Methods to assess physical load at work

With a focus on the neck and upper extremities

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Abstract

To prevent work-related musculoskeletal disorders (MSDs), useful, reliable and valid methods for assessing physical workload and risks for MSDs are needed. Ergonomists often assess work by short visual observations without a specific tool. A branch-specific tool was developed for assessing working technique during cash register work (BAsiK observation protocol).

Inclinometers are an alternative for assessing upper arm postures - over several days. Ergonomists need guidelines explaining how to analyze and interpret such data.

The aim was to examine and investigate methods for assessing physical load at work, with focus on the neck and upper extremities.

In Paper:
I, the reliability and criterion validity of the BAsiK observation protocol were assessed.
II, the reliability of risk assessments of repetitive work, based on visual observations performed by 21 ergonomists without a specific tool, was assessed.
III, whole-day inclinometer measurements of upper arm elevation were compared between work and leisure, across 13 different occupations – before and after arm elevations during sitting time was excluded.
IV, the association between inclinometer-based upper arm elevation and neck/shoulder pain was assessed among 654 blue-collar workers.

The intra-observer reliability of the BAsiK protocol was deemed acceptable, but only 3 of 10 questions in the protocol showed acceptable inter-observer reliability, and 3 showed acceptable criterion validity.

Neither the inter- or intra-observer reliability of risk assessment without any specific method was acceptable for any upper body regions.

None of the occupation groups, in paper III, had higher proportion of time with arm elevation during work than leisure. However, when arm elevation during sitting was excluded, 8 occupation groups had higher proportion of time with elevated arms during work than leisure.

Whole-workday inclinometer-based upper arm elevation was not associated with neck/shoulder pain within the assessed population.

The results indicate that, in most cases, a single visual observation of a work sequence is not a reliable means of assessing repetitive work. A large proportion of arm elevation may derive from sitting time. At low exposure levels, arm elevation per se may not be a risk factor for neck/shoulder pain.

This must be taken into account when evaluating the risk for MSDs.

Keywords: risk assessment, physical load, upper extremities, ergonomics

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“Variety's the very spice of life, that gives it all it's flavour.”

William Cowper 1785

To my family
This thesis is based on the following papers, which are referred to in the text by their Roman numerals.


III Palm, P. Gupta, N., Forsman, M., Skotte, J., Nordquist, T., Holtermann, A., Exposure to upper arm elevation during work compared to leisure among 13 different occupations measured with triaxial accelerometers. (submitted)

IV Palm, P., Forsman, M., Mathiassen, S. E., Birk Jørgensen, M., Madeleine, P., Holtermann, A. Whole workday measurements of arm elevation and associations with neck shoulder pain among blue-collar workers in the DPHACTO cohort. (submitted)

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Abbreviations

MSDs: musculoskeletal disorders

OHS: Occupational health

NSP: Neck Shoulder Pain

BAsIK: Swedish abbreviation for Better Workstyle in Cash register work

NOMAD: New Method for Objective Measurements of Physical Activity in Daily living

DPHACTO: Danish Physical Activity Cohort with Objective measurements
Introduction

Work-related musculoskeletal disorders (MSDs)

Early retirement, sickness absence, decreased productivity and quality of work due to musculoskeletal disorders result in large costs to society, organizations (1) and individuals. MSDs, together with mental disorders, are the most prevalent diagnosis leading to sick leave in Sweden (2).

Neck pain varies across countries and across occupations in the same country. The one-year prevalence of neck pain is between 30-50% in the general population. The one-year prevalence of activity-limiting neck pain ranges between 2-11% (3). Shoulder pain is almost as common as neck pain. The one-year prevalence of shoulder pain ranges between 5-47% (4). The prevalence values for pain in elbows/lower arms and hands are about half compared to those for neck pain (5).

The etiology of musculoskeletal disorders in the neck and upper extremities is multifactorial. Psychosocial factors has been related to neck pain (6–8) and upper extremity disorders (9,10). Apart from these factors, it is evident that physical load at work is an important risk factor for neck pain (3,7,8) and upper extremity disorders (7,9–13). Physical load at work has also been shown to be a risk factor for long-term sick leave (14–16).

Physical load

Sometimes the term mechanical load or exposure is used instead of physical load in order to exclude other aspects at work such as lightning, noise, temperature, etc. (17). In this thesis, physical load is defined as the mechanical forces that arise in the body (18).

