

Physical demands at work: objectively measured exposure and musculoskeletal pain in construction- and healthcare workers

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SUMMARY

Background: Musculoskeletal disorders are a major global problem contributing to huge society costs in terms of sick leave, medical treatments, and disability pensions. Physical exposures like manual material handling, postures, repetitive work, and work with high pace or force are thought to have important impact on musculoskeletal health. Professions within construction and healthcare have a high prevalence of musculoskeletal disorders, and reports to be exposed to high physical demands. These sectors are among the largest working sectors in Norway, employing approximately 29% of the Norwegian working stock. Previous knowledge of occupational physical exposures are largely based on self-reports, which are known to have limitations. Thus, there is a need for implementation of objective measurements providing valid information on physical workplace exposures within these sectors.

Objectives: The overall objective of this thesis was to increase knowledge on physical exposures by objective measures of sitting, standing, moving, arm- and trunk inclination, and cardiovascular load and to elucidate relationships between objectively measured exposures and musculoskeletal health in construction- and healthcare workers.

Methods: From the 594 construction- (n = 293) and healthcare workers (n = 301) agreeing to participate in the questionnaire part of the study, we performed technical measurements with continuous sampling for 3-4 days on 125 volunteering workers (construction n = 62, healthcare n = 63). Clinical examinations including physical fitness tests were performed on all 125 subjects prior to measurement. Subjects with inadequate skills in reading and writing Norwegian, known allergic reaction to plaster, tape, and bandages, or subjects that were pregnant or being diagnosed with cardiovascular disease were not included in technical measurements. *Paper I* used the full sample (n = 125) of participants with technical measurements, where we determined duration of daily activities (standing, moving, sitting, number of steps), postures (inclination of the arm and the trunk), and relative heart rate from accelerometers and heart rate monitors. Self-reported physical exposures and covariates were obtained by a baseline questionnaire and a questionnaire answered after the first day of technical measurements concerning physical exposures on that day in particular. *Paper II* was based on a subsample (n = 42) of construction workers only, and relative heart rate was determined from heart rate measurements. This paper included fitness data from the clinical examination and variables from the baseline questionnaire. *Paper III* was based on the full

sample (n = 125) of participants with technical measurements, and obtained sitting and standing durations from accelerometers. Covariates and low back pain intensity were obtained from the baseline questionnaire and a 6 months follow-up questionnaire.

Results: *Paper I* showed that objectively measured activities (standing, moving, sitting) were significantly and moderately correlated to their respective questionnaire item. We found weaker correlations for postures (arm and trunk inclination), and relative heart rate. Stratified analyses showed no correlation between postures and relative heart rate, and questionnaire items for healthcare workers. When compared to objective measures, self-reported physical demands overestimated duration of exposure. Further, we found a significant day-to-day variability in physical exposure between consecutive days of measurement. Objective measures for several consecutive days produced higher intraclass correlation coefficients than single day measurements. *Paper II* found that construction workers, on average, spent approximately 60% of their workday below 20% of relative heart rate. Fourteen percent of the workday was spent above the recommended threshold of 33% for an 8-hour period. A small portion of the study population (10%) had a mean relative heart rate throughout the workday above this threshold. Seven persons (17%) experienced on average one or more episode(s) of 5 min or more continuously above 33% of relative heart rate. The cardiovascular load at work decreased with increasing age and maximal oxygen consumption. We found no associations between cardiovascular load and self-reported work ability, musculoskeletal pain, or general health. In *Paper III* increasing duration of sitting at work was associated with decreasing intensity of low back pain at both baseline and after 6 months for healthcare workers, but not for construction workers. This association attenuated, but remained significant when adjusting for other work-related variables. We found no consistent associations between standing durations at work or throughout the full day (work + leisure) and the intensity of low back pain.

Conclusions: From *Paper I* we concluded that questionnaires do not provide a precise measure of physical demands and may not be satisfactory when investigating relations between physical exposures at work and health outcomes. Additionally, we recommend to measure physical demands objectively for several consecutive days in occupations with significant day-to-day variations in exposure. Using objective measures of cardiovascular load over several consecutive days, we concluded in *Paper II* that construction work is characterized by cardiovascular demands mainly in ranges of relative heart rate below 39%, with few continuous periods above the recommended threshold. The cardiovascular demands

at work do differ between professions within the construction sector, and loads are associated with age and state of aerobic fitness, but not musculoskeletal disorders. *Paper III* concluded that increasing duration of objectively measured sitting at work is associated with decreasing intensity of low back pain in the healthcare sector, but not in the construction sector.

Objectively measured standing at work was not associated with intensity of low back pain.

The findings in this thesis should be of interest when interpreting previous knowledge extracted from self-reported physical exposures. Additionally, these findings should assist sampling strategy and choice of methods in studies aiming to study relationships between physical exposures and musculoskeletal health. Finally, this thesis contributes to identify physical exposures of importance for musculoskeletal health in construction- and healthcare work.

LIST OF PUBLICATIONS

This thesis is based on the following three papers, in the text referred to by their Roman numbers:

Paper I

Markus Koch, Lars-Kristian Lunde, Tonje Gjulem, Stein Knardahl, Kaj Bo Veiersted. Validity of questionnaire and representativeness of objective methods for measurements of mechanical exposure assessment in construction and health care work. PLoS One 2016, 11 (9): e0162881.

Paper II

Lars-Kristian Lunde, Markus Koch, Kaj Bo Veiersted, Gunn-Helen Moen, Morten Wærsted, Stein Knardahl. Heavy physical work: Cardiovascular load in male construction workers. International Journal of Environmental Research and Public Health 2016, 13(4):354.

Paper III

Lars-Kristian Lunde, Markus Koch, Stein Knardahl, Kaj Bo Veiersted. Associations of objectively measured sitting and standing with intensity of low back pain: a 6 months follow-up of construction and health care workers. Second round of review in Scandinavian Journal of Work, Environment & Health.

ABBREVIATIONS

ECG	–	Electrocardiogram
HR	–	Heart rate
ICC	–	Intraclass correlation coefficient
LBP	–	Low back pain
MSD	–	Musculoskeletal disorders
MSI	–	Musculoskeletal complaint-severity index
PSI	–	Psychological complaint-severity index
RHR	–	Relative heart rate
SCH	–	Subjective health complaints
$\dot{V}O_{2max}$	–	Maximal oxygen consumption
WMSD	–	Work-related musculoskeletal disorders
YLD	–	Years lived with disability

PREFACE

Among employees working in construction- and healthcare sectors there is a common agreement that their work is physically demanding, and that these demands have negative effects on health. This is also a broad perception in the community, and studies have shown that characteristics of such work may include risk factors for developing several disorders within the musculoskeletal system.

In Norway, musculoskeletal disorders contribute to huge society costs in terms of sick leave, medical treatments, and disability pensions. For the individual worker, strategies to preserve good health are accordingly important. Thus, it is of great importance to reduce the number of musculoskeletal disorders in the population, both from a societal- and from an individual perspective.

As an attempt to answer unsolved questions concerning nature of work and its relation to health, sickness absence, and early retirement, The Research Council of Norway started the Research Programme on Sickness Absence, Work, and Health as a long-term initiative (2007-2016). This programme had a total budget of NOK 310 million and a focus on discovering factors related to work that lead to sickness absence and exclusion from working life (1).

In March 2012, the project *Work ability for employees in physically demanding work*, planned by The National Institute of Occupational Health, was granted funds to contribute to this programme. Collaborating with four construction companies and two healthcare distributors the data sampling for this project started in the second quarter of 2014. Clinical examinations, self-reports, and a comprehensive set of technical measurements were implemented in the study design. Materials presented here are based on some of the assessments and exposure measurements carried out in accordance with this project.



Photos. Healthcare- and construction workers during field measurements (Photo, Lars-Kristian Lunde).

1. BACKGROUND

1.1 MUSCULOSKELETAL DISORDERS IN SOCIETY

In 2012, results from one of the largest international collaborations within health research was published in the academic journal *The Lancet*. In the Global Burden of Disease Study 2010, disability-adjusted life years for 291 different diseases and injuries was investigated prospectively over 20 years, from the study's initiation in 1990. The study used a global perspective based on 21 regions created from countries with epidemiological homogeneity and geographical contiguity (2, 3). Results pointed at a general shift from diseases causing premature deaths towards diseases increasing years lived with disability (YLD). In this publication, Musculoskeletal Disorders (MSDs) were considered one of the most prominent among the diseases increasing YLD in the past 20 years. A recent update continues to support these findings and puts low back pain (LBP) as number one and neck pain as number four on the global ranking of health problems causing YLD (4).

The survey of level of living in Norway reports a stable high level of MSDs the last 20 years. In the 2013 survey, approximately 70% of the working population reported to have had musculoskeletal pain the previous month, with neck/shoulder and low back being the most frequent pain locations (5). The point prevalence of LBP and neck pain is in Norway considered to be between 15% and 20% (6). Most of these experienced pains are classified as mild pain and it is estimated that up to 80% of the population will experience such pain during their lifetime (6, 7). In a majority of patients musculoskeletal pain is shown to be recurrent (8), which may lead to a state of chronic pain (9). Large Norwegian population studies indicate that 40-50% suffer from any musculoskeletal pain for at least three months per year (10, 11), while a survey of 15 European countries reported that 19% of respondents had chronic pain (determined from study criteria), of moderate to severe intensity (12).

Since MSDs are such a common health problem it is causing a large burden on the society with costs of sick leave, medical treatment, and loss of productivity (13-15). This is also reflected in Norwegian sick leave and disability benefits, with MSDs being the largest contributor (6).

In September 2016, the World Health Organization European Region officially recognized musculoskeletal conditions as the greatest cause of disability in Europe and recommended all European countries to take specific actions to promote musculoskeletal health. Among the

specific actions implemented in the new Action Plan is the integration of musculoskeletal health promotion and occupational health in the workplace (16).

Development of MSDs are multifactorial and previous research has identified risk factors of individual, behavioral, psychological, physical, and social character (17-21). Gender, age, genetics, health, previous pain, physical capacity, socioeconomic status, and smoking are all factors linked to MSD (18, 20, 22), but are not necessarily related to work. However, many aspects assumed risk factors are related to occupational conditions.

1.2 MUSCULOSKELETAL DISORDERS IN AN OCCUPATIONAL SETTING

The investigation of relationships between working conditions and health outcomes has been a field of interest for centuries. Already in 1713 the Italian physician Bernardino Ramazzini classified diseases and injuries based on health risk from different occupations. He found that it was clearly health problems that could be associated with certain occupations (23). In 2013, MSD was reported main diagnosis in approximately 40% of all sickness absence and 30% of disability pensioners had a MSD related diagnosis in Norway (5, 6). Twenty-seven percent of the working population reported to be “rather bothered” or “very bothered” by musculoskeletal pain the previous month, and around half of these claimed their complaints were totally or partially a result of their work (5). Results from the British Labour Force Survey 2016 showed that 41% of all cases of work-related illness and 34% of all days lost to ill health were due to work-related musculoskeletal disorders (WMSDs) (24).

Traditionally, the physical aspects of work and work-related mechanical loads has received the main focus of research, and repetitive work, vibrations, postures, heavy physical work, elevated arms, and heavy lifting are among commonly reported risk factors (18, 25-27). However, it is put forward that physical exposures do not provide strong enough associations to be awarded the only explanatory work-related factor (28). Although this could be explained by measurement of wrong factors or due to the use of self-reports, it is now a common notion that several psychosocial factors may contribute to WMSDs (29, 30). Social climate, role conflict, decision control, leadership, job- demands, satisfaction, and strain may be of indirect or direct importance in the development of such disorders (21, 29-32).

1.3 CONSTRUCTION AND HEALTHCARE WORK

In most developed countries, many previously physically demanding occupations are now to a higher degree depending on machines (e.g. in assembly lines, farming), which reduces work

involving several potential risk factors for WMSDs. Thus, more of the work in the modern society is now carried out in a sedentary position (33). Even though it varies between job titles and tasks, construction and healthcare are two work sectors where physically demanding risk factors still are highly present (34-37). Workers in these sectors report high levels of MSDs (5, 38-41), and relate these MSDs to their occupation to a high degree (5, 24). Studies show that heavy work increases the risk of early disability pension due to MSDs (42-44). From the 2.7 million registered workers in Norway 2015, 787 000 people were employed in construction (221 000) and health- and social care (566 000) sectors (45). This makes healthcare and construction the largest and third largest sectors, respectively, in Norway. To characterize the physical demands in these occupations and to highlight how these demands are associated to MSDs are therefore of importance and constitute the main reason for the choice of study population in the present thesis.

1.4 MUSCULOSKELETAL PAIN

The term MSD is widely used, however not a well-defined condition. It can refer to illness involving the nerves, tendons, muscles, and supporting structures of the body. These illnesses may or may not be clinically diagnosed (46) and have a range of symptoms, from light discomfort to serious medical conditions (47). Commonly, disorders in the musculoskeletal system are experienced as pains. The International Association for the Study of Pain defines pain as “an unpleasant sensory and emotional experience associated with actual or potential tissue damage, or described in terms of such damage”. Therefore, pain may act as a precursor to disorders or act as a signal when having disorders. However, the definition does not tie pain to the stimulus and despite the close relation between pain and tissue damage, they are not necessarily always coexistent (48).

Until the 1960s, research on pain was seen strictly from a neurophysiological perspective with normal pain starting with nociception. Briefly explained; some kind of potential or actual tissue damage activates nerve endings (nociceptors) at site of stimuli and causes signals to travel to areas of the cortex where they are realized as an experience of pain (49). Such pain would by Cervero and Lairds (50) be either classified as *acute physiological nociceptive pain* when acute stimulus are inflicted and a protective mechanism (e.g. withdrawal reflex) is engaged to avoid (further) tissue damage, or as *pathophysiological nociceptive pain* when tissue is inflamed or injured. A third type of pain; *neuropathic pain* would be a result of injury or disease located in the nervous system. However, this is a relatively simple classification

and is in more recent time modified e.g. due to coexistence of more than one type of “pain system”, other types of pain (51), and the recognition that the experience of pain is of physiological, anatomical, and psychological nature (49). The task of measuring pain objectively is impossible considering its various manifestations and its definition as being of subjective character (51). Recently, approaches to measure stimuli based on neurological signatures in functional magnetic resonance imaging have been put forward, however, such methods have several limitations (52, 53). As of today, no satisfactory objective method to measure pain is available (51, 54) and we have to acknowledge that the perception of pain is subjective, and that pain perception may differ between persons despite equal stimuli (48, 49). Thus, we must rely on self-reported pain. Many of the musculoskeletal pains experienced by individuals are difficult to ascribe a specific pathological diagnosis, thus they are often labeled as non-specific (55, 56). All musculoskeletal pain outcomes in this thesis are self-reported and without emphasis on clinical diagnosis.

1.5 WORKLOAD AND MUSCULOSKELETAL PAIN

Considering the amount of research investigating how workload affects the musculoskeletal system there is considerable evidence that physical exposures can generate short- and long term physiological changes in human tissue. Generally, force exertions that are repeated or held continuous over a significant period may result in tissue changes (e.g. muscle, tendons, bone, nerves). These changes may be an adaptation, increasing capacity or an impairment, reducing capacity. One may imagine that when tissues are exposed to high force exertions repeatedly for several consecutive weeks, months, or years without sufficient time for recovery this could reduce tolerance for new exertions (57). When evaluating such exposures, the level (intensity, magnitude), duration (exposure time), and frequency (number of shifts between force levels) are suggested to be important dimensions (58, 59). How an individual copes with this total impact of the exposure may differ between subjects based on various factors, which may or may not change over time, determining a person’s capacity of tolerance (60, 61). Workload issues and pain are also important from a psychosocial perspective since psychosocial factors may directly or indirectly affect the development of pain. Climates where employees feel they have fair- and empowering leadership, a high level of support and decision control may have a protective effect on neck/shoulder and back pain (21, 29, 31). High job demands, strain, or conflict are on the contrary suggested to increase pain levels (21, 29, 62). Accordingly, it is also believed that the tolerance for pain may change over time and the concept of tolerance can therefore be seen as a dynamic process (60). Imbalance between

individual capacity and physical work demands may lead to increased risk for developing MSD, which eventually may lead to further reductions in capacity (57).

Workload mechanisms of failure and pain

As described above, the scientific literature provides a significant amount of information concerning many risk factors for developing musculoskeletal pain. However, the pathophysiological mechanisms causing the pain are less certain. The cause and pathways for non-specific pain are, by definition, unknown. Thus, we have a symptom we cannot fully identify the pathology of (56). Below is a brief introduction to how physical workload mechanisms could cause MSDs and how such events may lead to pain. It is, however, beyond the scope of this thesis to provide a detailed and complete overview of this topic or to verify pathophysiological theories of pain.

Previous experimental studies investigating muscle biopsies taken from human muscle found myofibrillar disturbances indicating muscle fiber overload for up to several days following exercise (63, 64). Similar findings were also seen in relation to occupational work, in terms of increased serum creatine kinase indicating muscle strain (65, 66). More recent studies have later confirmed these findings and it is believed that high tensions especially seen in eccentric contractions, lead to muscle damage (67, 68). In studies on how cells detect strain and provide a cellular response (mechanotransduction), biochemical responses to strain can be located also in other tissues like cartilage and bone (69). Regularly, the mechanical loads acting on a body segment are put forward as a main reason for tissue damage (60, 61, 70), which could be a result of instantaneous or cumulative negative impact (71-73). Particularly, spine compressions are hypothesized to cause low back disorders due to endplate microfractures, trabecular buckling or other types of degenerations within the spine (56, 60, 74). Compression may also act as a mechanism for pain development during static activities without external loads, like sitting and standing (75, 76). Prolonged isometric contractions forceful enough to increase intramuscular tissue pressure to a state where blood flow is impeded may damage poorly vascularized muscle, tendon tissue (77, 78), and nerves (79). Studies on the effect of highly repetitive low force loads on body tissues showed these loads to cause failure in collagen fibers and bone, and it was suggested as a slow failure mechanism (80, 81). The well-known *Cinderella hypothesis* claims that monotonous low load work, even though the demand at a specific point in time is low, are activating the same low threshold motor units for a long time, restricting time for recovery (82, 83). Such scenarios are hypothesized to

cause a state of fatigue including hypoxia and intracellular Ca^{2+} disturbance (*The Calcium Hypothesis*), resulting in muscle damage and pain (84, 85). Based on the knowledge that skeletal muscle nociceptors are located near arteriolar walls and in connective tissue (86), it is also hypothesized that muscle pain has less to do with muscle cell activity per se, and is rather linked to arterial vasodilation, and the release of pain producing substances and inflammatory factors (87, 88). Acid-sensing ion channels may also mediate situations of pain and inflammation (89).

The mechanisms above indicate plausible paths that may initiate a pain response. *The vicious circle model* is a further development of earlier theories on muscle hyperactivity (90), and aims to explain how muscle pain is maintained (91). The model by Johansson and Sojka suggests that substance driven activation of specific chemosensitive muscle afferents will trigger reflexes increasing muscle spindle activity, thereby increasing γ -motoneurons activity. This will again lead to increased level of metabolites and inflammatory substances acting on muscle afferents. This positive feedback loop will then cause fatigue and nociceptor activation, resulting in pain being maintained. *The pain adaption model* by Lund and colleagues does on the contrary suggest that when experiencing pain muscle activity is being reduced, initiating muscle relaxation as a protective mechanism (92). A central aspect for a continuing pain state could be also the plasticity of the nervous system. As stated by Brodal, even a relatively short period of continuous signaling from nociceptors may alter the receiving neurons in the spinal cord (93).

Generally, it seems like musculoskeletal damage may occur from acute and cumulative scenarios, arise from both dynamic and static muscle activation patterns, and may be triggered by high as well as low levels of force. Additionally, the pain response itself may be linked to both mechanical and metabolic events, and may be acute and short lasting, recurrent, or chronic (49, 94). It is also likely that several of the different theories and mechanisms described above may act simultaneously and that the existence of one does not necessarily exclude another.

1.6 PHYSICAL WORKLOAD AND RISK FOR HEALTH IMPAIRMENT

When using the term physical workload or physical exposure in this thesis I am referring to workload factors like manual material handling, postures, repetitive work, and work with high pace or force. A number of these exposures are in the literature also referred to as mechanical exposures due to their link to biomechanical events (59). Physical agents in terms of

inhalation, radiation, skin exposure, ingestion etcetera are not the type of physical aspects considered in this thesis.

Cardiovascular load

Even though they are often used, the content of terms like physically demanding work, physical workload, occupational workload, and occupational physical activity are not necessarily intuitive. Such terms may include a variety of exposures during work; lifting, carrying, pushing, pulling, working with high pace or force, etc. In the task to assess the total physical demand imposed on workers, the cardiovascular load may be a meaningful measure to use (95) since most demanding exposures will lead to increased activity in the cardiovascular system.

Working with high physical demands has previously been associated with several aspects of ill health; e.g. cardiovascular disease, all-cause mortality (96, 97), and musculoskeletal pain (18, 98). Negative health effects from such work may reduce work ability (99) and increase sickness absence and risk for disability pensioning (42-44, 100).

The safe upper limits for load during mixed physical work were by Jørgensen and colleagues estimated to be approximately 30-35% of aerobic capacity for an 8-hour workday, based on the literature available (101). Similarly, the guidelines to avoid fatigue provided by Rogers et al. recommended to not exceed an average of 33% of cardiovascular load for full-body work (102). These recommendations was set mostly based on lab studies of bicycle ergometer and treadmill exercises, and may therefore be criticized to have low generalizability. However, similar levels were also established in a more recent study by Brighenti-Zogg et al., who found an average upper limit of 31% in workers during field measurements (103).

Boschman and colleagues state that high energetic loads increase fatigue and risk for LBP in their review on construction workers (104). However, few studies that use objective measurements of cardiovascular load during heavy physical work and investigates how cardiovascular load is related to health parameters are available. In a number of studies by Van Der Molen and coworkers, cardiovascular demands in construction workers were measured by heart rate (HR) and oxygen consumption during several work tasks (105-107). These measures were from single days, with the aim to measure specific tasks and material handling. Thus, results gave valuable information on task related loads, but the studies did not aim to characterize general workload or relation to health outcomes. Gupta et al. did study the

relative heart rate in blue-collar workers for several days continuously, and found that the male subjects with the highest cardiovascular load were more likely to report reduced work ability (108).

1.7 OCCUPATIONAL SITTING AND STANDING BEHAVIOR AND RISK FOR LOW BACK PAIN

Sitting

The literature focusing on how health impairments are connected to sitting and sedentary behavior is rapidly growing. Previous studies have found associations between time spent sedentary and a variety of health effects: all-cause mortality (109, 110), cancers (111, 112), cardiovascular diseases (109, 110), metabolic diseases (113), indicators of obesity (114), musculoskeletal disorders (115), and mental health (116).

The thought of sitting as a cause of musculoskeletal pain is not new. In 1970, Van Wely stated that postures maintained for too long resulted in aching back and shoulder muscles (117). Later, reviews show that many researchers have based their work on the hypothesis that prolonged static sitting is associated with risk for developing LBP (118, 119), and several authors provide theories on the mechanisms of sitting as a cause of back pain. Studies by Sato (75) and Nachemson (120) suggests that sitting activity increases intervertebral- and vertebral endplate compression and interdisc pressure, and that this may be related to pain. However, more recent results suggests that increased interdisc pressure is an unlikely cause of damage in non-degenerated discs (121). Prolonged sitting may be related to discomfort due to lack of movement variation (122) and additionally cause lumbar stiffness that may contribute to LBP (123). Other possible biological pathways are fatigue, and the reduced oxygenation seen with sustained muscle contraction during sitting (124). LBP may also be induced through increased weight as a result of sedentary behavior (125, 126).

Despite theories of mechanisms and that associations are found in some studies, currently available reviews on occupational sitting and LBP are concluding that no evidence for an associations between sitting and LBP can be found, due to inconsistent results and low-quality studies (118, 119).

Objective field measurements and prospective designs should improve study quality; however, very few studies have implemented this strategy. Two recent cross-sectional studies of blue-collar workers, that measured sitting objectively for several consecutive days by accelerometers found sitting duration to be associated with musculoskeletal discomfort in low

back (127) and neck (128). Both studies encouraged similar studies with objective measures for several days and prospective designs to be carried out.

Standing

For all-cause mortality, recent prospective population studies suggests standing to be associated with a better outcome than sitting (129, 130). However, the association between standing and MSDs, a disabling rather than deadly health problem, may behave differently. A cross-sectional study on employees in manufacturing work found standing work to increase odds of getting LBP significantly (131). This association is also shown in other occupational groups and in prospective studies of larger populations (132-134).

Even though mechanisms on how standing could cause LBP are not clear, some hypotheses are provided. The spinal load in terms of spinal shrinkage or measured intradiscal pressure is of a greater magnitude during standing than sitting (76, 135), and is, as is for sitting, suggested to be associated with LBP. Results from cadaveric segments models, imitating load during standing position, indicate that prolonged loading of intervertebral discs may cause stress concentrations resulting in pain and structural disruption (136). Pain is also suggested to be a result of -, or to be associated with fatigue from prolonged standing (137). A recent publication by Garcia and colleagues found a significant muscle fatiguing effect (quantified by electrically induced muscle twitches) in workers after 5-hours of simulated standing work (138). This fatigue was significantly related to an increase in self-reported muscle discomfort. Others have pointed towards muscle activation patterns during standing as a potential predisposing factor for LBP (139, 140).

Even though their review has been criticized for having too restrictive inclusion criteria and thereby leaving to many studies out (137), Roffey and colleagues were not able to find high-quality evidence for potential causality of LBP from standing (141). In a recent systematic review and meta-analysis by Coenen et al., the authors suggested that a substantial amount of occupational standing was associated to LBP, but emphasized that results were tentative due to limited evidence from high-quality prospective studies with objective measurements (142).

Very few field studies have investigated the association between standing and LBP by objective measures. A recent cross-sectional study by Munch Nielsen et al. reported ambiguous associations between objectively measured standing for several consecutive days and LBP (143).

From the literature available, it is not clear if sitting and/or standing during work contributes to MSDs. A huge proportion of the studies are cross-sectional, and there is a large degree of methodological heterogeneity between the studies. This may make it more difficult to draw conclusions. Further, the often used categorizing of jobs as e.g. sitting- or standing jobs leads to reduced precision in exposure assessment, and the lack of objectively obtained exposures is therefore a drawback in many studies (144). There is a need for studies describing dose-response relationships using more valid measures than self-reports. Whether occupational sitting or standing is related to musculoskeletal pain, is yet to be settled.

1.8 APPROACHES TO MEASURE PHYSICAL EXPOSURE

When deciding on method of measurement one should always consider the trade-off between precision and feasibility, since higher precision often costs more time and money. As a consequence, comprehensive measurement strategies are generally implemented for smaller samples, whereas simpler methods like self-reports are used for larger groups (59).

The collaboration: Partnership for European Research in Occupational Safety and Health (PEROSH) consists of 12 national occupational research institutes across Europe and “aim to coordinate and cooperate on European research and development efforts in occupational safety and health”. They state that even though physical demands at the workplace are acknowledged to be one of the main determinants for MSD, sickness absence, and early determination from the labor market, there is a great need for valid information on physical workplace exposures (145). Many recommendations and indications of relationships between occupational physical exposures and health outcomes are based on self-reports, which in many cases may be the best practical solution, or even the only solution possible. However, the self-reported exposure is often recognized as a study limitation (146). Self-reported assessments of physical exposures in work settings have varying validity (147), and questionnaire data have low correlations with objective measures of movements and postures (148). Low correlations may be due to self-reports overestimating durations of postural positions when compared to objective measures (149). Self-reported physical exposure is also suggested to be more of a psychophysical measure, reflecting several dimensions of stimuli (147). A review by Kwak and colleagues (150) did find four questionnaires on occupational physical activity to have acceptable reliability, while few showed good validity. Reasons for differences between objective and self-reported exposures may be dependent on individual characters (151), activity patterns (151), work patterns (152), respondents’ occupation (153),

and recalling and averaging activities (154). To assess body postures in field, researchers also use observational methods. With trained observers evaluating large-scale body postures, these methods are considered valid, and have moderate-to-good repeatability within and between raters (155). However, such evaluations have generally showed low agreement when compared to technical measurements and have difficulties to determine postures of wrist and hand. Additionally, it is a time- and money consuming method that may be prone to bias (155). To reduce bias and increase precision objective measures are recommended (150, 151, 156) and thus, researchers should strive for such measurements whenever applicable and possible.

Luckily, the ongoing progress and improvements within instrumentation continues in the spirit of Moore's law; technology reduces cost and equipment size, thereby making it more convenient to substitute self-reports with instrumental measurements. This is making it possible to search for associations between objective exposure measurements and health outcomes in ever-increasing areas. Considering physical workload exposure, the use of objective measurements may have physiological- or biomechanical approaches, both including a wide range of techniques.

Electrical heart rate measurement is a physiological approach based on the electrical signals generated by the heart muscle during depolarization of the right and left ventricles. Such measurements generate HR from the unique pattern of the electrical signal produced during this scenario. By identifying the R-waves in the QRS-complex and thus the number of waves within an epoch, the HR can be calculated (157). Measures of HR can be used as a direct indication of the cardiovascular load an occupational task put on workers (158, 159). Modern HR equipment are small, can be attached directly on the skin, are waterproof, and may measure for several days. Based on the aforementioned knowledge an electrocardiogram (ECG) based HR measurement during work and leisure, worn continuously for several days was included in this thesis (Paper I and II) as an estimate of cardiovascular load.

Accelerometer measurement is one of the most essential methods to capture human movement from a biomechanical perspective. Based on gravity the accelerometer determines the static spatial orientation, while changes in acceleration detect dynamic movements. Accelerometers measure in one (uniaxial) or multiple (triaxial) dimensions and can store data for several days during long-lasting measurements. These wireless devices are constantly improving by becoming smaller and more powerful. With the addition of being waterproof they are

unobtrusive for subjects to wear and very practical for field measurements (160, 161). The progress within data processing have further provided algorithms that makes it possible to use information from several accelerometers placed on various body segments to describe a variety of positions and postures (162, 163). These traits of the accelerometer were the rationale for its use in this thesis to measure sitting, standing, moving, steps, and arm- and trunk inclination (Paper I and III).

If we want to provide precise measurements of physical exposures, objective measures must be involved. Since there is a high possibility that not all workdays involve the exact same level of exposure (164, 165), single samples may be associated with a higher level of uncertainty than several samples. This thesis is based on objective measures sampling 24-hours a day for several consecutive days, to provide precise and representable data for work and leisure exposures.

2. THESIS OBJECTIVES

In summary, this thesis is a result of the following notions:

- MSDs are a national and international problem with huge impact on society and individuals.
- Physical exposures at work are thought to have important impacts on musculoskeletal health.
- Construction and healthcare sectors are two of the largest working sectors in Norway and have workers with high prevalence of MSDs and supposedly frequent exposure to physical demands.
- Knowledge of work-related physical demands is largely based on self-reports, which is known to have limitations.

Thus, there is a need for implementation of technical measurements providing valid information on physical work place exposure within these sectors.

The overall objective of this thesis was to increase knowledge on physical exposures by objective measures of sitting, standing, moving, arm- and trunk inclination, and cardiovascular load and to elucidate relationships between objectively measured exposures and musculoskeletal health in construction- and healthcare workers.

2.1 SPECIFIC AIMS FOR THE PAPERS PRESENTED

Paper I

Validity of Questionnaire and Representativeness of Objective Methods for Measurements of Mechanical Exposures in Construction and Health Care work

1. To determine the criterion validity of a questionnaire on physical exposures compared to objective measurements at construction- and healthcare worksites.
2. To examine variation in exposure over several working days.

Paper II

Heavy Physical Work: Cardiovascular Load in Male Construction Workers

1. To elucidate cardiovascular load in male construction workers during work and leisure by relative heart rate from objective measures over several days.
2. Evaluate the level of cardiovascular load in relation to individual factors, work ability, MSDs, and general health.

Paper III

Associations of objectively measured sitting and standing with intensity of low back pain: a 6 months follow-up of construction and healthcare workers

1. To determine if the objectively measured time spent sitting and standing was associated with intensity of low back pain in construction- and healthcare workers at baseline and after 6 months.

3. MATERIALS AND METHODS

3.1 STUDY DESIGN

All results in this thesis are based on a larger longitudinal cohort study collecting a comprehensive set of technical measurements at baseline and a two-year follow-up of each subject. The main design included a baseline questionnaire concerning psychosocial- and organizational factors, working postures and workload, physical activity and exercise, health, sickness and disorders, and work ability. Clinical examinations were carried out on a subgroup that volunteered for technical measurements. These objective technical measurements obtained muscle activity and ground reaction forces during approximately eight hours of work. Further, body positions, physical activity, and heart rate were measured during work and leisure for 3-4 consecutive days. These subjects additionally filled out a questionnaire concerning self-perceived physical exposures the first day of technical measurements. The follow-up consisted of a two-year period with self-reports every 6th month through a smaller questionnaire covering the same topics as the baseline questionnaire. Figure 1 shows the timeline for the study and indicates where data for the papers presented in this thesis were obtained.

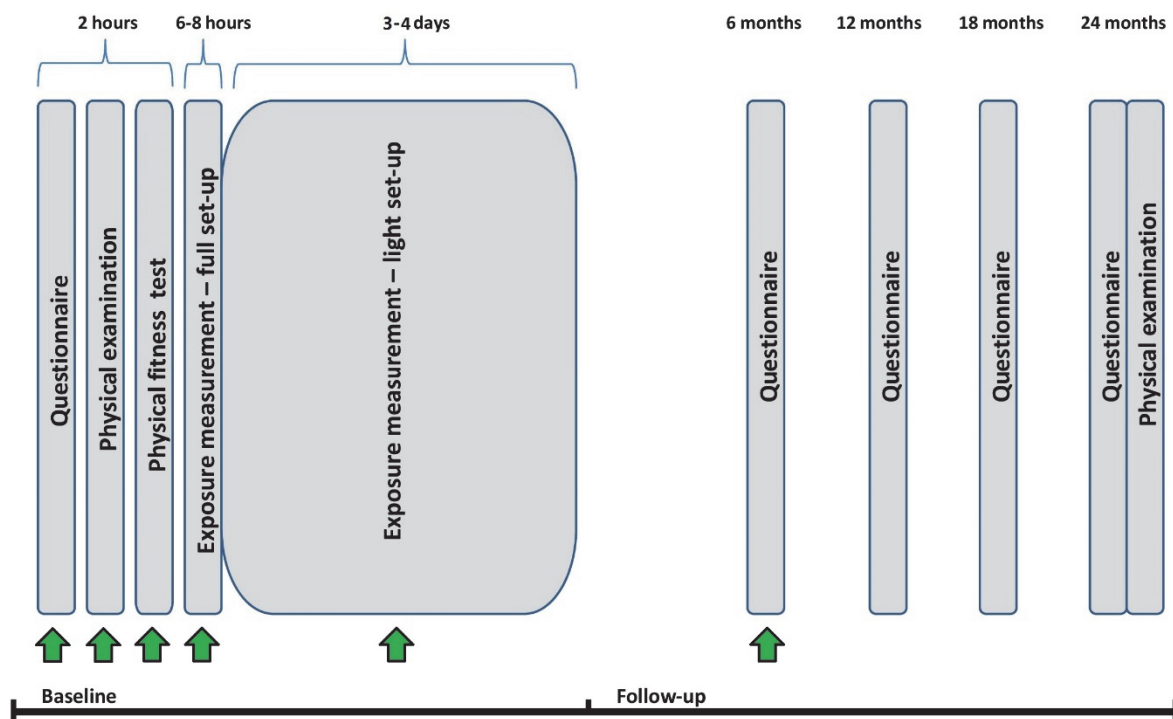


Figure 1. Timeline for data collection. Green arrows mark time points where data for paper I, II, and III were obtained.

3.2 SUBJECTS

Participants were recruited from four large construction enterprises and two healthcare distributors located in the eastern part of Norway (mainly in Oslo and Akershus districts). Information meetings were held at work sites, and workers were given the purpose and methods of the study. From 1165 workers (construction workers: $n = 580$; healthcare workers: $n = 585$), 594 (construction workers: $n = 293$; healthcare workers: $n = 301$) agreed to participate in the questionnaire part of the study and filled out the baseline questionnaire. From these, 371 (construction workers: $n = 178$; healthcare workers: $n = 193$) additionally agreed to participate in technical measurements. Subjects with inadequate skills in reading and writing Norwegian, known allergic reaction to plaster, tape, and bandages, and participants who were pregnant or diagnosed with cardiovascular disease were not included in technical measurements. We performed technical measurements on 125 workers (construction workers: $n = 62$; health care workers: $n = 63$) selected to best fit logistics (availability, work schedules and profession). See table 1 for baseline characteristics for participants in questionnaire and technical measurement groups.

Due to differences in measurement types, numbers of days analyzed, and thus level of erroneous/missing data, the number of subjects varies between papers based on parameters and groups.

Table 1. Baseline characteristics for participants in questionnaire- and technical measurement group.

	<u>Questionnaire only</u>	<u>Technical measurements</u>
	(n=469)	(n=125)
	Mean	Mean
Age	43.4 (11.9)	42.4 (11.7)
Weight (kg)	77.9 (15.8)	76.9 (13.6)
Height (cm)	173.1 (9.5)	173.6 (9.6)
Gender ^a	263 male, 206 female	75 male, 50 female
Normal working hours (hours/week)	36.9 (4.8)	36.7 (4.2)
Self-reported sitting (0-5)	2.1 (1.7)	1.6 (1.6)*
Self-reported standing (0-5)	3.1 (1.9)	3.5 (1.7)
Self-reported forward bending (0-5)	1.0 (1.7)	1.1 (1.2)
Self-reported arms above shoulders (0-5)	1.1 (1.3)	1.1 (1.2)
Physically demanding work (1-13)	4.9 (2.6)	5.1 (2.6)
General health (1-5)	2.7 (0.9)	2.5 (1.0)
Work ability (0-10)	8.3 (1.6)	8.8 (1.4)
LBP intensity (0-3)	0.8 (0.9)	0.9 (0.9)
MSI ^b (0-12)	2.6 (2.0)	2.9 (2.0)
PSI ^c (0-12)	2.1 (2.2)	1.7 (1.4)

*Significant difference $p < 0.05$. ^aFrequencies instead of mean values. ^bMSI = musculoskeletal complaint-severity index; ^cPSI = Psychological complaint-severity index.

