBP sufficient enough to cause sick leave and to make them consult their doctor for treatment. The study was conducted in a maintenance shop of a steel factory. All subjects, regardless of their LBP status, carried out work which required standing, walking, lifting activities, and bending and/or rotating of the trunk during these activities.

Muscle trunk performance was measured with a computer-controlled triaxial dynamometer (B200 ISOSTATION) that provides constant resistance during movement in all cardinal planes independently. This device registers angular position and angular velocity of the trunk and strength of trunk muscles during lumbar flexion/extension, axial rotation and lateral bending.[7] This information is used to present parameters of torque, velocity and power of trunk movements in the three separate axes. Ranges of motion were also measured using the same device.

The subjects were asked to flex, extend, bend laterally side to side, and rotate left to right without any resistance being applied. The tests were performed with the subjects in upright standing posture and positioned to the device with pads and straps to restrain motion to the lumbar region, defined as T_{12}-S_1. During maximum dynamic performance, subjects were asked to move as hard and as fast as possible for five repetitions with a moderate and a high resistive load in the three separate axes. The parameters identified for the second, third and fourth repetitions were averaged for the maximum velocity and the average torque and power during both the movements with moderate and high resistive load. The resistances used during the movements are presented in table 1. The nine signals (three from every axis) were sampled by an A/D converter with a frequency of 50 Hz and stored by a personal computer. Validation and reproducibility of the B200 ISOSTATION has been tested in extend by several researchers.[7,9,10] In combination with this equipment a special software programme, BSAFE, was used which supplied the standard protocol for testing individuals.[9,10]

In order to test differences between the means of muscle strength parameters for workers with and without LBP, unpaired Student's *t*-tests were performed. The predictive potential of a multiplicity of strength parameters with respect to LBP was addressed with discriminant analysis. This statistical technique calculates how well it is possible to separate workers

Table 1 The variables of trunk muscle strength used in the discriminant analysis

Muscle trunk strength parameter	Number	Direction of motion	Resistance during measurements	SI units
Isometric strength	2	Lateral right and left	-	Nm
	4	Flexion and extension	-	Nm
	6	Rotation right and left	-	Nm
Maximum velocity	10	Lateral right and left	Moderate (54 Nm)	deg/s
			High (82 Nm)	deg/s
	14	Flexion and extension	Moderate (68 Nm)	deg/s
			High (136 Nm)	deg/s
	18	Rotation right and left	Moderate (41 Nm)	deg/s
			High (82 Nm)	deg/s
Average torque	22	Lateral right and left	Moderate (54 Nm)	Nm
			High (82 Nm)	Nm
	26	Flexion and extension	Moderate (68 Nm)	Nm
			High (136 Nm)	Nm
	30	Rotation right and left	Moderate (41 Nm)	Nm
			High (82 Nm)	Nm
Average power	34	Lateral right and left	Moderate (54 Nm)	Nm/s
			High (82 Nm)	Nm/s
	38	Flexion and extension	Moderate (68 Nm)	Nm/s
			High (136 Nm)	Nm/s
	42	Rotation right and left	Moderate (41 Nm)	Nm/s
			High (82 Nm)	Nm/s

with LBP from those without, given the measurements on muscle strength for these individuals, with adjustment for ranges of motion and personal characteristics like age, height and weight. The 42 muscle strength variables used in the discriminant analysis are described in table 1. Linear combinations of discriminating strength parameters were formed to classify subjects into both groups. Stepwise selection was used to find the set of variables that maximized discriminating power; variables with a significance level below 0.10 were rejected during analysis.[11] In this study, the analysis is restricted to the procedures needed to estimate the extent to which it is possible to express the known classification of low-back pain as a function of trunk muscle strength parameters.

Results

The subjects ranged in age between 20 and 60 years with an average of 35 years. No significant difference in age distribution was found between workers with LBP and those without; the mean height and weight did not differ significantly between the two groups.

Comparison of all variables of muscle strength and ranges of motion in the three planes showed that subjects with LBP had a significant lower average torque during lateral right movement with moderate resistance when compared to subjects without LBP, respectively 51.2 N m (SD 2.4 N m) and 52.5 N m (SD 2.1 N m). Significant differences were not observed between subjects with LBP and those without for any of the other variables of trunk muscle strength and ranges of motion.