Forces and movements

According to Newton’s first law of motion, there has to be a force acting on an object to start, stop or change the speed or direction of an object. Thus when a worker initiates, stops, or changes the direction or speed of body parts in relation to each other, there are forces involved. These forces (F) are proportional to the object’s mass (m) and the acceleration (a) of the object (F= m X a). The unit of force is the Newton, and forces can be described by their
different modes (friction, compression tension and shear), direction and magnitude.

A force moment is the turning effect of a force. When the force moments create movement, this is referred to as torque. The magnitude of a force moment can be calculated by multiplying the force that is applied at a right angle to a lever by the length of the lever. For example, the force moment on the shoulder, when the arm is outstretched 90° from the upright body, can be estimated by multiplying the distance from the center of mass on the arm by the mass of the arm.

Due to the gravity, there is always a force acting on objects and our body. To withstand this force and keep our upright posture, there are forces constantly being created by our muscles. The magnitude of these forces, to withstand the gravity, is dependent on body postures. A situation in which the center of mass of a burden is horizontally far from a joint that it is loading, and in which there is no unloading support, creates a high moment on the joint.

Thus, both the mass of handled objects together with body parts, movements and postures are of importance when considering physical load at work.

Total and local load

In work physiology, physical load can be described as total load (central load) on the body or local load on specific body parts. For example, when running or bicycling, large body parts are engaged and this leads to an increased total load. Large muscle groups need oxygen to create movements through forces, and therefore this puts strain on the cardiovascular system.

Examples of local load on specific body parts are when forces act on the lower arm when performing repetitive gripping work or the compression forces that are created within the shoulder when the arms are elevated without support (19).

In the present thesis, the focus is on local load acting on the neck and upper extremities.

External load, modifying factors and internal load

The external load is the load that acts on the body. Internal load is the force on the tissues in the body that is an effect of the external load and modifying factors (17) (Figure 1). This can be illustrated by an example where the task is to lift an object. Gravity acts on the object, which works as an external load on the worker. The internal load is then the forces in the body. Those forces can be friction between the tendons and the torque on the joints that is created by the force from the muscles lifting the object. If the task is performed in a non-optimal posture, with long levers, this will create a high torque on the joints. This non-optimal posture may be an example of an adverse working
technique. Thus, working technique is an example of a modifying factor between the external and internal load. This is illustrated in Figure 1.

Working technique

Working technique has been defined as “the individual’s way of performing a work task, as determined and modified by demands and conditions associated with the work task, the workplace design and how the work is organized” (20). Examples of adverse working technique that is related to MSDs are applying greater forces than needed to perform a task and working with unnecessarily quick and jerky movements (21). Working technique is closely related to the concept of workstyle.

Workstyle

Workstyle has been developed as an explanation for why some, but not all, workers who are exposed to the same type of work tasks develop MSDs (21–23). Workstyle is the way a worker response to increased work demands. Workstyle takes both physical and psychological aspects into account. According to the theory workstyle consists of three domains: a) the cognitive response, b) the behavioral response, and c) the physiological response (Figure 1). The cognitive response is the thoughts and feelings the worker has. The behavioral response is how the worker performs the task, e.g., in what posture, at what speed and how often the worker takes a break. The behavioral response can be considered synonymous with a person’s working technique. The physiological response is the effect of cognition and behavior, such as increased muscle tension, release of stress hormones etc. The physiological response is related to the concept of internal load.

This can be illustrated by an example. If the worker feels stressed, this can cause changed behavior in the form of performing work using quick and jerky movements. Quick and jerky movements mean high accelerations, which according to Newton’s first law of motion lead to higher internal forces. Stress will also directly affect the physiological response of higher muscle tension, which will further increase the internal forces from the muscles. As illustrated in Figure 1, the behavioral and cognitive domains are modifying factors in the link between external exposure and physiological response.
Figure 1. Theoretical model of how occupation may affect musculoskeletal health through physical load and modifying factors. Modified and further developed from Westgaard and Winkel 1996 (17) and Feuerstein 1997 (23).