3.3 DATA COLLECTION

Data were collected through questionnaires, clinical examinations, and technical measurements. Details on data collection methods used in this thesis are given below. For an overview of variable types included in each of the three papers, please see table 2.

Table 2. Variables included in paper I, II and, III.

	<u>Paper I</u>	<u>Paper II</u>	<u>Paper III</u>
Self-reports			
General	Age Gender Weight Height Seniority Smoking	Age Gender Weight Height Seniority Smoking	Age Gender Weight Height Seniority Smoking
Physical exposures	Standing work Sitting work Hands above shoulder Forward bending Increased breathing Physical demand work	Physical demand work	Standing work Standing work FU6 ^a Sitting work Sitting work FU6 ^a Heavy lifting
Musculoskeletal	Overall (MSI)	Overall (MSI)	Low back pain (intensity) Low back pain (intensity) FU6 ^a
Psychological Psychosocial	Overall (PSI)		Decision control Social climate Social climate FU6 ^a Fair leadership Empowering leadership
General health		Perceived health	
Physical activity		Work ability Physical activity in leisure	
Objective measures			
Accelerometer	Sitting Standing Moving Steps Arm inclination Trunk inclination		Sitting Standing Trunk inclination
Heart rate	Relative heart rate	Relative heart rate	
Aerobic fitness		$\dot{V}O_{2max}$	
Muscular strength		Handgrip	

^a FU6 = variable at 6 months follow-up; MSI = musculoskeletal complaint-severity index; PSI = Psychological complaint-severity index.

3.3.1 Questionnaire

Subjects included in the three studies comprising this thesis stem from the same sample, and were thus provided the same baseline questionnaire. However, the questionnaire items used in the separate papers vary based on aims and analyses of the respective study. Additionally, in paper I, we used self-reported questions concerning physical exposures on the first day of technical measurements and in paper III, we used questions on self-reported sitting, standing, social climate, and LBP intensity from the 6-month follow-up questionnaire.

General questions on individual characteristic; age, gender, weight, height, seniority, and smoking status, were used in all three papers.

Questions on the *physical exposures* sitting, standing, hands above shoulder height, forward bending, and increased breathing had the common introduction: “How often in your daily work are you exposed to [. . .]”. Subjects answered according to the response categories: 0 = never, 1 = sometimes, 2 = approximately 25% of the time, 3 = approximately 50% of the time, 4 = approximately 75% of time, and 5 = all the time” (166). Participants should determine amount of heavy lifting by stating if they normally lifted something weighing more than 20 kg, with the response alternatives: 0 = No, 1 = Yes, 1-4 times, 2 = Yes, 5-19 times and 3 = Yes, at least 20 times a day (166). We additionally asked how physically demanding their work was, with a 13-point scale reference ranging from “not at all” to “maximally demanding” (167).

A variety of questions concerning *musculoskeletal health* was included in the respective papers. Participants rated intensity of musculoskeletal complaints (neck, shoulders, upper- and lower back, hip, knees, ankles and feet, upper extremity, and head) on a four-point scale (0 = not troublesome, 1 = a little troublesome, 2 = quite troublesome, 3 = seriously troublesome). Accordingly, they rated the duration of the complaint on a four-point scale (1 = 1–5 days, 2 = 6–10 days, 3 = 11–14 days, 4 = 15–28 days). To calculate a complaint severity score we multiplied the scores from intensity and duration (range 0–12). When investigating overall musculoskeletal health we calculated a musculoskeletal complaint-severity index (MSI) as the mean of all included complaint severity scores (168).

Subjects were asked to rate intensity of *psychological state* (fear, depression, fatigue) on a four-point scale (0 = not troublesome, 1 = a little troublesome, 2 = quite troublesome, 3 = seriously troublesome) and the duration of these complaints (1 = 1–5 days, 2 = 6–10 days, 3 =

11–14 days, 4 = 15–28 days). By multiplying the rating of intensity and duration we calculated a complaint severity score (range 0–12). For an overall psychological score we calculated a psychological complaint-severity index (PSI) as the mean of all severity scores (168).

Participants rated their self-perceived health from the question: “How is your general health at present?” with five response alternatives ranging from poor to excellent (169). Subjects answered a single item taken from the Work Ability Index: “current work ability compared with lifetime best”, to range their current work ability (0 = completely unable to work to 10 = work ability at its best) (170).

We asked for *psychosocial* situation through questions on decision control, social climate, fair-, and empowering leadership taken from the General Nordic Questionnaire for Psychological and Social Factors at work (QPS_{Nordic}) (171, 172). For details on psychosocial questions, please see appendix A.

The participants reported *leisure-time physical activity* level by stating the level corresponding best to their own the previous four weeks: 1 = almost completely inactive (e.g., reading, watching TV, movies); 2 = some physical activity at least four hours per week (e.g., bicycling, walking, gardening); 3 = regular activity (e.g., running, tennis); 4 = regular hard physical training for competition several times per week (173).

3.3.2 Clinical examination

Prior to technical measurements, a physician or a nurse gave the eligible participants a clinical examination. Included in this examination was the measurement of aerobic fitness and handgrip strength.

3.3.2.1 Aerobic fitness

To establish aerobic fitness in terms of maximal oxygen uptake ($\dot{V}O_{2\max}$) we used a standardized cycle ergometer test (Ergometer 839 E, Varberg, Sweden) (174). An external power between 75 and 150 watts was set based on assumed level of fitness and subjects pedaled at a rate of 50 revolutions per minute. When the subject reached a steady state HR above 120 beats per minute, the test was terminated and $\dot{V}O_{2\max}$ was calculated from the obtained steady state HR (175).

3.3.2.2 Muscle strength

Handgrip was measured as a proxy for muscle strength and determined through standardized procedures (176) with a hand dynamometer (Lafayette Instrument, Lafayette, IN, USA). The highest obtained value of two attempts was used.

3.3.3 Technical measurement - instrumentation

3.3.3.1 Heart rate

We measured HR with Actiheart 4 monitors (Camntech, Cambridge, United Kingdom) attached to two ECG electrodes (Blue sensor VL-00-S/25 Ambu, Ballerup, Denmark). The skin was shaved and cleaned with ethanol prior to affixing electrodes at the apex of the sternum and at the left intercostals in level with 6th and 7th costae. We used a positioning at the level of the third intercostal space (as seen in the picture below) as an alternative to the preferred lower position (177). The Actiheart sensor is found valid and reliable both in lab settings and in free-living conditions (177, 178).



Photo. Left: Healthcare workers showing Actiheart equipment (Photo, National Research Center for the Working Environment). Right: Actiheart 4 monitor.

3.3.3.2 Accelerometer

We obtained acceleration, body position, and angle of body segments based on measurements with the Actigraph GT3X+ sensors (Actigraph LLC, Pensacola, FL, United States). This is a waterproof, tri-axial accelerometer of relatively small size ($46 \times 33 \times 15$ mm), with a sample frequency of 30 Hz. We attached the Actigraphs to the skin with double-sided tape (Fixomull, BSN medical, Hamburg, Germany) covered by transparent film (Tegaderm 3M, Minnesota, United States). We used the following bodily positions: upper back (level T1-T2), dominant

arm (3 cm below the deltoid muscle insertion), hip (top of iliac crest on the right side), and right upper leg (medially between the iliac crest and the upper crest of the patella). Recent studies have determined the Actigraph to be valid for measuring upper arm and body inclination (163) and the detection of several physical activities (162, 179).



Photo. Left: Construction worker with Actigraph equipment during work (Photo, Lars-Kristian Lunde). Arrows mark Actigraph placements for units used in the papers presented in this thesis. Right: Actigraph GT3X+.

3.3.4 Technical measurement - data processing and quality management

We uploaded and stored raw data from the Actigraph sensors on a personal computer with the Actilife 6.11.5 software (Actigraph LLC, Pensacola, Florida, USA). Actiheart was initialized, and data were read by The Actiheart Software (CamNtech Ltd., Cambridge, United Kingdom). From accelerometer data, we calculated: duration of sitting, standing, moving (in upright position, neither still nor walking), and number of steps. Further, arm inclination above 30°, 60°, 90°, 120°, and 150° and trunk inclination along the sagittal plane greater than 20°, 30°, 60°, and 90°. The custom-made software Acti4 was used for this purpose (162, 163) (National Research Center for the Working Environment, Copenhagen, Denmark and Federal Institute of Occupational Safety and Health, Berlin, Germany). Categorization into work and leisure periods were based on participants' diaries. We excluded data from periods when a sensor was not worn and if periods (work or leisure) were shorter than four hours or shorter than 75% of the mean average length of all respective periods. HR data were excluded if the beat error (a difference between two consecutive beats > 15, HR <

30 or $HR > 230$) was higher than 50% for a period. We additionally performed visual quality controls.

From HR data we calculated the relative heart rate (RHR) as follows (158):

$$RHR_{work} = \frac{(HR_{work} - HR_{min})}{(HR_{max} - HR_{min})} \times 100 \quad RHR_{leisure} = \frac{(HR_{leisure} - HR_{min})}{(HR_{max} - HR_{min})} \times 100$$

For each participant we established HR_{max} by the formula $208 - 0.7 \times \text{age}$ (180). HR_{min} was based on a sex- and age-adjusted population (181). We performed visual quality checks and data processing for HR data with Acti4 and Matlab R2013b (Math Works, Inc., Natick, Massachusetts, USA). See figure 2 for example data.

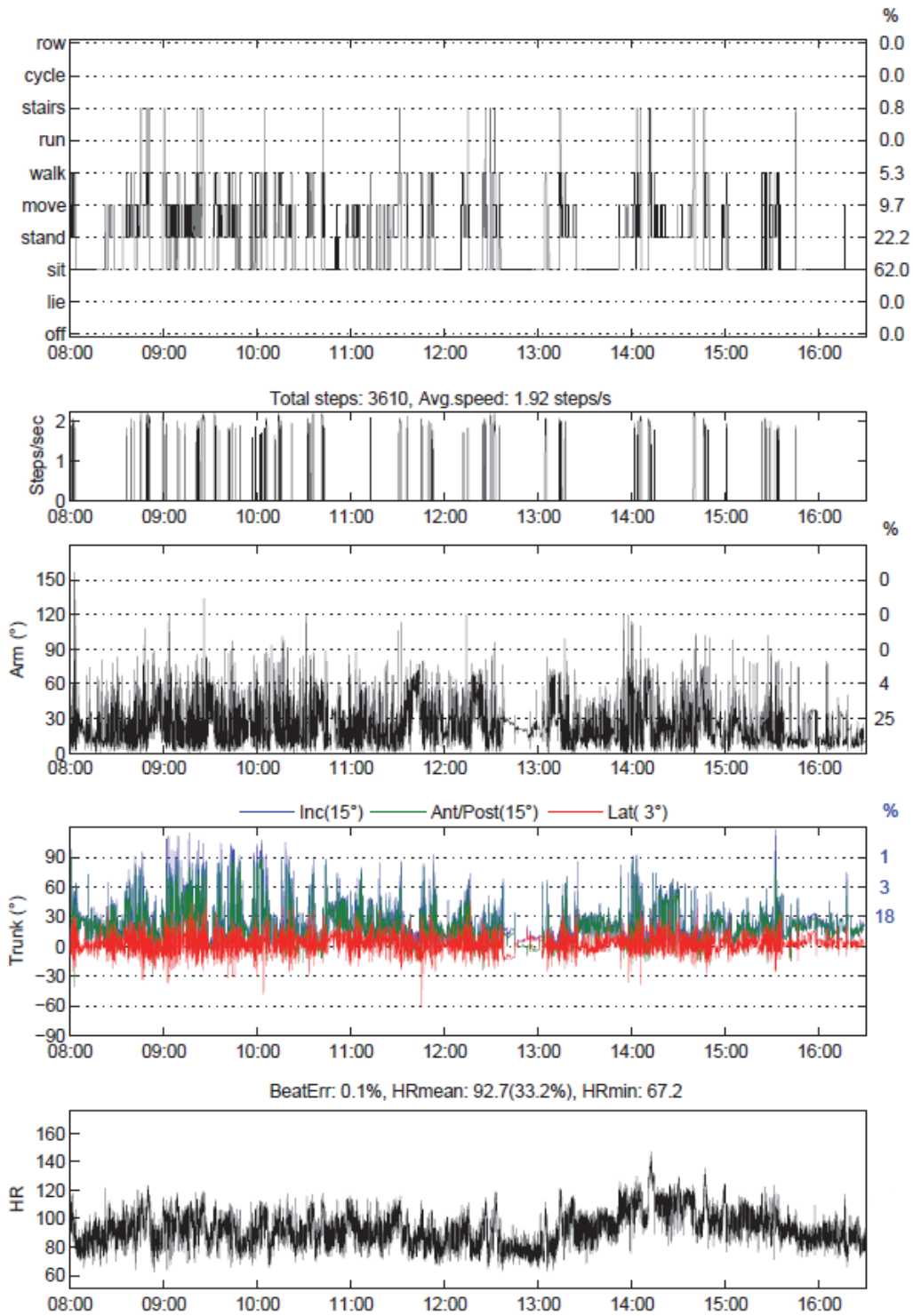


Figure 2. Example of exposure distribution of activities, steps, arm inclination, trunk inclination, and heart rate during work for a 44-year-old female healthcare worker.

3.4 STATISTICAL ANALYSIS

A brief description of statistical methods used in the different papers is stated below. In paper I and II the statistical tool used was IBM SPSS Statistics 22 (IBM Corporation, New York, United States). For paper III we used STATA version 13.0 (StataCorp, College Station, Texas, USA). Significance level was set as $p < 0.05$ for all papers.

Paper I

We used Spearman's rho to calculate correlations between self-reported and objective data. To test for criterion validity we used unadjusted and adjusted linear regressions. To determine the reliability between consecutive days of objective measurements we calculated intraclass correlation coefficients (ICC) for single day measurements and average measures of three days. We used Friedman one-way analysis of variance to determine differences between days of consecutive objective recordings of physical exposure.

Paper II

We tested differences between questionnaire and technical measurement group, and differences between work and leisure in time spent in various RHR ranges by independent sample t-tests and Mann-Whitney U tests. Simple and multiple linear regression analyses were used to investigate associations between individual factors, work ability, general health, and musculoskeletal pain and the independent variable RHR.

Paper III

We tested associations between sitting and standing exposures, and intensity of LBP using linear mixed models with random intercept for subject. For each of the two exposures, we investigated both exposure during work only and exposure throughout the full day (work + leisure). Furthermore, we analyzed each exposure in five models; from a crude unadjusted model to a fully adjusted model adjusting for individual, work-related mechanical factors, work-related psychosocial factors, and objectively measured exposure during leisure time. The fully adjusted model for full-day exposure analysis did not include adjustment for leisure time exposure.

Additional analyses

Based on findings in paper I, additional analyses were carried out to investigate if self-reported sitting and standing would provide similar associations with LBP intensity as found

for objective measures in paper III. These analyses mimicked the statistic models in paper III, with the only exception being the use of self-reported- rather than objectively measured sitting and standing. The self-reported variables were rated on a 0-5 scale (“never” to “all the time”) and were treated as continuous in the linear mixed model.

Baseline characteristics for responders versus nonresponders in technical group at 6 months are given as a supplementary to paper III.

3.5 ETHICS

The study was approved (2014/138/REK) by the Regional Committee for Medical Health Research Ethics (REC). We provided the informed consent approved by REC to all participants, and all participants signed this prior to participation. Participation was voluntary and participants could decide to leave the study at any time, without giving a reason.

4. RESULTS IN SUMMARY

Here I provide an overview of the most important findings in the respective papers included in this thesis. For the full and detailed results, I refer to the attached papers.

Paper I

Markus Koch, Lars-Kristian Lunde, Tonje Gjulem, Stein Knardahl, Kaj Bo Veiersted.

Validity of questionnaire and representativeness of objective methods for measurements of mechanical exposure assessment in construction and health care work. PLoS One 2016, 11 (9): e0162881.

This study on construction- and healthcare workers was undertaken to determine criterion validity of a questionnaire on physical exposures by comparing it to objective measurements from accelerometers and heart rate monitors. Further, we aimed to examine exposure variation over several working days.

For all objective activity measurements (sitting, standing, moving) we found moderate significant correlations to their respective questions. Lower correlations were found between objectively measured arm- and trunk inclination and relative heart rate, and the baseline questionnaire. Stratified analyses showed no correlation between arm- and trunk inclination or relative heart rate, and the questionnaire items for healthcare workers. Overall, self-report overestimated duration of physically demanding exposures. In adjusted models with self-reported variables we found the highest explained variance for objectively measured sitting ($R^2 = 0.559$) and arm inclination $> 60^\circ$ ($R^2 = 0.420$). There was significant variability in daily exposure to several physically demanding factors between days measured consecutively. We found a higher reliability for several days of objective measurements as compared to single day measurements.

We concluded in this study that questionnaires do not provide a precise measure of physical exposure variables. Additionally, we recommend to measure physical demands objectively for several consecutive days in occupations with day-to-day variation in exposure.

Paper II

Lars-Kristian Lunde, Markus Koch, Kaj Bo Veiersted, Gunn-Helen Moen, Morten Wærsted, Stein Knardahl. Heavy physical work: Cardiovascular load in male construction workers. *International Journal of Environmental Research and Public Health* 2016, 13(4):354.

In this study we aimed to elucidate cardiovascular loads in male construction workers during work and leisure by objective measures over several days. Furthermore, we evaluated how the level of cardiovascular load related to individual factors, work ability, MSDs, and general health.

We found that workers spent approximately 60% of the workday at cardiovascular loads below 20% RHR. A small proportion of the workers (10%) had a mean RHR throughout the workday above the recommended threshold of 33% for an 8-hour period. On average, workers spent 14% of the workday above this threshold. Seventeen percent of the workers experienced daily one or more episode(s) of 5 minutes or more continuously above 33% RHR. Only one worker experienced such continuous periods of durations of 15 minutes or more. The cardiovascular load at work decreased with increasing age and aerobic fitness ($\dot{V}O_{2max}$). No associations were found between cardiovascular load and self-reported work ability, musculoskeletal pain, or general health.

In paper II we concluded that construction work is characterized by cardiovascular demands mainly in ranges of relative heart rate below 39%, with few continuous periods above one-third of capacity. Cardiovascular demands at work do differ between professions within the construction sector, and loads are influenced by age and state of aerobic fitness.

Paper III

Lars-Kristian Lunde, Markus Koch, Stein Knardahl, Kaj Bo Veiersted. Associations of objectively measured sitting and standing with intensity of low back pain: a 6 months follow-up of construction and healthcare workers. Second round of review in *Scandinavian Journal of Work, Environment & Health*.

In paper III we aimed to determine if objective measures of time spent sitting and standing during work and full-day was associated with intensity of LBP at baseline and after 6 months in construction- and healthcare workers.

The main result from this study was that sitting duration at work was associated with lower levels of LBP intensity at both baseline and after 6 months in the healthcare sector, but not in construction sector. Findings for exposure throughout the full day were not consistent. We found no consistent associations between standing durations at work or during the full day, and LBP intensity. In adjusted analyses associations attenuated when adjusting for other work-related variables.

In paper III we concluded that increasing duration of objectively measured sitting at work is associated with decreasing intensity of low back pain in the healthcare sector, but not in the construction sector. No association between objectively measured standing and LBP intensity was found.

Additional analyses

Findings in paper I indicated that for large-scale activities, such as sitting and standing, there was possibly sufficient compliance between self-reports and objective measures, suggesting that self-reported exposure might provide an acceptable measure for these activities.

Additional analyses were performed for paper III to investigate whether self-reported sitting and standing would provide similar associations with LBP intensity as found for objective measures.

As for analyses using objectively measured standing, there were no significant associations between self-reported standing and LBP intensity neither for the construction nor for the healthcare sector. See table 3. The additional analyses using self-reported sitting did also show no significant associations for either sector. These analyses data did therefore not reflect the significant negative findings between sitting and LBP intensity in the healthcare sector as seen in paper III. See table 4.

Table 3. Linear mixed model with self-reported standing exposure at work and low back pain.

		<u>Model 1</u>			<u>Model 2</u>		
		Observations = 107/110			Observations = 88/95		
		Coef.	95% CI	P-value	Coef.	95% CI	P-value
Construction	T1	0.010	-0.10– 0.12	0.866	-0.10	-0.33– 0.13	0.399
	T2	0.002	-0.11– 0.12	0.972	-0.10	-0.34– 0.13	0.375
Healthcare	T1	0.11	-0.02– 0.24	0.090	-0.002	-0.18– 0.17	0.984
	T2	0.13	-0.006– 0.26	0.060	-0.0007	-0.18– 0.18	0.994

T1: baseline; T2: 6 month; Observations: total observations included in linear mixed models for construction/healthcare; P-values < 0.05 in bold

Dependent variable: Pain (T1, T2)

Independent variables:

Model 1 (Crude): Self-reported standing at work (0-5 treated as continuous variable)

Model 2 (Fully adjusted): As model 1 + adjustments for age, gender, smoking, BMI, heavy lifting, forward bending at work, social climate, decision control, fair leadership, empowering leadership, sitting (minutes) in leisure time

Table 4. Linear mixed model with self-reported sitting exposure at work and low back pain.

		<u>Model 1</u>			<u>Model 2</u>		
		Observations = 107/110			Observations = 88/95		
		Coef.	95% CI	P-value	Coef.	95% CI	P-value
Construction	T1	-0.05	-0.16– 0.07	0.434	-0.05	-0.27– 0.18	0.687
	T2	-0.02	-0.14– 0.09	0.689	-0.02	-0.25– 0.21	0.874
Healthcare	T1	-0.13	-0.31– 0.06	0.187	0.04	-0.22– 0.30	0.773
	T2	-0.15	-0.34– 0.04	0.124	0.02	-0.24– 0.28	0.879

T1: baseline; T2: 6 month; Observations: total observations included in linear mixed models for construction/healthcare; P-values < 0.05 in bold

Dependent variable: Pain (T1, T2)

Independent variables:

Model 1 (Crude): Self-reported sitting at work (0-5 treated as continuous variable)

Model 2 (Fully adjusted): As model 1 + adjustments for age, gender, smoking, BMI, heavy lifting, forward bending at work, social climate, decision control, fair leadership, empowering leadership, sitting (minutes) in leisure time

Analyses on 6 months responders versus nonresponders for paper III did not show any significant differences between groups for the variables tested. See table 5.

Table 5. Baseline characteristics for responders and nonresponders at 6 months in technical measurement group in paper III.

	<u>Responders 6 months</u>	<u>Nonresponders 6 months</u>
	(n = 97)	(n = 27)
Age	43.2 (12.2)	38.6 (9.97)
Weight (kg)	76.4 (14.0)	78.1 (12.7)
Height (cm)	173.3 (9.5)	174.9 (10.5)
Gender	55 male, 42 female	19 male, 8 female
Normal working hours	36.7 (4.8)	36.9 (1.2)
Heart rate mean (bpm) ^a	86.4 (11.4)	87.0 (10.2)
Dominant arm \geq 60 degrees (min) ^a	32.3 (27.7)	37.9 (28.3)
Forward bending \geq 60 degrees (min) ^a	22.1 (21.0)	19.0 (14.1)
Sitting (min) ^a	171.2 (108.8)	139.3 (82.3)
Standing (min) ^a	134.0 (66.3)	159.9 (62.9)
General health (1-5)	2.52 (0.97)	2.44 (0.97)
LBP intensity (0-3)	0.88 (0.90)	0.88 (0.91)
MSI (0-12)	3.0 (2.3)	2.7 (1.7)
PSI (0-12)	1.8 (1.5)	1.5 (1.0)

^a Objective measure during work. MSI = musculoskeletal complaint-severity index; PSI = Psychological complaint-severity index.

5. DISCUSSION

This thesis is based on a larger prospective cohort study where we, in collaboration with four Norwegian construction companies and two Norwegian healthcare distributors, investigated physical exposures. Our findings showed that objectively measured large-scale body activities (sitting, standing, moving) were significantly and moderately correlated to their respective self-reported measures, while arm- and trunk postures and RHR generally showed weaker correlations to their respective self-reports. Generally, self-reports seemed to overestimate duration of physical exposures. Analysis of objective measures showed significant variability in physical exposures between days of measurement, where several days of consecutive measuring produced more reliable results. With such a sample strategy, we showed that cardiovascular loads in ranges below 39% RHR characterized the average workday for employees in the construction sector. Very few persons had an average load exceeding recommended thresholds. The cardiovascular load at work decreased with increasing age and aerobic fitness, but was not associated with self-reported work ability, musculoskeletal pain, or general health. Further, increased duration of sitting at work was associated with decrease in present and future LBP intensity in healthcare workers, but not in construction workers. No association was found between standing duration and the intensity of LBP. This thesis contributes to increase knowledge on measurement of physical demands in construction- and healthcare work and the relationships between such measures and musculoskeletal health. The results presented should be of interest when interpreting previous findings based on self-reported physical exposures, for future research aiming to study relationships between physical exposures and musculoskeletal health, and for identifying physical exposures of importance for musculoskeletal health in construction- and healthcare work.

5.1 METHODOLOGICAL CONSIDERATIONS

5.1.1 Study design

If one wants to examine the effect of a certain exposure on change in a health outcome of interest, a longitudinal study will have advantages compared to a cross-sectional study. A prospective study is necessary to describe possible causal relationships, since the exposure must precede the outcome. With such design, you will capture the within-subject change, a necessity to determine causal relationships. In comparison, a cross-sectional study will only be able to obtain between subject differences (182). A cross-sectional design does not take into consideration the dimension of time, and can therefore only be used to study exposure –

outcome associations, not causality. For the papers presented in this study, only paper III makes use of prospective data. Considering the aims of paper I and II, the cross-sectional design may be sufficient. In paper I, the main aims are focused on the measurement of exposure outcome in terms of self-reports and objectively measured data, and the fact that data are collected at the same time point should not be considered a weakness. In paper II we aimed to elucidate the cardiovascular load in construction workers. For this determination of cardiovascular load the cross-sectional design should be sufficient, at least if one is not aiming to investigate seasonal variation. However, we cannot indicate any causality between the objectively measured cardiovascular load and health outcomes, merely associations. In paper III, the outcome LBP was of particular interest and should benefit from the 6-month follow-up. However, our analysis included a relatively short follow-up with only one repeated measure. A more frequent sampling of LBP intensity could improve reliability of the variable, by accounting for possible fluctuations often seen in pain reporting (183). A long and frequent follow-up generally increases risk of dropouts, due to reasons such as participation wear. In such cases one must consider outcome differences between stable participants and dropouts (184).

5.1.2 Reflections on validity

Validity is a very central term in scientific research, since it considers: “how much can we trust the results?” and “how transferrable are these results to other populations than the one we investigated?” The first question relates to the ability of a study to handle any systematic error that may give incorrect estimates and thereby inaccurate associations (i.e. biased). This is referred to as the *internal validity* of the study and violations are generally a result of one or more of three issues: selection bias, information bias, and confounding. The internal validity is seen as a prerequisite for the second question, concerning the other main component of validity: *external validity* or *generalizability* (185). For the pages to come I will discuss choices of methodology and the conduct of the study in relation to these concepts.

5.1.2.1 Internal validity – selection bias

Selection bias reflects a possible distortion that occurs because of how subjects are included in a study. A different behavior in the relationship between exposure and outcome of interest in actual participants than in theoretically eligible subjects is central in this type of bias (185). The theoretically eligible subjects in our study would be all Norwegian construction- and healthcare workers. When launching a study that focus on certain exposures or health

outcomes, *self-selection* may come into play. For our study in particular, employees with the most demanding work, or employees with more musculoskeletal pain could be more eager to participate. Similarly, bias due to *non-response* (i.e. invited subjects that reject participation) would also cause bias, if these subjects are systematically different from those that are investigated. In our study we had an initial participation rate of 51%, which means that almost half the invited workers did not wish to participate. Additionally, only a subsample was included in technical measurements. With unlimited resources, the optimal methodological strategy could be to measure exposure objectively on all participants. A downside with this strategy would be a possibly lower total number of participants for the questionnaire part, due to the burden of several days of technical measures. Our study included 594 subjects in the questionnaire group. From these, 371 were willing to participate in technical measurements. Those not willing to participate in technical measurements would possibly be lost with a strict “objective measures for all” criteria. Still, with more resources a greater part of the 371 could have been measured. However, for a selection bias to occur, selection probabilities must be related to both exposure and outcome (185, 186). For our technical measures we aimed to include participants from a variety of professions within the working sectors, which could possibly reduce selection bias (186). Analyses showed that there was a difference in self-reported sitting between the questionnaire only group and the group with technical measurements, with on average less sitting in the latter group. This was possibly due to an overrepresentation of manual workers in this group. No other differences were found between the two groups.

A high level of loss to follow-up may lower statistical power and limit validity of associations, which may be especially problematic if loss is related to outcome (185, 187). Since papers I and II in this thesis are based on cross-sectional data, *loss to follow-up* is only applicable in paper III. Here, 22% of the 125 with objective measures at baseline did not answer the questionnaire after 6 months. Even though there are huge variations between studies, this may be considered a low drop-out rate when compared to other longitudinal studies on MSDs (184), and acceptable for data missing completely at random or missing at random (187). The percentage of follow-up is partly explained by the relatively short follow-up duration of 6 months and that this was the first follow-up for the group. It is clear that longer duration of follow-up and more frequent follow-ups increase loss (184). Additionally, those participating in technical measures were the most devoted and motivated, and compared to the questionnaire-only group they had lower loss to follow-up after 6 months. As shown in

additional analyses we found no differences in the tested variables between those who responded and those who did not respond at 6 months in paper III.

The *healthy worker effect* is also a regular issue of concern when studying health outcomes in an occupational setting (185, 186). Normally, workers becoming ill will to a larger degree change their job or become unemployed. Similarly, one may have a greater opportunity to be selected into a job and stay there, when in good health. This will leave the workforce in relatively good health, and possibly more withstanding towards hazardous exposures. Such scenarios will lead to an underestimation of the actual effect in an exposure-outcome relationship. Our sample population was a well-established group of workers, with a mean seniority in profession of approximately 16 years. We cannot exclude that our sample of workers are a selected group, and that previous workers with MSDs has transferred to other jobs or have quit. Still, when compared to the general working population in Norway, our samples had overall higher prevalence of MSDs. Fifty-five percent of the subjects in the technical measurement group reported to have had some degree of LBP the previous four weeks compared to 37% when the similar question was asked in the Norwegian workforce (5).

5.1.2.2 Internal validity - Information bias: mismeasurement

Information bias is bias related to errors in the measured variables of interest. Relevant examples are technical error in objective exposure measurement or misclassification due to misinterpretation of self-reported questions.

In epidemiology, *differential misclassification* occurs when there is an unequal possibility for misclassification of exposure in diseased compared to non-diseased (185, 186). Recall bias is one example that leads to such bias, e.g. if those with high levels of MSDs remember their exposures differently than those without any MSDs.

Misclassifications are called *non-differential* when all study subjects are equally likely to be misclassified independently of e.g. disease status (185, 186).

Objectively measured exposures

In our papers we measured exposures objectively to provide precise measures-, and to avoid bias normally seen in self-reports. The results in paper I indicated the extent of misclassification that may be present in several self-reported physical exposure variables.

Such misclassification issues connected to the rater (participant) or construction of the questionnaire in exposure variables are not relevant for objective measures. By using objective exposure measures and e.g. self-reported LBP, we also avoid *common method bias* in the exposure-outcome associations. This is a type of differential misclassification often occurring in surveys with multiple-item scales, because equal methods are used to determine both exposure and outcome (188).

We have used neither a binary, “exposed or non-exposed”, view, nor a low-high exposure categorization, primarily to avoid loss of information. Exposure variables are continuous and thus there will be a continuum of exposure rather than classification as exposed or not exposed (e.g. cardiovascular load in paper II and standing in paper III). However, misclassification could be an issue if those in the higher range of for example standing exposure were more likely to misclassify LBP intensity than those with low exposure, e.g. because they feel they have more exposure and therefore expect more pain. This would lead to an overestimated association between the two variables. For this to occur in our study subjects need to be aware of the supposed association, know their objectively measured exposure, and act on it when reporting LBP. That participants were not aware of their own measured exposure at the time of pain reporting and that exposure and outcome was not sampled with common methods makes it less probable that such misclassification occurred.

A great proportion of the work forming this thesis aims to contribute with knowledge based on data from objective measures, based on the notion that this would reduce bias and increase precision. However, despite good intentions, approaches using objective measures may also be subject to information bias. In paper I+II we used Actiheart to measure HR. This device shows a high agreement when compared to standard ECG measurements (intraclass correlation = 0.999) and high intra- and interinstrument reliability (median coefficients of variation of 0.0% (0-3.3) and 0.03% (0-0.9)) (189). We urged the use of a low chest placement (just below the apex of the sternum) since this is considered to be less prone to movement artifacts along with higher ECG amplitudes compared to a high placement (at the level of the third intercostal space) (177). In a few female participants, the high placement was more appropriate. A continuous measurement of HR for several days gives an opportunity to obtain a good description of cardiovascular load during work and leisure. A drawback for the cardiovascular load measure was the use of estimates for HR_{\min} and HR_{\max} , which leads to less precision when calculating the RHR. There was also a higher level of

erroneous data than expected (mainly due to sweat disturbing contact of electrodes or due to equipment malfunctioning). Thus, our relatively strict criteria for approval of data sequences lead to a loss of measurement periods. We did however take precautions from study start by instructing participants on reattachment of electrodes and equipped them with new electrodes. Our choice of electrodes were also done for best performance in long-term ECG measurements. As noted by Butte et al. (161) it is important when interpreting HR data, to be aware that HR is prone to stimuli from other sources than physical activity: e.g. medications, caffeine, heat, and emotional state.

In paper I and III we used triaxial Actigraph® accelerometers for measurement of postures and activities. We chose these wireless, water resistant, small, light, noninvasive, and nonintrusive devices in our study due to their suitability in field measurements. Validation studies have shown that these devices, in combination with the acti4 program used in this study, have high sensitivity and specificity for detecting different activity types (sitting, standing, walking, running, and cycling). In standardized tests, both sensitivity and specificity for all positions used in the papers presented in this thesis was above 99% (162). The detection of activities is considered valid also in free-living situations, but this seems in some cases to lower both sensitivity and specificity (162, 179). Therefore, in occupational situations where the movement complexity is high and subjects consequently change between body positions at a high rate, the level of detection of specific activities may be reduced.

The use of Actigraph® and Acti4 to measure arm and upper body inclination was found valid when tested against a reference system through standardized protocols in a lab setting (163). Errors for arm inclination were low for movements with slow and intermediate speed, but at high speed, the deviation from the reference system was up to 10°. The deviation for back inclination was below 5° for the work tasks simulated. The notion of reduced precision at high speeds could be relevant in occupational tasks like hammering. Still, in the construction enterprises investigated in our study, the use of nailer tools was widespread.

Deviations may also occur if there are skin movements on the site of accelerometer attachment that are not coherent with the movement of underlying bone, which is the ultimate reference. For the accelerometers attached at the back and below the deltoid on the upper arm, these movements are assumed to be small. Attachments at hip and thigh may be more prone to such movements depending on body composition characteristics like amount of fat and musculature between device and underlying bone.

When doing long-term continuous objective measurements, time-varying offsets in devices should be considered. In studies like ours, a clock drift is relevant, since experience show that the same type of measurement device might have different offsets in timestamps. This offset is seldom large, and a minor drift for a single device may not necessarily cause problems. However, when using several individual devices that relies on synchronization it might be a considerable issue. For example, when estimating of sitting, we use both hip and thigh accelerometers. If these are not synchronized in terms of time, estimates may diverge from the true position. To overcome this issue when collecting data for several days, the acti4 program corrects for such drift differences between accelerometers. We used a standardized position performed and logged by the participants at specific time points every day, to synchronize accelerometers prior to variable calculations.

To avoid bias when carrying out a study in an occupational setting, it is of major importance that the measurement devices do not intervene with normal work patterns (190). Devices should not restrict movement or otherwise alter participant behavior; otherwise, data will not represent normal work. Normally, when increasing measurement accuracy and complexity, wearing comfort decreases. During study planning we put much emphasize on how we could obtain our measurement goals without interfering with normal participant behavior. As a result, and based on participant feedback after measurements, it is not likely that our measurement devices did hinder normal work. However, due to skin irritation some people did detach equipment prematurely. This resulted also in varying quantity of data (sample time) based on equipment type. Exemplified, a subject may remove an accelerometer on the upper arm if it bothers them, however, the HR data for this subject will remain. Additionally, there was a larger amount of error/missing for data collected during leisure compared to work. Based on conversations with subjects possible reasons for this are: project members observed the initial work day, tape and attachments wear off after many hours of use and subjects may not bother to reattach them, subjects became tired of wearing equipment, and subjects felt that it was more important to measure onlu during work time. In general, this resulted in lowered n for leisure time data. Even though magnitude and mechanisms are unknown, behavioral change because participants know they are being studied, (the *Hawthorne effect*) is also relevant for our study (191). In paper I, we found that e.g. heart rate was significantly higher on the first day of measurement as compared to following days. The first day was the day with most contact between participants and members of the research team, and thus could have altered their behavior in some way. Still, our sampling strategy culminated from the goal

of producing representable data on exposure levels. Aiming to account for possible day-to-day variability (as later shown in paper I), we sampled continuously for several consecutive days. This may reduce bias from possible initial behavioral change.