The variables entered into the stepwise discriminant analysis were the 42 trunk muscle strength variables, three ranges of motion and the individual characteristics age, height and weight. A significant discriminant function was obtained (P<0.005) which accounted for 24% of the total variance in the data. Table 2 shows the significant variables with discriminatory power. Their standardized coefficients of the discriminant function are presented, which

Table 2 The significant variables retained in the discriminant analysis and their standardized coefficients

Muscle trunk strength parameter	Direction of motion	Resistance	Standardized coefficient
Isometric strength	Rotation right	-	0.91*
Maximum velocity	Flexion	High	-0.81*
Average torque	Lateral right	Moderate	-0.69**
	Flexion	Moderate	0.90**
Average power	Lateral right	Moderate	-0.69*

** P<0.05
* 0.05≤P<0.10

Table 3 The classification results for discriminant analysis in respects of groups of subjects with and without low-back pain

Actual group membership	Predicted group membership: Subjects without low-back pain	Subjects with low-back pain	
Subjects without low-back pain	**36** (68%)	17 (32%)	53
Subjects with low-back pain	10 (32%)	**21** (68%)	31

indicate the direction and relative contribution of the independent variables to the discriminating power. It can be seen that lower values for average torque and power in lateral right direction and for maximum velocity during flexion were associated with low-back pain. In contrast, higher values for average torque during flexion and for isometric strength during right rotation contributed positively to the probability of LBP. None of the parameters for range of motion and for individual characteristics showed a significant contribution to the power of the discriminant function.

Table 3 presents the classification results for all subjects. Over two-thirds of the subjects were correctly allocated to either the group of subjects with LBP or the group of subjects without. The proportion of subjects that would be classified correctly, purely by chance, is 0.50. The application of information on individual measurements of five trunk muscles strength parameters has raised the accuracy of classification from 50% to 68%.

Discussion and conclusion

This study has provided some evidence that trunk muscle strength measures can be used to discriminate between subjects with a history of LBP in the past 12 months and those without. Comparison of separate dynamic measurements between both groups only showed a significant difference for average torque during lateral right movement with moderate resistance. Multivariate analysis techniques can be used to explore the relationship between the presence of LBP and a mixture of different continuous independent variables,[2] like trunk muscle strength measures and individual characteristics. Since most strength measures are strongly correlated, discriminant analysis is an appropriate statistical technique for analysing the importance of these variables simultaneously.[11]

The discriminant analysis resulted in a significant discriminant function which could correctly allocate 68% of the subjects with LBP and also 68% of the subjects without LBP. This discriminant function can be regarded as a risk function measuring the risk of having had an episode of LBP in the previous 12 months. Since the proportion of erroneous classification of subjects is considerable, the information concerning trunk muscle strengths will be invaluable to any future decision making on the level of individual subjects, eg in pre-employment screening procedures.

The variables selected by the discriminant analysis only included trunk muscle strength parameters. Individual characteristics like age, height and body weight did not contribute to the distinction between those with and without LBP. Five out of 42 trunk muscle strength variables were found to have discriminatory power. The relative contribution of each variable is difficult to interpret, since positive as well as negative associations with the occurrence of LBP were observed. A firm statement on the direction of the relationship between trunk strength measures and low-back pain cannot be made. Contradictory results have been published with regard to the role of trunk extensors and flexors in individuals with LBP.[4,12] The same variety of results has been noted for differences in left side bending strength versus right side bending strength associated with the presence of LBP.[13,14] In conclusion, these findings clearly do not allow specific trunk muscle strength parameters to be considered as objective measures of LBP.

However, the results of this study suggest that discriminant analysis can offer a suitable approach for analysing the importance of trunk muscle strength parameters simultaneously. The hypothesis was supported that the occurrence of LBP can be objectively discriminated, with greater success than by chance, using the combination of specific trunk muscle strength parameters. Future research is planned to investigate whether the results presented are repeatable in other industrial populations and whether the method has any predictive value for first attacks of LBP.