How to operationalize physical load

In order to communicate about physical load at work, it has to be operationalized. Such terms need to be quantifiable and relevant to interventions meant to prevent musculoskeletal disorders.
The dose is the product of the force and the time the force acts on the tissues. The forces are not constant, but vary considerably over time. This temporal pattern of a load is of importance with respect to MSDs. Therefore the load should be quantified according to the following dimensions: amplitude, repetitiveness and duration (18).

It would be optimal if the internal load, in terms of forces and force moments, could be assessed in each situation. However, this is impossible to observe.

One rough alternative way to estimate the physical load of workers is to categorize them by their occupation. However within an occupation there are several different jobs, and any given job consists of several tasks (Figure 1). Therefore, a more specific alternative is to perform task-based assessments. The physical load in each task can be assessed using operationalized terms that are observable.

Forceful work and manual handling, repetitive work, static load, awkward postures and vibrations are commonly used terms to describe physical load at work.

Forceful work and manual handling

Forceful work is work that requires the muscles to contract close to their maximum voluntary contraction (MVC). This can be operationalized into percent of MVC. One method of operationalizing forceful work is to use the Borg CR 10 scale (24). Other alternatives are to define the handling of objects in terms of object weight and how frequently the objects need to be handled. In Sweden, about 15% of all women and 21% of all men in the working population report lifting more than 15 kg several times a day (25).

Repetitive work

Repetitive work is when similar work cycles and movements are performed repeatedly. There is no consensus on a definition of repetitive work. One definition that has been used is when the duration of a task cycle is less than 30 sec or when the worker performs the same movements for more than half of the time within the cycle (26).

In Sweden, about a third of all workers report that they repeat the same movements at least twice each minute at least a fourth of their working time (25).

Static load

Static load is a term often used to describe exertions in which the same posture is held continuously for a long period of time. This may be described as continuous muscle tension or muscle activity with low variation and without short
breaks, often referred to as gaps. Static load may be operationalized in terms of limited variation in exposure (27). For example static load may occur in the neck and shoulder muscles when the arm is outreached continuously without being supported by a surface. Static load may restrict blood flow in a muscle and reduce the supply of oxygen and nutrients as well as removal of acid. This, in turn, will contribute to muscle fatigue (28).

Awkward postures
Awkward postures are positions in which the limbs and joints deviate significantly from their neutral position or postures that create large force moments on the joints. Common examples of operationalizing work in awkward posture are working with elevated arms above a certain angle (29,30), or working with a twisted or forward bended neck to a certain degree (31,32). In Sweden 18% of the working population reports that they work with elevated arms more than a fourth of the time. Work with elevated arms is common among construction workers, cleaners and in assembly work (25).

Vibration
Vibrations can be transferred to the hand and arm when hand-held vibrating tools are used. Vibration is measured in acceleration in three directions using the unit m/s². There is an ISO standard (33) describing how to measure and calculate the daily dose of vibration A(8). In Sweden, there are regulations stating that action should be taken when the daily dose exceeds 2.5 m/s² and that 5 m/s² should not be exceeded. In Sweden about 3% of women and 14% of men report that they work with hand held vibrating tools more than a fourth of the time (25).

Physical load and associations with MSDs in neck and upper extremities
Several physical factors have been shown to be related to MSDs in the neck and upper extremities (Table 1).

Forceful work and manual handling
Forceful work is related to neck pain (7,8). Lifting more than 20 kg > 10 times/day or being exposed to high force requirements is related to shoulder disorders (9,11). Forceful power grip and handling load >20 kg > 10 time/day is related to elbow disorders (10). Forceful work is also related to carpal tunnel syndrome (12,13,34)
Repetitive work
Repetitive work has been observed to be associated with chronic neck pain (7,8), shoulder disorders (9,11), elbow disorders (10) and carpal tunnel syndrome (12,13,34).

Static load
Static load of the neck/shoulder muscles is related to chronic neck pain (7,8). Static work of the hand during the majority of the working time has been related to elbow disorders (10).

Awkward postures
Work with forward bended neck (31,32) and twisted neck (35) has been related to neck pain. Work with elevated arms is related to shoulder disorders (9,11).

Vibration
Hand/arm vibration is related to carpal tunnel syndrome (10,12,13,34) as well as vascular and neuropathic disorders of the hand and finger (36).