Self-reported variables.

In this section, musculoskeletal pain is used as an example of self-reported variables. However, the issues discussed may also be relevant for other self-reported variables in this thesis.

There are several measures to obtain state or level of discomfort and pain in adults (192). In paper I and II we asked participants to rate both the intensity and duration of pain in several body sites the previous four weeks, which we used to calculate a musculoskeletal complaint severity score for each site. The average of each score from the different pain sites acted as a musculoskeletal complaint severity index. Eriksen et al. suggested this way of scoring pain in their scoring system for subjective health complaints (SHC) in the general population (193). The method has acceptable one-month test-retest correlation (194) and internal consistency between musculoskeletal pain items (Cronbach's $\alpha = 0.77$ for women and 0.63 for men) (193). Steingrimsdóttir and colleagues used a similar scoring system and established equal levels of agreement between items, with internal consistency of $\alpha = 0.75$ (195). Pain is a subjective matter that is affected by e.g. individuals understanding and tolerance of pain, and there is a strong association between psychological and musculoskeletal complaints (168). Scoring systems like the SHC aim to find this individual experience of pain or discomfort. Therefore, it is no gold standard of pain measurement, which makes it difficult to evaluate all validity aspects of pain measurements (192). A possibility is however to compare self-reported values to outcomes like sickness absence or clinical examinations. Tveito et al. showed that degree of reported discomforts (high SHC-values) was highly correlated to sick leave (196). This is also shown when compared to medical examination (195).

The use of an index indicating overall musculoskeletal pain will not give any information on specific pain in body sites, but suits the intentions of papers I and II well. Due to the nature of exposure variables and our aims in these papers a measure of overall MSD complaints is more appropriate. In paper III our main aim is to investigate the association between sitting and standing duration and LBP, and thus a specific measure is appropriate. In paper III we do not consider the aspect of pain duration, which mean we cannot discriminate between subjects with high, but short term pain, and high and long term pain. The index based on intensity

times duration discriminate between these two pain conditions, but will fail to discriminate between high, but short term, and low, but long term, since some of these combinations will give an equal score. Measurement issues may also occur using this method, since small changes in either intensity or duration may give large changes in the stability of complaint severity (195). The use of only pain intensity as a measure alone is very common (197) and it is unknown if one improves information on complaints by including duration.

We know that pain and a variety of other health-related measures are fluctuating variables, and that a single-sample may not be representable for average complaints (168, 198). To reduce such issues one may, as in this study, ask the participant to report pain experienced over a wider time period. Then again, the pain reporting may become more prone to *recall bias*, since increased length of period to recall is considered to increase risk of bias (199). A study by Brauer and colleagues showed that subjects in a workplace setting were able to recall the intensity of pain or discomfort in eight different anatomic regions accurately for a 3-month period (200). The recall of pain is not only affected by time, but may also be modified by the participant's mood or symptom level at the time of reporting or the characteristics of the experienced pain (201, 202). The self-reports used in paper I and II were taken from the first questionnaire answered by the participants (at baseline). This could influence answers in the terms of bringing attention to discomforts, and thereby increase ratings of pain intensity. However, data used for paper III showed that mean LBP intensity was higher at follow-up than at baseline.

5.1.2.3 Internal validity – Confounding

Confounding is the distortion of the relationship between exposure and outcome caused by the existence of external factors that effects both exposure and outcome. This can lead to the real effect being under- or overestimated, or change in the apparent direction of an effect. A confounding has three characteristic traits: A) it is independently predictive of outcome, B) it is associated with the exposure of interest, and C) it is not an intermediate in the causal path linking exposure and outcome (185, 186).

Measures to reduce confounding may be taken both in terms of study design (randomization, restriction, and matching) and through statistical choices (adjusted models and stratification) (186, 203). In this thesis we used, restriction, stratification, and adjustment of statistical models are to limit possible confounding. Overall, the study population is restricted to working age subjects within the healthcare- and construction sector. In paper I and III, where

both sectors are represented, stratification is additionally implemented. The multivariate models in all papers were adjusted for theoretically potential confounders. Still, due to unmeasured variables, unknown confounding, or limited sample sizes, there is always a possibility for residual confounding. Thus, the measures implemented are a way of limiting, but not fully excluding confounding.

5.1.3.1 External validity - Generalizability

Biological effects can, and in many cases do, differ between populations and subpopulations. Thus, researchers often design studies to capture information on a particular sample of interest (185). In many cases, studies will be restrictive by nature. As discussed for internal validity, when a study limits variability for confounding factors, it is consequently stronger (204). As a consequence, results from human studies are often considered to have a limited generalizability beyond the study setting (185). We introduced several aspects of homogeneity in terms of age, profession, nationality etc. in our study since population of interest was Norwegian construction- and healthcare workers. This may reduce generalizability of results to other settings. It is furthermore important that our sample of construction- and healthcare workers are comparable to other workers in similar Norwegian sectors, since large differences between the population studied and the population it should represent would lead to a decrease in generalizability.

Generally, a low level of initial response may indicate selection bias. Often, this proportion of non-responders in a study is also considered a measure of the generalizability, where low response rates equals low generalizability. The initial response rate of our study, at just above 51%, can be considered moderate. Unfortunately, we do not have data for the initial non-responders to give meaningful information on differences between those who did and did not participate. As previously mentioned, a research study aiming to increase exposure validity through objective measures are often prone to a trade-off due to the resource demand from such investigations. This is also evident for our data collection, where we sampled all technical measurements from subgroups of the 594 participating with self-reported data. It is reasonable that initial participation also did suffer from the comprehensive battery of technical investigations, even though this was a voluntary part of the study. Still, the objective measures for several days must be considered a strength of this study.

The impression that low response rates equal low generalizability and loss of validity is not necessarily always true, and it is highly important to discuss other factors that may affect generalizability (203, 205).

For the study to be feasible, we were dependent on cooperation with large enterprises that from top management and throughout the company structure approved for us to engage. Consequently, the involved enterprises are large, robust workplaces, probably with high awareness and attention towards regulations and working conditions. For data concerning the construction sector, it is possible that results are less generalizable to workers in smaller companies with fewer employees, which may have other working conditions. Another issue is foreign speaking workers (not able to respond to questionnaire), and workers from subcontractors (not organized within the cooperating enterprises). In 2013, 3.3% of all salaried employees did not have a Norwegian registered address. These immigration workers are often on short-term contracts, but may end up working in Norway for several years. Of these short-term working immigrants, 23% work within construction. Additionally, many are working for manpower supply companies, which are also often being directed towards construction sectors (5).

The investigation in healthcare did not include workers in a hospital environment, and one should be very careful to generalize the results to that setting. With this said, it is likely that results will pertain also to workers in Norwegian companies with similar characteristics as the collaborating enterprises in this study. It may also be argued that it could be generalized to workers in foreign enterprises with similar legislations and working environments as Norway.

As discussed for selection bias, if dropouts are distinctively different from the remaining participants, loss to follow-up another threat to generalizability. This will possibly increase differences between the remaining group and the population it is supposed to represent. For this thesis, dropout is only applicable in paper III, where we found no differences in baseline values between the participants remaining and those lost to follow-up at 6 months.

Summarized; the main strength is the sampling strategy and use of objective measures in these studies. Some aspects of the investigations could benefit from longer follow-up periods with a more frequent sampling. With increased resources, we could also have included a larger part of the 371 that initially volunteered for technical measures.

5.2 REFLECTIONS ON MAIN RESULTS

5.2.1 Subjective and objective exposure measurement

Paper I

In paper I, we provide knowledge on the use of self-reports and objective measures to determine a variety of occupational exposures. One of the most important findings was the general overestimation of physical exposures with self-reported data. Several questions were correlated to their respective objective measures; however, the durations were generally exaggerated. A study on workers in heavy industries by Teschke and colleagues did find a general over-reporting of postures and activities at work when comparing self-reports to observations (149). Hansson et al. compared postures of the head, upper back, arms and hands, measured by questionnaire or by inclinometers and goniometers, and found low agreement between the subjective and objective measurements (148). A review investigating reproducibility and validity of self-reports on physical demands did find that questions on activities like sitting and standing performed better than questions on specific body regions when compared to objective measures (206). Most of these studies did however use observation as a reference, a method with its own limitations. Our results for mean exposures, derived from direct measurements, did show that arm and back inclinations had lower correlation than large-scale body activities like sitting. This suggests that it might be more difficult for subjects to estimate exposure durations for specific body regions. However, stratified analyses showed good correlation between arm inclination when using measures and questions concerning the first day of measurement in the group of construction workers.

The conditions for measuring are different between self-reports and direct measurements. Stock et al. reflected in their review that the agreement between self-reports and objective measurements declined with increased number of response categories (206). To be able to remember exposure, on average (last four weeks) or short-term (the same day) basis, it is likely that self-reports reflect time of doing tasks that involves the exposure, rather than the exact exposure duration. A measurement device will on the contrary precisely break down the exposure within these tasks to its exact seconds and minutes.

Results from paper I question previous findings using self-reported physical work exposures and underline importance of objective measurements if one wants to investigate exposure durations precisely. The additional analyses provided in this thesis did also indicate that you

might end up with different conclusions when analyzing exposure data as self-reported compared to when exposure is objectively measured.

Another result of importance is that the first day of measurement seemed to differ from the following days, and the reliability increased with increasing days of measurements. This should be considered in future sampling strategies. However, the number of days measured must be determined based on the particular study characteristics, since single day measurements may be sufficient if mean exposure variation is small, e.g. jobs with light and repetitive tasks (207, 208).

Two studies by the Malmö Shoulder/Neck study group showed that subjects with muscular complaints reported higher exposure than those without complaints, despite having similar or even lower objectively measured exposure (148, 209). Further, the researchers argued that due to the fact that workers with pain might reduce their exposure, self-reports may be more relevant in relation to risk evaluation. This suggests that in such scenarios self-reported pain and discomforts may be more prone to be associated to self-reported exposure than to objectively measured exposure. Meaning that self-reports may create associations that are based on other connections than real time exposure-outcome. In paper I, we determined current work exposures, and did not find that objectively measured exposures were associated with self-reported overall musculoskeletal or psychological complaints. Therefore, we cannot claim that total level of pain reduced any of the measured work exposure in our sample. However, we did not aim to evaluate risk of MSI or PSI based on exposures in this paper. These indexes do not separate between areas of pain and would possibly not be area-specific enough for some plausible exposure-outcome relationships. For example, exposure to elevated arms is often thought to be related to neck-shoulder pain, while forward bending is thought to cause discomfort in the back.

Summarized; the results in paper I are of importance for studies planning to carry out measurement of physical exposures in construction- and healthcare sectors, both in terms of choosing method of exposure measurement, and concerning number of days to sample. The findings brought forward are also of importance for previous studies that have used self-reported measures of exposure.

5.2.2 Cardiovascular load in construction workers

Paper II

In paper II, we provide objective information on cardiovascular load in male construction workers. On average, the construction workers spent almost 60% of their workday below 20% RHR, with few episodes of continuous high RHR (>33% RHR). The results did also show that the different professions within the construction sector had different demands, with carpenters, henchmen, and bricklayers having highest demands. Several studies by van der Molen and colleagues on bricklayers, masons, and carpenters found mean RHR for a full workday ranging from 21-39% (105-107). However, these studies are not easy to compare since they were mainly designed to evaluate workers during single days where they performed specific tasks of interest. Our study attempted to provide general, not task oriented, work characteristics. Additionally, we measured workers continuously for several days, while the mentioned studies measured single days. As presented in paper I, there was day-to-day variation in physical exposures, and RHR was significantly higher for the initial day of measurement. Both these differences in study design suggest that the studies by van der Molen reflect somewhat higher cardiovascular loads when compared to our study.

Cardiovascular load during work decreased significantly with increase in age, despite subjects showing the normal development of reduced aerobic fitness with increasing age (decline in $\dot{V}O_{2max}$). If work remains unchanged and aerobic fitness declines, then relative demand should increase. Our findings suggest a decrease in demands with age. This could be explained by some form of healthy worker effect, resulting in less fit subjects leaving their profession after some years. However, because we saw a reduction in $\dot{V}O_{2max}$ with age, it seems less likely to be the sole explanation. The decrease in cardiovascular demands with increasing age could be a result of decreased physiological cost for standardized work tasks in experienced workers, as compared to inexperienced workers (102). A study by Jebens and colleagues measuring aerobic demand objectively during work does not support this theory. Relative to their $\dot{V}O_{2max}$ the senior workers in this study showed a higher O_2 demand during work than the younger workers (210). However, in contrast to our study, Jebens et al. carried out 1 hour of sampling while workers performed predetermined tasks. Thus, when constricted to do the same physical tasks during a limited period the strain is likely larger for the older workers. However, when an everyday work situation is more similar to the one we provide with several days of continuous measurement, the setting is changed. A likely explanation for

our results is that a high level of control and autonomy enables older workers to alter work or delegate heavy tasks to younger workers. A construction worker not included in the present study described that employees in his enterprise even had their own term for the phenomenon of delegating heavy tasks to younger colleagues, and was not surprised when informed of our results. One might not expect to find similar results in occupations where levels of autonomy and control are lower. However, similar findings were also presented recently in a sample of various blue-collar workers, where seniority was higher in the group with low RHR during work, as compared to the group with high RHR during work (108). Even though other aspects could also explain these findings, a recent report on young workers in the Nordic countries found that younger workers reported to be more exposed to physical work than older workers (211).

The finding that higher $\dot{V}O_{2max}$ was associated with lower cardiovascular load during work is not surprising, considering that a high $\dot{V}O_{2max}$ indicates high fitness. In a standardized physically demanding task, the relative exhaustion will be lower in an individual with high fitness, as compared to one with low fitness. Physiological adaptations characterizing aerobically fit subjects and determining $\dot{V}O_{2max}$ values, like enlarged stroke volume and increased quantity of oxygen extraction from circulating blood, enable these subjects to operate at lower heart rates for a given task (212). A recent study where the metabolic equivalent calculated from accelerometer measurements represented workload, confirmed this relationship between $\dot{V}O_{2max}$ and workload in a sample of various occupations (103). Our results are a direct indication that individual fitness is a determinant of physical work demands in construction work. Still, very few persons seemed to work at relative loads considered too high throughout the workday.

A relatively low RHR would be considered positive, because this supposedly reflects a more healthy working condition. Previous studies have found that fit workers had better work ability and had lower risk of starting a sick leave period (213, 214). However, we did not find any associations between musculoskeletal pain, work ability, or general health and RHR. That few subjects had high levels of RHR might partly explain lack of findings. It is also possible that these relationships are less pronounced in males. A study by Karlqvist et al. found that females that were required to exceed one-third of their aerobic capacity during a typical workday had reduced general health and a higher level of MSDs when compared to those with lower aerobic work demands (215). This association was not found in males.

There is an ongoing debate on the apparent health paradox of occupational and leisure time physical activity (96, 216, 217). Why is physical activity at work considered as detrimental for health, while physical activity in leisure often is considered to improve health? The results in paper II indicate that manual work in the construction sector do not consist of burst of work with high enough intensity to provide training adaptations and health promotion (212). This, along with other physiological and psychological differences between physical activity during work and leisure is probably a major reason for the contradicting findings in health effects (96, 217). It is also possible that employees with manual work to a lesser degree achieve health benefits connected to recreational exercise. Previous research has indicated that participation in leisure time physical activity is negatively associated with occupational physical activity (218), and that construction workers may have lower aerobic fitness than comparable groups in the working population (219). The pathogenic role of some risk factors may also have been obscured from u-shaped relationships where one can imagine that low levels may represent underuse and high levels represents overuse, both being related to a negative health outcome (115).

Summarized; the results in paper II are of importance in the evaluation of the cardiovascular demands of construction work in Norway, and indicates individual characteristics that is associated with these demands.

5.2.3 Sitting, standing, and low back pain

Paper III

One of the interesting findings in paper III was the reduced intensity of LBP with increased duration of sitting during work in healthcare workers. A finding that was reflected both for baseline and follow-up data. This is in contrast with one of few comparable studies such as a recent cross-sectional study by Gupta et al. of various blue-collar workers that also measured sitting duration objectively for several consecutive days (127). Both studies have put effort in providing objectively measured exposures for consecutive days in an attempt to improve quality and avoid limitations with self-reported exposure, which might contribute to bias and discrepancy between previous study findings (156, 220). A possible explanation for the contradicting findings between our studies may be differences between sample compositions. As our results reflected, the relationship between sitting and intensity of LBP behaved differently in the two working sectors we measured. Another difference between the studies is also the rating of LBP intensity. While Gupta and colleagues did do analysis on a 0-9 rating of

LBP intensity dichotomized into low (≤ 5) and high (≥ 5), our LBP intensity was rated on a 0-3 scale and was analyzed as such. Our sensitivity analyses using dichotomizations of no pain (0) versus pain (1-3) and low pain (0-1) versus high pain (2-3) did support our initial results.

Further, it is relevant to question if it is the sitting posture itself that is connected to the development of LBP, or if the type of work that involves long durations of sitting have additional characteristics that affect LBP reporting? It could be that employees in jobs with long sitting duration are less likely to be exposed to other physical risk factors than those in jobs with less sitting (146), e.g. if you sit, you do not lift. It could also be that sitting jobs have different psychological and social work factors, reducing LBP reporting (31, 221). Thus, the researchers emphasized that studies on health effects of various work postures should account for associated working conditions. We did include other work-related physical and psychosocial factors, and analyses including these variables indicate the relevance of some of the discussed aspects. In the analysis on exposure during work only, we did see attenuated estimates when adjusting for other work related factors. For work data, the associations remains significant in the adjusted models for healthcare. This was not the case in the analysis on sitting exposure throughout the full day. There, significant associations were reflected for crude model and the model adjusting for individual factors (age, gender, smoking, BMI), however these associations turned non-significant when adjusting for other work related factors. This suggests that not adjusting for such factors may provide significant associations for full-day data that are driven by work-related relationships.

A review by Roffey et al. concluded there was no evidence for a causal relationship between occupational standing and LBP, due to low-quality studies and contradicting results (141). The more recent review with meta-analysis by Coenen and colleagues concluded that substantial standing was associated with increased LBP (142). However, the authors emphasized that conclusions were tentative due to lack of longitudinal studies with fully adjusted models and objective measures of standing. Our paper provides these kinds of data and cannot support an association. One of few comparable studies; a cross-sectional study measuring occupational standing objectively for several days did reflect mixed and non-significant associations between standing and LBP intensity (143). Again, this was a group representing various blue-collar professions (constructions workers, cleaners, garbage collectors, manufacturing work, assembly workers, drivers, healthcare workers, and mobile plant operators), which may have affected results if the association behaves differently between professions.

It is possible that the degree of which the standing during work is fixed or not will alter associations between this exposure and LBP. Tissot and coworkers suggest that the different levels of constraint and mobility when standing at work were differently connected to other work-related factors (221) and that standing without being able to sit at will was the most significant determinant for standing to cause LBP (134). Therefore level of freedom to break up fixed standing matters (by moving, sit down at will etc.). A study by Munch Nielsen et al. found that those with a substantial amount of objectively measured walking during work experienced less LBP (143). Overall, the workers in our study had the possibility to move short or long distances, take short breaks, or sit down at will. Intervention studies have also suggested that shifts between standing and sitting may be an important factor (222), something we have not taken into consideration.

The lack of association between standing and LBP could be explained by the healthy worker effect, the possibility that people with LBP are not assigned to tasks including long durations of standing, or that people with pain change standing behavior. With this said, a great proportion of studies reporting on associations between standing and LBP report non-significant findings (141, 142), suggesting there is no relationship. However, more high-quality longitudinal studies with objective measures of sitting and standing are needed before concluding on this issue.

Summarized; this study provides new knowledge on objectively measured duration of sitting and standing at work and associations with LBP intensity in construction- and healthcare workers. Such studies are scarce and we need more studies using objectively measured sitting and standing before we can draw conclusions.

5.3 GENDER OR SECTOR DIFFERENCES

This thesis has no intentions to investigate gender differences. Still, the construction- and healthcare sectors are both work sectors with a distinct gender domination. Of the participants answering the baseline questionnaire, 94% of the construction workers were male and 79% of the healthcare workers were female. Of the participants in the technical measurements, 98% of the construction workers were male and 78% of the healthcare workers were female. At the same time, there are large occupational differences between the two sectors, making it difficult to disentangle gender and sector differences.

In paper I, we found significant correlations between objectively measured arm inclination and questionnaires for construction workers. However, these results were not reflected in the healthcare sector. Generally, differences in work tasks performed by work sectors may partly explain such discrepancies. For arm inclination in our case specifically, this difference between sectors is possibly due to a very small amount of work with elevated arms for the average healthcare worker. Further, there were also differences in day-to-day variation in objectively measured variables between construction- and healthcare sectors. The healthcare sector reflected day-to-day variation in far fewer exposure variables than the construction workers did. This is likely a result of differences in work characteristics between the two sectors. A healthcare worker often belongs to a certain department of a specific nursing home/sheltered housing where he/she has responsibility for a specific group of patients. These institutions often have morning, midday, and afternoon routines, which the nurses and patients follow throughout all days of the week. These settings may provide less day-to-day variation. The workdays for construction workers are possibly more dependent on the nature of the construction projects as it progresses. Tasks and where on the construction site workers are stationed might change depending on the need for manpower. Additionally, the structural characteristics of the construction site change throughout each project. Dependency of material delivery and availability of heavy machinery or tools are other factors that may also provide day-to-day variation.

In paper III, the associations between sitting duration and LBP intensity was consistent for healthcare sector but no consistent significant results were established for the construction sector. An explanation for this could be that the seemingly protective effect of prolonged sitting at work among healthcare workers is due to a strong association between standing and lifting, i.e. confounding. When you sit, you do not lift. If this association was less pronounced among construction workers one would see these differences. Additional analyses for paper III (data not shown) did show significant negative correlations between sitting and self-reported lifting. However, this negative correlation was stronger for construction workers ($r = -0.6, p < 0.001$) than for healthcare workers ($r = -0.3, p < 0.05$). Additionally, we did adjust for the variable heavy lifting in an attempt to cancel this confounding from lifting. In an attempt to explain the higher prevalence of musculoskeletal complaints normally seen in females (also found in our material), research has shown that there are gender differences in how physical and psychosocial risk factors at work relate to musculoskeletal pain (223). This might explain why there are differences in exposure – outcome relationships between work

sectors dominated by opposite genders. Hansson et al. found in their study that women rated exposure higher than men did, despite having same levels of exposure (148). This difference between exposure reporting despite equal objective measures was seen also between occupations. This indicates the importance of objectively measured exposures if one is aiming for accurate measures of physical exposures.

It could also be argued that women report more complaints because high physical demands are relatively more exhausting for women than for men (224, 225). Thus, sitting work may be more rewarding in terms of protecting against LBP for women. However, then one would also expect to get a consistent significant positive association between standing duration and intensity of LBP for healthcare workers in paper III.

To remove the effect of gender, one could adjust for gender in analyses. This is common procedure in research studies, and we have done this in our analyses. However, with the high percentage of gender domination seen in construction and healthcare work adjustment for gender in stratified analyses will have less impact on estimates.

Summarized; the findings should be representable for the Norwegian work sectors investigated, with the typical gender distribution found in such sectors.

6. CONCLUSIONS

A main contribution from this thesis and the connected data collection is the comprehensive set of physical exposures objectively measured for several consecutive days in Norwegian construction- and healthcare workers. Objective measurements increase precision in determination of physical exposures, and should be considered when investigating associations between physical exposures and health outcomes like musculoskeletal disorders. This work has added to the understanding of the relationship between objective and subjective measures of physical exposures, and indicated that self-reports cannot provide an accurate description. This work has increased knowledge on levels of cardiovascular load in construction work in Norway, and put awareness towards how such demands are associated with age and fitness. It has further contributed with objectively measured exposure and prospective outcome data on understanding of the relations between sitting and standing exposure and the intensity of LBP in the construction- and healthcare sector.

The findings in this thesis should be of interest when interpreting previous knowledge extracted from self-reported physical exposures. It should also contribute to future research in terms of sampling strategy and choice of methods in studies aiming to study relationships between physical exposures and musculoskeletal health. Finally, it contributes to identify physical exposures of importance for musculoskeletal health in construction- and healthcare work.

We will continue to follow-up the participants in this study, to provide additional prospective data for investigating relationships between physical exposures and health outcomes. Additionally, there is great potential in expanding physical exposure analyses to investigate combinations of several objectively measured exposures.

FUTURE RESEARCH

The considerable amount of research examining physical exposures at work has provided knowledge of its link to development of musculoskeletal disorders and ill health. However, as stated in this thesis, a substantial part of this research is based on self-reported exposures. As shown in paper I and exemplified in the additional analyses, self-reports do not provide precise information on physical exposures and may lead to different conclusions than if exposures are measured objectively. A challenge is to obtain these objective measures and additionally achieve large study populations, since such measures often are time consuming and demanding for both participants and researchers.

Even though new equipment reduces efforts of measuring objectively, I think a huge advantage would be to increase national and international collaboration. Most researchers do not have the resources to improve precision, increase sample size, and provide long follow-ups. One solution would be exchange of technical equipment and data-pooling.

There is also potential in data sets like ours to estimate “objective numbers” from self-reported physical exposures, which if successful would reduce the need of large samples of objective measures. In a recent study by Gupta and colleagues, 63% of the real duration participants spent sedentary or being physically active by predications could be predicted based on self-reports (226).

It is further necessary to investigate to what extent there is a need for repeated objective measurements. Will there be large differences in physical exposures within subjects with unchanged work tasks if similar measures are carried out with significant time in between measurements? This would possibly also vary between work sectors. Is there such a thing as an optimal length between measures, and which factors should determine sample strategy?

Future studies should also investigate the combined effect and the single contributions in analyses including several objectively measured exposures on musculoskeletal outcomes. This includes developing acceptable mechanisms to synchronize and analyze data from multiple measurements systems.

REFERENCES

1. The Research Council of Norway. Sickness absence, work and health (SYKEFRAVAER). [Internet]. [cited 10.20.2016]. Available from: http://www.forskningsradet.no/prognett-sykefravaer/Home_Page/1226993895541.
2. Murray CJ, Ezzati M, Flaxman AD, Lim S, Lozano R, Michaud C, et al. GBD 2010: design, definitions, and metrics. *Lancet*. 2012;380(9859):2063-6.
3. Murray CJ, Vos T, Lozano R, Naghavi M, Flaxman AD, Michaud C, et al. Disability-adjusted life years (DALYs) for 291 diseases and injuries in 21 regions, 1990-2010: a systematic analysis for the Global Burden of Disease Study 2010. *Lancet*. 2012;380(9859):2197-223.
4. Vos T, Global Burden of Disease Study C. Global, regional, and national incidence, prevalence, and years lived with disability for 301 acute and chronic diseases and injuries in 188 countries, 1990-2013: a systematic analysis for the Global Burden of Disease Study 2013. *Lancet*. 2015;386(9995):743-800.
5. Nasjonal overvåkning av arbeidsmiljø og helse. Faktabok om arbeidsmiljø og helse 2015. Status og utviklingstrekk (Facts about work environment and health 2015). Oslo, Norway: National Institute of Occupational Health, 2015.
6. Lærum E, Brage S, Ihlebæk C, Johnsen K, Natvig B, Aas E. Et muskel- og skjelettregnskap. Forekomst og kostnader knyttet til skader, sykdommer og plager i muskel- og skjelettsystemet. [Musculoskeletal accounting. Incidence and costs of injuries, disorders and complaints of the musculoskeletal system.]. Oslo, Norway: FORMI, 2013. Report No.: MST-rapport 1/2013.
7. Manchikanti L, Singh V, Datta S, Cohen SP, Hirsch JA, American Society of Interventional Pain P. Comprehensive review of epidemiology, scope, and impact of spinal pain. *Pain physician*. 2009;12(4):E35-70.
8. Andersson GBJ. Epidemiological features of chronic low-back pain. *Lancet*. 1999;354:581-5.
9. Kovacs FM, Abraira V, Zamora J, Fernandez C. The transition from acute to subacute and chronic low back pain: a study based on determinants of quality of life and prediction of chronic disability. *Spine (Phila Pa 1976)*. 2005;30(15):1786-92.
10. Holth HS, Werpen HK, Zwart JA, Hagen K. Physical inactivity is associated with chronic musculoskeletal complaints 11 years later: results from the Nord-Trøndelag Health Study. *BMC Musculoskelet Disord*. 2008;9:159.
11. Sirnes E, Sødal E, Nurk E, Tell GS. Forekomst av muskel- og skjelettplager i Hordaland [Occurrence of musculoskeletal complaints in Hordaland]. *Tidsskr Nor Legeforen*. 2003;123(20):2855-9.
12. Breivik H, Collett B, Ventafridda V, Cohen R, Gallacher D. Survey of chronic pain in Europe: prevalence, impact on daily life, and treatment. *Eur J Pain*. 2006;10(4):287-333.

13. Goetzel RZ, Hawkins K, Ozminkowski RJ, Wang S. The health and productivity cost burden of the "top 10" physical and mental health conditions affecting six large U.S. employers in 1999. *J Occup Environ Med.* 2003;45(1):5-14.
14. Jacobs JJ, King TR, Klippel JH, Berven SH, Burr DB, Caskey PM, et al. Beyond the decade: strategic priorities to reduce the burden of musculoskeletal disease. *J Bone Joint Surg Am.* 2013;95(17):e1251-6.
15. Leijten FRM, van den Heuvel SG, Ybema JF, van der Beek AJ, Robroek SJW, Burdorf AA. The influence of chronic health problems on work ability and productivity at work: a longitudinal study among older employees. *Scand J Work Environ Health.* 2014;40(5):473-82.
16. World Health Organization Europe. Action plan for the prevention and control of noncommunicable diseases in the WHO European Region. 2016.
17. The Research Council of Norway. Musculoskeletal disorders and the workplace. Low back and upper extremities. Washington, D.C.: National Academy Press; 2001.
18. da Costa BR, Vieira ER. Risk factors for work-related musculoskeletal disorders: A systematic review of recent longitudinal studies. *Am J Ind Med.* 2010;53(3):285-323.
19. Hamberg-van Reenen HH, Ariëns GAM, Blatter BM, Twisk JWR, van Mechelen W, Bongers PM. Physical capacity in relation to low back, neck, or shoulder pain in a working population. *Occup Environ Med.* 2006;63(6):371-7.
20. Nilsen TIL, Holtermann A, Mork PJ. Physical exercise, body mass index, and risk of chronic pain in the low back and neck/shoulders: longitudinal data from the nord-trondelag health study. *Am J Epidemiol.* 2011;174(3):267-73.
21. Christensen JO, Knardahl S. Work and neck pain: a prospective study of psychological, social, and mechanical risk factors. *Pain.* 2010;151(1):162-73.
22. Livshits G, Popham M, Malkin I, Sambrook PN, MacGregor AJ, Spector T, et al. Lumbar disc degeneration and genetic factors are the main risk factors for low back pain in women: the UK Twin Spine Study. *Ann Rheum Dis.* 2011;70(10):1740-5.
23. Ramazzini B. *De morbis artificum 1713; Diseases of workers* (translated from latin to english by W.C. Wright). New York: Hafner publishing company; 1964.
24. Labour Force Survey [Internet]. [cited 11.14.2016]. Available from: <https://www.ons.gov.uk/>.
25. Mayer J, Kraus T, Ochsmann E. Longitudinal evidence for the association between work-related physical exposures and neck and/or shoulder complaints: a systematic review. *Int Arch Occup Environ Health.* 2012;85(6):587-603.
26. Hoogendoorn WE, van Poppel MNM, Bongers PM, Koes BW, Bouter LM. Physical load during work and leisure time as risk factors for back pain. *Scand J Work Environ Health.* 1999;25(5):387-403.
27. Knardahl S, Veiersted B, Medbø JI, Matre D, Jensen J, Strøm V, et al. Arbeid som årsak til muskelskjelettlidelser: Kunnskapsstatus 2008. 2008. Report No.: STAMI-rapport, 9(22).

28. Weiser S. Psychosocial aspects of work-related musculoskeletal disorders: clinical implications. *Musculoskeletal Disorders in the Workplace: Principles and Practice*. Second ed. Philadelphia, USA: Mosby:Elsevier; 2007. p. 13-8.
29. Kraatz S, Lang J, Kraus T, Münster E, Ochsmann E. The incremental effect of psychosocial workplace factors on the development of neck and shoulder disorders: a systematic review of longitudinal studies. *Int Arch Occup Environ Health*. 2013;86(4):375-95.
30. Lang J, Ochsmann E, Kraus T, Lang JWB. Psychosocial work stressors as antecedents of musculoskeletal problems: A systematic review and meta-analysis of stability-adjusted longitudinal studies. *Soc Sci Med*. 2012;75(7):1163-74.
31. Christensen JO, Knardahl S. Work and back pain: a prospective study of psychological, social and mechanical predictors of back pain severity. *Eur J Pain*. 2012;16(6):921-33.
32. Ariëns GAM, van Mechelen W, Bongers PM, Bouter LM, van der Wal G. Psychosocial risk factors for neck pain: a systematic review. *Am J Ind Med*. 2001;39:180-93.
33. Brown WJ, Bauman AE, Owen N. Stand up, sit down, keep moving: turning circles in physical activity research? *Br J Sports Med*. 2009;43(2):86-8.
34. Moriguchi CS, Carnaz L, Veiersted KB, Hanvold TN, Hæg LB, Hansson GÅ, et al. Occupational posture exposure among construction electricians. *Appl Ergon*. 2013;44(1):86-92.
35. Torgén M, Nygård CH, Kilbom Å. Physical work load, physical capacity and strain among elderly female aides in home-care service. *Eur J Appl Physiol*. 1995;71:444-52.
36. Engholm G, Holmström E. Dose-response associations between musculoskeletal disorders and physical and psychosocial factors among construction workers. *Scand J Work Environ Health*. 2005;31 Suppl 2:57-67.
37. Skotte JH, Essendrop M, Hansen AF, Schibye B. A dynamic 3D biomechanical evaluation of the load on the low back during different patient-handling tasks. *J Biomech*. 2002;35(10):1357-66.
38. Long MH, Bogossian FE, Johnston V. The prevalence of work-related neck, shoulder, and upper back musculoskeletal disorders among midwives, nurses, and physicians: a systematic review. *Workplace Health Saf*. 2013;61(5):223-9.
39. Videman T, Ojarjarvi A, Riihimaki H, Troup JD. Low back pain among nurses: a follow-up beginning at entry to the nursing school. *Spine*. 2005;30(20):2334-41.
40. Boschman JS, van der Molen HF, Sluiter JK, Frings-Dresen MHW. Musculoskeletal disorders among construction workers: a one-year follow-up study. *BMC Musculoskelet Disord*. 2012;13:196.
41. Stocks SJ, Turner S, McNamee R, Carder M, Hussey L, Agius RM. Occupation and work-related ill-health in UK construction workers. *Occup Med (Lond)*. 2011;61(6):407-15.
42. Järvholm B, Stattin M, Robroek SJW, Janlert U, Karlsson B, Burdorf AA. Heavy work and disability pension - a long term follow-up of Swedish construction workers. *Scand J Work Environ Health*. 2014;40(4):335-42.

43. Karpansalo M, Manninen P, Lakka TA, Kauhanen J, Rauramaa R, Salonen JT. Physical workload and risk of early retirement: prospective population-based study among middle-aged men. *J Occup Environ Med.* 2002;44(10):930-9.
44. Hagen KB, Tambs K, Bjerkedal T. A prospective cohort study of risk factors for disability retirement because of back pain in the general working population. *Spine (Phila Pa 1976).* 2002;27(16):1790-6.
45. Labour Force Survey [Internet]. [Cited 11.14.2016] Available from: <https://www.ssb.no/en/statistikkbanken>.
46. Bernard BP. Musculoskeletal disorders and workplace factors. A critical review of epidemiologic evidence for work-related musculoskeletal disorders of the neck, upper extremity, and low back. Cincinnati, OH: U.S.: Department of health and Human Services, NIOSH; 1997.
47. Brage S. Musculoskeletal health problems and sickness absence - an epidemiological study of concepts, determinants, and consequences (thesis). Oslo: University of Oslo; 1998.
48. Merskey H, Bogduk N. Classification of chronic pain. International Association for the Study of Pain Press. 1994:210.
49. Loeser JD, Melzack R. Pain: an overview. *Lancet.* 1999;353(9164):1607-9.
50. Cervero F, Laird JMA. One pain or many pains? A new look at pain mechanisms. *News Physiol Sci.* 1991;6:268-73.
51. Jaillard A, Ropper AH. Pain, heat, and emotion with functional MRI. *N Engl J Med.* 2013;368(15):1447-9.
52. Wager TD, Atlas LY, Lindquist MA, Roy M, Woo CW, Kross E. An fMRI-based neurologic signature of physical pain. *N Engl J Med.* 2013;368(15):1388-97.
53. Brown JE, Chatterjee N, Younger J, Mackey S. Towards a physiology-based measure of pain: patterns of human brain activity distinguish painful from non-painful thermal stimulation. *PLoS One.* 2011;6(9):e24124.
54. Chapman CR. Pain perception and assessment. *Minerva Anesthesiol.* 2005;71(7-8):413-7.
55. Waddell G. Preventing incapacity in people with musculoskeletal disorders. *Br Med Bull.* 2006;77-78:55-69.
56. Balagué F, Mannion AF, Pellisé F, Cedraschi C. Non-specific low back pain. *Lancet.* 2012;379(9814):482-91.
57. Armstrong TJ, Buckle P, Fine LJ, Hagberg M, Jonsson B, Kilbom Å, et al. A conceptual model for work-related neck and upper-limb musculoskeletal disorders. *Scand J Work Environ Health.* 1993;19(2):73-84.
58. Burdorf A. The role of assessment of biomechanical exposure at the workplace in the prevention of musculoskeletal disorders. *Scand J Work Environ Health.* 2010;36(1):1-2.