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Appendix B

Epidemiologic study of low-back pain in crane operators*

Abstract

A survey among workers in a steel factory was conducted to determine the risk for low-back pain (LBP) among male crane operators. Crane operators (n=33) were matched for age with male controls (n=30) and examined for frequency and nature of LBP at the on-site medical service. Comparison between crane operators and controls showed a statistically significant odds ratio for LBP of 3.6. Although crane operators had been exposed more often to backstraining factors in previous occupations, in the employed logistic analysis only their current job explained the elevated occurrence of LBP. It is suggested that workers in sedentary position with exposure to whole-body vibration are at special risk for LBP. The results of this study provide evidence to recommend persons with a history of back complaints not to seek employment as crane operators.

Introduction

The relationship between occupation and the risk of developing low-back pain (LBP) is not well understood, although several risk factors are known. There is evidence that workers in heavy manual jobs have a higher prevalence of LBP than light manual workers. Heavy lifting, frequent bending, static work posture, and whole-body vibration have been identified as important factors for the onset of LBP.[1,2] Because of the multifactorial nature of the etiology of LBP, the importance of individual risk factors remains still unclear.[3]

In the work conditions of operators on overhead travelling cranes, several strenuous work postures occur which can be assumed to increase the risk for LBP. In order to maintain a good view of the lifting device and the transported goods, several trunk movements are required. Frequent twist-

* Burdorf A, Zondervan H. *Ergonomics* 1990;33:981-7

ing, deep sideways bendings and stooped positions occur frequently. Operating a crane demands a static sedentary position with hands held steady on the operating handles. While driving, the crane operators are exposed to whole-body vibration. On the basis of these known risk factors for LBP in the occupational environment of crane operators, a study was conducted to determine the frequency and nature of LBP and its occupational origin.

Materials and Methods

The survey population was restricted to subjects with a minimal duration of employment of one year, in order to avoid disturbances due to high labour turnover in the first months of employment. A total of 49 male operators working on overhead travelling cranes in a steel factory were invited by letter to take part in the study. They were asked to visit the occupational physician for a medical examination. For each crane operator entering the study, in the same week a control worker was asked to participate in the study. The control group worked as crane helpers, general operators or maintenance workers (n=281 in the factory) and were matched for age by a five year range. The workload between crane operators and controls was not comparable for all risk factors of LBP. The controls carried out moderate or heavy physical work with more standing, walking and lifting, and less sitting than crane operators.

All subjects were examined at the on-site medical service. Each person had to answer 15 questions from a medical and occupational questionnaire, administered by an occupational physician. The medical questionnaire, derived from the standarized Nordic questionnaire,[4] concerned frequency, duration, nature and medical treatment of LBP. The prevalence of LBP was estimated by using the standardized question: "Have you had pain in your lower back within the last twelve months?".[5] The presence of sciatica was derived from reported complaints on pain radiating to one or both legs. The occupational questionnaire was designed to obtain information of the earlier employment history and details of the present risk factors in the occupational environment in previous jobs, both inside and outside the steel company.

In the statistical analysis the comparisons between cases and controls were based on the χ^2-test and the Fisher's exact test for categorical variables and the *t*-test for continuous variables. Univariate logistic analyses were carried out in order to determine the importance of different variables for the occurrence of LBP. The regression coefficients in the logistic models were used to calculate odds ratios.[6] Finally, a multivariate logistic regression was performed with all variables that in previous steps of the logistic regression analyses showed statistical significance at $P<0.10$.

Table 1 Comparison of individual characteristics and working experience for crane operators and controls

	Crane operators (n=33)			Controls (n=30)		
Individual characteristics						
Age (yr)	42.2	±	7.2	41.3	±	10.7
Height (cm)*	176.5	±	7.4	171.1	±	7.5
Weight (kg)*	87.1	±	14.8	74.6	±	9.6
Work history						
Total working experience (yr)	24.5	±	7.5	24.3	±	11.7
Work at the steel factory (yr)	13.4	±	8.7	14.3	±	9.5
Years on a crane (yr)	13.0	±	6.4	-		

* *t*-test, $P<0.05$

Results

Thirty-three out of the 49 (67%) crane operators invited participated in this study. The selection of matched controls was easy because none of the controls approached personally refused to participate. During the analyses three control workers were excluded because they worked on a crane for more then 10% of their daily working time or they were exposed to whole-body vibration for more then one year in the past. Therefore, the final control group consisted of 30 subjects.