Combination of exposures
In real-life situations, many exposures co-exist, and in many studies having a combination of exposures has been shown to be associated with disorders. For example, doing repetitive work in combination with neck flexion has been identified as a risk factor for developing chronic neck pain (8). The combination of repetitive and forceful work (37) and upper arm flexion and forceful work has been related to shoulder disorders (38). The combination of repetitive work and forceful grip has been related to the incidence of wrist disorders, e.g., carpal tunnel syndrome (12,13,34,39,40).
Table 1. Overview of studies in which associations between physical factors and MSDs in neck and upper extremities are concluded.

<table>
<thead>
<tr>
<th></th>
<th>Forceful work</th>
<th>Repetitive work</th>
<th>Static load</th>
<th>Awkward postures</th>
<th>Vibration</th>
<th>Combination of exposures</th>
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</thead>
<tbody>
<tr>
<td>Neck</td>
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<td>(7)(8)</td>
<td>(7)(8)</td>
<td></td>
<td>(7)(8)</td>
</tr>
<tr>
<td>Shoulder</td>
<td>(9)(11)</td>
<td>(9)(11)</td>
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<td>(9)(11)</td>
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<td>(9)(11)</td>
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<td></td>
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<td>(13)(34)</td>
<td>(10)</td>
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<td>(13)(34)</td>
<td>(36)</td>
</tr>
</tbody>
</table>

Risk assessment and prevention of MSDs

To prevent MSDs, employers are obligated to perform regular risk assessments to identify cases of harmful physical load at work and intervene (41). The first step in risk assessments of physical load is to identify the type of load. Then the magnitude, dose and temporal pattern should be assessed. Subsequently, the risk of developing MSDs when exposed to this load may be evaluated. Ergonomists working in occupational health services (OHS) are often employed to perform such assessments. To do this work, OHS ergonomists need proper methods for assessing physical load at work. Ergonomists often claim that such methods must be quick and feasible to use (42).

How to measure physical load

Subjective methods

Subjective methods are methods that rely on a person’s perception or interpretation of a situation. A method can be more or less reliable depending on how the variables in the method are operationalized. For example, calculating the number of boxes weighting more than 10 kg that are lifted during an hour is a more reliable than evaluating the magnitude of the load that occurs during the workday on a scale.

Self-ratings

Self-ratings made on a questionnaire or in an interview are an easy way to assess physical load at work. Many respondents can be reached at a small cost. However, self-ratings may suffer from misclassification. There are studies showing that workers with musculoskeletal disorders may overestimate the
physical load compared to those without disorders (43,44). Thus the misclassifi-
cation is dependent on the outcome. This is referred to as differential mis-
classification (45). In epidemiological studies, this will lead to a false associ-
ation, or overestimation of associations between physical load at work and
MSDs.

Visual observations

Visual observations can be performed either in real time at the workplace or
by recording video sequences of the work, which are later analyzed in varying
degrees of depth by one or several observers. Visual observation is a com-
monly used method by ergonomists when they perform assessments of work
(46). There are several visual observational methods developed to assess phys-
ical load at work. Many of them suits the OHS-ergonomists (47). Using these
methods, the physical load is operationalized into different entities. In Table
2, there are examples of methods that cover variables that are relevant when
evaluating the load on the neck and upper extremities. Most methods are gen-
eral and developed to function in many different kinds of jobs.
Table 2. An overview of examples of observational methods that may be relevant for an OHS ergonomist to use when assessing the load on neck and upper extremities

<table>
<thead>
<tr>
<th>Physical factor</th>
<th>QEC (42)</th>
<th>HARM (48)</th>
<th>KIM MHO (49)</th>
<th>OCRA (50)</th>
<th>SI (51)</th>
<th>HAL (52)</th>
<th>RULA (53)</th>
<th>REBA (54)</th>
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<td>Neck</td>
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<td>Shoulders</td>
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<td>Hand forearm</td>
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<td>Force</td>
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<tr>
<td>Static load</td>
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<td>Awkward posture</td>
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<td>(X)</td>
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<tr>
<td>Vibration</td>
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<td>X</td>
<td>-</td>
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<td>-</td>
</tr>
</tbody>
</table>

X = includes this aspect, (X) = includes this aspect to some extent, (-) = Does not include this aspect

Objective methods

Objective methods are not dependent on a person’s perception or interpretation. Direct measurement using technical devices is an example of an objective method. Several objective methods have been used to measure physical load on the neck and upper extremities at work.