59. Winkel J, Mathiassen SE. Assessment of physical work load in epidemiologic studies: concepts, issues and operational considerations. *Ergonomics*. 1994;37:979-88.
60. Marras WS. The complex spine: the multidimensional system of causal pathways for low-back disorders. *Hum Factors*. 2012;54(6):881-9.
61. Chaffin DB. The evolving role of biomechanics in prevention of overexertion injuries. *Ergonomics*. 2009;52(1):3-14.
62. Hoogendoorn WE, Bongers PM, de Vet HCW, Houtman ILD, Ariens GAM, van Mechelen W, et al. Psychosocial work characteristics and psychological strain in relation to low-back pain. *Scand J Work Environ Health*. 2001;27(4):258-67.
63. Fridén J, Sjöström M, Ekblom B. A morphological study of delayed muscle soreness. *Experientia*. 1981;37:506-7.
64. Fridén J, Seger J, Ekblom B. Sublethal muscle fibre injuries after high-tension anaerobic exercise. *Eur J Appl Physiol*. 1988;57:360-8.
65. Hagberg M, Michaelson G, Örtelius A. Serum creatine kinase as an indicator of local muscular strain in experimental and occupational work. *Int Arch Occup Environ Health*. 1982;50:377-86.
66. Malcolm SA, Anstee A, Halloran M. Time course changes in plasma creatine kinase over four days of repetitive manual work. *Ergonomics*. 1995;38(5):1019-24.
67. Semmler JG, Ebert SA, Amarasena J. Eccentric muscle damage increases intermuscular coherence during a fatiguing isometric contraction. *Acta Physiol (Oxf)*. 2013;208(4):362-75.
68. Lavender AP, Nosaka K. Changes in markers of muscle damage of middle-aged and young men following eccentric exercise of the elbow flexors. *J Sci Med Sport*. 2008;11(2):124-31.
69. Bloomfield SA. Cellular and molecular mechanisms for the bone response to mechanical loading. *Int J Sport Nutr Exerc Metab*. 2001;11:128-36.
70. Wells R, Van Eerd D, Hagg G. Mechanical exposure concepts using force as the agent. *Scand J Work Environ Health*. 2004;30(3):179-90.
71. Coenen P, Kingma I, Boot CRL, Bongers PM, van Dieën JH. Cumulative mechanical low-back load at work is a determinant of low-back pain. *Occup Environ Med*. 2014;71(5):332-7.
72. Norman R, Wells R, Neumann P, Frank J, Shannon H, Kerr M, et al. A comparison of peak vs cumulative physical work exposure risk factors for the reporting of low back pain in the automotive industry. *Clin Biomech*. 1998;13:561-73.
73. Neumann WP, Wells RP, Norman RW, Andrews DM, Frank J, Shannon HS, et al. Comparison of four peak spinal loading exposure measurement methods and their association with low-back pain. *Scand J Work Environ Health*. 1999;25(5):404-9.
74. Hadjipavlou AG, Tzermiadianos MN, Bogduk N, Zindrick MR. The pathophysiology of disc degeneration: a critical review. *J Bone Joint Surg Br*. 2008;90(10):1261-70.

75. Sato K, Kikuchi S, Yonezawa T. In vivo intradiscal pressure measurement in healthy individuals and in patients with ongoing back problems. *Spine (Phila Pa 1976)*. 1999;24(23):2468-74.
76. van Deursen LL, van Deursen DL, Snijders CJ, Wilke HJ. Relationship between everyday activities and spinal shrinkage. *Clin Biomech (Bristol, Avon)*. 2005;20(5):547-50.
77. Jensen BR, Jørgensen K, Sjøgaard G. The effect of prolonged isometric contractions on muscle fluid balance. *Eur J Appl Physiol Occup Physiol*. 1994;69(5):439-44.
78. Jensen BR, Jørgensen K, Huijing PA, Sjøgaard G. Soft tissue architecture and intramuscular pressure in the shoulder region. *Eur J Morphol*. 1995;33(3):205-20.
79. Werner CO, Elmquist D, Ohlin T. Pressure and nerve lesions in the carpal tunnel. *Acta Orthop Scand*. 1983;54(2):312-6.
80. Goldstein SA, Armstrong TJ, Chaffin DB, Matthews LS. Analysis of cumulative strain in tendons and tendon sheaths. *J Biomech*. 1987;20:1-6.
81. Brinckmann P, Johannleueling N, Hilweg D, Biggemann M. Fatigue fracture of human lumbar vertebrae. *Clin Biomech (Bristol, Avon)*. 1987;2(2):94-6.
82. Edwards RHT. Hypotheses of peripheral and central mechanisms underlying occupational muscle pain and injury. *Eur J Appl Physiol*. 1988;57:275-81.
83. Westgaard RH, Bjørklund R. Generation of muscle tension additional to postural muscle load. *Ergonomics*. 1987;30:911-23.
84. Gissel H. Ca²⁺ accumulation and cell damage in skeletal muscle during low frequency stimulation. *Eur J Appl Physiol*. 2000;83(2-3):175-80.
85. Westerblad H, Bruton JD, Allen DG, Lännergren J. Functional significance of Ca²⁺ in long-lasting fatigue of skeletal muscle (review). *Eur J Appl Physiol*. 2000;83(2-3):166-74.
86. Mense S. Peripheral mechanisms of muscle nociception and local muscle pain. *J Musculoske Pain*. 1993;1(1):133-70.
87. Knardahl S. Psychophysiological mechanisms of pain in computer work: the blood vessel-nociceptor interaction hypothesis. *Work & Stress*. 2002;16(2):179-89.
88. Barbe MF, Barr AE. Inflammation and the pathophysiology of work-related musculoskeletal disorders. *Brain Behav Immun*. 2006;20(5):423-9.
89. Abdelhamid RE, Sluka KA. ASICs Mediate Pain and Inflammation in Musculoskeletal Diseases. *Physiology (Bethesda, Md)*. 2015;30(6):449-59.
90. Travell JG, Rinzler S, Herman M. Pain and disability of the shoulder and arm. *JAMA*. 1942;120:417-22.
91. Johansson H, Sojka P. Pathophysiological mechanisms involved in genesis and spread of muscular tension in occupational muscle pain and in chronic musculoskeletal pain syndromes: a hypothesis. *Med Hypotheses*. 1991;35:196-203.

92. Lund JP, Donga R, Widmer CG, Stohler CS. The pain-adaption model: a discussion of the relationship between chronic musculoskeletal pain and motor activity. *Can J Physiol Pharmacol.* 1991;69:683-94.
93. Brodal P. *Smerte. Sentralnervesystemet.* 5th ed. Oslo, Norway: Universitetsforlaget; 2013. p. 229-40.
94. Balagué F. The Bone and Joint Decade (2000-2010) Task Force on Neck Pain and Its Associated Disorders: A clinician's perspective. *Spine.* 2008;33(4):4.
95. Åstrand PO, Rodal K, Dahl HA, Strømme BS. *Applied Work Physiology. Textbook of Work Physiology.* Fourth Edition ed. United States: Human Kinetics Publishers, Inc; 2003. p. 503-40.
96. Harari G, Green MS, Zelber-Sagi S. Combined association of occupational and leisure-time physical activity with all-cause and coronary heart disease mortality among a cohort of men followed-up for 22 years. *Occup Environ Med.* 2015;72(9):617-24.
97. Krause N, Brand RJ, Kaplan GA, Kauhanen J, Malla S, Tuomainen TP, et al. Occupational physical activity, energy expenditure and 11-year progression of carotid atherosclerosis. *Scand J Work Environ Health.* 2007;33(6):405-24.
98. Haukka E, Ojajärvi A, Takala EP, Viikari-Juntura E, Leino-Arjas P. Physical workload, leisure-time physical activity, obesity and smoking as predictors of multisite musculoskeletal pain. A 2-year prospective study of kitchen workers. *Occup Environ Med.* 2012;69(7):485-92.
99. van den Berg TIJ, Elders LAM, de Zwart BCH, Burdorf A. The effects of work-related and individual factors on the Work Ability Index: a systematic review. *Occup Environ Med.* 2009;66(4):211-20.
100. Andersen LL, Fallentin N, Thorsen SV, Holtermann A. Physical workload and risk of long-term sickness absence in the general working population and among blue-collar workers: prospective cohort study with register follow-up. *Occup Environ Med.* 2016;73(4):246-53.
101. Jorgensen K. Permissible loads based on energy expenditure measurements. *Ergonomics.* 1985;28(1):365-9.
102. Rodgers SH, Kenworth DA. *Heart rate interpretation methodology. Ergonomic Design for People at Work.* New York, USA: Van Nostrand Reinhold; 1986. p. 178-9.
103. Brighenti-Zogg S, Mundwiler J, Schupbach U, Dieterle T, Wolfer DP, Leuppi JD, et al. Physical Workload and Work Capacity across Occupational Groups. *PLoS One.* 2016;11(5):e0154073.
104. Boschman JS, van der Molen HF, Sluiter JK, Frings-Dresen MHW. Occupational demands and health effects for bricklayers and construction supervisors: A systematic review. *Am J Ind Med.* 2011;54(1):55-77.
105. van der Molen HF, Kuijjer PPFM, Formanoy M, Bron L, Hoozemans MJM, Visser B, et al. Evaluation of three ergonomic measures on productivity, physical work demands, and workload in gypsum bricklayers. *Am J Ind Med.* 2010;53(6):608-14.

106. Van Der Molen HF, Kuijer PP, Hopmans PP, Houweling AG, Faber GS, Hoozemans MJ, et al. Effect of block weight on work demands and physical workload during masonry work. *Ergonomics*. 2008;51(3):355-66.
107. van der Molen HF, Mol E, Kuijer PP, Frings-Dresen MH. The evaluation of smaller plasterboards on productivity, work demands and workload in construction workers. *Appl Ergon*. 2007;38(5):681-6.
108. Gupta N, Jensen BS, Sogaard K, Carneiro IG, Christiansen CS, Hanisch C, et al. Face validity of the single work ability item: comparison with objectively measured heart rate reserve over several days. *Int J Environ Res Public Health*. 2014;11(5):5333-48.
109. Katzmarzyk PT, Church TS, Craig CL, Bouchard C. Sitting time and mortality from all causes, cardiovascular disease, and cancer. *Med Sci Sports Exerc*. 2009;41(5):998-1005.
110. Wijndaele K, Brage S, Besson H, Khaw KT, Sharp SJ, Luben R, et al. Television viewing time independently predicts all-cause and cardiovascular mortality: the EPIC Norfolk Study. *Int J Epidemiol*. 2011;40(1):150-9.
111. Schmid D, Leitzmann MF. Television viewing and time spent sedentary in relation to cancer risk: a meta-analysis. *J Natl Cancer Inst*. 2014;106(7).
112. Zhou Y, Zhao H, Peng C. Association of sedentary behavior with the risk of breast cancer in women: update meta-analysis of observational studies. *Ann Epidemiol*. 2015;25(9):687-97.
113. Ford ES, Li C, Zhao G, Pearson WS, Tsai J, Churilla JR. Sedentary behavior, physical activity, and concentrations of insulin among US adults. *Metabolism*. 2010;59(9):1268-75.
114. Stamatakis E, Hirani V, Rennie K. Moderate-to-vigorous physical activity and sedentary behaviours in relation to body mass index-defined and waist circumference-defined obesity. *Br J Nutr*. 2009;101(5):765-73.
115. Heneweer H, Vanhees L, Picavet HSJ. Physical activity and low back pain: a U-shaped relation? *Pain*. 2009;143(1-2):21-5.
116. Hamer M, Coombs N, Stamatakis E. Associations between objectively assessed and self-reported sedentary time with mental health in adults: an analysis of data from the Health Survey for England. *BMJ open*. 2014;4(3):e004580.
117. van Wely P. Design and Disease. *Appl Ergonomics*. 1970;1:262-9.
118. Hartvigsen J, Leboeuf-Yde C, Lings S, Corder EH. Is sitting-while-at-work associated with low back pain? A systematic, critical literature review. *Scand J Public Health*. 2000;28(3):230-9.
119. Roffey DM, Wai EK, Bishop P, Kwon BK, Dagenais S. Causal assessment of occupational sitting and low back pain: results of a systematic review. *Spine J*. 2010;10(3):252-61.
120. Nachemson AL. Disc pressure measurements. *Spine (Phila Pa 1976)*. 1981;6(1):93-7.
121. Claus A, Hides J, Moseley GL, Hodges P. Sitting versus standing: does the intradiscal pressure cause disc degeneration or low back pain? *J Electromyogr Kinesiol*. 2008;18(4):550-8.

122. Srinivasan D, Mathiassen SE. Motor variability in occupational health and performance. *Clin Biomech (Bristol, Avon)*. 2012;27:979-93.
123. Beach TA, Parkinson RJ, Stothart JP, Callaghan JP. Effects of prolonged sitting on the passive flexion stiffness of the in vivo lumbar spine. *Spine J*. 2005;5(2):145-54.
124. McGill SM, Hughson RL, Parks K. Lumbar erector spinae oxygenation during prolonged contractions: implications for prolonged work. *Ergonomics*. 2000;43(4):486-93.
125. Gupta N, Hallman DM, Mathiassen SE, Aadahl M, Jorgensen MB, Holtermann A. Are temporal patterns of sitting associated with obesity among blue-collar workers? A cross sectional study using accelerometers. *BMC Public Health*. 2016;16(1):148.
126. Ferreira PH, Beckenkamp P, Maher CG, Hopper JL, Ferreira ML. Nature or nurture in low back pain? Results of a systematic review of studies based on twin samples. *Eur J Pain*. 2013;17(7):957-71.
127. Gupta N, Christiansen CS, Hallman DM, Korshøj M, Carneiro IG, Holtermann A. Is objectively measured sitting time associated with low back pain? A cross-sectional investigation in the NOMAD study. *PLoS One*. 2015;10(3):e0121159.
128. Hallman DM, Gupta N, Mathiassen SE, Holtermann A. Association between objectively measured sitting time and neck-shoulder pain among blue-collar workers. *Int Arch Occup Environ Health*. 2015.
129. Katzmarzyk PT. Standing and mortality in a prospective cohort of Canadian adults. *Med Sci Sports Exerc*. 2014;46(5):940-6.
130. van der Ploeg HP, Chey T, Ding D, Chau JY, Stamatakis E, Bauman AE. Standing time and all-cause mortality in a large cohort of Australian adults. *Prev Med*. 2014;69:187-91.
131. Roelen CA, Schreuder KJ, Koopmans PC, Groothoff JW. Perceived job demands relate to self-reported health complaints. *Occup Med (Lond)*. 2008;58(1):58-63.
132. Andersen JH, Haahr JP, Frost P. Risk factors for more severe regional musculoskeletal symptoms: a two-year prospective study of a general working population. *Arthritis Rheum*. 2007;56(4):1355-64.
133. Sterud T, Tynes T. Work-related psychosocial and mechanical risk factors for low back pain: a 3-year follow-up study of the general working population in Norway. *Occup Environ Med*. 2013;70:296-302.
134. Tissot F, Messing K, Stock S. Studying the relationship between low back pain and working postures among those who stand and those who sit most of the working day. *Ergonomics*. 2009;52(11):1402-18.
135. Wilke HJ, Neef P, Caimi M, Hoogland T, Claes LE. New in vivo measurements of pressures in the intervertebral disc in daily life. *Spine (Phila Pa 1976)*. 1999;24(8):755-62.
136. Adams MA, McMillan DW, Green TP, Dolan P. Sustained loading generates stress concentrations in lumbar intervertebral discs. *Spine (Phila Pa 1976)*. 1996;21(4):434-8.

137. Waters TR, Dick RB. Evidence of health risks associated with prolonged standing at work and intervention effectiveness. *Rehabil Nurs.* 2015;40(3):148-65.
138. Garcia MG, Laübli T, Martin BJ. Long-Term Muscle Fatigue After Standing Work. *Hum Factors.* 2015;57(7):1162-73.
139. Nelson-Wong E, Callaghan JP. Is muscle co-activation a predisposing factor for low back pain development during standing? A multifactorial approach for early identification of at-risk individuals. *J Electromyogr Kinesiol.* 2010;20(2):256-63.
140. Nelson-Wong E, Gregory DE, Winter DA, Callaghan JP. Gluteus medius muscle activation patterns as a predictor of low back pain during standing. *Clin Biomech (Bristol, Avon).* 2008;23(5):545-53.
141. Roffey DM, Wai EK, Bishop P, Kwon BK, Dagenais S. Causal assessment of occupational standing or walking and low back pain: results of a systematic review. *Spine J.* 2010;10(3):262-72.
142. Coenen P, Willenberg L, Parry S, Shi JW, Romero L, Blackwood DM, et al. Associations of occupational standing with musculoskeletal symptoms: a systematic review with meta-analysis. *Br J Sports Med.* 2016.
143. Munch Nielsen C, Gupta N, Knudsen LE, Holtermann A. Association of objectively measured occupational walking and standing still with low back pain: a cross-sectional study. *Ergonomics.* 2016:1-20.
144. van Uffelen JGZ, Wong J, Chau JY, van der Ploeg HP, Riphagen I, Gilson ND, et al. Occupational sitting and health risks: a systematic review. *Am J Prev Med.* 2010;39(4):379-88.
145. PEROSH. PEROSH recommendations for procedures to measure occupational physical activity and workload. [internet]. [cited 10.24.2016]. Available from: <http://www.perosh.eu/>.
146. Picavet HS, Pas LW, van Oostrom SH, van der Ploeg HP, Verschuren WM, Proper KI. The Relation between Occupational Sitting and Mental, Cardiometabolic, and Musculoskeletal Health over a Period of 15 Years - The Doetinchem Cohort Study. *PLoS One.* 2016;11(1):e0146639.
147. Barrero LH, Katz JN, Dennerlein JT. Validity of self-reported mechanical demands for occupational epidemiologic research of musculoskeletal disorders. *Scand J Work Environ Health.* 2009;35(4):245-60.
148. Hansson GÅ, Balogh I, Byström JU, Ohlsson K, Nordander C, Asterland P, et al. Questionnaire versus direct technical measurements in assessing postures and movements of the head, upper back, arms and hands. *Scand J Work Environ Health.* 2001;27(1):30-40.
149. Teschke K, Trask C, Johnson P, Chow Y, Village J, Koehoorn M. Measuring posture for epidemiology: comparing inclinometry, observations and self-reports. *Ergonomics.* 2009;52(9):1067-78.

150. Kwak L, Proper KI, Hagströmer M, Sjöström M. The repeatability and validity of questionnaires assessing occupational physical activity - a systematic review. *Scand J Work Environ Health*. 2011;37(1):6-29.
151. Dyrstad SM, Hansen BH, Holme IM, Anderssen SA. Comparison of self-reported versus accelerometer-measured physical activity. *Med Sci Sports Exerc*. 2014;46(1):99-106.
152. Barrero LH, Katz JN, Perry MJ, Krishnan R, Ware JH, Dennerlein JT. Work pattern causes bias in self-reported activity duration: a randomised study of mechanisms and implications for exposure assessment and epidemiology. *Occup Environ Med*. 2009;66(1):38-44.
153. Unge J, Hansson GA, Ohlsson K, Nordander C, Axmon A, Winkel J, et al. Validity of self-assessed reports of occurrence and duration of occupational tasks. *Ergonomics*. 2005;48(1):12-24.
154. Ainsworth B, Cahalin L, Buman M, Ross R. The current state of physical activity assessment tools. *Prog Cardiovasc Dis*. 2015;57(4):387-95.
155. Takala EP, Pehkonen I, Forsman M, Hansson GÅ, Mathiassen SE, Neumann WP, et al. Systematic evaluation of observational methods assessing biomechanical exposures at work. *Scand J Work Environ Health*. 2010;36(1):3-24.
156. Lagersted-Olsen J, Korshøj M, Skotte J, Carneiro IG, Sjøgaard K, Holtermann A. Comparison of Objectively Measured and Self-reported Time Spent Sitting. *Int J Sports Med*. 2013;35(6):534-40.
157. McArdle WD, Katch FI, Katch VL. Cardiovascular Regulation and Intergration. *Exercise Physiology*. Sixth ed. Baltimore, Maryland, U.S.A: Lippincott Williams & Wilkins; 2007. p. 334-7.
158. Wu HC, Wang MJ. Relationship between maximum acceptable work time and physical workload. *Ergonomics*. 2002;45(4):280-9.
159. Shimaoka M, Hiruta S, Ono Y, Nonaka H, Hjelm EW, Hagberg M. A comparative study of physical work load in Japanese and Swedish nursery school teachers. *Eur J Appl Physiol Occup Physiol*. 1998;77(1-2):10-8.
160. Freedson P, Bowles HR, Troiano R, Haskell W. Assessment of physical activity using wearable monitors: recommendations for monitor calibration and use in the field. *Med Sci Sports Exerc*. 2012;44(1):1-4.
161. Butte NF, Ekelund U, Westerterp KR. Assessing physical activity using wearable monitors: measures of physical activity. *Med Sci Sports Exerc*. 2012;44(1 Suppl 1):S5-12.
162. Skotte J, Korshøj M, Kristiansen J, Hanisch C, Holtermann A. Detection of physical activity types using triaxial accelerometers. *Journal of physical activity & health*. 2014;11(1):76-84.
163. Korshøj M, Skotte JH, Christiansen CS, Mortensen P, Kristiansen J, Hanisch C, et al. Validity of the Acti4 software using ActiGraph GT3X+accelerometer for recording of arm and upper body inclination in simulated work tasks. *Ergonomics*. 2014;57(2):247-53.

164. Wahlström J, Mathiassen SE, Liv P, Hedlund P, Ahlgren C, Forsman M. Upper arm postures and movements in female hairdressers across four full working days. *Ann Occup Hyg.* 2010;54(5):584-94.
165. Wahlström J, Bergsten E, Trask C, Mathiassen SE, Jackson J, Forsman M. Full-Shift Trunk and Upper Arm Postures and Movements Among Aircraft Baggage Handlers. *Ann Occup Hyg.* 2016;60(8):977-90.
166. Statistics, Norway. Levekårsundersøkelsen 2009 (Survey of level of living 2009). 2009. [Internet]. [cited 11.20.2016]. Available from: <https://www.ssb.no>.
167. Noble BJ, Borg GAV, Jacobs I, Ceci R, Kaiser P. A category-ratio perceived exertion scale: relationship to blood and muscle lactates and heart rate. *Med Sci Sports Exerc.* 1983;15:523-8.
168. Steingrimsdóttir ÓA, Vøllestad NK, Røe C, Knardahl S. Variation in reporting of pain and other subjective health complaints in a working population and limitations of single sample measurements. *Pain.* 2004;110(1-2):130-9.
169. Ware JE, Jr. SF-36 health survey update. *Spine (Phila Pa 1976).* 2000;25(24):3130-9.
170. Ahlstrom L, Grimby-Ekman A, Hagberg M, Dellve L. The work ability index and single-item question: associations with sick leave, symptoms, and health - a prospective study of women on long-term sick leave. *Scand J Work Environ Health.* 2010;36(5):404-12.
171. Wännström I, Peterson U, Åsberg M, Nygren Å, Gustavsson JP. Psychometric properties of scales in the General Nordic Questionnaire for Psychological and Social Factors at Work (QPSNordic): confirmatory factor analysis and prediction of certified long-term sickness absence. *Scand J Psychol.* 2009;50(3):231-44.
172. Dallner M, Elo AL, Gamberale F, Hottinen V, Knardahl S, Lindström K, et al. Validation of the General Nordic Questionnaire (QPS_{Nordic}) for psychological and social factors at work. *Nordic Council of Ministers, Nord.* 2000;12:(171 pages).
173. Saltin B, Grimby G. Physiological analysis of middle-aged and old former athletes. Comparison with still active athletes of the same ages. *Circulation.* 1968;38(6):1104-15.
174. Åstrand PO, Rodahl K, Dahl HA, Strømme BS. Evaluation of physical performance on the basis of tests. *Textbook of Work Physiology. Fourth Edition edn.* United states: Human Kinetics Publishers, Inc; 2003. p. 283-4.
175. Åstrand PO, Ryhming I. A nomogram for calculation of aerobic capacity (physical fitness) from pulse rate during sub-maximal work. *J Appl Physiol.* 1954;7(2):218-21.
176. Essendrop M, Schibye B, Hansen K. Reliability of isometric muscle strength tests for the trunk, hands and shoulders. *International Journal of Industrial Ergonomics.* 2001;28(6):379-87.
177. Brage S, Brage N, Ekelund U, Luan J, Franks PW, Froberg K, et al. Effect of combined movement and heart rate monitor placement on physical activity estimates during treadmill locomotion and free-living. *Eur J Appl Physiol.* 2006;96(5):517-24.

178. Kristiansen J, Korshøj M, Skotte JH, Jespersen T, Søgaard K, Mortensen OS, et al. Comparison of two systems for long-term heart rate variability monitoring in free-living conditions-a pilot study. *Biomed Eng Online*. 2011;10:27.
179. Stemland I, Ingebrigtsen J, Christiansen CS, Jensen BR, Hanisch C, Skotte J, et al. Validity of the Acti4 method for detection of physical activity types in free-living settings: comparison with video analysis. *Ergonomics*. 2015:1-13.
180. Tanaka H, Monahan KD, Seals DR. Age-predicted maximal heart rate revisited. *J Am Coll Cardiol*. 2001;37(1):153-6.
181. The Nord Trøndelag Health Study. [Internet]. [cited 11.10.2016]. Available from: <https://www.ntnu.edu/hunt/databank>.
182. Fitzmaurice GM, Laird NM, James HW. *Applied Longitudinal Analysis*. Second ed. New Jersey; U.S.A.: John Wiley & Sons, Inc.; 2011.
183. Leboeuf-Yde C, Lemeunier N, Wedderkopp N, Kjaer P. Evidence-based classification of low back pain in the general population: one-year data collected with SMS Track. *Chiropractic & manual therapies*. 2013;21:30.
184. Bildt C, Alfredsson L, Punnett L, Theobald H, Torgén M, Wikman A. Effects of drop out in a longitudinal study of musculoskeletal disorders. *Occup Environ Med*. 2001;58(3):194-9.
185. Rothman KJ, Greenland S, Lash TL. *Validity in Epidemiologic Studies*. Modern Epidemiology. Third ed. Philadelphia, U.S.A.: Lippencott Williams & Wilkins; 2008. p. 128-47.
186. Pearce N, Checkoway H, Kriebel D. Bias in occupational epidemiology studies. *Occup Environ Med*. 2007;64(8):562-8.
187. Kristman V, Manno M, Cote P. Loss to follow-up in cohort studies: how much is too much? *Eur J Epidemiol*. 2004;19(8):751-60.
188. Podsakoff PM, MacKenzie SB, Lee JY, Podsakoff NP. Common method biases in behavioral research: a critical review of the literature and recommended remedies. *J Appl Psychol*. 2003;88(5):879-903.
189. Brage S, Brage N, Franks PW, Ekelund U, Wareham NJ. Reliability and validity of the combined heart rate and movement sensor Actiheart. *European journal of clinical nutrition*. 2005;59(4):561-70.
190. Valero E, Sivanathan A, Bosche F, Abdel-Wahab M. Musculoskeletal disorders in construction: A review and a novel system for activity tracking with body area network. *Appl Ergon*. 2016;54:120-30.
191. McCambridge J, Witton J, Elbourne DR. Systematic review of the Hawthorne effect: new concepts are needed to study research participation effects. *J Clin Epidemiol*. 2014;67(3):267-77.
192. Hawker GA, Mian S, Kendzerska T, French M. Measures of adult pain: Visual Analog Scale for Pain (VAS Pain), Numeric Rating Scale for Pain (NRS Pain), McGill Pain Questionnaire (MPQ), Short-Form McGill Pain Questionnaire (SF-MPQ), Chronic Pain Grade Scale (CPGS), Short

- Form-36 Bodily Pain Scale (SF-36 BPS), and Measure of Intermittent and Constant Osteoarthritis Pain (ICOAP). *Arthritis Care Res (Hoboken)*. 2011;63 Suppl 11:S240-52.
193. Eriksen HR, Ihlebaek C, Ursin H. A scoring system for subjective health complaints (SHC). *Scand J Public Health*. 1999;27(1):63-72.
194. Eriksen HR, Olff M, Ursin H. The CODE: A revised battery for coping and defense and its relations to subjective health. *Scand J Psychol*. 1997;38:175-82.
195. Steingrimsdóttir ÓA. Subjective health complaints and their relation to muscle responses in a working population (thesis): Faculty of Medicine, University of Oslo and National Institute of Occupational Health, Oslo, Norway; 2005.
196. Tveito TH, Halvorsen A, Lauvålien JV, Eriksen HR. Room for everyone in working life? 10% of the employees - 82% of the sickness leave. *Norsk Epidemiologi*. 2002;12(1):63-8.
197. Price DD, Patel R, Robinson ME, Staud R. Characteristics of electronic visual analogue and numerical scales for ratings of experimental pain in healthy subjects and fibromyalgia patients. *Pain*. 2008;140(1):158-66.
198. Tuomisto MT, Terho T, Korhonen I, Lappalainen R, Tuomisto T, Laippala P, et al. Diurnal and weekly rhythms of health-related variables in home recordings for two months. *Physiol Behav*. 2006;87(4):650-8.
199. Eisenhower D, Mathiowetz NA, Morganstein D. Recall Error - Sources and Bias Reduction Techniques. Wiley S Pro. 1991:127-44.
200. Brauer C, Thomsen JF, Loft IP, Mikkelsen S. Can we rely on retrospective pain assessments? *Am J Epidemiol*. 2003;157(6):552-7.
201. Barsky AJ. Forgetting, fabricating, and telescoping: the instability of the medical history. *Arch Intern Med*. 2002;162(9):981-4.
202. Miranda H, Gold JE, Gore R, Punnett L. Recall of prior musculoskeletal pain. *Scand J Work Environ Health*. 2006;32(4):294-9.
203. Rothman KJ, Greenland S, Lash TL. *Modern epidemiology*. 3 ed. Philadelphia: Lippencott Williams & Wilkins; 2008.
204. Rothman KJ. Six persistent research misconceptions. *J Gen Intern Med*. 2014;29(7):1060-4.
205. Visser PS, Krosnick JA, Marquette J, Curtin M. Mail surveys for election forecasting? An evaluation of the Columbus Dispatch poll. *Public Opin Q*. 1996;60(2):181-227.
206. Stock SR, Fernandes R, Delisle A, Vézina N. Reproducibility and validity of workers' self-reports of physical work demands. *Scand J Work Environ Health*. 2005;31(6):409-37.
207. Mathiassen SE, Burdorf A, van der Beek AJ, Hansson GÅ. Efficient one-day sampling of mechanical job exposure data - a study based on upper trapezius activity in cleaners and office workers. *Am Ind Hyg Assoc J*. 2003;64(2):196-211.

208. Veiersted KB. Reliability of myoelectric trapezius muscle activity in repetitive light work. *Ergonomics*. 1996;39(5):797-807.
209. Balogh I, Ørbæk P, Ohlsson K, Nordander C, Unge J, Winkel J, et al. Self-assessed and directly measured occupational physical activities - influence of musculoskeletal complaints, age and gender. *Appl Ergonomics*. 2004;35(1):49-56.
210. Jebens E, Medbø JI, Knutsen O, Mamen A, Veiersted KB. Association between perceived present working conditions and demands versus attitude to early retirement among construction workers. *Work*. 2014;48(2):217-28.
211. Hanvold TN, Kines P, Nykänen J, Ólafsdóttir S, Thomeé S, Holte KA, et al. Young workers and sustainable work life. Special emphasis on Nordic conditions. 2016.
212. McArdle WD, Katch FI, Katch VL. Training for anaerobic and aerobic power. *Exercise Physiology*. 6th ed. Baltimore, Maryland, U.S.A: Lippincott Williams & Wilkins; 2007.
213. Strijk JE, Proper KI, van Stralen MM, Wijngaard P, van Mechelen W, van der Beek AJ. The role of work ability in the relationship between aerobic capacity and sick leave: a mediation analysis. *Occup Environ Med*. 2011;68(10):753-8.
214. Arvidson E, Börjesson M, Ahlborg G, Jr., Lindegård A, Jonsdottir IH. The level of leisure time physical activity is associated with work ability-a cross sectional and prospective study of health care workers. *BMC Public Health*. 2013;13(1):855.
215. Karlqvist L, Leijon O, Härenstam A. Physical demands in working life and individual physical capacity. *Eur J Appl Physiol*. 2003;89(6):536-47.
216. Hubscher M, Ferreira ML, Junqueira DR, Refshauge KM, Maher CG, Hopper JL, et al. Heavy domestic, but not recreational, physical activity is associated with low back pain: Australian Twin low BACK pain (AUTBACK) study. *Eur Spine J*. 2014;23(10):2083-9.
217. Holtermann A, Hansen JV, Burr H, Sogaard K, Sjogaard G. The health paradox of occupational and leisure-time physical activity. *Br J Sports Med*. 2012;46(4):291-5.
218. Mäkinen T, Kestilä L, Borodulin K, Martelin T, Rahkonen O, Leino-Arjas P, et al. Occupational class differences in leisure-time physical inactivity--contribution of past and current physical workload and other working conditions. *Scand J Work Environ Health*. 2010;36(1):62-70.
219. Gram B, Holtermann A, Sogaard K, Sjogaard G. Effect of individualized worksite exercise training on aerobic capacity and muscle strength among construction workers - a randomized controlled intervention study. *Scand J Work Environ Health*. 2012;38(5):467-75.
220. Celis-Morales CA, Perez-Bravo F, Ibanez L, Salas C, Bailey ME, Gill JM. Objective vs. self-reported physical activity and sedentary time: effects of measurement method on relationships with risk biomarkers. *PLoS One*. 2012;7(5):e36345.
221. Tissot F, Messing K, Stock S. Standing, sitting and associated working conditions in the Quebec population in 1998. *Ergonomics*. 2005;48(3):249-69.
222. Gallagher KM, Campbell T, Callaghan JP. The influence of a seated break on prolonged standing induced low back pain development. *Ergonomics*. 2014;57(4):555-62.

223. Hooftman WE, van Poppel MNM, van der Beek AJ, Bongers PM, van Mechelen W. Gender differences in the relations between work-related physical and psychosocial risk factors and musculoskeletal complaints. *Scand J Work Environ Health*. 2004;30(4):261-78.
224. van der Beek AJ, Kløver BD, Frings-Dresen MH, Hoozemans MJ. Gender differences in exerted forces and physiological load during pushing and pulling of wheeled cages by postal workers. *Ergonomics*. 2000;43(2):269-81.
225. Lindbeck L, Kjellberg K. Gender differences in lifting technique. *Ergonomics*. 2001;44(2):202-14.
226. Gupta N, Heiden M, Mathiassen SE, Holtermann A. Prediction of objectively measured physical activity and sedentariness among blue-collar workers using survey questionnaires. *Scand J Work Environ Health*. 2016;42(3):237-45.

APPENDIX

Appendix A: Psychosocial questions - full description

Questionnaire (baseline and follow-up) (English)

The current study assessed decision control, fair and empowering leadership and social climate using items taken from the General Nordic Questionnaire for Psychological and Social Factors at work (QPS_{Nordic}), a validated instrument for research and tool for employers to monitor and improve working conditions. For each of the four subjects a mean was calculated based on the responses.

Participants were asked for decision control at work through the five questions: 1) *If there are alternative methods for doing your work, can you choose which method to use?* 2) *Can you influence the amount of work assigned to you?* 3) *Can you influence decisions concerning the persons you will need to collaborate with?* 4) *Can you decide when to be in contact with clients?* 5) *Can you influence decisions that are important for your work?* Response alternatives (1-5) were *very seldom or never, rather seldom, sometimes, rather often* and *very often or always*.

Three questions investigated empowering leadership: 1) *Does your immediate superior encourage you to participate in important decisions?* 2) *Does your immediate superior encourage you to speak up, when you have different opinions?* 3) *Does your immediate superior help you to develop your skills?* Response alternatives (1-5) were *very seldom or never, rather seldom, sometimes, rather often* and *very often or always*.

For fair leadership we used the three questions: 1) *Does your immediate superior distribute the work fairly and impartially?* 2) *Does your immediate superior treat the workers fairly and equally?* 3) *Is the relationship between you and your immediate superior a source of stress to you?* Response alternatives (1-5) were *very seldom or never, rather seldom, sometimes, rather often* and *very often or always*.

We asked for social climate in participants work unit through three questions: *What is the climate like in your work unit?* Items asked for were: 1) *Encouraging and supportive*, 2) *Distrustful and suspicious*, 3) *Relaxed and comfortable*. Response alternatives (1-5) were *very little or not at all, rather little, somewhat, rather much* and *very much*.

PAPERS I-III

RESEARCH ARTICLE

Validity of Questionnaire and Representativeness of Objective Methods for Measurements of Mechanical Exposures in Construction and Health Care Work

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Abstract

Objectives

To determine the criterion validity of a questionnaire on physical exposures compared to objective measurements at construction and health care sites and to examine exposure variation over several working days.

Methods

Five hundred ninety-four construction and health care workers answered a baseline questionnaire. The daily activities (standing, moving, sitting, number of steps), postures (inclination of the arm and the trunk), and relative heart rate of 125 participants were recorded continuously over 3–4 working days. At the end of the first measurement day, the participants answered a second questionnaire (workday questionnaire).

Results

All objective activity measurements had significant correlations to their respective questions. Among health care workers, there were no correlations between postures and relative heart rate and the baseline questionnaire. The questionnaires overestimated the exposure durations. The highest explained variance in the adjusted models with self-reported variables were found for objectively measured sitting ($R^2 = 0.559$) and arm inclination $> 60^\circ$ ($R^2 = 0.420$). Objective measurements over several days showed a higher reliability compared to single day measurements.