Table 1 summarizes personal characteristics and employment history of crane operators and controls. The mean height and weight differed significantly between the groups, the controls being shorter and lighter.

Table 2 shows that the 12-month prevalence of LBP among crane operators was significantly higher than among the controls, respectively 61% against 27%. Only two crane operators indicated that they had experienced their first attack of LBP before entering their current occupation. Among crane operators and controls with LBP, the proportion of subjects who reported symptoms of sciatica was the same. None of the subjects with LBP could remember a specific incident which caused the onset of symptoms of LBP.

Table 2 Prevalence of LBP and associated symptoms among crane operators and controls during the last 12 months

	Crane operators (n=33)		Controls (n=30)	
Subjects with low-back pain*	20	(61%)	8	(27%)
Subjects with low-back pain and sciatica	9	(27%)	3	(10%)
Subjects with onset of low-back pain before starting their present job	2	(6%)	0	

* χ^2 $P<0.05$

The duration of LBP episodes for each individual was estimated in number of days with LBP within the last month. None of the subjects with LBP indicated they were free of complaints during the month preceding the medical investigation. The duration of LBP episodes was equally distributed among both groups and 29% had pain for less then 2 days, 33% had pain lasting 3-7 days, 17% had pain lasting 1-3 weeks, and 21% reported daily LBP. The history of recurrent LBP of the persons reporting LBP in this study, was the same for crane operators and controls. The distribution was as follows: 12 (43%) had pain 1 year or less, 10 (36%) had pain for 2-5 years, 2 (7%) had pain for 6-10 years and 3 (11%) had LBP for 11-20 years. For one person the duration of complaints of LBP was unknown.

None of the subjects with LBP had been admitted to a hospital or had received back surgery. The proportion of persons with LBP who sought medical care was high. Most crane operators with LBP had visited a general practitioner (85%), used medicaments (55%), or received medical treatment from a physiotherapist (60%). Slightly fewer controls with LBP had visited a general practitioner (75%) or used medicaments (50%). Only 38% received medical treatment from a physiotherapist. The use of specific treatments was influenced by two factors. Subjects with LBP and symptoms of sciatica more often used medicaments than subjects without sciatica-like pain (32% versus 21%, $P<0.05$). Also treatment by a physiotherapist was more frequently used with increasing duration of pain ($r=0.45$, $P<0.02$).

The elevated risk for LBP among crane operators compared to controls may have been influenced by occupational exposures in the past. As shown in table 3, more crane operators had previous jobs with heavy physical demands compared to the controls. They also drove a vehicle more frequently in the past, and therefore were exposed to whole-body vibration and prolonged sitting more often. In identifying assocations between these risk factors in previous employment and the present complaints of LBP, univariate logistic analyses were carried out. The two crane operators who reported to have experienced LBP before starting their present job were excluded

Table 3 Estimated univariate odds ratios for low-back pain among crane operators (n=31) and controls (n=30) comparing workers with a specific risk factor in their work history and those without

	Crane operators			Controls		
	n	Odds Ratio	95%-confidence interval	n	Odds Ratio	95%-confidence interval
Prolonged sedentary posture	13	0.5	(0.1-2.2)	2	-	
Whole-body vibration	12	0.7	(0.1-3.1)	1	-	
Heavy physical work	23	4.0*	(0.8-21.2)	14	1.2	(0.2-6.1)
Frequent lifting	20	5.2**	(1.1-25.5)	17	0.7	(0.1-3.5)

* $0.05 \leq P < 0.10$
** $P<0.05$

from the analyses. Table 3 summarizes the data, presenting the logistic regression coefficient as odds ratio. Among crane operators heavy physical work and frequently lifting in the past were associated with LBP. These findings suggest a strong influence of back-straining factors in the past on the present probability of LBP. In the univariate analysis age was not found to be a significant indicator. Also in separate logistic analyses of both groups age did not contribute to the occurrence of LBP.