Electromyography

Muscle force can be estimated by measuring the electric activity produced by the nervous system within the muscle in order to make the muscle contract. Such technique is called electromyography (EMG).

In a muscle that is not fatigued, the EMG activity increases with the force the muscle produces (55). Thus forceful work may be estimated from EMG activity.
Static load has been operationalized using EMG. The number of short interruptions of muscle activity (EMG gaps) has been related to trapezius myalgia (56). The duration of periods with sustained low level muscle activity (SULMA) is another measure that has been related to neck pain (57). In field situations, EMG measurements can be complicated and costly for an OHS ergonomist to perform.

**Electrogoniometers**
Joint postures and movements can be measured with electrogoniometers (58). Wrist movement is of specific interest, because there are studies showing a dose-response association between median velocity of wrist movement and upper extremity disorders (59).

**Accelerometers**
Accelerometers have become affordable and are therefore a realistic alternative for use by OHS ergonomists. Accelerometers can be used to assess energy expenditure and sedentary behavior by transforming the accelerometric data into counts (60). A triaxial accelerometer measures acceleration in three directions: two horizontal directions (X and Y) and one vertical direction (Z). The acceleration of gravity is always acting on the accelerometer vertically. This can be used to measure angles towards the line of gravity, in which case the equipment is referred to as an inclinometer (61,62). At present, there is equipment available that has enough memory and battery capacity to capture accelerometric data over several workdays.

**Challenges when assessing physical load at work**
As mentioned above, the internal load is modified by the individual worker’s behavior or in other words the worker’s working technique. Thus the physical load can vary across workers at the same workplace and doing the same work tasks (63,64).

The physical load in a job can also vary considerably within a given day, between days, and even across months or years (65). The result of an assessment is therefore dependent on when the assessment occurs and how long it is.

Studies have shown that short visual observation, which is the most common method for assessing physical load, may suffer from limitations in precision due to the variation in load over time (66).

Another problem with short observations is that they cannot fully cover the temporal aspects, such as the duration of a task or exposure related to the physical load. Time is a key issue regarding evaluation of physical load (67). It is also known that temporal variables are difficult to estimate and (68) and may be biased (69).
Objective methods in which the load is measured over the whole workday or over several workdays are therefore an attractive alternative to methods that rely solely on information from short periods during the workday.

**Measurements’ reliability and validity**

Reliability is a term used to describe the consistency of a method. The reliability of an observational method can be divided into intra-observer reliability and inter-observer reliability. Intra-observer reliability describes the degree of consistency when one observer uses an observational method on separate occasions to assess the same work sequence. Inter-observer reliability describes the consistency between several observers using the same method to observe the same work sequence.

Validity describes the degree to which the method measures what it is meant to measure. Validity can be divided into several sub terms. Content validity is the degree to which the content of an instrument is an adequate reflection of the construct to be measured (70). Criterion validity is the similarity between the method and a criterion that is assumed to be valid. Predictive validity is the degree to which the method is consistent with the hypothesis (71). A method for assessing work-related risk of MSDs has good predictive validity if it can predict future cases of MSDs.

Reliability and validity are illustrated in the example in Figure 2. In situation a) several users of a method have made consistent but erroneous assessments, thus there is high reliability but low validity. In situation b) there is low reliability. Situation c) illustrates the optimal situation when there is both high reliability and validity.

![Figure 2](image)

**Figure 2.** Illustration of reliability and validity. In situation a) there is high reliability but low validity in b) there is low reliability in c) there is both high reliability and validity.

It is often said that a method can have high reliability and low validity, but not vice versa. Thus many authors consider high reliability to be necessary but not sufficient for high validity (72,73). In theory, however, if there is no system-
atic bias and the low reliability is only due to random factors, then low reliability can be compensated for with many observations. This is illustrated in Figure 3.

![Figure 3](image)

*Figure 3.* Illustration of a method with low reliability but high validity. There is a small chance that one single observation will measure correctly. With repeated observations the mean value will approach the true value with more observations, as illustrated to the right.

**Need for methods for specific situations**

**Branch-specific methods**

Observational methods meant to cover many work situations are sometimes too general to give valuable information. Branch-specific methods then can be a more specific alternative. There are some branch-specific tools developed for OHS ergonomists. For example KILA that is a tool for kitchen work (74). ROSA (75) is a tool for assessment of office work, MAPO index (76) DINO (77), Care thermometer and PTAI are tools to assess patient handling (78). RAMP is a tool to assess manual handling in industrial work (79).