Conclusions

Questionnaires cannot provide an accurate description of mechanical exposures. Objective measurements over several days are recommended in occupations with varying tasks.

Competing Interests: The authors have declared that no competing interests exist.

Abbreviations: HR, Heart rate; ICC, Intraclass Correlation Coefficient; IncArm, Inclination of the arm; IncTrunk, Forward inclination of the trunk; Max, Maximum; Min, Minimum; MSD, Musculoskeletal disorders; MSI, Musculoskeletal severity index; PSI, Psychological severity index; RHR, Relative heart rate; SD, Standard deviation.

Introduction

Musculoskeletal disorders (MSD) are the most prevalent cause of sickness absence and early retirement [1,2]. There is a high prevalence of MSD in occupations with high physical demands [2]. Mechanical exposures at work, such as repeated movements, heavy physical load [2], vibrations and awkward postures [3], and psychosocial exposures [4] are risk factors for work-related MSD [5]. Valid measures of mechanical exposures are pivotal in determining risk factors in efforts to reduce the occurrence of MSD. Mechanical exposures are characterized by the type of work and postures, movements, and exerted forces measured in terms of level, duration, and frequency [6,7]. The assessments may be based on self-reports, observational methods and direct measurements. The appropriate assessment method should be selected according to the study's aims, the applicability and validity of these methods and economic aspects [8].

Self-reported assessments (e.g., questionnaires, diaries) of mechanical exposures at work-sites have shown varying validity [9] and are often tested against observational methods with their own strengths and limitations [9–11]. For measuring physical activity, one review concluded that questionnaires have shown acceptable reliability [12], while Dyrstad and colleagues concluded that subjective measurements are inadequate [13]. For estimating movements and postures, data from questionnaires were found to have low correlations with data obtained with objective measurements by accelerometers [14]. Furthermore, self-reported measures seem to overestimate the duration of postural positions [15], and the errors were found to be dependent on the respondent's occupation [16]. To obtain valid exposure measurements, objective measurements are recommended [12]. Several accelerometers attached to the participant's body have been found to be a valid method for recording movements [17–19] and postures [20] over several days [17]. To measure work intensity or aerobic strain, the recording of heart rate (HR) is a valid method. A linear relationship was found between HR and oxygen consumption during exercise or work [21]. The RHR takes the individual's minimal and maximal HR into account and was chosen to describe the physical work load [22,23].

In a longitudinal study of people in occupations generally considered to have high physical demands—namely, construction and health care—we examined mechanical exposures using both methods: questionnaires at two different time points and objective measurements on several consecutive working days [24]. The aim of the present study was to determine the criterion validity [25] of the questionnaires at baseline and on the first day of the objective measurements, using valid objective methods as a comparative standard. Furthermore, we considered whether a one-day recording is representative of the exposures during a typical work week and aimed to determine the differences in exposures between consecutive working days.

Methods

Study population

In total, 1165 baseline questionnaires (construction workers: $n = 580$; health care workers: $n = 585$) were distributed to employees of four construction companies and two local health service distributors in the area of Oslo, Norway. Five hundred ninety-four participants (construction workers: $n = 293$, 50.3%; health care workers: $n = 301$, 51.8%) responded.

Of the responders, 178 people in construction work and 193 people in health care work were willing to participate in the technical measurements, and a sample of 125 people was examined (construction workers: $n = 62$; health care workers: $n = 63$) based on availability and work schedules. This sample was selected to provide a representative sample of the occupations examined in the study. An overview of the participants' individual characteristics is presented in [Table 1](#). The exclusion criteria for the study were inadequate skills in reading and writing

Norwegian, known allergic reaction to plaster / tape / bandages, and a diagnosed cardiovascular or musculoskeletal disease that made it impossible for the subject to perform physical tests.

Ethical aspects

Prior to participation, all subjects were informed of the purpose and methods of the study and signed a written consent form. This study was conducted in accordance with the 1964 Helsinki Declaration and approved by the Regional Committee for Medical and Health Research Ethics in Norway (2014/138/REK sør-øst D).

Study design

After answering the baseline questionnaire, the participants selected for the technical measurements underwent a physical examination by a nurse or a physician. If the participants were physically healthy, instruments for technical recordings were attached to the participant's body at the beginning of a subsequent work day. The recordings were performed during work and leisure time on three to four consecutive work days, including at least two work days. At the end of the first day, the participants were asked to answer a second questionnaire ("workday questionnaire"). They were instructed to log the start and stop of their work and leisure periods or the removal of the sensors in a diary.

Questionnaires

The present study included subjective reports of mechanical exposures [26], musculoskeletal and psychological complaints in the preceding four weeks [27], perceived exertion [28], seniority, weight, height, and smoking status from the baseline questionnaire. Mechanical exposures

Table 1. Descriptive statistics of the samples.

		Technical measurements	
Participants		n = 125	
Age (years)		42.38 (SD 11.73)	
Height (cm)		173.64 (SD 9.64)	
Weight (kg)		76.85 (SD 13.64)	
		Gender	
		Male	Female
Construction work	Project manager / leader in construction work	5	0
	Carpenter	21	0
	Bricklayer	6	0
	Concrete worker	14	0
	Assistant worker	4	0
	Driver	0	0
	Foreman	7	0
	Engineer in construction work	2	1
Health care work	Leader health care work	1	5
	Nursing professional / nurse	0	15
	Registered nurse for the mentally handicapped	3	4
	Cook or kitchen helper	4	4
	Personal care worker in health services	5	17
Other	Cleaning worker	0	2
	Work with various tasks	2	2
	Other occupations	1	0
Total		75	50

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and musculoskeletal complaints were also measured a second time with the workday questionnaire.

Mechanical exposures. The questions regarding mechanical exposures had a common introduction: “How often in your daily work are you exposed to [. . .]”. The participants were asked about the following exposures: work standing, work sitting, work with hands above shoulder height, work with forward-bent trunk, and work in which your breathing rate increases. The answer categories were “never”, “sometimes”, “approximately 25% of the time”, “approximately 50% of the time”, “approximately 75% of time”, and “all the time” and were re-coded on a scale from 0 (“never”) to 5 (“all the time”).

Physical demands. Exertion at work was measured with the question “How physically demanding is your work?” The question was answered on a 13-point scale ranging from “not at all” to “maximally demanding”.

Musculoskeletal and psychological complaints. Musculoskeletal (neck, shoulders, upper and lower back, hip, knees, ankles and feet, upper extremity, head) and psychological (fear, depression, fatigue) complaints were rated on a four-point scale for intensity (0 = not troublesome, 1 = a little troublesome, 2 = quite troublesome, 3 = seriously troublesome) and a four-point scale for duration (1 = 1–5 days, 2 = 6–10 days, 3 = 11–14 days, 4 = 15–28 days). For all complaints, a complaint severity score was calculated by multiplying the intensity score by the duration score (range 0–12). One musculoskeletal complaint severity index (MSI) and one psychological severity index (PSI) were calculated as the mean of all included complaint severity indexes [27].

Smoking status. Smoking status was measured on a four-point scale (1 = never, 2 = in the past, 3 = sometimes, 4 = every day).

Instrumentation for technical measurements

To measure the acceleration, position and angle of various body segments of the participants, we used commercially available ActiGraph GT3X+ sensors (ActiGraph LLC, Pensacola, FL, United States). The ActiGraph GT3X+ is a tri-axial accelerometer that is small (46 x 33 x 15 mm), light (19 g) and waterproof. With a sampling frequency of 30 Hz, it allows data recording for up to 10 days continuously. Previous studies have found that the Actigraph GT3X+ sensors are valid for measuring the inclination of the upper arm and body during work tasks [20] and for detecting physical activity [18,19]. Four accelerometers were attached to the participant's body as follows: dominant arm (3 cm below the deltoid muscle insertion), right upper leg (medially between the iliac crest and the upper crest of the patella), hip (top of iliac crest on the right side), and upper back (level T1-T2). The accelerometers were fixed to the skin, using double-sided tape (Fixomull, BSN medical, Hamburg, Germany) and covered with transparent film (Tegaderm, 3 M, Minnesota, United States).

To measure heart rate, an Actiheart monitor (Camntech, Cambridge, United Kingdom) was attached at the apex of the sternum and at the left intercostals at the level of the sixth and seventh costae [29]. Heart-rate monitors have been found to be valid and reliable for use both in the laboratory and in the field [30,31].

Data and quality management

The raw data from the Actigraph sensors were stored on a personal computer using Actilife 6.11.5 software (Actigraph LLC, Pensacola, Florida, USA). The intensity and frequency of positions, various activities, and steps were calculated using the custom-made software Acti4 [18,20] based on the raw data and the participants' diaries. Data were excluded when a sensor was not worn and when the work period was shorter than four hours or shorter than 75% of the mean average length of all working periods. The following variables were obtained: time

spent standing, sitting and moving (movement in upright position, neither still or walking); the number of steps; the duration of arm inclination above 30°, 60°, 90°, 120° and 150° (IncArm); and trunk inclination along the sagittal plane greater than 20°, 30°, 60° and 90° (IncTrunk). These variables were normalized to one hour (e.g., steps per hour).

The relative heart rate (RHR) was calculated as follows [22]:

$$RHR_{work} = \frac{(HR_{work} - HR_{min})}{(HR_{max} - HR_{min})} \times 100$$

HR_{max} was calculated for each participant using the formula $208 - 0.7 \times \text{age}$ [32], and HR_{min} was based on a sex- and age-adjusted population [29]. Heart rate data were quality controlled visually and deleted if the beat error (a difference between two consecutive beats > 15 , $HR < 30$, $HR > 230$) was higher than 50% for a work period. The data were calculated for each measurement day and averaged across all measurement days. Data processing was performed with Matlab R2013b (Math Works, Inc., Natick, Massachusetts, USA).

Statistical analyses

The distributions of the variables were tested using the Kolmogorov-Smirnov test. The correlations between the questionnaire responses and the objectively measured data were calculated using Spearman's rho, and the significance level was set as $p = 0.005$. The Spearman correlation coefficient was interpreted as follows: < 0.2 : very low; $0.21-0.5$: low; $0.51-0.7$: moderate; $0.71-0.9$: strong and > 0.9 : very strong. The criterion validity of the exposure measurements was tested using linear regression analyses in two steps [33]. The objectively measured exposure variables were the dependent variables. The first step tested the corresponding subjective measurements for day 1, gender, height, weight, BMI, age, profession, work sector, MSI, PSI and smoking status separately as independent variables (unadjusted models). Those variables that exhibited associations with p -values < 0.1 were entered into a multiple linear regression for adjusted models. To determine the day to day reliability of objectively measured exposures, intraclass correlation coefficients (ICC) were calculated (single day measures: ICC 3, 1; average measures of 3 days: ICC 3, 3). To determine differences in objectively recorded mechanical exposures between consecutive working days, a Friedman one-way analysis of variance was used. The statistical data analyses were performed with IBM SPSS Statistics 22 (IBM Corporation, NY, United States).

Results

The variables age, height, weight and objectively measured time spent standing and moving, trunk inclination $> 20^\circ$ and RHRmean were normal distributed. All other objectively measured variables were not normally distributed. There were no significant differences ($p < 0.05$) in age, height, weight, gender, MSI, PSI and smoking status between the questionnaire group at baseline ($n = 594$) and the group that underwent technical measurements ($n = 125$). Due to early removal of equipment or data not fulfilling quality criteria, some data were missing or had to be excluded. The total number of valid measurements from day one to day four were as follows: 125, 102, 72 and 27 (daily activities: 125, 101, 71, 27; Arm: 119, 96, 67, 27; Trunk: 121, 98, 66, 27; HR: 103, 83, 45, 13).

Association between data from workday questionnaire responses and objective measurements of day one

[Fig 1](#) illustrates the amplitudes of the objective measurements compared with the responses to the corresponding subjective measurements.

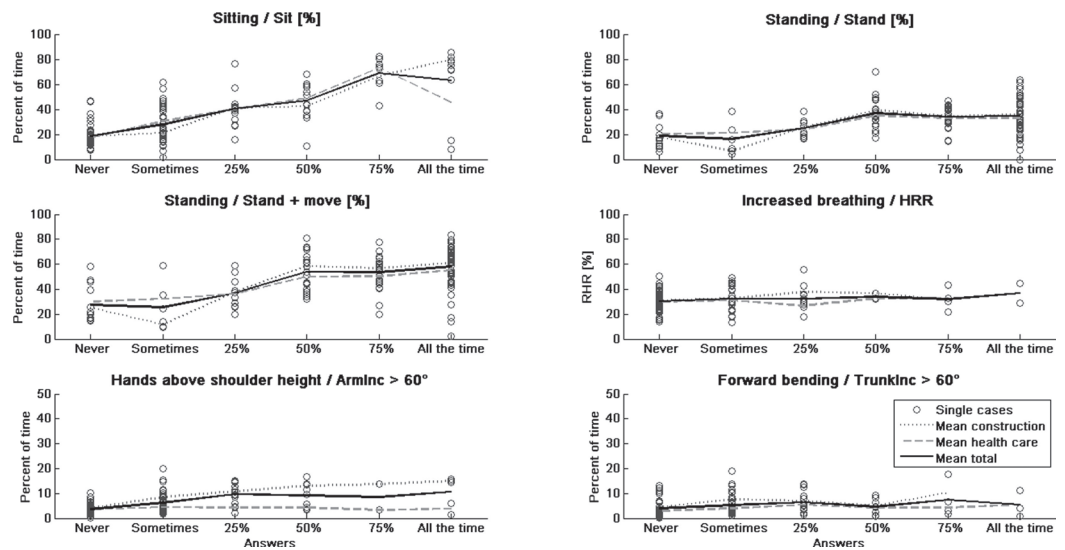


Fig 1. Categories of subjective vs. objective measures of exposures. The title of each subplot indicates the compared subjective and (/) objective variables. Single values (circles) of objective measures are plotted in the categories of the corresponding subjective measures. Mean values were calculated for each category for the total group (solid line), for construction workers (pointed line) and for health care workers (dashed line).

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Daily activities. Subjectively measured time spent standing showed moderate correlations with objectively measured time spent sitting and moving in all groups ($p < 0.001$). Furthermore, moderate correlations were found with objectively measured time spent standing and moving in the total group and the group of construction workers and with the number of steps in the group of construction workers ($p < 0.001$). Low correlations were found with objectively measured time spent standing and with the number of steps in the total group ($p < 0.001$) and with time spent standing and moving in the group of construction workers ($p < 0.001$). Moderate correlations were found in all groups for subjectively measured time spent sitting and objectively measured time spent sitting and moving ($p < 0.001$). Furthermore, moderate correlations were found between subjectively measured time spent sitting and objectively measured time spent standing and moving in the total group and the group of construction workers ($p < 0.001$) and with objectively measured number of steps in the total group and the group of health care workers ($p < 0.001$). Low correlations with objectively measured standing were found in all groups ($p < 0.005$), with time spent standing and moving in the group of health care workers ($p < 0.001$) and with the number of steps in the group of construction workers ($p < 0.005$).

Postures of the arm and the trunk. Objectively measured arm inclination $> 60^\circ$, $> 90^\circ$, and $> 120^\circ$ showed low correlations with the subjective measures of “work with hands above shoulder height” in the total group ($p < 0.001$). In the group of construction workers, there were moderate correlations between subjectively measured arm lifting and objectively measured arm inclination $> 60^\circ$ and $> 90^\circ$ ($p < 0.001$) and relatively low correlations with objectively measured arm inclination $> 120^\circ$ ($p < 0.001$). No significant correlations between subjectively and objectively measured arm inclination were found for the group of health care workers. For objectively measured trunk inclination $> 60^\circ$, a low correlation was found with subjective measures in the total group ($p < 0.005$).

Physical exhaustion. No correlations were found between the self-reports of “How physically demanding was your work today?” and “How often were you exposed to increased breathing?” and RHR.

Table 2. Correlations of objective measurements (Actigraph / Actiheart) and questionnaire responses (Spearman's rho).

		Workday questionnaire			Baseline questionnaire		
		-			-		
		Objective measurements on first measurement day			Objective measurements: mean of all days		
How often are you exposed to:	Objective measures:	Total	Construction work	Health care work	Total	Construction Work	Health care work
standing work?	Stand [%]	0.321**	0.292	0.311	0.526**	0.565**	0.501**
	Move [%]	0.563**	0.601**	0.502**	0.522**	0.483**	0.574**
	Stand + Move [%]	0.514**	0.546**	0.480**	0.506**	0.569**	0.409*
sitting work?	Sit [%]	0.686**	0.687**	0.538**	0.731**	0.732**	0.520**
work with hands above shoulder height?	IncArm >30° [%]	0.063	0.165	- 0.199	0.010	0.054	- 0.268
	IncArm >60° [%]	0.489**	0.732**	0.179	0.364**	0.514**	0.069
	IncArm >90° [%]	0.484**	0.646**	0.208	0.352**	0.458**	0.146
	IncArm >120° [%]	0.361**	0.454**	0.054	0.174	0.087	0.099
	IncArm >150° [%]	0.169	0.228	- 0.031	0.001	- 0.117	- 0.016
work with forward-bent trunk?	IncTrunk >20° [%]	0.076	0.089	0.063	- 0.068	- 0.037	- 0.069
	IncTrunk >30° [%]	0.162	0.206	0.155	0.084	0.205	0.004
	IncTrunk >60° [%]	0.267*	0.332	0.276	0.278*	0.361	0.198
	IncTrunk >90° [%]	0.228	0.318	0.271	0.147	0.209	0.112
increased breathing?	RHRmean [%]	0.108	0.152	- 0.029	0.123	0.089	0.040
How physically demanding is / was your work?							
	RHRmean [%]	0.225	0.401	- 0.033	0.280*	0.235	0.197

* p-value < 0.005

** p-value < 0.001.

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Quantitative relationships of subjective and objective measures. Regression analyses showed an explained variance of 18.9% for objectively measured standing in an adjusted model that included the variables subjectively measured time spent standing ($\beta = 0.141$, $p < 0.001$), age and profession (see Table 2). A variance of 34.6% for objectively measured time spent standing and moving could be explained by an adjusted model that included the variables subjectively measured standing ($\beta = 0.285$, $p < 0.001$), gender, age, profession and work sector. For objectively measured time spent sitting, 55.9% of the variance could be explained by an adjusted model that included the variables subjectively measured sitting ($\beta = 0.498$, $p < 0.001$), gender, age, profession and work sector ($\beta = 10.199$, $p < 0.05$; see Table 3).

Regression analyses were calculated for all objectively measured arm inclination variables. The highest explained variance (42%) was calculated for arm inclination > 60° in an adjusted model that included the variables subjectively measured time with hands above shoulder height ($\beta = 0.080$, $p < 0.001$), gender, height, weight, profession and work sector ($\beta = -3.918$, $p < 0.001$).

For objectively measured trunk inclination, no significant regression model could be calculated that included subjective measurements of forward bending.

The regression analysis for the RHR showed no significant associations with the subjective measures “How physically demanding was your work today?” and “Increased breathing”, nor were the associations between RHR mean and gender, height, weight, BMI, age, profession and work sector significant. In total, the calculated beta values showed an overestimation of the times spent in various activities or postures. The overestimation was greater for time spent with arms above shoulder height or with a forward-bent trunk (see also Fig 1).

Table 3. Unadjusted and adjusted regression analyses for objective und subjective measures.

Standing					Sitting				
Sub. measures:	Unadjusted		Adjusted		Sub. measures:	Unadjusted		Adjusted	
	β	p-value	β	p-value		β	p-value	β	p-value
Standing	0.145	0.000	0.141	0.000	Sitting	0.500	0.000	0.498	0.000
Gender	-1.541	0.528	not included		Gender	7.166	0.065	-6.697	0.100
Height (cm)	-0.004	0.976	not included		Height (cm)	-0.106	0.597	not included	
Weight(kg)	0.028	0.755	not included		Weight(kg)	-0.017	0.906	not included	
BMI (kg/m ²)	0.166	0.626	not included		BMI (kg/m ²)	0.146	0.786	not included	
Age (years)	-0.189	0.066	-0.117	0.232	Age (years)	-0.189	0.066	0.186	0.117
Profession	-0.124	0.041	-0.111	0.051	Profession	0.188	0.054	-0.167	0.125
Work sector	-2.904	0.164	not included		Work sector	8.175	0.014	10.199	0.033
MSI	-0.014	0.982	not included		MSI	0.558	0.558	not included	
PSI	0.781	0.387	not included		PSI	-0.575	0.691	not included	
Smoking	0.387	0.711	not included		Smoking	-0.894	0.592	not included	
Model summary: R² adjusted = 0.189					Model summary: R² adjusted = 0.559				
Standing + Moving					RHRmean				
Sub. measures:	Unadjusted		Adjusted		Sub. measures:	Unadjusted		Adjusted	
	β	p-value	β	p-value		β	p-value	β	p-value
Standing	0.293	0.000	0.285	0.000	Physical demands	0.726	0.065	0.630	0.112
Gender	-4.694	0.174	not included		Increased breathing	0.915	0.206	Not included	
Height (cm)	0.080	0.652	not included		Gender	-3.108	0.073	-1.716	0.444
Weight(kg)	0.005	0.969	not included		Height	0.093	0.309	Not included	
BMI (kg/m ²)	-0.122	0.799	not included		Weight	0.036	0.565	Not included	
Age (years)	-0.280	0.055	-0.146	0.246	BMI	0.029	0.901	Not included	
Profession	-0.170	0.049	-0.067	0.511	Age	-0.125	0.090	-0.088	0.245
Work sector	-6.024	0.041	-2.464	0.488	Profession	-0.058	0.152	Not included	
MSI	-0.223	0.805	not included		Work sector	-2.837	0.053	-1.323	0.491
PSI	1.015	0.429	not included		MSI	0.089	0.843	Not included	
Smoking	0.165	0.911	not included		PSI	-0.275	0.670	Not included	
Model summary: R² adjusted = 0.346					Model summary: R² adjusted = 0.084				
Arm inclination > 60°					Trunk inclination > 90°				
Sub. measures:	Unadjusted		Adjusted		Sub. measures:	Unadjusted		Adjusted	
	β	p-value	β	p-value		β	p-value	β	p-value
Hands above shoulder height	0.080	0.000	0.063	0.000	Forward bended trunk	0.008	0.229	not included	
Gender	-3.529	0.000	-1.615	0.175	Gender	-0.688	0.017	0.334	0.493
Height (cm)	0.109	0.010	-0.099	0.093	Height (cm)	0.045	0.002	0.041	0.110
Weight(kg)	0.088	0.003	0.038	0.226	Weight(kg)	0.022	0.042	0.000	0.978
BMI (kg/m ²)	0.171	0.137	not included		BMI (kg/m ²)	0.009	0.826	not included	
Age (years)	-0.047	0.166	not included		Age (years)	-0.008	0.519	not included	
Profession	-0.062	0.002	0.033	0.221	Profession	-0.005	0.494	not included	
Work sector	-3.916	0.000	-3.918	0.001	Work sector	-0.714	0.003	-0.553	0.093
MSI	-0.281	0.194	not included		MSI	-0.097	0.216	not included	
PSI	-0.375	0.220	not included		PSI	-0.116	0.295	not included	
Smoking	0.414	0.246	not included		Smoking	0.152	0.223	not included	
Model summary: R² adjusted = 0.420					Model summary: R² adjusted = 0.100				

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Association of subjective reports (questionnaire at baseline) with the mean of objective measurements over several days

In the analysis of the mean values of objective measurements taken over several work days and the results of the baseline questionnaire, all groups showed moderate correlations for objectively and subjectively measured time spent standing ($p < 0.001$) and time spent sitting ($p < 0.001$).

Low correlations were found for objectively measured arm inclination $> 60^\circ$ and $> 90^\circ$ and subjectively measured hands above shoulder heights ($p < 0.001$), both for the total group and for the group of construction workers. Furthermore, objectively measured trunk inclination $> 60^\circ$ showed a low correlation with subjectively measured forward bending of the trunk in the total group and in the group of construction workers ($p < 0.005$).

A low correlation between RHR and the question “How physically demanding is your work?” was found only for the total group (0.280, $p < 0.005$).

Day to day reliability of objective measurements

For all objectively measured variables, we found a higher ICC for the average measures over several working days than for the single day measures (see [Table 4](#)). Except for the number of steps in construction work, all of the average measures of daily activities showed a good or excellent reliability (range: 0.80–0.93). An arm inclination $> 30^\circ$ presented the highest ICC for all average measures of arm inclination (ICC 0.70, CI: 0.54–0.81) in the total group. Concerning arm inclination, construction workers had the highest ICC for average measures of arm inclination $> 90^\circ$ (ICC: 0.56, CI: 0.25–0.75), whereas health care workers showed the highest ICC for average measures of arm inclination $> 30^\circ$ (ICC: 0.84, CI: 0.66–0.93). Trunk inclination showed the highest degree of reliability in average measurements of trunk inclination $> 20^\circ$. Health care workers showed higher ICCs for average measures of trunk inclination $> 30^\circ$ (ICC: 0.94, CI: 0.87–0.97), $> 60^\circ$ (ICC: 0.86, CI: 0.70–0.94) and $> 90^\circ$ (ICC: 0.82, CI: 0.62–0.92) than construction workers (ICC: 0.71, CI: 0.50–0.84; ICC: 0.37, CI: -0.06–0.65; ICC: 0.45, CI: 0.06–0.69, respectively). In all of the groups, the reliability for the average measures of RHRmean was good (range 0.84–0.89).

Comparison of objective measurements on the first measurement day with the following days

All groups were found to have spent a significantly lower amount of time with arm inclination $> 120^\circ$ (total: $p < 0.001$, construction workers: $p < 0.01$, health care workers: $p < 0.05$) on day 1 compared with the following days (see [Table 5](#), [Fig 2](#)). For the total group and the group of construction workers, the time spent standing ($p < 0.05$ / $p < 0.05$), time spent moving ($p < 0.05$ / $p < 0.05$), trunk inclination $> 60^\circ$ ($p < 0.05$ / $p < 0.05$) and RHRmean ($p < 0.001$ / $p < 0.001$) were higher on day 1 compared with the following days. Furthermore, while the work hours for the total group and the group of health care workers was lowest on day 1 ($p < 0.01$ / $p < 0.01$), the group of construction workers had the lowest number of work hours on day 3 ($p < 0.05$).

Discussion

Knowledge of the role of workplace mechanical exposures in the pathogenesis of musculoskeletal disorders depends on the valid measurement of these exposures. The present study examined the association between exposures that were subjectively reported via questionnaires and objectively measured daily activities (sitting, standing, moving), postures of the trunk and arm,

Table 4. Overview of intraclass correlation coefficients (95% confidence intervals) for objectively measured variables for the total group, construction and health care workers. For each variable, the ICC is presented for single day measures and for the average measures of 3 consecutive working days.

	Measures	Total	Construction work	Health care work
Time	Single	0.42 (0.27–0.57)	0.44 (0.25–0.62)	0.33 (0.08–0.59)
	Average	0.69 (0.53–0.80)	0.70 (0.50–0.83)	0.59 (0.20–0.81)
Sit [%]	Single	0.81 (0.73–0.88)	0.81 (0.70–0.88)	0.77 (0.59–0.89)
	Average	0.93 (0.89–0.95)	0.93 (0.88–0.96)	0.91 (0.81–0.96)
Stand [%]	Single	0.62 (0.49–0.74)	0.57 (0.40–0.72)	0.70 (0.48–0.85)
	Average	0.83 (0.75–0.89)	0.80 (0.67–0.89)	0.87 (0.74–0.94)
Move [%]	Single	0.68 (0.55–0.78)	0.68 (0.53–0.80)	0.63 (0.39–0.81)
	Average	0.86 (0.79–0.91)	0.86 (0.77–0.92)	0.84 (0.66–0.93)
Steps [Steps/h]	Single	0.59 (0.45–0.71)	0.50 (0.31–0.67)	0.69 (0.48–0.85)
	Average	0.81 (0.71–0.88)	0.75 (0.57–0.86)	0.87 (0.73–0.94)
IncArm > 30° [%]	Single	0.44 (0.28–0.59)	0.29 (0.10–0.50)	0.64 (0.40–0.82)
	Average	0.70 (0.54–0.81)	0.56 (0.25–0.75)	0.84 (0.66–0.93)
IncArm > 60° [%]	Single	0.21 (0.06–0.38)	0.13 (-0.05–0.34)	0.63 (0.37–0.82)
	Average	0.44 (0.15–0.65)	0.30 (-0.16–0.60)	0.83 (0.64–0.93)
IncArm > 90° [%]	Single	0.43 (0.27–0.58)	0.38 (0.19–0.57)	0.43 (0.15–0.70)
	Average	0.69 (0.53–0.81)	0.65 (0.41–0.80)	0.70 (0.34–0.88)
IncArm > 120° [%]	Single	0.38 (0.22–0.54)	0.32 (0.13–0.52)	0.36 (0.09–0.64)
	Average	0.65 (0.46–0.78)	0.58 (0.30–0.76)	0.63 (0.24–0.84)
IncArm > 150° [%]	Single	0.08 (-0.06–0.24)	0.05 (-0.12–0.26)	0.30 (0.03–0.60)
	Average	0.20 (-0.22–0.49)	0.13 (-0.45–0.51)	0.56 (0.08–0.82)
IncTrunk > 20° [%]	Single	0.66 (0.53–0.77)	0.57 (0.39–0.73)	0.82 (0.66–0.92)
	Average	0.85 (0.77–0.91)	0.80 (0.65–0.89)	0.93 (0.86–0.97)
IncTrunk > 30° [%]	Single	0.53 (0.38–0.66)	0.45 (0.25–0.63)	0.84 (0.69–0.93)
	Average	0.77 (0.64–0.86)	0.71 (0.50–0.84)	0.94 (0.87–0.97)
IncTrunk > 60° [%]	Single	0.20 (0.04–0.37)	0.17 (-0.02–0.38)	0.67 (0.43–0.84)
	Average	0.43 (0.12–0.64)	0.37 (-0.06–0.65)	0.86 (0.70–0.94)
IncTrunk > 90° [%]	Single	0.24 (0.08–0.41)	0.21 (0.02–0.43)	0.60 (0.35–0.79)
	Average	0.49 (0.21–0.68)	0.45 (0.06–0.69)	0.82 (0.62–0.92)
RHRmean [%]	Single	0.66 (0.45–0.80)	0.64 (0.33–0.83)	0.74 (0.52–0.88)
	Average	0.85 (0.71–0.92)	0.84 (0.60–0.93)	0.89 (0.77–0.96)

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and RHR. The objective recordings were performed continuously over up to four consecutive working days. The subjective measurements were administered both at baseline prior to the first recording day and at the end of the work period on the first day of the objective measurements.

Daily activities—In the total group, analyses of the subjective and objective measurements on the first measurement day showed low correlations for time spent standing and moderate correlations for time spent sitting. The participants were not able to accurately estimate their daily activities on a working day. The lower correlations for time spent standing could be related to the participants’ interpretation of the question “How often in your daily work are you exposed to work standing?” It is possible that the participants could not discriminate between standing work and work in a moving upright position (neither still or walking). The higher correlations found for the sum of the objectively measured time spend standing and moving support this hypothesis. Depending on the study aim, the applied question should be more specified to differentiate between work when standing in one place or work in an upright

Table 5. Comparison of objective measurements of several working days (Friedman Test).

	Total				Construction work				Health care work			
	N = 72				N = 42				N = 28			
	Mean ranks			p-value	Mean ranks			p-value	Mean ranks			p-value
Day 1	Day 2	Day 3	Day 1		Day 2	Day 3	Day 1		Day 2	Day 3		
Time	1.74	2.34	1.92	< 0.01	1.90	2.29	1.80	< 0.05	1.48	2.41	2.11	< 0.01
Sit [%]	1.90	2.09	2.01	n.s.	1.89	2.07	2.04	n.s.	1.88	2.12	2.00	n.s.
Stand [%]	2.24	2.00	1.76	< 0.05	2.23	2.09	1.68	< 0.05	2.31	1.79	1.90	n.s.
Move [%]	2.27	1.92	1.81	< 0.05	2.30	1.89	1.80	< 0.05	2.26	1.98	1.76	n.s.
Steps [steps/h]	2.06	2.01	1.93	n.s.	2.01	1.98	2.01	n.s.	2.17	2.12	1.71	n.s.
IncArm > 30° [%]	1.90	1.86	2.25	n.s.	2.06	1.68	2.26	< 0.05	1.55	2.26	2.18	n.s.
IncArm > 60° [%]	1.90	1.87	2.23	n.s.	1.78	1.96	2.26	n.s.	2.13	1.74	2.13	n.s.
IncArm > 90° [%]	1.81	2.11	2.08	n.s.	1.76	2.17	2.08	n.s.	1.87	2.05	2.08	n.s.
IncArm > 120° [%]	1.58	2.25	2.18	< 0.001	1.58	2.35	2.08	< 0.01	1.55	2.11	2.34	< 0.05
IncArm > 150° [%]	1.82	2.13	2.05	n.s.	1.83	1.99	2.18	n.s.	1.84	2.42	1.74	n.s.
IncTrunk > 20° [%]	2.14	1.92	1.94	n.s.	2.09	1.88	2.03	n.s.	2.18	2.05	1.78	n.s.
IncTrunk > 30° [%]	2.09	1.92	1.99	n.s.	2.04	1.96	2.00	n.s.	2.23	1.80	1.98	n.s.
IncTrunk > 60° [%]	2.26	1.78	1.96	< 0.05	2.31	1.69	2.00	< 0.05	2.13	1.95	1.93	n.s.
IncTrunk > 90° [%]	1.97	1.91	2.13	n.s.	2.01	1.88	2.11	n.s.	1.83	2.00	2.18	n.s.
RHRmean [%]	2.56	1.66	1.78	< 0.001	2.80	1.66	1.55	< 0.001	2.24	1.71	2.06	n.s.

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position. Moderate correlations were found between subjectively measured time spent standing and the sum of the objectively measured time spent standing and time spent moving. In terms of group differences, the construction workers showed higher correlations between objectively and subjectively measured daily activities than the health care workers did.

Postures of the arm and the trunk—The correlations between subjectively and objectively measured arm inclination in the total group were low for arm angles > 60–> 120°. Trunk inclination > 60° showed a low correlation with subjective measures. For the construction

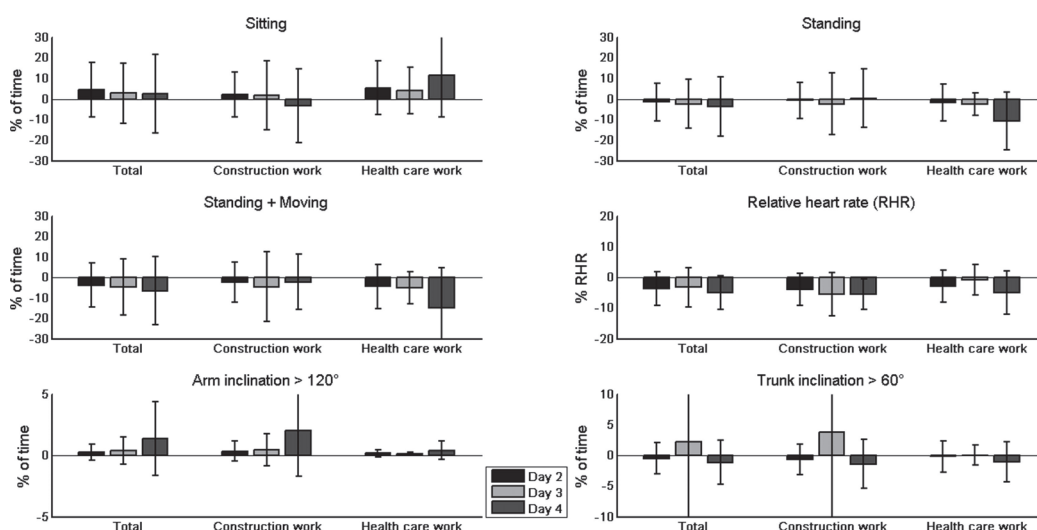


Fig 2. The mean of the differences between objective measurements taken over several working days and on the first day. The mean values for each variable were calculated according to individual differences between the multiday measurements and the day one measurement.

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workers, correlations ranging from 0.48 to 0.73 were found for arm inclination of $> 60^\circ$ – $> 120^\circ$, and no correlations were found for trunk inclination. The health care workers exhibited no correlations between subjective and objective measures of arm and trunk inclination. Except for arm inclination in the group of construction workers, the accuracy of subjective posture measurements was low. One reason for the low accuracy may be the way that the workers recalled a work day; they could have thought of the frequency with which they performed work tasks with specific postures. The inclinometers measure the exact angle of a body segment, and small and frequent periods with an angle outside a specific range are not detected as an exposure. Therefore, the total measured amount of the exposure duration may be lower than what the participant remembered.

Physical exhaustion—The questions “How physically demanding was your work today?” and “How often in your work today were you exposed to increased breathing?” were not correlated with the RHR mean. This may be explained by the absence of constant physical exposure during the working day: Frequent small breaks may lower the mean heart rate per day, despite high heart rates in situations with exposures. It is possible that the workers selectively remembered the higher-effort situations.

The differences between the groups may be partly explained by the difference in work tasks performed [16]. Construction work commonly consists of periods of repeated work tasks, e.g., building a brick wall the whole day. Health-care work consists of work cycles with more variation in movements and more tasks performed on demand. These factors may also influence the workers’ recall of exposures during a single working day.