In the multivariate logistic regression exploring the effects of the significant risk factors in the past, possible confounding factors like age, height and weight, and the current crane work simultaneously, most associations disappeared. The high prevalence of LBP among crane operators was only explained by their current work on the crane (β=1.39, $P<0.05$). Length of employment as a crane operator was not associated with the first-time occurrence of LBP during crane work. Comparison between crane operators and controls with logistic regression showed a statistically significant odds ratio for LBP of 3.6 (95%-confidence interval of 1.2-10.6).

Discussion

In this study the prevalence of LBP was compared between crane operators and a control group. Ideally, the subjects in the control group should have worked in an occupational environment where risk factors for LBP did not occur. This is, however, not possible. The controls were exposed to several risk factors associated with a dynamic work load, such as heavy physical work and lifting and carrying of loads. Due to the presence of these risk factors for LBP in the control group, the estimated risk for LBP among crane operators will be underrated.

The response rate of 67% among crane operators may introduce serious difficulties in interpreting the association between work on a crane and the existence of LBP. It was found that among non-responding crane operators, workers with a history of long work absence were strongly overrepresented. Also, crane operators with sick leave during the period of investigation were less willing to visit the occupational physician voluntarily. These patterns are reflected in the figures of sick leave. Comparison of all invited crane operators and respondents showed significant differences in general sick leave (14.0% against 10.0%) and sick leave due to disorders of back, neck or shoulder (5.1% against 3.7%). The controls were selected by asking workers present in the factory on specific days to participate in the study, thereby excluding workers with sick leave on the specific day that a control worker was drawn from the personnel. It is clear that participating controls are expected to be in better health than other workers from the control departments. Comparison of all possible controls and the actually participating controls showed significant differences in general sick leave (15.1% against 10.3%) and sick leave due to disorders of back, neck or shoulder (1.6% against 1.0%). These figures of sick leave show the same selection process among crane operators and controls. Because the selection of cases and controls appears not to introduce systematic significant differences in the replies from both groups, it is believed that comparisons between both groups is not biased seriously.

The results of this study show that LBP occurred more often among crane operators than among controls. An age-adjusted odds ratio for LBP was found of 3.6. Although some striking differences in mean weight and height were observed, neither of these possible risk factors contributed significantly to the prevalence of LBP. This result indicates that work as crane operator is a much stronger risk factor for LBP than personal characteristics like height and weight.

Since a cross-sectional study has several methodological limitations this finding must be interpreted with some caution. The comparison between crane operators and controls is very sensitive to health selection during a worker's lifetime. It is not likely that bias has been introduced due to self-selection at initial employment. Almost all crane operators and controls reported that they entered their work without having ever experienced LBP earlier. Another possibility for bias is a difference in termination of employment, influenced by health status. Because duration of LBP is equally distributed among the two groups it is not likely that crane operators with LBP stay on the job whereas controls with LBP leave the workforce. The observed duration of LBP among the steel workers is short: 89% reported to have experienced pain for 5 years or less. In a recent survey of LBP among workers in different occupations it was noted that the majority of the workers with LBP (72%) had had this pain for 6 years or more although their mean age was 8 years less.[7] This suggest a rather fast turnover of workers with LBP in this steel factory. It is also a possible explanation for the lack of any association between length of employment and the occurrence of LBP.

In a cross-sectional study like this, it cannot be proved that the observed association between crane operation and the occurrence of LBP is causal. However, according to the results of this study it is suggested that the current job as crane operator accounts mainly for the onset of LBP. Although crane operators had been exposed more often to back-straining factors in their previous occupations, in the employed multivariate logistic analysis these risk factors showed no significant influence on the occurrence of LBP. Because most crane operators started their job without LBP, the elevated occurrence of LBP is not likely to be the result of already existing disorders of the spine which worsened due to the current work load and led to the onset of LBP.