The computed regression analyses showed the highest explained variances for the objective measurements of time spent sitting ($R^2 = 0.559$) and time with hands above shoulder height ($R^2 = 0.420$) on a single working day. On average, the participants overestimated the duration of exposures. The overestimation was higher for postures (e.g., sitting, β -value: 0.498) than for activities (e.g., hands above shoulder height / arm inclination $> 60^\circ$, β -value: 0.063). Simplified, a self-reported time spent sitting of 50% of the working day will correspond an actual duration of approximately 25%. Similar results were found by Teschke and colleagues, who also found an overestimation of the duration of postural positions with questionnaires [15]. One should note that self-reports represent the perceived exposure, but other factors (e.g., psychosocial, psychological, physical fitness) may also influence the individuals’ judgment, leading to possible bias / overestimation. To determine the actual objective exposure from self-reports, specific models should be developed. In a recent study, Gupta and co-workers could predict 63% of the actual time the subjects were physically active or sedentary using a predictive model based on individual parameters and self-reported activities [34].

When comparing the correlations of the objective and subjective measures on day 1 and the mean values of objective measures of several days to the baseline measurements, contrasting effects can be observed. For the time spent standing and sitting and the association between the question “How physically demanding was your work today?” and the RHR mean, the correlations were higher when the objective average values were compared with the subjective baseline measurements. The correlations between arm inclination and the corresponding subjective measures were higher when the single-day measurements were analyzed. It can be assumed that the daily activities and the physical exposure would on average be constant over time in a specialized occupation, while the postures would be dependent on the actual work task, especially in the case of construction work. In longitudinal studies, these differences may be important when inquiring about exposures on single days or during a work period.

Technical recordings from a single day are representative if the variation of the mean exposure across the days is minimal [35]. Measurements performed on a single work day are useful for jobs with light and repetitive work tasks [36]. The present study found a higher degree of

reliability for all of the objectively measured variables when measuring several consecutive working days compared to single day measurements. Although the reliability for the total group average measures of daily activities and RHRmean were good or excellent, the reliability of arm inclination and trunk inclination ranged from unacceptable to good, depending on the degree of inclination. In particular, for the highest amplitudes (arm inclination $> 150^\circ$, trunk inclination $> 60^\circ$ and $> 90^\circ$), the reliability was unacceptable. When comparing construction and health care workers, the main differences could be found for arm and trunk inclination. Construction workers had an unacceptable to questionable reliability for all variables of arm inclination. However, health care workers maintained an acceptable or good reliability when measuring arm inclinations of $> 30^\circ$, $> 60^\circ$ and $> 90^\circ$. Concerning trunk inclination, construction workers showed a strong decreasing reliability with an increasing inclination amplitude (good to unacceptable), whereas health care workers showed an excellent or good reliability.

This leads to the question of what causes these differences in reliability for the various groups or variables. When analyzing day-to-day differences, we found that all of the groups had shorter work periods and the lowest duration with arm inclination $> 120^\circ$ on the first day of measurement. Additionally, the construction workers exhibited higher values for time spent standing and moving, trunk inclination $> 60^\circ$ and heart rate parameters on day 1. One possible reason for these differences could be the application of the measurement equipment, which occurred during the first 30 minutes of day 1, in combination with occupation-specific work tasks. Construction workers may have had to finish the same work in less time on the first day, and their work tasks may be more dependent on the nature of the construction project or the work of other colleagues. In contrast, health care workers have a more continuous set of tasks with more frequent small breaks in between, which may compensate for lost time in the beginning of a work shift. The higher RHR found on day 1 for the construction workers supports the possibility of a higher work speed on day 1. However, the presence of an observer could also have had an impact on the participant's heart rate. A possible consequence of all these facts might be a reduced construct validity, resulting in a decreasing reliability of the objective measurements that attempt to describe the exposure of a typical working day. Therefore, conducting measurements over several days is recommended, for both working sectors that were examined in this study.

Methodological considerations

In this study, two sectors with unequal gender distributions were examined: construction and health care. The aim of this study was not to examine gender differences. Still, regression analyses showed no significant effect of gender on the association between objective and subjective measurements in the adjusted models. The results can be seen as representative for both sectors with their typical gender distributions. Other occupational sectors may show different results.

When comparing objective and subjective measures, errors must be taken into account depending on the precision of the questions asked and the participants' interpretations of the questions. The questionnaire asked about the working time spent with the hands above shoulder height. Objectively considered, this question implies a wide range of the upper arm elevation (0–180 degrees, depending on individual constitution and the angle in the elbow). Arm inclination was objectively measured in a range of severities of the exposure (30, 60, 90, 120 and 150 degrees). Additionally, subjective and objective measurements examine different outcomes, such as the position of the hand and the elevation of the arm. Because of the anatomy of the body, the position of the hand depends on the inclination of the upper arm, but there are also some degrees of freedom because of the angle in the elbow and the shoulder. When examining the association of neck and shoulder pain with the risk factor "Work with elevated arms" [37], other or modified questions asking about arm elevation may achieve higher correlations

to objectively measured arm inclination. In contrast with these assumptions, the subjectively (“How often during work today were you exposed to work with forward-bent trunk”) and objectively measured trunk inclination showed almost no significant associations.

The bias in the association of subjective and objective measurements could also be generated as a result of recording only the inclination of the dominant upper arm, while asking for bilateral information regarding “hands above shoulder height”. Additionally, although the inclinometers had a sample frequency of 30 Hz, the questionnaire measured the duration of the exposures in six categories ranging from 0 to 100%.

Conclusion

The self-reported measurement tools used in this study cannot provide an accurate description of mechanical exposures neither in construction nor health care work. Self-reports showed greater precision for the measurement of daily activities, when several work days rather than single days were examined. The precision of the arm posture measurements was higher when single days were assessed. Nevertheless, objective measurements are necessary. Measurements over several work days are recommended to detect the entire exposure variance. When performing longitudinal studies, repeated objective measurements of activities, postures and cardiovascular exposures are necessary to obtain better knowledge regarding the effects of these exposures on MSD. The application of measurement equipment should not affect the participants’ work or hours worked. To adjust for overestimated exposures in questionnaires, detailed regression models are necessary and will require further investigation.

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References

1. Murray CJ, Vos T, Lozano R, Naghavi M, Flaxman AD, Michaud C, et al. Disability-adjusted life years (DALYs) for 291 diseases and injuries in 21 regions, 1990–2010: a systematic analysis for the Global

- Burden of Disease Study 2010. *Lancet*. 2012; 380: 2197–2223. doi: [10.1016/S0140-6736\(12\)61689-4](https://doi.org/10.1016/S0140-6736(12)61689-4) PMID: [23245608](https://pubmed.ncbi.nlm.nih.gov/23245608/)
2. Punnett L, Wegman DH. Work-related musculoskeletal disorders: the epidemiologic evidence and the debate. *J Electromyogr Kinesiol*. 2004; 14: 13–23. doi: [10.1016/j.jelekin.2003.09.015](https://doi.org/10.1016/j.jelekin.2003.09.015) PMID: [14759746](https://pubmed.ncbi.nlm.nih.gov/14759746/)
 3. Magnusson ML, Pope MH. A review of the biomechanics and epidemiology of working postures: it isn't always vibration which is to blame! *J Sound Vib*. 1998; 215: 965–976.
 4. Bernal D, Campos-Serna J, Tobias A, Vargas-Prada S, Benavides FG, Serra C. Work-related psychosocial risk factors and musculoskeletal disorders in hospital nurses and nursing aides: a systematic review and meta-analysis. *Int J Nurs Stud*. 2015; 52: 635–648. doi: [10.1016/j.ijnurstu.2014.11.003](https://doi.org/10.1016/j.ijnurstu.2014.11.003) PMID: [25480459](https://pubmed.ncbi.nlm.nih.gov/25480459/)
 5. Yassi A, Lockhart K. Work-relatedness of low back pain in nursing personnel: a systematic review. *Int J Occup Environ Health*. 2013; 19: 223–244. doi: [10.1179/2049396713Y.0000000027](https://doi.org/10.1179/2049396713Y.0000000027) PMID: [23885775](https://pubmed.ncbi.nlm.nih.gov/23885775/)
 6. Westgaard RH, Winkel J. Guidelines for occupational musculoskeletal load as a basis for intervention: a critical review. *Appl Ergon*. 1996; 27: 79–88. doi: [10.1016/0003-6870\(95\)00062-3](https://doi.org/10.1016/0003-6870(95)00062-3) PMID: [15677047](https://pubmed.ncbi.nlm.nih.gov/15677047/)
 7. van der Beek AJ, Frings-Dresen MH. Assessment of mechanical exposure in ergonomic epidemiology. *Occup Environ Med*. 1998; 55: 291–299. PMID: [9764106](https://pubmed.ncbi.nlm.nih.gov/9764106/)
 8. David GC. Ergonomic methods for assessing exposure to risk factors for work-related musculoskeletal disorders. *Occup Med (Lond)*. 2005; 55: 190–199.
 9. Barrero LH, Katz JN, Dennerlein JT. Validity of self-reported mechanical demands for occupational epidemiologic research of musculoskeletal disorders. *Scand J Work Environ Health*. 2009; 35: 245–260. PMID: [19562235](https://pubmed.ncbi.nlm.nih.gov/19562235/)
 10. Takala EP, Pehkonen I, Forsman M, Hansson GA, Mathiassen SE, Neumann WP, et al. Systematic evaluation of observational methods assessing biomechanical exposures at work. *Scand J Work Environ Health*. 2010; 36: 3–24. PMID: [19953213](https://pubmed.ncbi.nlm.nih.gov/19953213/)
 11. Stock SR, Fernandes R, Delisle A, Vezina N. Reproducibility and validity of workers' self-reports of physical work demands. *Scand J Work Environ Health*. 2005; 31: 409–437. PMID: [16425584](https://pubmed.ncbi.nlm.nih.gov/16425584/)
 12. Kwak L, Proper KI, Hagströmer M, Sjöström M. The repeatability and validity of questionnaires assessing occupational physical activity—a systematic review. *Scand J Work Environ Health*. 2011; 37: 6–29. PMID: [20802979](https://pubmed.ncbi.nlm.nih.gov/20802979/)
 13. Dyrstad SM, Hansen BH, Holme IM, Anderssen SA. Comparison of self-reported versus accelerometer-measured physical activity. *Med Sci Sports Exerc*. 2014; 46: 99–106. doi: [10.1249/MSS.0b013e3182a0595f](https://doi.org/10.1249/MSS.0b013e3182a0595f) PMID: [23793232](https://pubmed.ncbi.nlm.nih.gov/23793232/)
 14. Hansson G-Å, Balogh I, Unge Byström J, Ohlsson K, Nordander C, Asterland P, et al. Questionnaire versus direct technical measurements in assessing postures and movements of the head, upper back, arms and hands. *Scand J Work Environ Health*. 2001; 27: 30–40. PMID: [11266144](https://pubmed.ncbi.nlm.nih.gov/11266144/)
 15. Teschke K, Trask C, Johnson P, Chow Y, Village J, Koehoorn M. Measuring posture for epidemiology: comparing inclinometry, observations and self-reports. *Ergonomics*. 2009; 52: 1067–1078. doi: [10.1080/00140130902912811](https://doi.org/10.1080/00140130902912811) PMID: [19787510](https://pubmed.ncbi.nlm.nih.gov/19787510/)
 16. Unge J, Hansson GA, Ohlsson K, Nordander C, Axmon A, Winkel J, et al. Validity of self-assessed reports of occurrence and duration of occupational tasks. *Ergonomics*. 2005; 48: 12–24. doi: [10.1080/00140130412331293364](https://doi.org/10.1080/00140130412331293364) PMID: [15764303](https://pubmed.ncbi.nlm.nih.gov/15764303/)
 17. Korshoj M, Krstrup P, Jespersen T, Sogaard K, Skotte JH, Holtermann A. A 24-h assessment of physical activity and cardio-respiratory fitness among female hospital cleaners: a pilot study. *Ergonomics*. 2013; 56: 935–943. doi: [10.1080/00140139.2013.782427](https://doi.org/10.1080/00140139.2013.782427) PMID: [23586528](https://pubmed.ncbi.nlm.nih.gov/23586528/)
 18. Skotte J, Korshoj M, Kristiansen J, Hanisch C, Holtermann A. Detection of physical activity types using triaxial accelerometers. *J Phys Act Health*. 2014; 11: 76–84. doi: [10.1123/jpah.2011-0347](https://doi.org/10.1123/jpah.2011-0347) PMID: [23249722](https://pubmed.ncbi.nlm.nih.gov/23249722/)
 19. Stenlund I, Ingebrigtsen J, Christiansen CS, Jensen BR, Hanisch C, Skotte J, et al. Validity of the Acti4 method for detection of physical activity types in free-living settings: comparison with video analysis. *Ergonomics*. 2015; 58: 953–965. doi: [10.1080/00140139.2014.998724](https://doi.org/10.1080/00140139.2014.998724) PMID: [25588819](https://pubmed.ncbi.nlm.nih.gov/25588819/)
 20. Korshoj M, Skotte JH, Christiansen CS, Mortensen P, Kristiansen J, Hanisch C, et al. Validity of the Acti4 software using ActiGraph GT3X+accelerometer for recording of arm and upper body inclination in simulated work tasks. *Ergonomics*. 2014; 57: 247–253. doi: [10.1080/00140139.2013.869358](https://doi.org/10.1080/00140139.2013.869358) PMID: [24392673](https://pubmed.ncbi.nlm.nih.gov/24392673/)
 21. Karvonen J, Vuorimaa T. Heart rate and exercise intensity during sports activities. Practical application. *Sports Med*. 1988; 5: 303–311. PMID: [3387734](https://pubmed.ncbi.nlm.nih.gov/3387734/)
 22. Wu HC, Wang MJ. Relationship between maximum acceptable work time and physical workload. *Ergonomics*. 2002; 45: 280–289. doi: [10.1080/00140130210123499](https://doi.org/10.1080/00140130210123499) PMID: [12028725](https://pubmed.ncbi.nlm.nih.gov/12028725/)

23. Shimaoka M, Hiruta S, Ono Y, Nonaka H, Hjelm EW, Hagberg M. A comparative study of physical work load in Japanese and Swedish nursery school teachers. *Eur J Appl Physiol Occup Physiol*. 1998; 77: 10–18. PMID: [9459515](#)
24. Lunde LK, Koch M, Knardahl S, Waersted M, Mathiassen SE, Forsman M, et al. Musculoskeletal health and work ability in physically demanding occupations: study protocol for a prospective field study on construction and health care workers. *BMC Public Health*. 2014; 14: 1075. doi: [10.1186/1471-2458-14-1075](#) PMID: [25318646](#)
25. Porta M. *A dictionary of epidemiology*. 6 ed. Oxford, New York: Oxford University Press; 2014.
26. Statistics Norway. *Statistics Norway: Levekårsundersøkelsen 2009 (Survey of level of living 2009)*. Oslo. 2009
27. Steingrimsdottir OA, Vollestad NK, Roe C, Knardahl S. Variation in reporting of pain and other subjective health complaints in a working population and limitations of single sample measurements. *Pain*. 2004; 110: 130–139. doi: [10.1016/j.pain.2004.03.016](#) PMID: [15275760](#)
28. Noble BJ, Borg GA, Jacobs I, Ceci R, Kaiser P. A category-ratio perceived exertion scale: relationship to blood and muscle lactates and heart rate. *Med Sci Sports Exerc*. 1983; 15: 523–528. PMID: [6656563](#)
29. Brage S, Brage N, Ekelund U, Luan J, Franks PW, Froberg K, et al. Effect of combined movement and heart rate monitor placement on physical activity estimates during treadmill locomotion and free-living. *Eur J Appl Physiol*. 2006; 96: 517–524. doi: [10.1007/s00421-005-0112-6](#) PMID: [16344938](#)
30. Brage S, Brage N, Franks PW, Ekelund U, Wareham NJ. Reliability and validity of the combined heart rate and movement sensor Actiheart. *Eur J Clin Nutr*. 2005; 59: 561–570. doi: [10.1038/sj.ejcn.1602118](#) PMID: [15714212](#)
31. Kristiansen J, Korshoj M, Skotte JH, Jespersen T, Sogaard K, Mortensen OS, et al. Comparison of two systems for long-term heart rate variability monitoring in free-living conditions—a pilot study. *Biomed Eng Online*. 2011; 10: 27. doi: [10.1186/1475-925X-10-27](#) PMID: [21481282](#)
32. Tanaka H, Monahan KD, Seals DR. Age-predicted maximal heart rate revisited. *J Am Coll Cardiol*. 2001; 37: 153–156. PMID: [11153730](#)
33. Rothman KJ. *Epidemiology—an introduction*. Oxford: Oxford University Press; 2012.
34. Gupta N, Heiden M, Mathiassen SE, Holtermann A. Prediction of objectively measured physical activity and sedentariness among blue-collar workers using survey questionnaires. *Scand J Work Environ Health*. 2016; 42: 237–245. doi: [10.5271/sjweh.3561](#) PMID: [27067991](#)
35. Mathiassen SE, Burdorf A, van der Beek AJ, Hansson GA. Efficient one-day sampling of mechanical job exposure data—a study based on upper trapezius activity in cleaners and office workers. *AIHA J (Fairfax, Va)*. 2003; 64: 196–211.
36. Veiersted KB. Reliability of myoelectric trapezius muscle activity in repetitive light work. *Ergonomics*. 1996; 39: 797–807. doi: [10.1080/00140139608964499](#) PMID: [8635451](#)
37. Mayer J, Kraus T, Ochsmann E. Longitudinal evidence for the association between work-related physical exposures and neck and/or shoulder complaints: a systematic review. *Int Arch Occup Environ Health*. 2012; 85: 587–603. doi: [10.1007/s00420-011-0701-0](#) PMID: [22038085](#)



Article

Heavy Physical Work: Cardiovascular Load in Male Construction Workers

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Abstract: This study aimed to elucidate cardiovascular loads (CVL) in construction workers during work and leisure by relative heart rate (RHR) over several days. Furthermore, we sought to evaluate the level of CVL in relation to individual factors, work ability, musculoskeletal pain and subjective general health. From a group of 255 construction workers responding to the baseline questionnaire, the CVL during work and leisure time was determined by recording RHR in 42 workers over 3–4 days. Almost 60% of the workday was spent below 20% RHR. The mean RHR during work for all participants was 16% RHR, with large differences between professions. On average, the 42 workers spent 14% of the workday at a RHR above 33%, and four subjects (10%) had a mean RHR above 33% during work. Eight (19%) of the participants had a mean length of their workday exceeding calculated maximal acceptable work time. Seven persons (17%) experienced on average one or more episode(s) of 5 min or more continuously above 33% RHR. The cardiovascular load at work was significantly associated with age and $\dot{V}O_{2max}$, but not with work ability, musculoskeletal pain or subjective general health.

Keywords: construction work; general health; musculoskeletal pain; physical demands; work ability

1. Introduction

Physical demands at work are considered an important risk factor of several musculoskeletal disorders (MSD; see [1] for a systematic review). Moreover, heavy physical work may be associated with level of work ability [2]. Heavy physical work is a general term, encompassing both working at high levels of aerobic load relative to maximum oxygen uptake, handling of heavy objects, and performing tasks demanding sustained exertion at high levels of force. Hence, the term heavy physical work does not specify pathogenic factors to target for workplace interventions to prevent health problems.

Individual performance and production output depend on being able to sustain workload over a period of time, which depends on both individual capacity and type of tasks performed. Several authors have suggested guidelines for work-intensity and -duration to ensure safety, health, and productivity of employees [3,4]. Åstrand and coworkers have pointed out that the physical workload should be determined with indirect calorimetry and that the oxygen uptake must be evaluated with regard to the capacity of the working muscles [5]. A criterion for the limit of acceptable workload is the occurrence of a marked increase in heart rate (HR; >10 beats per minute) after a period of working at a steady state with constant HR [6], a sign of physiological fatigue. Rodgers and co-workers proposed that a workload of one third of the individual's maximum capacity should be the upper limit for an eight-hour workday [7]. Others have described workload limits for physically demanding jobs through

“maximal acceptable work time” (MAWT), a term referring to workloads that can be sustained by an individual in physiologically steady state without causing exhaustion or discomfort [8].

Work in the construction industry is generally considered physically demanding and construction workers show high prevalence of musculoskeletal pain [9,10]. Higher rates of disability, lowered physical function, and reduction in muscular strength have been found in occupations with high levels of physical demands [11–13]. However, the majorities of studies of heavy physical work were based on subjective measurements of physical demands. The validity and reliability of these exposure measurements are questionable [14]. Van der Molen and co-workers did measure cardiovascular demands objectively by HR and oxygen consumption in groups of construction workers during several work tasks [15–17]. These studies had a limited number of participants ($N= 8, 10, \text{ and } 15$, respectively) and measured demands during one single period. Two recent studies have objectively measured cardiovascular load for more than one day within other occupations commonly considered as physically demanding, female hospital cleaners [18] and an unspecified group of blue-collar workers [19]. Still, within construction work there is a paucity of studies with objective measurements of cardiovascular load over several days. Therefore, there is a need for knowledge of physical workload based on objective measurement of cardiovascular load in employees performing heavy physical work in the construction sector.

It seems a paradox, that physical activity during leisure time is considered health-promoting and essential for maintaining and increasing physical capacity and work ability [20–22], while physical demands at work may be harmful. One might expect that heavy physical work would produce positive training effects [23,24]. However, negative or no training effects from a life-time of heavy work exposure have been reported [25,26]. Differences in patterns of physical activity during work and leisure could be an important factor when explaining this phenomenon [27]. Moreover, heavy physical work may be a risk factor for leisure time physical inactivity [28]. Therefore, information on physical demands and activity patterns during both work and leisure is needed.

There is a linear relationship between HR and oxygen consumption during a bout of work or exercise [29]. Hence, HR may be measured as a proxy of workload or work intensity or aerobic strain. Some previous recommendations of workload have related work duration to workload operationalized as % of maximum O_2 uptake ($\dot{V}O_{2\max}$) or % of maximum HR (HR_{\max}) for the individual. HR_{\max} depends on age and there are several formulas for calculating HR_{\max} [30]. One problem with the % HR_{\max} approach is the fact that resting HR (HR_{\min}) never is zero, hence the percentage of HR_{\max} does not represent load above the resting state. Furthermore, some physically fit individuals exhibit very low HR_{\min} , hence their range of HR-variation (HR reserve) is larger for a given age. The relative HR (RHR or % of HR reserve) takes HR_{\min} into account by subtracting HR_{\min} from the HR measured during work and from HR_{\max} .

In the present study we aimed to elucidate cardiovascular loads in construction workers during work and leisure by relative HR (RHR) from objective measures over several days. We further evaluated the level of cardiovascular load in relation to individual factors, work ability, MSDs and general health.

2. Methods

2.1. Participants

Subjects for this study were recruited from three large construction enterprises during April–September 2014. A total of 579 employees were invited to fill out a baseline questionnaire and give their consent to participate. Two hundred and fifty-five answered the baseline questionnaire and 161 stated they were also willing to participate in ambulatory technical measurements. From the 161 a sample of 57 was invited to the technical recordings presented in this paper. The 57 were selected to best fit logistics (based on availability and work schedules) and to give a reasonable representation of occupational titles. The construction sector consists of a high proportion of men, hence all participating volunteers investigated by technical measurements in this study are men. Individual characteristics

for participants in the technical measurement group and the questionnaire group are shown in Table 1. Exclusion criterion for answering the questionnaire was inadequate skills in reading and writing Norwegian. Diagnosed cardiovascular disease or known allergic reaction to plaster/tape/bandages were exclusion criteria for technical measurements of HR. Subjects with considerable musculoskeletal pain on the test day or diagnosed with back or shoulder disorders, were not subjected to physical capacity tests they were unable to perform.

Table 1. Characteristics of the study population divided in technical and questionnaire groups.

Variable	Technical	Questionnaire	Profession	Technical	Questionnaire
	<i>n</i> = 42	<i>n</i> = 255		<i>n</i> = 42	<i>n</i> = 255
	Mean (SD)	Mean (SD)		Number (%)	Number (%)
Age (years)	40.4 (13.6)	42.7 (12.9)	Project manager	5 (11.9)	52 (20.4)
Male gender (frequency and %) ^a	42 (100%) *	237 (93%)	Carpenter	12 (28.6)	70 (27.5)
Height (cm)	179.1 (6.2)	179.6 (7.1)	Bricklayer	5 (11.9)	11 (4.3)
Body mass (kg)	82.5 (11.5)	85.2 (12.9)	Concrete worker	8 (19.0)	41 (16.1)
Body mass index (kg/m ²)	25.8 (3.5)	26.4 (4.0)	Henchman	7 (16.7)	13 (5.1)
Normal work hours per week	37.7 (4.9)	38.4 (3.7)	Foreman	4 (9.5)	26 (10.2)
Smokers (frequency and %) ^a	13 (31%) *	46 (18%)	Working with various tasks	1 (2.4)	16 (6.3)
Perceived health (1–5)	2.6 (0.9)	2.6 (0.9)	Driver	0 (0)	9 (3.5)
Waist circumference (cm)	93.1 (10.4)	NA	Missing	0 (0)	17 (6.7)
HR _{max} (bpm)	179.7 (9.5)	NA	Total	42 (100)	255 (100)
HR _{min} (bpm)	68.7 (0.5)	NA			
Estimated $\dot{V}O_{2max}$ (L·min ⁻¹)	3.1 (0.9)	NA			
Estimated $\dot{V}O_{2max}$ (mL·kg ⁻¹ ·min ⁻¹)	38.4 (10.7)	NA			
Handstrength (kg)	54.6 (8.9)	NA			
Blood pressure systolic (mmHg)	135.2 (12.1)	NA			
Blood pressure diastolic (mmHg)	78.9 (9.2)	NA			

* Significant differences between groups ($p < 0.05$); ^a Variable is presented as frequency and percentage.

2.2. Compliance with Ethical Standards

All participants were informed of the purpose and content of the study and signed an informed consent prior to participation. The study was conducted in accordance with the 1964 Helsinki declaration and approved by The Regional Committee for Medical and Health Research Ethics in Norway (2014/138/REK south-east D).

2.3. Study Procedure

Participants volunteering for the study answered first the baseline questionnaire before proceeding to a physical examination (including weight and height measurements) carried out by a physician or nurse. If none of the exclusion criteria were present, the participant carried out a physical fitness test determining aerobic fitness and muscular strength. On a succeeding (separate) workday morning, instruments for ambulatory technical measurement were attached. The instruments for recording physical exposure sampled 24-h a day for three to four consecutive days or until deliberately removed by the subject. Measurement were targeted to include at least two working days. On the first day of measurement all participants were given a small diary where they should note time of day they got out of bed in the morning, started work (if workday), ended work (if workday), and went to bed at night for the days they were measured. Additionally, if the instruments at any time were detached subjects

were instructed to note time periods when the monitor was not worn. They were also given extra electrodes and instruction on how to attach the measurement equipment if it detached unintentionally.

2.4. Questionnaire

The following self-reported measures from questionnaire were included in this study: seniority, height, weight, smoking status, perceived exertion at work [31], work ability [32], perceived health [33], musculoskeletal disorders previous four weeks [34] and level of leisure time physical activity [35].

2.4.1. Smoking

Smoking status was determined by the question: “do you smoke or have you ever smoked?” with the four response alternatives: No, never (0), yes, but not anymore (1), yes, occasionally (2) and yes, every day (3). The responses were dichotomized in to non-smoking (0–1) and smoking (2–3).

2.4.2. Perceived Exhaustion during Work

The question “how physically demanding do you normally find your work?” with a response scale of 13 categories, ranging from “not exhausting at all” to “maximally exhausting” measured self-reported exertion during work [31].

2.4.3. Work Ability

Work ability was measured by a single item taken from the Work Ability Index: “current work ability compared with lifetime best”. The score range for this question is from 0 (“completely unable to work”) to 10 (“work ability at its best”). This single item has previously shown strong predictive value for health outcomes [32].

2.4.4. Perceived Health

Self-perceived health was measured using the question: “How is your general health at present?”. Participants had five response alternatives ranging from excellent to poor [33].

2.4.5. Musculoskeletal Disorders

Musculoskeletal pain in neck, shoulders, back (upper, lower), elbow, hip, knee and foot/ankle were measured by assessing pain intensity and duration during the previous four weeks. Pain intensity was classified by participants to be no pain (0), mild pain (1), moderate pain (2) or severe pain (3) with the pain duration alternatives 1–5 (1), 6–10 (2), 11–14 (3) and 15–28 (4) days. From these answers a pain score was calculated, ranging from 0 (no pain × no duration) to 12 (severe pain × 15–28 days). A musculoskeletal complaint-severity index (MSI) was computed as a mean of the pain scores for all pain sites [34].

2.4.6. Self-Reported Leisure-Time Physical Activity Level

Leisure-time physical activity level was determined by a single item. The participants reported which of the following activities levels that corresponded best to their own level the previous four weeks: (1) Almost completely inactive (e.g., reading, watching TV, movies); (2) Some physical activity at least four hours per week (e.g., bicycling, walking, gardening); (3) Regular activity (e.g., running, tennis); (4) Regular hard physical training for competition several times per week [35].

2.5. Physical Capacity Assessment

2.5.1. Aerobic Fitness

Aerobic fitness was established using a standardized cycle ergometer test (Ergometer 839 E, Varberg, Sweden) [36]. Based on assumed state of fitness an external power was set between 75 and

150 watts and subjects performed a cycling rate of 50 revolutions per minute. The test was terminated when heart rate obtained a steady state at a level greater than 120 beats per minute (bpm), normally within the period between the 5th and 6th minute. The mean steady-state heart rate was used to estimate $\dot{V}O_{2\max}$ based on the Åstrand nomogram [37].

2.5.2. Muscular Strength

Handgrip strength was tested according to standardized procedures [38] by a hand dynamometer (Lafayette Instrument, Lafayette, IN, USA). For each hand, the highest obtained value of two attempts was used.

2.6. Assessment of Cardiovascular Load

2.6.1. Instrumentation

Heart rate recording was carried out with, Actiheart 4 (Camntech, Cambridge, UK), a small chest-worn monitoring device consisting of two clips attached to standard electrocardiogram electrodes (Blue sensor VL-00-S/25 Ambu, Ballerup, Denmark) placed at the apex of the sternum and at the left intercostals at the level of the 6th and 7th costae [39]. Before affixing the electrodes, the skin was prepared by shaving and cleaning with ethanol spirits. Analog signals of the Actiheart were filtered (10 Hz–35 Hz) and sampled with a frequency of 128 Hz. The Actiheart measures HR by calculating the R-R intervals of the ECG. For analysis of HR a custom made software, Acti4 (National Research Centre for the Working Environment, Copenhagen, Denmark and Federal Institute of Occupational Safety and Health, Berlin, Germany) was used [19]. The Actiheart produces reliable 24-h measurement in physically active workers [18].

2.6.2. Data Processing

Based on the diary data, each day was categorized into periods: before work, work, after work, sleep and leisure (off days). In this study the periods analyzed were work time and leisure time on work days (before and after work). Sleep periods and leisure on off days are not reported here. To be eligible in the analysis participants needed to have valid measurement periods (work or leisure) lasting four hours or longer than $\geq 75\%$ of the length of a normal period. The definition of a normal period was the average of the measured periods. Data were also excluded if beat error exceeded 50% for a measurement period, defined as HR <35 or >230 bpm or >15% difference between two succeeding beats. In addition, all measurement periods were visually checked. Data for the valid time periods within work and leisure categories were then aggregated and averaged for each individual.

To evaluate the relative cardiovascular load the RHR during work and leisure respectively, was calculated as follows:

$$RHR_{work} = \frac{(HR_{work} - HR_{min})}{(HR_{max} - HR_{min})} \times 100 \text{ and } RHR_{leisure} = \frac{(HR_{leisure} - HR_{min})}{(HR_{max} - HR_{min})} \times 100$$

In this equation the HR_{max} is given by $208 - 0.7 \times \text{age}$ [30]. The HR_{min} entered into the equation was a sex- and age-adjusted value obtained from a Norwegian population study (HUNT3) [40] (20–29 yrs; 69.4 bpm, 30–39 yrs; 68.7 bpm, 40–49 yrs; 68.2 bpm, 50–59 yrs; 68.6 bpm, 60–69 yrs; 68.1 bpm). HR_{work} and $HR_{leisure}$ in the equation is the mean HR measured for the respective periods.

To calculate MAWT the equation $26.12 \times e^{-4.81 \times RHR/100}$ using mean RHR during work was implemented [8].

2.7. Statistical Analysis

Normal distribution of independent variables was tested by the Shapiro-Wilk tests of normality. Differences between questionnaire and technical measurement groups and differences in percentage distribution of RHR ranges between work and leisure were tested with independent samples *T*-tests

and Mann-Whitney U tests. The associations between individual factors, work ability, and MSD and CVL at work were tested with simple and multiple linear regression analyses. Associations between independent variables were assessed by Pearson correlation prior to multiple regression. If variables were highly correlated ($r > 0.6$), the variable with highest predictive value was used in the analysis. For the statistical analyses IBM SPSS Statistics 23 (IBM Corporation, Armonk, NY, USA) was used. Significance level was set at $p = 0.05$.

3. Results

There were significant ($p < 0.05$) differences in smoking status and gender distribution between the questionnaire group and the technical measurement group, with more men and smokers in the latter (Table 1). The technical measurement group did not differ from the questionnaire group in: age, height, body mass, body mass index, number of normal working hours, perceived exhaustion at work, perceived health or work ability.

Of the 57 who recorded HR, 15 subjects were not included in the final analysis due to technical measurement error (blank measurements), too many measurement periods with beat error above 50% or unfulfilled length of measurements criteria. Hence, the sample available for analysis of cardiovascular strain at work was 42. Two subjects did not have any valid measurements outside working hours, thus 40 subjects were available for leisure time HR analysis. A total of 85 days of work were measured with a mean length of measured workday being 8.1 h (± 2.2). For leisure time measurements the total was 81 days with a mean length 7.3 h (± 2.6). Figure 1 shows example measurements taken from a foreman and a carpenter.

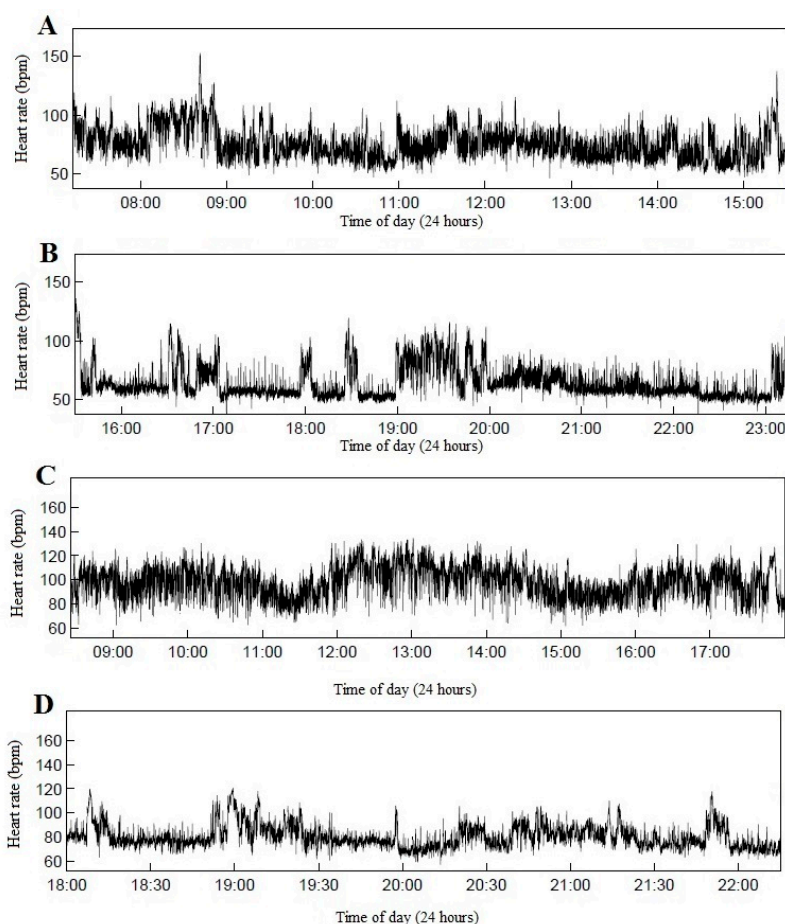


Figure 1. Examples of single periods of measured work and leisure heart rate for a foreman and a carpenter. (A) work foreman; (B) leisure foreman; (C) work carpenter and (D) leisure carpenter.

3.1. Cardiovascular Load during Work

The average RHR during work for all participants was 16.4% (± 11.4). The distribution within different ranges of RHR showed that for 58.6% (± 28.5) of the work day RHR levels were lower than 20% RHR. Furthermore, for 19.5% (± 13.3) and 11.1% (± 10.2) of the day RHR level ranged between 20%–29% RHR and 30%–39% RHR, respectively. A small proportion of the day, 5.0 percent (± 7.4) of the day in a RHR between 40%–49% and 1.9% (± 3.6), the work was accompanied by cardiovascular demands in range of 50%–59% RHR.

For the group as a whole, 14.4% (± 18.4) of the working day was spent above 33% RHR. Out of 42 subjects, 10% (4) did have a mean RHR above 33% during work, 90% (38) did not. Foremen and project leaders spent fewest minutes above 33% RHR during work (6.5 ± 8.3 min and 22.9 ± 42.4 min), see Figure 2. Foremen and project leaders had lowest mean RHR ($4.2\% \pm 2.0\%$ and $6.6\% \pm 11.9\%$) while carpenters, henchmen and bricklayers all had a mean RHR of approximately 20% (19.4 ± 7.2 , 21.6 ± 14.3 and 22.9 ± 11.5), see Figure 3.

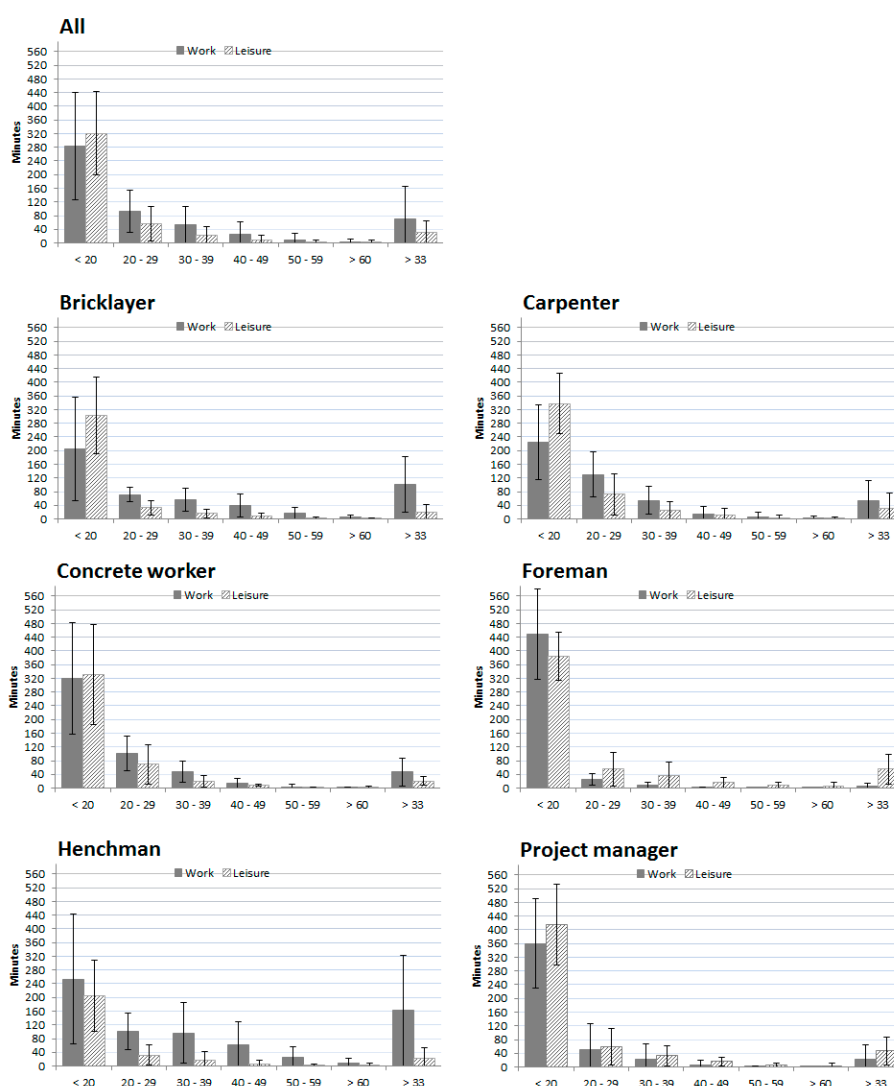


Figure 2. Relative heart rate distribution during work and leisure presented as minutes with standard deviation. *During work:* All; $n = 42$, Bricklayer; $n = 5$, Carpenter; $n = 12$, Concrete worker; $n = 8$, Foreman; $n = 4$, Henchman; $n = 8$, Project manager; $n = 5$. *During leisure:* All; $n = 36$, Bricklayer; $n = 3$, Carpenter; $n = 11$, Concrete worker; $n = 7$, Foreman; $n = 4$, Henchman; $n = 6$, Project manager; $n = 5$.

Maximal Acceptable Work Time and Continuous Work and Rest Periods

The average MAWT for this sample was 14.1 (± 8.4) hours, while mean length of work shifts was 8.1 (± 2.2) hours. Eight (19%) subjects exhibited work lengths exceeding mean calculated MAWT (1 out of 9 with mostly administrative tasks and 7 out of 33 with manual tasks), 34 (81%) did not. Foremen had highest and bricklayers had the lowest MAWT, see Figure 3.

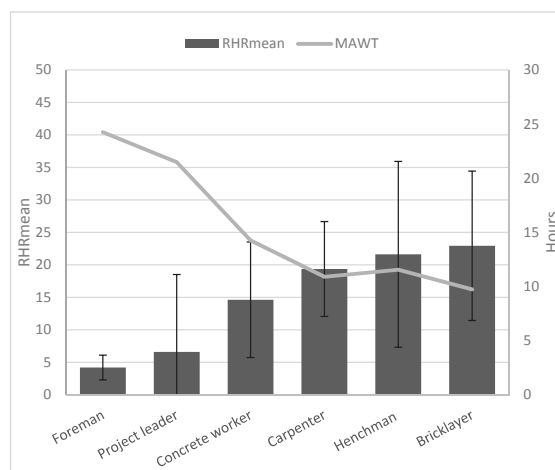


Figure 3. Mean relative heart rate during work and maximal acceptable worktime for professions.

Seven persons had on average one or more episode per day of RHR above 33% continuously for 5 min duration or more (exertion periods). Five persons showed one or more episodes of 10 min or more and one person had episodes of RHR above 33% continuously for 15 min or longer. See Table 2. Henchmen had highest number of continuous periods of more than 5 min above 33% RHR, while there were no such periods among project leaders and foremen. Foremen did have the highest mean number of rest periods, defined as periods of 5 min continuously below 10% RHR, with 7.5 (± 10.7), see Figure 4.

Table 2. Participants experiencing continuous episodes of relative heart rate above 33% during work.

	Continuously ≥ 5 min	Continuously ≥ 10 min	Continuously ≥ 15 min
Mean number of episodes			
>0 times	7 persons (16.7%)	5 persons (11.9%)	1 person (2.4%)
≥ 3 times	3 persons (7.1%)	0 persons (0%)	0 persons (0%)
≥ 5 times	2 persons (4.8%)	0 persons (0%)	0 persons (0%)

Mean episodes is an average from the continuous workdays measured. Percentages represented is related to the total measured sample, $n = 42$.

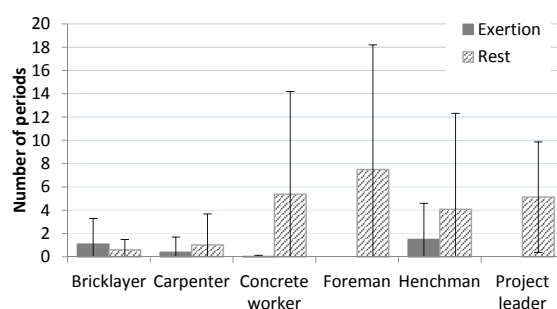


Figure 4. Number of episodes with mean RHR above 33% (exertion) or below 10% (rest) continuously for 5 min or more.

3.2. Cardiovascular Load during Leisure Time

The mean load during leisure time was significantly lower compared to work, with mean RHR of 9.2% (± 7.8), $p < 0.01$. Moreover, when compared to work, the distribution of the leisure time periods spent in different RHR ranges showed that a significantly higher proportion was spent below 20% RHR ($75.2\% \pm 16.9\%$; $p < 0.01$) and significantly lower proportions in RHR ranges of 20%–29% ($19.5\% \pm 13.3\%$; $p < 0.01$), 30%–39% ($11.1\% \pm 10.2\%$; $p < 0.01$) and 40%–49% ($5.0\% \pm 7.4\%$; $p < 0.05$), see Figure 2.

3.3. Cardiovascular Load and Individual Factors

3.3.1. Age and Seniority

Unadjusted linear regression analysis showed RHR during work to be significantly associated with age ($\beta = -0.298$, $p < 0.05$), indicating decreasing levels of RHR with increasing age. Seniority (years in profession) showed similar tendency, however, did not reach significance criteria ($\beta = -0.234$, $p = 0.085$). In the adjusted multiple linear regression model age remained significant ($\beta = -0.414$, $p < 0.01$). Seniority was strongly ($r = 0.845$, $p < 0.001$) correlated to age.

3.3.2. Aerobic Fitness, Leisure Time Physical Activity and Muscular Strength

RHR was dependent on aerobic fitness level, showing a significant association to estimated $\dot{V}O_{2\max}$ ($\beta = -5.924$, $p < 0.01$). Higher levels of $\dot{V}O_{2\max}$ was associated to lower RHR during work. The $\dot{V}O_{2\max}$ variable remained significant ($\beta = -5.098$, $p < 0.01$) in the adjusted analysis. Higher self-reported physical activity levels did also seem to lower RHR during work, but was not significant. Further, we were unable to find any association between RHR and hand strength.

3.3.3. Work Ability

There was a trend towards lower reported work ability with higher RHR during work. However, this did not reach customary criteria for statistical significance ($\beta = -1.844$, $p = 0.076$) and was cancelled out in the adjusted analysis.

3.3.4. Musculoskeletal Pain and Perceived Health

We did not find any association between RHR during work and MSI. Similarly, perceived health did not show any significant associations to RHR. Additionally, there was no associations between leisure time RHR and MSI or perceived health.

3.3.5. Perceived Exhaustion

Self-reported perceived exhaustion at work was significantly associated to levels of RHR. Those reporting high level of perceived exhaustion did also tend to have higher cardiovascular loads during work ($\beta = 1.598$, $p < 0.05$). This relationship was cancelled out in the adjusted analysis.

3.3.6. Smoking

Our analysis showed no association between smoking and level of RHR during work. See Table 3 for the adjusted and unadjusted linear regressions.

Table 3. Unadjusted and adjusted regression analyses with mean percentage relative heart rate at work as dependent variable.

Variable	Unadjusted		Adjusted ^a	
	Beta	p-Value	Beta	p-Value
Age (years)	−0.298	0.021	−0.414	0.002
Body mass index (kg/m ²)	−0.266	0.613	Not included	Not included
Seniority (years) ^b	−0.234	0.085	Not included	Not included
Smoking	1.390	0.377	Not included	Not included
Estimated $\dot{V}O_{2max}$ (L·min ^{−1})	−5.924	0.002	−5.098	0.008
Physical activity (1–4)	−3.205	0.109	−2.025	0.304
Hand strength (kg)	0.169	0.401	Not included	Not included
Work ability	−1.844	0.076	−0.255	0.800
Musculoskeletal pain	0.569	0.617	Not included	Not included
Perceived exhaustion at work	1.598	0.043	0.713	0.288
Perceived health	1.802	0.346	Not included	Not included

^a Multiple regression including the variables: Age, Estimated $\dot{V}O_{2max}$, Physical activity, Work ability and Perceived exhaustion at work. Due to variable to participant ratio, BMI, smoking, hand strength, musculoskeletal complaint-severity index and perceived health were excluded from the adjusted model because of low explanatory value; ^b seniority was not included in the adjusted model due to high ($r = 0.845$) significant ($p < 0.001$) correlation to age; Model $r^2 = 0.454$.

4. Discussion

The results demonstrated cardiovascular load characteristics in male construction workers during work and leisure. Further, the association between RHR at work and the participants' age and aerobic fitness level is highlighted. We did not find any significant associations between cardiovascular demands at work and work ability, musculoskeletal complaints or general perceived health.

For the group as a whole an average workday was characterized by most time spent in ranges below 20% RHR and less time in higher ranges. For an average workday of 8 h, approximately 5 h were below 20% RHR, while approximately 40 min were spent in ranges above 40% RHR. A limited proportion of the participants (10%) had a mean RHR above the recommended threshold of 33% RHR and for the whole group approximately 70 min were in load ranges above this level of cardiovascular load on an average workday. Carpenters, henchmen and bricklayers represented professions with the highest mean RHR. Compared to carpenters and bricklayers, henchmen did have more episodes of both continuous exertion and rest periods, indicating a somewhat different work pattern. Foremen and project leaders seemed to have less physical demands, with lowest levels of RHR, no continuous periods of exertion and highest number of rest periods. This reflects that different professions within construction will have different physical demands, which should be taken into consideration when evaluating the construction sector. The physical demands of construction supervisors (e.g., foremen and project leaders) have previously been very scarcely investigated [41].

Previous studies investigating masons, bricklayers and plasterboard work (carpenter task) during a full workday have found mean RHR ranging from 21 to as high as 39% RHR, with factors as brick and plasterboard sizes as important load varying factors [15–17]. From our data the three professions found to have the highest cardiovascular demands (carpenter, bricklayer and henchman) exhibited HRs in the lower part of this range. However, the above-mentioned studies measured cardiovascular loads for one workday only. We found that the recorded HRs were significantly higher during the first day of measurement compared to following workdays (Koch *et al.* work in progress). This finding indicates that work behavior may be altered the on first day of measurement. Still, compared to the general working life [42], construction workers exhibit a higher level of cardiovascular load.

The mean MAWT for this sample was 14 hours, and a mismatch between length of workday and MAWT were found in approximately 1 in 5 individuals. A mean RHR of 24.4% would represent MAWT equal to the average workday of 8.1 h. Thus, all professions were within these limits. With this said, the distribution within RHR ranges and exertion/rest periods does imply that construction work is not a physiologically steady-state situation, but is rather fluctuating between levels of cardiovascular load. Therefore, this kind of work may not fulfil the assumptions behind the MAWT-equation, which is set pace ergometer cycling [8]. Additionally, we may expect load carrying tasks to need additional predicting factors [43]. Hence, there is a need for new approaches to estimate workload limits in physical occupations.

Age was significantly associated with RHR during work. Increasing age was associated with reduced cardiovascular load, indicating that younger workers had higher cardiovascular loads during work, compared to older workers. Similarly, Gupta and colleagues found seniority to be significantly more prevalent in workers with low RHR during work, compared to those with high RHR [19]. Possibly, higher seniority workers allocate the more physically demanding tasks to younger workers. Alternatively, inexperienced workers perform tasks at a higher physiological cost than more experienced workers [7]. It is possible that the senior workers are a selection of more fit individuals or that senior workers are relocated to less physically demanding professions within construction. However, as found in the general population, $\dot{V}O_{2max}$ decreased significantly with age in our sample (results not shown), and there were no significant age difference between professions measured.

$\dot{V}O_{2max}$ was significantly associated with RHR during work. An increase in aerobic fitness will result in work being less physically demanding, with lower RHR as long as the level of physical demands remains unchanged. Even though there are differences in physical demands between professions, the relative demands for each person will be individually determined by level of fitness. We recorded large individual differences in the relative physical demands within the same profession.

There is an ongoing discussion concerning the paradoxical effect of physical exercise: seemingly negative effects of high physical activity at work and the health-improving effects of physical activity in leisure time [44,45]. Our study shows that few individuals had continuous periods with RHR above one-third of their capacity and very few minutes were spent above 60% RHR during the workday. Intensive bursts of exhausting physical activity are needed to achieve a training effect on the cardiovascular system [46]. Thus, the combination of duration and intensity seen in construction work do not meet levels required to achieve training effects. For the 10% of our cohort having a mean RHR above one third of maximal capacity, the demands may possibly have a negative effect, rather than a training effect [47,48]. Foremen and project managers had the lowest amount of minutes above 33% RHR during work, the highest amount of minutes above 33% RHR during leisure and were the only professions spending more minutes in high ranges of RHR during leisure than during work. Generally, the present measurements indicated that cardiovascular load in spare-time was low. This may indicate the suggestion that occupations with manual work might have low levels of leisure time physical activity [28].

Construction work has been associated to development of MSDs and reduction in work ability, and heavy physical work commonly is considered a major risk factor [1,2]. Our data did not show any significant increase on musculoskeletal complaints or decrease in reported work ability with increasing cardiovascular demands. If musculoskeletal complaints develop over time, and RHR declines with increasing age, this combination could cancel out any possible association. Follow-up investigations of outcome based on these initial objective measurements, may provide more information concerning this issue. Reduction in work ability with high physical demands has also been shown in cross-sectional studies [2]. A recent cross-sectional investigation on cardiovascular load and work ability found that high physical workload was associated with self-reported work ability in women, but not in men [19]. Similarly, Karlqvist *et al.* found that women needing to exceed their physical demands regularly during work had reduced general health and increased level of musculoskeletal complaints, however, men had no such problems [42]. Thus, there may also be sex differences that we did not explore here.

The methods and design used in this study were chosen to provide a thorough objective description of the cardiovascular demands in construction work. The continuous measurement over several days provide a more solid foundation when describing general demands compared to studies with task or short period measurements, which may serve other purposes.

The formula for HR_{max} presented by Tanaka and coworkers [30] produced a standard deviation ~10 bpm for individuals of any age. Hence, the calculation of RHR can only give an approximate measure of cardiovascular load. Since arousal-inducing psychological factors may introduce large errors in measuring HR during rest and moderate levels of physical workload, obtaining valid measurements of HR_{min} is difficult at the workplace. Therefore, we based HR_{min} on the sex- and age-adjusted population means. The study participants were drawn from a variety of occupational titles within construction and will thereby give a good overall description of this work sector. However, they were male employees at Norwegian large-scale enterprises and data may not be generalized small enterprises and builders of private homes. In addition, there is possibility of selection bias of participants. From the 579 invited, 255 answered the questionnaire, 161 volunteered for technical measurement, and a sample of 57 were selected. Still, the participants monitored in the present study did not differ from the questionnaire group in any variable investigated, except smoking and gender. Concerning gender, there were only 18 females in total answering the questionnaire, hence females were weakly represented. However, at present this is the normal gender distribution in the construction sector. Long-term follow-ups are needed to determine the long term health effects of cardiovascular load during work.

5. Conclusions

Cardiovascular demands in construction are characterized by mainly work in ranges of relative heart rate below 39%, with few continuous periods above one-third of capacity. Few minutes are spent in high load intensities needed to achieve training effect. Cardiovascular load differs between professions within construction and both age and aerobic fitness are individual factors influencing cardiovascular load at work.

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References

1. Da Costa, B.R.; Vieira, E.R. Risk factors for work-related musculoskeletal disorders: A systematic review of recent longitudinal studies. *Am. J. Ind. Med.* **2010**, *53*, 285–323. [[CrossRef](#)] [[PubMed](#)]
2. Van den Berg, T.I.J.; Elders, L.A.M.; de Zwart, B.C.H.; Burdorf, A. The effects of work-related and individual factors on the Work Ability Index: A systematic review. *Occup. Environ. Med.* **2009**, *66*, 211–220. [[CrossRef](#)] [[PubMed](#)]
3. Bink, B. The physical working capacity in relation to working time and age. *Ergonomics* **1962**, *5*, 25–18. [[CrossRef](#)]
4. Bonjer, F.H. Actual energy expenditure in relation to the physical working capacity. *Ergonomics* **1962**, *5*, 29–31. [[CrossRef](#)]
5. Åstrand, P.O.; Rodal, K.; Dahl, H.A.; Strømme, B.S. Applied Work Physiology. In *Textbook of Work Physiology*, 4th ed.; Human Kinetics Publishers, Inc.: Champaign, IL, USA, 2003; pp. 503–540.

6. Saha, P.N.; Datta, S.R.; Banerjee, P.K.; Narayane, G.G. An acceptable workload for Indian workers. *Ergonomics* **1979**, *22*, 1059–1071. [[CrossRef](#)] [[PubMed](#)]
7. Rodgers, S.H.; Kenworth, D.A. Heart rate interpretation methodology. In *Ergonomic Design for People at Work*; Van Nostrand Reinhold: New York, NY, USA, 1986; pp. 178–179.
8. Wu, H.C.; Wang, M.J. Relationship between maximum acceptable work time and physical workload. *Ergonomics* **2002**, *45*, 280–289. [[CrossRef](#)] [[PubMed](#)]
9. Boschman, J.S.; van der Molen, H.F.; Sluiter, J.K.; Frings-Dresen, M.H.W. Musculoskeletal disorders among construction workers: A one-year follow-up study. *BMC Musculoskelet. Disord.* **2012**, *13*, 196. [[CrossRef](#)] [[PubMed](#)]
10. Stocks, S.J.; Turner, S.; McNamee, R.; Carder, M.; Hussey, L.; Agius, R.M. Occupation and work-related ill-health in UK construction workers. *Occup. Med.* **2011**, *61*, 407–415. [[CrossRef](#)] [[PubMed](#)]
11. Russo, A.; Onder, G.; Cesari, M.; Zamboni, V.; Barillaro, C.; Capoluongo, E.; Pahor, M.; Bernabei, R.; Landi, F.; Ferrucci, L. Lifetime occupation and physical function: A prospective cohort study on persons aged 80 years and older living in a community. *Occup. Environ. Med.* **2006**, *63*, 438–442. [[CrossRef](#)] [[PubMed](#)]
12. Cassou, B.; Derriennic, F.; Iwatsubo, Y.; Amphoux, M. Physical disability after retirement and occupational risk factors during working life: A cross sectional epidemiological study in the Paris area. *J. Epidemiol. Community Health* **1992**, *46*, 506–511. [[CrossRef](#)] [[PubMed](#)]
13. Li, C.Y.; Wu, S.C.; Wen, S.W. Longest held occupation in a lifetime and risk of disability in activities of daily living. *Occup. Environ. Med.* **2000**, *57*, 550–554. [[CrossRef](#)] [[PubMed](#)]
14. Kwak, L.; Proper, K.I.; Hagströmer, M.; Sjöström, M. The repeatability and validity of questionnaires assessing occupational physical activity—A systematic review. *Scand. J. Work Environ. Health* **2011**, *37*, 6–29. [[CrossRef](#)] [[PubMed](#)]
15. Van der Molen, H.F.; Mol, E.; Kuijer, P.P.; Frings-Dresen, M.H. The evaluation of smaller plasterboards on productivity, work demands and workload in construction workers. *Appl. Ergon.* **2007**, *38*, 681–686. [[CrossRef](#)] [[PubMed](#)]
16. Van Der Molen, H.F.; Kuijer, P.P.; Hopmans, P.P.; Houweling, A.G.; Faber, G.S.; Hoozemans, M.J.; Frings-Dresen, M.H. Effect of block weight on work demands and physical workload during masonry work. *Ergonomics* **2008**, *51*, 355–366. [[CrossRef](#)] [[PubMed](#)]
17. Van der Molen, H.F.; Kuijer, P.P.F.M.; Formanoy, M.; Bron, L.; Hoozemans, M.J.M.; Visser, B.; Frings-Dresen, M.H.W. Evaluation of three ergonomic measures on productivity, physical work demands, and workload in gypsum bricklayers. *Am. J. Ind. Med.* **2010**, *53*, 608–614. [[CrossRef](#)] [[PubMed](#)]
18. Korshøj, M.; Krustrup, P.; Jespersen, T.; Søgaard, K.; Skotte, J.H.; Holtermann, A. A 24-h assessment of physical activity and cardio-respiratory fitness among female hospital cleaners: A pilot study. *Ergonomics* **2013**, *56*, 935–943. [[CrossRef](#)] [[PubMed](#)]
19. Gupta, N.; Jensen, B.S.; Søgaard, K.; Carneiro, I.G.; Christiansen, C.S.; Hanisch, C.; Holtermann, A. Face validity of the single work ability item: Comparison with objectively measured heart rate reserve over several days. *Int. J. Environ. Res. Public Health* **2014**, *11*, 5333–5348. [[CrossRef](#)] [[PubMed](#)]
20. Alavinia, S.M.; van Duivenbooden, C.; Burdorf, A. Influence of work-related factors and individual characteristics on work ability among Dutch construction workers. *Scand. J. Work Environ. Health* **2007**, *33*, 351–357. [[CrossRef](#)] [[PubMed](#)]
21. Strijk, J.E.; Proper, K.I.; van Stralen, M.M.; Wijngaard, P.; van Mechelen, W.; van der Beek, A.J. The role of work ability in the relationship between aerobic capacity and sick leave: A mediation analysis. *Occup. Environ. Med.* **2011**, *68*, 753–758. [[CrossRef](#)] [[PubMed](#)]
22. Arvidson, E.; Börjesson, M.; Ahlborg, G., Jr.; Lindegård, A.; Jonsdottir, I.H. The level of leisure time physical activity is associated with work ability—A cross sectional and prospective study of health care workers. *BMC Public Health* **2013**, *13*, 855. [[CrossRef](#)] [[PubMed](#)]
23. Schibye, B.; Hansen, A.F.; Søgaard, K.; Christensen, H. Aerobic power and muscle strength among young and elderly workers with and without physically demanding work tasks. *Appl. Ergon.* **2001**, *32*, 425–431. [[CrossRef](#)]
24. Torgén, M.; Punnett, L.; Alfredsson, L.; Kilbom, Å. Physical capacity in relation to present and past physical load at work: A study of 484 men and women aged 41 to 58 years. *Am. J. Ind. Med.* **1999**, *36*, 388–400. [[CrossRef](#)]

25. Nygård, C.H.; Kilbom, Å.; Hjelm, E.W.; Winkel, J.; Group, S.M.S. Lifetime occupational exposure to heavy work and individual physical capacity. *Int. J. Ind. Ergon.* **1994**, *14*, 365–372. [[CrossRef](#)]
26. Savinainen, M.; Nygård, C.-H.; Ilmarinen, J. A 16-year follow-up study of physical capacity in relation to perceived workload among ageing employees. *Ergonomics* **2004**, *47*, 1087–1102. [[CrossRef](#)] [[PubMed](#)]
27. Garber, C.E.; Blissmer, B.; Deschenes, M.R.; Franklin, B.A.; Lamonte, M.J.; Lee, I.M.; Nieman, D.C.; Swain, D.P. American College of Sports Medicine position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: Guidance for prescribing exercise. *Med. Sci. Sports Exerc.* **2011**, *43*, 1334–1359. [[CrossRef](#)] [[PubMed](#)]
28. Fransson, E.I.; Heikkilä, K.; Nyberg, S.T.; Zins, M.; Westerlund, H.; Westerholm, P.; Väänänen, A.; Virtanen, M.; Vahtera, J.; Theorell, T.; *et al.* Job Strain as a Risk Factor for Leisure-Time Physical Inactivity: An Individual-Participant Meta-Analysis of Up to 170,000 Men and Women: The IPD-Work Consortium. *Am. J. Epidemiol.* **2012**, *176*, 1078–1089. [[CrossRef](#)] [[PubMed](#)]
29. Karvonen, J.; Vuorimaa, T. Heart rate and exercise intensity during sports activities. Practical application. *Sports Med.* **1988**, *5*, 303–311. [[CrossRef](#)] [[PubMed](#)]
30. Tanaka, H.; Monahan, K.D.; Seals, D.R. Age-predicted maximal heart rate revisited. *J. Am. Coll. Cardiol.* **2001**, *37*, 153–156. [[CrossRef](#)]
31. Noble, B.J.; Borg, G.A.V.; Jacobs, I.; Ceci, R.; Kaiser, P. A category-ratio perceived exertion scale: Relationship to blood and muscle lactates and heart rate. *Med. Sci. Sports Exerc.* **1983**, *15*, 523–528. [[CrossRef](#)] [[PubMed](#)]
32. Ahlstrom, L.; Grimby-Ekman, A.; Hagberg, M.; Dellve, L. The work ability index and single-item question: Associations with sick leave, symptoms, and health—A prospective study of women on long-term sick leave. *Scand. J. Work Environ. Health* **2010**, *36*, 404–412. [[CrossRef](#)] [[PubMed](#)]
33. Ware, J.E., Jr. SF-36 health survey update. *Spine* **2000**, *25*, 3130–3139. [[CrossRef](#)] [[PubMed](#)]
34. Steingrimsdóttir, Ó.A.; Vøllestad, N.K.; Røe, C.; Knardahl, S. Variation in reporting of pain and other subjective health complaints in a working population and limitations of single sample measurements. *Pain* **2004**, *110*, 130–139. [[CrossRef](#)] [[PubMed](#)]
35. Saltin, B.; Grimby, G. Physiological analysis of middle-aged and old former athletes. Comparison with still active athletes of the same ages. *Circulation* **1968**, *38*, 1104–1115. [[CrossRef](#)] [[PubMed](#)]
36. Åstrand, P.O.; Rodahl, K.; Dahl, H.A.; Strømme, B.S. Evaluation of physical performance on the basis of tests. In *Textbook of Work Physiology*, 4th ed.; Human Kinetics Publishers, Inc.: Champaign, IL, USA, 2003; pp. 283–284.
37. Åstrand, P.O.; Ryhming, I. A nomogram for calculation of aerobic capacity (physical fitness) from pulse rate during sub-maximal work. *J. Appl. Physiol.* **1954**, *7*, 218–221. [[PubMed](#)]
38. Essendrop, M.; Schibye, B.; Hansen, K. Reliability of isometric muscle strength tests for the trunk, hands and shoulders. *Int. J. Ind. Ergon.* **2001**, *28*, 379–387. [[CrossRef](#)]
39. Brage, S.; Brage, N.; Ekelund, U.; Luan, J.; Franks, P.W.; Froberg, K.; Wareham, N.J. Effect of combined movement and heart rate monitor placement on physical activity estimates during treadmill locomotion and free-living. *Eur. J. Appl. Physiol.* **2006**, *96*, 517–524. [[CrossRef](#)] [[PubMed](#)]
40. The Nord Trøndelag Health Study. Available online: <https://www.ntnu.edu/hunt/databank> (accessed on 10 January 2016).
41. Boschman, J.S.; van der Molen, H.F.; Sluiter, J.K.; Frings-Dresen, M.H.W. Occupational demands and health effects for bricklayers and construction supervisors: A systematic review. *Am. J. Ind. Med.* **2011**, *54*, 55–77. [[CrossRef](#)] [[PubMed](#)]
42. Karlqvist, L.; Leijon, O.; Härenstam, A. Physical demands in working life and individual physical capacity. *Eur. J. Appl. Physiol.* **2003**, *89*, 536–547. [[CrossRef](#)] [[PubMed](#)]
43. Drain, J.; Billing, D.; Neesham-Smith, D.; Aisbett, B. Predicting physiological capacity of human load carriage—A review. *Appl. Ergon.* **2016**, *52*, 85–94. [[CrossRef](#)] [[PubMed](#)]
44. Holtermann, A.; Hansen, J.V.; Burr, H.; Sogaard, K.; Sjogaard, G. The health paradox of occupational and leisure-time physical activity. *Br. J. Sports Med.* **2012**, *46*, 291–295. [[CrossRef](#)] [[PubMed](#)]
45. Hubscher, M.; Ferreira, M.L.; Junqueira, D.R.; Refshauge, K.M.; Maher, C.G.; Hopper, J.L.; Ferreira, P.H. Heavy domestic, but not recreational, physical activity is associated with low back pain: Australian Twin low BACK pain (AUTBACK) study. *Eur. Spine J.* **2014**, *23*, 2083–2089. [[CrossRef](#)] [[PubMed](#)]
46. Pollock, M.L. The quantification of endurance training programs. *Exerc. Sport Sci. Rev.* **1973**, *1*, 155–188. [[CrossRef](#)] [[PubMed](#)]

47. Ilmarinen, J. Work and cardiovascular health: Viewpoint of occupational physiology. *Ann. Med.* **1989**, *21*, 209–214. [[CrossRef](#)] [[PubMed](#)]
48. Krause, N. Physical activity and cardiovascular mortality—Disentangling the roles of work, fitness, and leisure. *Scand. J. Work Environ. Health* **2010**, *36*, 349–355. [[CrossRef](#)] [[PubMed](#)]



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Original article

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Associations of objectively measured sitting and standing with low-back pain intensity: a 6-month follow-up of construction and healthcare workers

by [Lunde L-K](#), [Koch M](#), [Knardahl S](#), [Veiersted KB](#)

This study investigated associations between sitting and standing, respectively, and low-back pain with objectively measured exposures for several days and a prospective design. Sitting at work and during full-day is negatively associated with cross-sectional- and prospective low-back pain intensity. This association was seen for the healthcare sector, but not for the construction sector.

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Associations of objectively measured sitting and standing with low-back pain intensity: a 6-month follow-up of construction and healthcare workers

by Lars-Kristian Lunde, MSc,¹ Markus Koch, PhD,¹ Stein Knardahl, PhD,¹ Kaj Bo Veiersted, PhD¹

Lunde L-K, Koch M, Knardahl S, Veiersted KB. Associations of objectively measured sitting and standing with low-back pain intensity: a 6-month follow-up of construction and healthcare workers. *Scand J Work Environ Health*. 2017;43(3):269–278. doi:10.5271/sjweh.3628

Objectives This study aimed to determine the associations between objectively measured sitting and standing duration and intensity of low-back pain (LBP) among Norwegian construction and healthcare workers.

Methods One-hundred and twenty-four workers wore two accelerometers for 3–4 consecutive days, during work and leisure. Minutes of sitting and standing was calculated from accelerometer data. We obtained self-reported LBP intensity (0–3) at the time of objective measurement and after six months. We examined associations with linear mixed models and presented results per 100 minutes.

Results For healthcare workers, the duration of sitting during work [$\beta = -0.33$, 95% confidence interval (95% CI) -0.55 – -0.10] and during full-day (work + leisure) ($\beta = -0.21$, 95% CI -0.38 – -0.04) was associated with baseline LBP intensity. Furthermore, minutes of sitting at work ($\beta = -0.35$, 95% CI -0.57 – -0.13) and during the full day ($\beta = -0.20$, 95% CI -0.37 – -0.04) were significantly associated with LBP intensity at six months. Associations were attenuated when adjusting for work-related mechanical and psychosocial covariates and objectively measured exposure during leisure time. No significant associations between sitting and LBP intensity were found for construction workers. Standing at work was not consistently associated with LBP intensity at baseline or after six months for any work sector.

Conclusions This study suggests that a long duration of sitting at work is associated with lower levels of LBP intensity among healthcare workers. Standing duration had no consistent associations with LBP intensity.

Key terms accelerometer; construction work; healthcare work; musculoskeletal disorder; objective measure; physical work; physical work exposure; prospective design.

As one of the largest contributors to years lived with disability (1), low-back pain (LBP) is a major global public health problem (2). Construction and healthcare work are two sectors with a high prevalence of musculoskeletal disorders (3–6) and thus it is important to identify work-related risk factors. Previous research found that long durations of sitting and standing during work are positively linked to LBP (7, 8). However, reviews have concluded that there is no evidence for an association due to low quality studies and inconsistent results (9–12). A major reason for the discrepant findings may be bias due to self-reported exposure duration (13–15). Self-reports may have reduced validity because they depend on recall, individual interpretation

of questions, and can be biased by pain levels and disability (16–18). Therefore, it has been recommended that activity exposures be measured using objective methods when investigating their associations to LBP (13). Moreover, objective measurements over several days are more reliable than single days of measurement (19). Thus, exposure measurements should be obtained on more than one day to better capture variations in exposure among work days. One of very few studies of objectively measured sitting for 1–4 working days found that longer sitting duration was associated with increased risk for high intensity LBP among blue-collar workers in cross-sectional data (20). Another cross-sectional study of objectively measured standing reported

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ambiguous associations between standing and LBP (21). Both studies emphasize that future studies should determine the association between sitting and standing duration at work and LBP by objectively measured exposures over several consecutive days using prospective designs. These criteria have also been requested by reviews on this topic (9, 10).

We currently do not understand the mechanisms surrounding why and how sitting and standing would cause pain. Intervertebral- and vertebral endplate compression and increases in inter-disc pressure (IDP) during sitting (22, 23) and standing activities (24) have been proposed as mechanisms. However, recent results consider increased IDP an unlikely cause of damage in non-degenerated discs (25). Prolonged flexion during sitting has been proposed to redistribute the nucleus within the annulus (26) or increase lumbar spine stiffness (27). Prolonged standing may also lead to pain from muscle fatigue (28). Further hypotheses imply reduced oxygenation in lumbar extensor musculature (29) and increased weight as result of inactivity in sitting (30, 31) as possible mechanisms.

The origin of LBP is multifactorial (32) and individual factors such as age and gender (33), smoking (30), and body mass index (BMI) (30, 34) are associated with LBP. Mechanical work factors such as awkward lifting, high muscular load, and stooped positions were found to be associated with LBP in a recent systematic review (35); accumulation of such exposures through high seniority may further increase the risk of LBP (36, 37). Psychosocial factors including decision control, type of leadership, and the social climate at work sites are also associated with LBP (33, 38, 39). Accordingly, both individual and work-related factors must be controlled for when studying the association between sitting and standing at work and LBP. Additionally, non-work activities may produce pain conditions (9, 40) and therefore exposures during leisure time should also be accounted for.

We aimed to determine whether objectively measured time spent sitting and standing was associated with intensity of LBP among construction and healthcare workers at baseline and after six months.

Methods

Study population and design

This study was designed as a part of a larger prospective cohort study among construction and healthcare workers (41). Four construction companies (N=580 workers) and two local healthcare distributors (N=585 workers) in the Oslo area agreed to participate. The purpose, format and

methods of the study were presented to the workers at informational meetings located at their work site. Of the 1165 workers, 594 participants (construction workers: N=293; healthcare workers: N=301) agreed to complete a questionnaire at baseline and six months later. Of these, 178 construction workers and 193 healthcare workers additionally agreed to participate in technical measurements at baseline, which included clinical examination and measurements using accelerometers for 3–4 days while maintaining a short diary. Exclusion criteria were: inadequate skills in reading and writing Norwegian, known allergic reaction to plaster, tape, or bandages, or being pregnant. Subjects diagnosed with severe or insufficiently treated cardiovascular disease or musculoskeletal disorders were not subjected to tests they could not perform. We performed technical measurements on 62 construction workers and 63 healthcare workers selected to best fit logistics (availability, work schedules and profession). We have previously provided a full description of job titles (19).

All subjects signed a written informed consent form. This study was conducted in accordance with the Helsinki Declaration and approved by the Regional Committee for Medical and Health Research Ethics in Norway (2014/138/REK south east D).

Instrumentation for technical measurements

We used ActiGraph GT3X+ sensors (ActiGraph LLC, Pensacola, FL, USA) to measure the acceleration, position and angle of body segments with a sampling frequency of 30 Hz. The accelerometers were placed at the participant's right thigh (medially between the iliac crest and the upper crest of the patella) and right side of the hip (just below iliac crest) (42, 43). The accelerometers are lightweight (19 grams) and were fixed on the skin using double-sided tape (Fixomull, BSN Medical, Hamburg, Germany) and covered with transparent film (Tegaderm, 3 M, St. Paul, MN, USA).