In this study it seems that the combination of twisting and bending of the body in sedentary position and whole-body vibration is of greater importance for the occurrence of LBP than the risk factors in the dynamic work load of the control group. The exposure to whole-body vibration can be considered as an important contributing factor for LBP among crane operators. In overhead travelling cranes vibrations range in frequency from 1.5 to 8 Hz.[8] This frequency range is known to have a great potential damage because at the resonating frequency of 4.5 Hz the spinal system is absorbing and transmitting motion in excess of the input.[9]

In a few other studies complementary observations are reported. According to national statistics in Sweden crane drivers suffer disorders of the back more often as expected in comparison with the average for all other occupations.[10] In a study in the steel industry disability of crane operators caused by intervertebral disc disorders was found to be raised.[11] In other studies it was postulated that sedentary workers with exposure to whole-body vibration are at special risk for LBP.[3,12]

From the present study it can be assumed that crane operation is a contributing cause of LBP. Pre-employment screening is of little value in preventing development of low-back pain among crane operators. In some occupational health services in the Netherlands, heavy physical load is regarded as the most important factor for the onset of LBP. Workers with back complaints are sometimes advised to change job and to become crane operator because working in a sedentary position is believed to put less strain upon the lumbar spine. The results of this study provide sufficient evidence to recommend persons with a history of back complaints not to enter the job as crane operator.

There is a clear need for constructive improvements of crane cabins in order to decrease twisting and bending of the trunk and to diminish the exposure to whole-body vibration.

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Summary

In the past ten years numerous reports have been published on the occurrence of disorders of the back, mainly of low-back pain, in different occupational populations and working conditions. The majority of these studies is descriptive, that is they focus on incidence, prevalence and severity of back disorders. Although differences in classification and diagnostic criteria of back disorders hinder interpretation, the figures presented in the first chapters clearly show that (low-) back pain is one of the most frequent reasons for sickness leave and permanent disability in working populations.

Although the importance of work-related factors in the causation of low-back pain has been acknowledged, the relations between low-back pain and risk factors at work are far from clear. Inappropriate modes of measurements of exposure to risk factors may partly explain this lack of knowledge. In chapter 4 a review of occupational epidemiologic studies is presented which showed that, in general, the quality of exposure data is poor. In too many studies conclusions about hazards at work have been drawn upon differences in the prevalence of back disorders in several occupations without verified information on exposure to back loading factors in the occupations under study.

Exposure characterization has to take into account relevant strenuous postures, their frequency and duration within and between shifts, and intra- and interindividual variability during work activities. In chapter 5 an analysis of the variability of exposure showed that considerable overlaps in the occupational group's exposure distributions were present, despite the fact that the partitioning of the total variability of exposure showed that the occupational group status was the principal source of variance. When using the area of overlap of two exposure distributions as measure of misclassification of exposure, in chapter 6 it could be shown that this misclassification may easily attenuate the risk estimate in cross-sectional studies.

Two studies were conducted to investigate the agreement between measurement techniques of postural load often used in epidemiologic surveys. It was concluded that at this moment the observational method seems the best practical means to be used in large epidemiologic surveys. However, chapter 7 ends with the conclusion that the challenge to develop valid and practical techniques for assessing exposure to postural load is still open.

Two examples of epidemiologic surveys with application of an observational technique at the workplace are presented in chapters 9 and 10. Among workers in the manufacturing of prefabricated concrete elements it was found that the average time spent working with a bent and/or twisted position of the back contributed to the prevalence of low-back pain. The study in the transport company showed that the workers in the three jobs involved experienced substantial postural load on the back due to non-neutral postures. This study particularly showed how difficult it is to point out work-related factors decisive to the occurrence of low-back pain.

This thesis focuses on postural load on the back. Strategies for assessing postural load on the back during work activities are still in their early days. The last chapter ends with four recommendations for the assessment of postural load on the back in occupational epidemiologic surveys within the next future.

Samenvatting

In de afgelopen tien jaar zijn er vele publikaties verschenen over het voorkomen van aandoeningen van de rug, met name lage rugpijn, in verschillende beroepsgroepen en arbeidsomstandigheden. De meeste studies zijn descriptief van aard; incidentie, prevalentie en ernst van de aandoeningen van de rug worden bechreven. Hoewel verschillen in classificatie en diagnostische criteria de interpretatie bemoeilijken, laten de gepresenteerde gegevens in de eerste hoofdstukken duidelijk zien dat (lage) rugpijn een van de belangrijkste redenen voor ziekteverzuim en arbeidsongeschiktheid is.