Sitting and standing activities

From raw data measured by accelerometers for 3–4 days, minutes spent in sitting and standing positions were determined by a custom-made MATLAB-based program, Acti4 (National Research Center for the Working Environment, Denmark and Federal Institute for Occupational Safety and Health, Germany). Based on acceleration and the calculated angles of the thigh and hip, Acti4 algorithms discriminate between different types of activities and estimate the time spent in activity periods. Studies have found the Actigraph GT3X+ sensors setup at hip and thigh to be valid for detecting different physical activities (42, 43). In standardized trials, both the sensitivity and specificity

for detecting sitting and standing are higher than 99% (43). From the participants' diary, we categorized each day into periods of work, periods of leisure, and periods of sleep. We excluded periods of sleep, periods during which the accelerometers were not worn, and when data did not fulfill the measurement criteria (<4 hours or 75% of the mean length of all respective periods) (20).

Low-back pain intensity

Subjects were asked to rate their LBP intensity for the preceding four weeks. They rated LBP intensity on a 4-point scale (not troubled=0, a little troubled=1, rather intensely troubled=2 and very intensely troubled=3) (44). A drawing adapted from the "Nordic questionnaire on musculoskeletal symptoms" was used to facilitate localization of body regions (45).

Gcovariates

Individual factors. Information on all individual factors were collected by self-report. Age, gender, seniority in profession, BMI (kg/m²), and smoking status were established by general questions. We classified participants as smokers if they smoked daily or occasionally.

Self-reported mechanical exposures. Participants reported time spent sitting and standing during work with five response categories (never=0, sometimes=1, approximately 25% of the time=2, approximately 50% of the time=3, approximately 75% of the time=4 or almost all the time=5). To assess heavy lifting, they were asked if they normally lifted something weighing more than 20 kg during work, with three response alternatives (no=0, 1–4 times=1, 5–19 times=2, and ≥20 times per day=3) (46).

Psychosocial factors. We assessed decision control, fair and empowering leadership and social climate in the organization using items adapted from the General Nordic Questionnaire for Psychological and Social Factors at work (QPS_{Nordic}) (47, 48). A full description of these questions is available online as supplementary material (www.sjweh.fi/index.php?page=data-repository).

Objectively measured forward bending. Forward bending during work was measured objectively by two accelerometers placed at the spinous processes at the level of T1–T2 and the halfway mark on the vertical line between the anterior superior iliac spine and the patella (43). We used minutes with ≥60° deviation from the upraised position as a measure for forward bending. Flexion ≥60° has previously been categorized as extreme flexion to very extreme flexion (49).

Statistical analysis

We tested associations between exposure and LBP intensity with linear mixed models fitted by restricted maximum likelihood with a random intercept added for subject. We did not adjust for baseline pain response, but we retained the baseline value as part of the outcome vector with no assumptions on its mean response at baseline, as recommended for observational data (50). Sitting or standing duration (in minutes) was entered as the main exposure variable and LBP intensity was entered as a dependent outcome variable. Analyses were carried out in two designs: (i) association between absolute work exposure duration (minutes) and LBP intensity; and (ii) association between absolute full-day (work + leisure) exposure duration (minutes) and LBP intensity. Analyses were performed stratified by work sector (construction and healthcare). Design 1 consisted of 5 models: model 1 – crude association between exposure and LBP; model 2 – as model 1 + adjustments for age, gender, smoking and BMI; model 3 – as model 2 + adjustments for objectively measured forward bending during work and heavy lifting; model 4 – as model 3 + adjustments for social climate, decision control, fair leadership, and empowering leadership; and model 5 – as model 4 + adjustment for objectively measured sitting or standing (minutes) during leisure. For Design 2, model 5 was not implemented. The mixed model may be expressed mathematically as where y_{it} is the LBP intensity of worker i at time t and X_{it} is a vector of regressors (sitting at work, age, ...) linking the observations to the fixed effects β . Furthermore, ϵ_{it} represents independent and identically distributed normal random effects, with a mean 0 and variance, while η_{it} are independent and identically distributed normal random residuals with a mean 0 and variance. All variables were selected prior to analyses and examined for collinearity. Seniority was excluded due to its high correlation with age. We performed sensitivity analyses to test the robustness of the main analyses: having or not having LBP (0 versus 1, 2, 3) and having low or moderate/high levels of LBP (0, 1 versus 2, 3) by multilevel mixed-effects logistic regression. Additionally, we performed non-responder analysis and performed analyses with the duration of sitting/standing as percentage of the individual's work- and full-day periods, instead of absolute values (minutes). As an indicator of change in job characteristics, we tested possible changes in self-reported sitting or standing duration and social climate between baseline and six months with Wilcoxon rank tests.

Associations were calculated by β coefficients (per 100 minutes) with 95% confidence intervals (95% CI). Statistical analyses were conducted in STATA, version 13.0 (StataCorp, College Station, TX, USA).

Results

There were no differences in self-reported sitting or standing time or social climate in the organization between baseline and six months follow-up, so we assumed these exposures to be unchanged.

Distribution of low-back pain intensity

At baseline, 41% of healthcare workers reported being untroubled by LBP, while 23% and 33% reported being a little or rather intensely troubled, respectively. Three percent reported being very intensely troubled. For construction, the corresponding percentages were 48, 25, 27 and 0%. At six months' follow-up, 45% of healthcare workers were not troubled by LBP; 14% reported being a little troubled, while 37% and 4% reported to be rather intensely troubled or very intensely troubled, respectively. The corresponding percentages for construction at six months were 51, 26, 19 and 4%.

Total measurement time and missing data

We measured a total of 944 hours of work and 971 hours of leisure with an average of 7.6 hours of work and 8.8 hours of leisure per day. From the 125 individuals initially measured, 1 subject did not have valid sit or stand exposure data for work and was therefore excluded. The characteristics of the subjects are provided in table 1: 15 did not have valid sit or stand exposure data for leisure, 3 did not answer the LBP intensity question at baseline, 1 did not answer the LBP intensity question at six months, and 27 did not respond to the six months questionnaire. The tested variables of age, gender, objectively measured sitting at work, objectively measured standing at work, and LBP intensity did not differ significantly between responders (N=97) and non-responders (N=27) (data not shown). The 124 participants reported lower perceived sitting time and higher perceived standing time at baseline compared to the 469 who completed questionnaire only (data not shown).

Sitting and low-back pain intensity at baseline

Healthcare sector. Duration of sitting at work was associated with baseline LBP intensity for the crude model ($\beta=-0.33$, 95% CI -0.55– -0.10) and models adjusted for individual and work related factors (models 2–4; table 2). For full-day data, significant associations with LBP intensity were found for the crude model ($\beta=-0.21$, 95% CI -0.38– -0.04) and the model adjusted for individual factors (model 2; table 4).

Table 1. Descriptive characteristics of study participants (N=124). [SD=standard deviation; LBP=low-back pain.]

Variables	Construction (N=61)			Healthcare (N=63)		
	%	Mean	SD	%	Mean	SD
Age (years)		39.9	13.6		44.5	9.6
Gender (male)	98.4			22.2		
Body mass index (kg/m ²)		25.7	3.3		25.1	3.8
Smokers	31.1			27.0		
Normal work hours per week		37.8	4.0		35.7	4.2
Work hours measured per day		8.2	1.8		7.1	0.8
Sitting at work (minutes)		156.8	114.2		171.6	93.8
Sitting in leisure (minutes)		282.0	78.4		274.0	94.3
Standing at work (minutes)		156.8	69.4		123.1	58.9
Standing in leisure (minutes)		88.3	45.9		100.8	46.1
Forward bending at work (minutes)		27.4	24.9		15.8	10.3
Heavy lifting at work (0–3) ^a		1.5	1.2		0.4	0.6
Social climate at work (1–5) ^b		3.2	0.5		3.2	0.6
Decision control at work (1–5) ^c		3.2	0.7		2.9	0.8
Fair leadership (1–5) ^c		3.3	0.5		3.3	0.7
Empowering leadership (1–5) ^c		3.1	0.9		3.9	1.0
LBP intensity at baseline (0–3)		0.5	0.5		0.6	0.5
LBP intensity at 6 months (0–3) ^d		0.7	0.9		1.0	1.0

^a Response alternatives: (0) No, (1) Yes, 1–4 times, (2) yes, 5–19 times and (3) yes, ≥ 20 times a day.

^b Response alternatives: (1) very little or not at all, (2) rather little, (3) somewhat, (4) rather much and (5) very much;

^c Response alternatives: (1) very seldom or never, (2) rather seldom, (3) sometimes, (4) rather often, and (5) very often or always

^d 71% of workers reporting pain at baseline had pain at follow up.

Construction sector. Sitting duration had no significant associations with LBP intensity at baseline, either for work- or full-day exposure (table 2 and 4).

Sitting at baseline and low-back pain intensity after six months

Healthcare sector. Sitting duration (minutes) at work was associated with 6-month LBP intensity in the crude ($\beta=-0.35$, 95% CI -0.57– -0.13) and all adjusted models (table 2). For full-day data, significant associations were also shown for the crude model ($\beta=-0.20$, 95% CI -0.37– -0.04) and the model adjusted for individual factors (model 2; table 4).

Construction sector. Sitting duration (minutes) had no significant associations with LBP intensity at six months for construction workers, either for exposure at work- or full-day (table 2 and 4).

Standing and low-back pain intensity at baseline

Healthcare sector. There was a significant association between standing duration at work and baseline LBP intensity in the fully adjusted model ($\beta=0.54$, 95% CI 0.01– 1.07; table 3). No associations were found in full-day data (table 5).

Table 2. Linear mixed model with sitting exposure at work per 100 minutes and low-back pain intensity (Design 1). **Bold denotes P<0.05.**

	Model 1 ^a			Model 2 ^b			Model 3 ^c			Model 4 ^d			Model 5 ^e		
	Observations ^f =107/110			Observations ^f =107/106			Observations ^f =101/104			Observations ^f =101/100			Observations ^f =88/95		
	Coef.	95% CI	P-value	Coef.	95% CI	P-value	Coef.	95% CI	P-value	Coef.	95% CI	P-value	Coef.	95% CI	P-value
Construction															
T1 ^g	-0.01	-0.19–0.17	0.914	-0.02	-0.22–0.19	0.863	-0.009	-0.28–0.29	0.950	-0.005	-0.34–0.32	0.977	-0.00001	-0.35–0.35	1.00
T2 ^h	-0.02	-0.20–0.16	0.836	-0.03	-0.24–0.18	0.795	-0.0007	-0.29–0.29	0.996	-0.014	-0.35–0.32	0.936	-0.003	-0.36–0.35	0.986
Healthcare															
T1 ^g	-0.33	-0.55–0.10	0.004	-0.31	-0.06–0.08	0.009	-0.32	-0.58–0.05	0.018	-0.28	-0.56–0.003	0.047	-0.31	-0.63–0.01	0.058
T2 ^h	-0.35	-0.57–0.13	0.002	-0.34	-0.58–0.10	0.005	-0.35	-0.61–0.08	0.012	-0.31	-0.60–0.03	0.029	-0.34	-0.66–0.02	0.040

^a Sitting at work (per 100 minutes). Dependent variable: Pain (T1, T2).

^b As model 1 + age, gender, smoking, body mass index.

^c As model 2 + heavy lifting, forward bending at work.

^d As model 3 + social climate, decision control, fair leadership, empowering leadership.

^e As model 4 + sitting (minutes) during leisure time.

^f Total observations included in linear mixed models for construction/healthcare.

^g T1: baseline.

^h T2: 6 month.

Table 3. Linear mixed model with standing exposure at work per 100 minutes and low-back pain intensity (Design 1). **Bold denotes P<0.05.**

	Model 1 ^a			Model 2 ^b			Model 3 ^c			Model 4 ^d			Model 5 ^e		
	Observations ^f =107/110			Observations ^f =107/106			Observations ^f =101/104			Observations ^f =101/100			Observations ^f =88/95		
	Coef.	95% CI	P-value	Coef.	95% CI	P-value	Coef.	95% CI	P-value	Coef.	95% CI	P-value	Coef.	95% CI	P-value
Construction															
T1 ^g	0.21	-0.08–0.50	0.152	0.22	-0.09–0.53	0.168	0.29	-0.11–0.70	0.156	0.29	-0.13–0.72	0.179	0.02	-0.51–0.55	0.940
T2 ^h	0.22	-0.07–0.52	0.135	0.23	-0.09–0.56	0.153	0.31	-0.11–0.72	0.144	0.31	-0.13–0.75	0.167	0.04	-0.50–0.58	0.873
Health care															
T1 ^g	0.29	-0.08–0.66	0.124	0.24	-0.14–0.63	0.220	0.29	-0.12–0.70	0.167	0.39	-0.07–0.85	0.095	0.54	0.01–1.07	0.045
T2 ^h	0.34	-0.05–0.72	0.084	0.29	-0.58–0.68	0.159	0.35	-0.07–0.77	0.106	0.42	-0.05–0.89	0.079	0.58	0.04–1.11	0.035

^a Standing at work (per 100 minutes). Dependent variable: Pain (T1, T2).

^b As model 1 + age, gender, smoking, body mass index.

^c As model 2 + heavy lifting, forward bending at work.

^d As model 3 + social climate, decision control, fair leadership, empowering leadership.

^e As model 4 + sitting (minutes) during leisure time.

^f Total observations included in linear mixed models for construction/healthcare.

^g T1: baseline.

^h T2: 6 month.

Construction sector. No significant associations were found (table 3 and 5).

Standing at baseline and low-back pain after six months

Healthcare sector. A significant association between standing at work and LBP intensity at baseline was found in the fully adjusted model only ($\beta=0.58$, 95% CI 0.04–1.11; table 3). Full-day data showed no significant associations (table 5).

Construction sector. No significant associations were found (table 3 and 5).

Additional analysis

The sensitivity analyses on dichotomized LBP variables supported the main analysis (data not shown). Furthermore, the analyses on the percentage of work or full-day

spent sitting/standing showed similar, but somewhat weaker, associations as in the analyses with duration in minutes (data not shown).

Discussion

For healthcare workers, this study showed a negative association between the duration of sitting at work and LBP intensity at baseline and at six months' follow-up. The duration of standing at work was positively associated with LBP intensity, but only in the fully adjusted models. For construction workers, no associations were found between sitting and standing, and LBP intensity.

Very few studies have investigated the association between objectively measured sitting and/or standing exposure and LBP. However, two cross-sectional studies based on similar objective measures as the present

Table 4. Linear mixed model on full-day sitting exposure per 100 minutes and low-back pain intensity (Design 2). **Bold denotes P<0.05.**

	Model 1 ^a			Model 2 ^a			Model 3 ^c			Model 4 ^d		
	Observations ^e =90/101			Observations ^e =90/99			Observations ^e =88/99			Observations ^e =88/95		
	Coef.	95% CI	P-value	Coef.	95% CI	P-value	Coef.	95% CI	P-value	Coef.	95% CI	P-value
Construction												
T1 ^f	-0.05	-0.20–0.11	0.555	-0.06	-0.22–0.11	0.511	-0.07	-0.29–0.16	0.515	-0.07	-0.31–0.18	0.596
T2 ^g	-0.05	-0.20–0.10	0.477	-0.07	-0.23–0.10	0.441	-0.08	-0.30–0.14	0.460	-0.08	-0.31–0.17	0.541
Health care												
T1 ^f	-0.21	-0.38– -0.04	0.016	-0.21	-0.39– -0.02	0.027	-0.18	-0.40–0.04	0.118	-0.16	-0.40–0.08	0.183
T2 ^g	-0.20	-0.37– -0.04	0.017	-0.20	-0.39– -0.02	0.028	-0.17	-0.40–0.05	0.125	-0.17	-0.40–0.07	0.168

^aSitting full-day (per 100 minutes). Dependent variable: Pain (T1, T2).

^bAs model 1 + age, gender, smoking, body mass index.

^cAs model 2 + heavy lifting, forward bending at work.

^dAs model 3 + social climate, decision control, fair leadership, empowering leadership.

^eTotal observations included in linear mixed models for construction/healthcare.

^fT1: baseline.

^gT2: 6 month.

Table 5. Linear mixed model with full-day standing exposure per 100 minutes and low-back pain intensity (Design 2).

	Model 1 ^a			Model 2 ^b			Model 3 ^c			Model 4 ^d		
	Observations ^e =90/101			Observations ^e =90/99			Observations ^e =88/99			Observations ^e =88/95		
	Coef.	95% CI	P-value	Coef.	95% CI	P-value	Coef.	95% CI	P-value	Coef.	95% CI	P-value
Construction												
T1 ^f	-0.005	-0.29–0.28	0.975	0.0005	-0.31–0.32	0.998	-0.033	-0.40–0.33	0.857	-0.06	-0.46– 0.34	0.759
T2 ^g	-0.0004	-0.29–0.29	0.998	0.004	-0.32–0.33	0.983	-0.030	-0.40–0.34	0.876	-0.06	-0.46– 0.35	0.776
Health care												
T1 ^f	0.11	-0.16–0.39	0.419	0.07	-0.21–0.36	0.626	0.10	-0.20–0.39	0.521	0.11	-0.21– 0.44	0.495
T2 ^g	0.14	-0.15–0.42	0.350	0.09	-0.20–0.38	0.548	0.12	-0.18–0.42	0.422	0.12	-0.20– 0.45	0.466

^aStanding at work (per 100 minutes). Dependent variable: Pain (T1, T2).

^bAs model 1 + age, gender, smoking, body mass index.

^cAs model 2 + heavy lifting, forward bending at work.

^dAs model 3 + social climate, decision control, fair leadership, empowering leadership.

^eTotal observations included in linear mixed models for construction/healthcare.

^fT1: baseline.

^gT2: 6 month.

study have recently been published. Gupta et al's cross-sectional study of 201 blue-collar workers reported that an increase in total hours of objectively measured sitting duration at work and throughout the day (work + leisure) was significantly associated with a higher LBP intensity (20). In contrast to those findings, the present study found an association between long sitting duration and lower LBP intensity. Our results agreed with the reviews of Hartvigsen (11) and Roffey (10).

There are several possible explanations for the mixed findings regarding sitting at work and LBP intensity. Sitting may be associated with jobs with higher levels of control and autonomy and more engaging tasks, reducing reported LBP intensity (38). Longer durations of sitting may also by exclusion be associated with lower exposures to other physical factors such as manual-materials handling (51). Models in the present study including self-reported physical and psychosocial exposures showed attenuated sitting associations (tables 2–5).

Munch Nielsen et al's cross-sectional study of 187 Danish workers based on objective measures of

standing duration at work reported a non-significant association between the time standing and level of LBP intensity (21). An association between prolonged standing at work and LBP intensity was only found in fully adjusted analysis among healthcare workers in our study. Thus, the present study does not permit the conclusion that the duration of standing during work or during the full-day is a risk factor for LBP. As discussed above for jobs involving sitting, there may be characteristics connected to jobs involving standing that affects pain reporting, creating the opposite scenario with increased reporting of LBP. It is also possible that subjects with LBP avoid activities causing pain or perform tasks differently (52, 53), obscuring cross-sectional results.

Our data indicated that the association between sitting, standing, and LBP intensity varied between work sectors and that the often used blue-collar classification may obscure possible sub-group associations. Moreover, the difference in gender composition between the two sectors involved in our study (healthcare=78% female,

construction=98% male) is characteristic for these sectors and suggests that disentangling work sector and gender in such cases is difficult.

Strengths and limitations

A major strength of the present study was the use of objectively measured sitting and standing for several consecutive days, both during work and leisure time, in combination with the prospective outcome. To our knowledge, this is the first study providing this kind of information. This gives a precise measure of exposure, and we avoid depending on self-reported exposures that may lead to biased estimations on association between exposure and LBP intensity (12).

By restricting the study to healthcare and construction workers, we attenuated confounding effects of large variations in work content and socioeconomic gradients. Furthermore, the analyses were adjusted for several potential confounders, including mechanical and psychosocial work-related factors. The confounders of forward bending at work and the respective exposure during leisure were also measured objectively.

The use of mixed models provides flexible variance structures, robustness against dropouts and full utilization of all available observations. We retained the baseline pain response as part of the outcome variable, and did not use it as an adjustment variable. This enabled us to study the change in pain response in a manner that did not make any assumptions that the baseline pain response is associated with other covariates (eg, sitting minutes) being studied. Adjusting for the baseline pain response requires that there is no association between baseline outcome and the covariates being studied (54).

An important issue is that the coefficients found for significant associations are small and therefore differences in exposure durations needs to be large for the changes in LBP to be of any clinical relevance. Depending on whether the pain is acute or chronic and the type of scoring, previous studies on various pain intensity scales suggests levels of 20–30% improvement in a variable as a minimally clinically important change (55, 56). In our case, a clinically relevant change in LBP corresponds to a change in sitting duration from the lowest measured values to the highest, a total change in sitting characteristics during work.

Our use of technical measurements does limit the size of the study population, which was a small fraction (11%) of those initially invited for participation. The 124 participants included in this study reported lower perceived sitting time and higher perceived standing time at baseline compared to the 469 who only completed questionnaires. This may be due to an overrepresentation of manual workers in our study (most represented professions: carpenter, concrete worker, nurse, and

personal care workers). Furthermore, data visualization indicates that results may be somewhat driven by few observations with high exposure values. Thus, larger groups and a longer follow-up with more measurements may provide a more accurate representation. Multiple follow-ups would also capture possible fluctuations in time observed with pain variables (57), thereby enhancing the reliability of outcome measurements.

We did not consider any possible seasonal changes, and although exposure was measured for several days it was only measured on one occasion. We did not collect specific information on long-term LBP history at baseline. However, very few participants reported serious spine related injuries in the previous 12 months. We cannot exclude the presence of a healthy-worker effect, due to unhealthy workers being on sick leave or outside the work force, or possible differences between individuals with a long or short history of LBP.

Concluding remarks

For healthcare workers, this study showed a negative association between the duration of sitting at work and LBP intensity at baseline and at 6-month follow-up. The duration of standing at work was positively associated with LBP intensity only in the fully adjusted models. For construction workers, we found no associations between sitting and standing, and LBP intensity.

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References

1. Murray CJ, Vos T, Lozano R, Naghavi M, Flaxman AD, Michaud C, et al. Disability-adjusted life years (DALYs) for 291 diseases and injuries in 21 regions, 1990-2010: a systematic analysis for the Global Burden of Disease Study 2010. *Lancet*. 2012;380(9859):2197–223. [https://doi.org/10.1016/S0140-6736\(12\)61689-4](https://doi.org/10.1016/S0140-6736(12)61689-4).
2. Hoy D, Bain C, Williams G, March L, Brooks P, Blyth F, et al. A systematic review of the global prevalence of low back

- pain. *Arthritis Rheum.* 2012;64(6):2028–37. <https://doi.org/10.1002/art.34347>.
3. Long MH, Bogossian FE, Johnston V. The prevalence of work-related neck, shoulder, and upper back musculoskeletal disorders among midwives, nurses, and physicians: a systematic review. *Workplace Health Saf.* 2013;61(5):223–9. <https://doi.org/10.1177/216507991306100506>.
 4. Videman T, Ojarjarvi A, Riihimaki H, Troup JD. Low back pain among nurses: a follow-up beginning at entry to the nursing school. *Spine.* 2005;30(20):2334–41. <https://doi.org/10.1097/01.brs.0000182107.14355.ca>.
 5. Boschman JS, van der Molen HF, Sluiter JK, Frings-Dresen MHW. Musculoskeletal disorders among construction workers: a one-year follow-up study. *BMC Musculoskelet Disord.* 2012;13:196. <https://doi.org/10.1186/1471-2474-13-196>.
 6. Stocks SJ, Turner S, McNamee R, Carder M, Hussey L, Agius RM. Occupation and work-related ill-health in UK construction workers. *Occup Med (Lond).* 2011;61(6):407–15. <https://doi.org/10.1093/occmed/kqr075>.
 7. Corlett EN. Background to sitting at work: research-based requirements for the design of work seats. *Ergonomics.* 2006;49(14):1538–46. <https://doi.org/10.1080/00140130600766261>.
 8. Sterud T, Tynes T. Work-related psychosocial and mechanical risk factors for low back pain: a 3-year follow-up study of the general working population in Norway. *Occup Environ Med.* 2013;70:296–302. <https://doi.org/10.1136/oemed-2012-101116>.
 9. Roffey DM, Wai EK, Bishop P, Kwon BK, Dagenais S. Causal assessment of occupational standing or walking and low back pain: results of a systematic review. *Spine J.* 2010;10(3):262–72. <https://doi.org/10.1016/j.spinee.2009.12.023>.
 10. Roffey DM, Wai EK, Bishop P, Kwon BK, Dagenais S. Causal assessment of occupational sitting and low back pain: results of a systematic review. *Spine J.* 2010;10(3):252–61. <https://doi.org/10.1016/j.spinee.2009.12.005>.
 11. Hartvigsen J, Leboeuf-Yde C, Lings S, Corder EH. Is sitting-while-at-work associated with low back pain? A systematic, critical literature review. *Scand J Public Health.* 2000;28(3):230–9. <https://doi.org/10.1177/14034948000280030201>.
 12. Kwon BK, Roffey DM, Bishop PB, Dagenais S, Wai EK. Systematic review: occupational physical activity and low back pain. *Occup Med (Lond).* 2011;61(8):541–8. <https://doi.org/10.1093/occmed/kqr092>.
 13. Lagersted-Olsen J, Korshøj M, Skotte J, Carneiro IG, Søgaard K, Holtermann A. Comparison of Objectively Measured and Self-reported Time Spent Sitting. *Int J Sports Med.* 2014;35(6):534–40. <https://doi.org/10.1055/s-0033-1358467>.
 14. Celis-Morales CA, Perez-Bravo F, Ibanez L, Salas C, Bailey ME, Gill JM. Objective vs. self-reported physical activity and sedentary time: effects of measurement method on relationships with risk biomarkers. *PLoS One.* 2012;7(5):e36345. <https://doi.org/10.1371/journal.pone.0036345>.
 15. Wick K, Faude O, Schwager S, Zahner L, Donath L. Deviation between self-reported and measured occupational physical activity levels in office employees: effects of age and body composition. *Int Arch Occup Environ Health.* 2016;89(4):575–82. <https://doi.org/10.1007/s00420-015-1095-1>.
 16. Dyrstad SM, Hansen BH, Holme IM, Anderssen SA. Comparison of self-reported versus accelerometer-measured physical activity. *Med Sci Sports Exerc.* 2014;46(1):99–106. <https://doi.org/10.1249/MSS.0b013e3182a0595f>.
 17. Kwak L, Proper KI, Hagströmer M, Sjöström M. The repeatability and validity of questionnaires assessing occupational physical activity - a systematic review. *Scand J Work Environ Health.* 2011;37(1):6–29. <https://doi.org/10.5271/sjweh.3085>.
 18. Hansson GÅ, Balogh I, Byström JU, Ohlsson K, Nordander C, Asterland P, et al. Questionnaire versus direct technical measurements in assessing postures and movements of the head, upper back, arms and hands. *Scand J Work Environ Health.* 2001;27(1):30–40. <https://doi.org/10.5271/sjweh.584>.
 19. Koch M, Lunde LK, Gjulem T, Knardahl S, Veierstedt KB. Validity of Questionnaire and Representativeness of Objective Methods for Measurements of Mechanical Exposures in Construction and Health Care Work. *PLoS One.* 2016;11(9):e0162881. <https://doi.org/10.1371/journal.pone.0162881>.
 20. Gupta N, Christiansen CS, Hallman DM, Korshøj M, Carneiro IG, Holtermann A. Is objectively measured sitting time associated with low back pain? A cross-sectional investigation in the NOMAD study. *PLoS One.* 2015;10(3):e0121159. <https://doi.org/10.1371/journal.pone.0121159>.
 21. Munch Nielsen C, Gupta N, Knudsen LE, Holtermann A. Association of objectively measured occupational walking and standing still with low back pain: a cross-sectional study. *Ergonomics.* 2016:1–20.
 22. Sato K, Kikuchi S, Yonezawa T. In vivo intradiscal pressure measurement in healthy individuals and in patients with ongoing back problems. *Spine (Phila Pa 1976).* 1999;24(23):2468–74. <https://doi.org/10.1097/00007632-199912010-00008>.
 23. Nachemson AL. Disc pressure measurements. *Spine (Phila Pa 1976).* 1981;6(1):93–7. <https://doi.org/10.1097/00007632-198101000-00020>.
 24. van Deursen LL, van Deursen DL, Snijders CJ, Wilke HJ. Relationship between everyday activities and spinal shrinkage. *Clin Biomech (Bristol, Avon).* 2005;20(5):547–50. <https://doi.org/10.1016/j.clinbiomech.2005.01.005>.
 25. Claus A, Hides J, Moseley GL, Hodges P. Sitting versus standing: does the intradiscal pressure cause disc degeneration or low back pain? *J Electromyogr Kinesiol.* 2008;18(4):550–8. <https://doi.org/10.1016/j.jelekin.2006.10.011>.
 26. McKenzie RA. Prophylaxis in recurrent low back pain. *N Z Med J.* 1979;89(627):22–3.
 27. Beach TA, Parkinson RJ, Stothart JP, Callaghan JP. Effects of prolonged sitting on the passive flexion stiffness of the in

- vivo lumbar spine. *Spine J.* 2005;5(2):145–54. <https://doi.org/10.1016/j.spinee.2004.07.036>.
28. Garcia MG, Laübli T, Martin BJ. Long-Term Muscle Fatigue After Standing Work. *Hum Factors.* 2015;57(7):1162–73. <https://doi.org/10.1177/0018720815590293>.
 29. McGill SM, Hughson RL, Parks K. Lumbar erector spinae oxygenation during prolonged contractions: implications for prolonged work. *Ergonomics.* 2000;43(4):486–93. <https://doi.org/10.1080/001401300184369>.
 30. Ferreira PH, Beckenkamp P, Maher CG, Hopper JL, Ferreira ML. Nature or nurture in low back pain? Results of a systematic review of studies based on twin samples. *Eur J Pain.* 2013;17(7):957–71. <https://doi.org/10.1002/j.1532-2149.2012.00277.x>.
 31. Gupta N, Hallman DM, Mathiassen SE, Aadahl M, Jorgensen MB, Holtermann A. Are temporal patterns of sitting associated with obesity among blue-collar workers? A cross sectional study using accelerometers. *BMC Public Health.* 2016;16(1):148. <https://doi.org/10.1186/s12889-016-2803-9>.
 32. Balagué F, Mannon AF, Pellisé F, Cedraschi C. Non-specific low back pain. *Lancet.* 2012;379(9814):482–91. [https://doi.org/10.1016/S0140-6736\(11\)60610-7](https://doi.org/10.1016/S0140-6736(11)60610-7).
 33. Hoy D, Brooks P, Blyth F, Buchbinder R. The epidemiology of low back pain. *Best Pract Res Clin Rheumatol.* 2010;24(6):769–81. <https://doi.org/10.1016/j.berh.2010.10.002>.
 34. Dario AB, Ferreira ML, Refshauge KM, Lima TS, Ordonana JR, Ferreira PH. The relationship between obesity, low back pain, and lumbar disc degeneration when genetics and the environment are considered: a systematic review of twin studies. *Spine J.* 2015;15(5):1106–17. <https://doi.org/10.1016/j.spinee.2015.02.001>.
 35. da Costa BR, Vieira ER. Risk factors for work-related musculoskeletal disorders: A systematic review of recent longitudinal studies. *Am J Ind Med.* 2010;53(3):285–323.
 36. Sluiter JK. High-demand jobs: age-related diversity in work ability? *Appl Ergon.* 2006;37(4):429–40. <https://doi.org/10.1016/j.apergo.2006.04.007>.
 37. Bern SH, Brauer C, Moller KL, Koblauch H, Thygesen LC, Simonsen EB, et al. Baggage handler seniority and musculoskeletal symptoms: is heavy lifting in awkward positions associated with the risk of pain? *BMJ open.* 2013;3(11):e004055. <https://doi.org/10.1136/bmjopen-2013-004055>.
 38. Christensen JO, Knardahl S. Work and back pain: a prospective study of psychological, social and mechanical predictors of back pain severity. *Eur J Pain.* 2012;16(6):921–33. <https://doi.org/10.1002/j.1532-2149.2011.00091.x>.
 39. Eriksen W, Bruusgaard D, Knardahl S. Work factors as predictors of intense or disabling low back pain; a prospective study of nurses' aides. *Occup Environ Med.* 2004;61(5):398–404. <https://doi.org/10.1136/oem.2003.008482>.
 40. Thorbjörnsson COB, Alfredsson L, Fredriksson K, Köster M, Michélsen H, Vingård E, et al. Psychosocial and physical risk factors associated with low back pain: a 24 year follow up among women and men in a broad range of occupations. *Occup Environ Med.* 1998;55:84–90. <https://doi.org/10.1136/oem.55.2.84>.
 41. Lunde LK, Koch M, Knardahl S, Wærsted M, Mathiassen SE, Forsman M, et al. Musculoskeletal health and work ability in physically demanding occupations: study protocol for a prospective field study on construction and health care workers. *BMC Public Health.* 2014;14(1):1075. <https://doi.org/10.1186/1471-2458-14-1075>.
 42. Stemland I, Ingebrigtsen J, Christiansen CS, Jensen BR, Hanisch C, Skotte J, et al. Validity of the Acti4 method for detection of physical activity types in free-living settings: comparison with video analysis. *Ergonomics.* 2015:1–13. <https://doi.org/10.1080/00140139.2014.998724>.
 43. Skotte J, Korshøj M, Kristiansen J, Hanisch C, Holtermann A. Detection of physical activity types using triaxial accelerometers. *J Physical Activity Health.* 2014;11(1):76–84. <https://doi.org/10.1123/jpah.2011-0347>.
 44. Steingrimsdóttir ÓA, Völlestad NK, Røe C, Knardahl S. Variation in reporting of pain and other subjective health complaints in a working population and limitations of single sample measurements. *Pain.* 2004;110(1-2):130–9. <https://doi.org/10.1016/j.pain.2004.03.016>.
 45. Kuorinka I, Jonsson B, Kilbom Å, Vinterberg H, Biering Sørensen F, Andersson G, et al. Standardised Nordic questionnaires for the analysis of musculoskeletal symptoms. *Appl Ergonomics.* 1987;18(3):233–7. [https://doi.org/10.1016/0003-6870\(87\)90010-X](https://doi.org/10.1016/0003-6870(87)90010-X).
 46. Statistics, Norway. Levekårsundersøkelsen 2009 (Survey of level of living 2009). Available from: <https://www.ssb.no/en/statistikkbanken>. 2009.
 47. Wännström I, Peterson U, Åsberg M, Nygren Å, Gustavsson JP. Psychometric properties of scales in the General Nordic Questionnaire for Psychological and Social Factors at Work (QPSNordic): confirmatory factor analysis and prediction of certified long-term sickness absence. *Scand J Psychol.* 2009;50(3):231–44. <https://doi.org/10.1111/j.1467-9450.2008.00697.x>.
 48. Dallner M, Elo AL, Gamberale F, Hottinen V, Knardahl S, Lindström K, et al. Validation of the General Nordic Questionnaire (QPSNordic) for psychological and social factors at work. *Nordic Council of Ministers, Nord.* 2000;12.
 49. Coenen P, Kingma I, Boot CRL, Twisk JWR, Bongers PM, van Dieën JH. Cumulative low back load at work as a risk factor of low back pain: a prospective cohort study. *J Occup Rehabil.* 2013;23(1):11–8. <https://doi.org/10.1007/s10926-012-9375-z>.
 50. Fitzmaurice GM, Laird NM, James HW. Modeling the mean: analyzing response profiles. *Applied longitudinal Analysis.* Second ed. New Jersey; U.S.A.: John Wiley & Sons, Inc.; 2011. p. 128–34.
 51. Picavet HS, Pas LW, van Oostrom SH, van der Ploeg HP, Verschuren WM, Proper KI. The Relation between Occupational Sitting and Mental, Cardiometabolic, and Musculoskeletal Health over a Period of 15 Years - The Doetinchem Cohort Study. *PLoS One.* 2016;11(1):e0146639. <https://doi.org/10.1371/journal.pone.0146639>.

52. Zemp R, Fliesser M, Wippert PM, Taylor WR, Lorenzetti S. Occupational sitting behaviour and its relationship with back pain - A pilot study. *Appl Ergon.* 2016;56:84–91. <https://doi.org/10.1016/j.apergo.2016.03.007>.
53. Ringheim I, Austein H, Indahl A, Roeleveld K. Postural strategy and trunk muscle activation during prolonged standing in chronic low back pain patients. *Gait Posture.* 2015;42(4):584–9. <https://doi.org/10.1016/j.gaitpost.2015.09.008>.
54. Fitzmaurice GM, Laird NM, James HW. *Applied Longitudinal Analysis*. Second ed. New Jersey; U.S.A.: John Wiley & Sons, Inc.; 2011.
55. Mannon AF, Balague F, Pellise F, Cedraschi C. Pain measurement in patients with low back pain. *Nat Clin Pract Rheumatol.* 2007;3(11):610–8. <https://doi.org/10.1038/ncprheum0646>.
56. Farrar JT, Young JP, Jr., LaMoreaux L, Werth JL, Poole RM. Clinical importance of changes in chronic pain intensity measured on an 11-point numerical pain rating scale. *Pain.* 2001;94(2):149–58. [https://doi.org/10.1016/S0304-3959\(01\)00349-9](https://doi.org/10.1016/S0304-3959(01)00349-9).
57. Leboeuf-Yde C, Lemeunier N, Wedderkopp N, Kjaer P. Evidence-based classification of low back pain in the general population: one-year data collected with SMS Track. *Chiropractic & manual therapies.* 2013;21:30. <https://doi.org/10.1186/2045-709X-21-30>.

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