Hoewel het belang van werk-gerelateerde factoren in het ontstaan van lage rugpijn is onderkend, zijn de relaties tussen lage rugpijn en risicofactoren in de arbeidssituatie grotendeels onbekend. Onvoldoende karakterisering van de blootstelling aan risicofactoren zal hieraan deels ten grondslag liggen. Uit het overzicht van arbeidsepidemiologische studies in hoofdstuk 4 is gebleken dat in het algemeen de kwaliteit van de gegevens over blootstelling pover is. In te veel studies worden conclusies over risicofactoren in het werk gebaseerd op verschillen in prevalentie van aandoeningen van de rug in beroepsgroepen zonder enige aanvullende informatie over de blootstelling aan deze risicofactoren in de onderzochte beroepen.

Bij de karakterisering van de blootstelling dient men rekening te houden met de relevante houdingen, hun frequentie en duur binnen en tussen werkdagen, en intra- en interindividuele verschillen tijdens arbeidsgebonden activiteiten. In hoofdstuk 5 is een analyse van de variatie in blootstelling beschreven waaruit blijkt dat er een aanzienlijke overlap kan zijn in blootstellingsverdelingen van beroepsgroepen, ondanks het feit dat een ontbinding van de variatiecomponenten aantoonde dat de beroepsgroep de belangrijkste bron van variatie was. Door het oppervlak van de overlap te gebruiken als schatting van de misclassificatie van blootstelling, kon in hoofdstuk 6 worden berekend dat deze misclassificatie kan leiden tot een aanzienlijke verzwakking van de risicomaat in dwarsdoorsnede-onderzoek.

In twee studies is de overeenkomst tussen meetmethoden voor fysieke belasting van de rug onderzocht. In epidemiologisch onderzoek lijkt de observatiemethode vooralsnog het best toepasbaar. Desalniettemin besluit hoofdstuk 7 met de conclusie dat de uitdaging om valide en praktisch toepasbare meetmethoden voor fysieke belasting van de rug nog steeds aanwezig is.

Twee voorbeelden van epidemiologisch onderzoek met veel nadruk op de karakterisering van de fysieke belasting zijn beschreven in hoofdstuk 9 en 10. In een beton-elementenfabriek bleek een verband aanwezig tussen de dagelijkse duur van een positie met gebogen en/of gedraaide rug en de prevalentie van lage rugpijn. De studie in het overslagbedrijf liet zien dat in de drie onderzochte beroepsgroepen een aanzienlijke fysieke belasting van de rug aanwezig was. Deze studie illustreerde tevens de moeilijkheden om verbanden te leggen tussen aspecten van fysieke belasting van de rug en de prevalentie van lage rugpijn.

Dit proefschrift is gewijd aan het schatten van fysieke belasting van de rug door houding. Meetstrategieën voor deze belasting in de arbeidssituaties zijn nog weinig ontwikkeld. In het laatste hoofdstuk worden daarom enkele aanbevelingen gedaan voor het opstellen van meetstrategieën in toekomstig arbeidsepidemiologisch onderzoek.

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About the author

Alex Burdorf was born on May 29th, 1958, in Heerlen, The Netherlands. He started to study at the Agricultural University in Wageningen in 1977. In 1985, after eight years of study, work and pleasure he obtained his doctoral degree in environmental sciences with specialization occupational hygiene. From September 1984 to December 1986 he worked in the Safety Science Group at the Delft University of Technology. During this period he was involved in research projects on health hazards at work of exposure to asbestos and vibration. From December 1986 onwards he is working at the Department of Public Health and Social Medicine. Currently, his research activities are focused on the exposure assessment of postural load on the back in working situations and the recognition of workers with chronic non-specific lung disorders in early stages. He is offered the opportunity to lecture occupational health for medical students at the Erasmus University and occupational hygiene in various vocational programmes for occupational physicians and occupational hygienists.