**Cash register work**

In Sweden, about 53,000 women and 25,000 men are employed as shop salespeople in food stores (80). Many of them perform cash register work. Cash register workers handle a large number of items during a work shift. Similar movements of the upper extremities are performed repeatedly. This work can be categorized as repetitive work. Symptoms in the upper extremities are common among cash register workers (81–86).

Cash register work is an example of a work task that involves limited opportunities to influence how the task is performed. How cash register workers perform their work task is largely determined by the physical design of the cash register. However, studies have shown that cashiers load their muscles in different ways even though they work in the same cash register (87).
seems to be differences in movement patterns between individual workers. This is illustrated by an example in Figure 4 (88).

Different working techniques may affect the internal load on muscles and joints, which can probably influence the risk of developing MSDs. Thus training in working technique for cash register workers has often been suggested as a method for preventing MSDs (87,89–91). Education in proper working technique has also been proposed by the Swedish work environment authorities. OHS ergonomists are well suited to performing such training. No specific method has been developed to guide OHS ergonomists and cashiers in such training.

Within the scope of this thesis work, we have developed a branch-specific instrument for OHS ergonomists to employ in their work with prevention of MSDs in cash register work (BAsIK) (92) (Appendix 1). BAsIK is a Swedish abbreviation for Better Workstyle in Cash register Work. BAsIK is mainly rooted in the workstyle model. The instrument consists of four parts: 1) a questionnaire about workstyle, 2) an observation protocol for work technique, 3) a checklist concerning the design of the checkout and 4) a questionnaire about work organization. The observation protocol for work technique is an example of when different aspects of physical load were operationalized into observable variables. These variables were deemed by cashiers and ergonomists to be appropriate targets for interventions aimed at preventing MSDs in the neck and upper extremities.
Methods for assessing repetitive work

Several methods have been developed to assess repetitive work (Table 2) (47,93). However, a Swedish survey revealed that these methods are not often used (Eliasson et al., unpublished results). Instead ergonomists typically perform visual observations without the use of an explicit method. Thus, in practice, physical load at work is usually assessed without well-defined operationalized variables. In Paper II, we have assessed how reliable assessments of repetitive work are, without the use of an explicit method.

Methods for assessing work with elevated arms

There are several methods that rely on visual observations to assess work with elevated arms. In these methods, there are several different ways of operationalizing elevated arms. In HARM, the observer is to compare the worker with a picture.
of a person elevating an arm about 25° and rate the percentage of time the arm is elevated without support on a 3-point scale (48).

In Quick Exposure Check (QEC), the observer is to rate whether the task is performed with the hands at or below waist level, at about chest height or above shoulder height (42). In OCRA, the observer is to rate on a 4-point scale the proportion of time the arm is abducted/flexed > 80° without support or/and extended > 20°(50). All of these visual methods suffer from being subjective and only assessing a short portion of the workday.

Inclinometers have been used in several studies to assess upper arm elevation toward the line of gravity (61). Inclinometer have been shown to be valid in semi standardized work tasks (94,95). There is also a developed smartphone app developed to assess upper arm elevation at work (96). In the literature, several different statistics have been used to describe upper arm elevation from inclinometer data: 10th 50th, 90th and 99th percentile of the upper arm elevation (97) or the proportion of time with the arm elevated above 30°, 60° or 90° (30); proportion of time above 60° or 90° during periods longer than 5, 10 and 20 seconds has also been used (29). There is mechanistic reasoning behind the level of 60°. When the arm is raised above 60° without support, there is a clearly increased internal compression load within the shoulder (19). A Swedish research group has suggested that arm elevation > 60° for more than 10% of the whole workday could imply a risk for disorders (98). In Paper IV, we have evaluated whether upper arm elevation, operationalized as proportion of time with the arm elevated above 60 degrees, is related to neck and shoulder pain.

However, accelerometers may suffer from issues related to validity. For example, based on an accelerometric measurement of upper arm elevation without simultaneous observations, we cannot determine whether the arm is supported or to what extent it is loaded. This is of great importance when evaluating the force moment on the arm. Based on common sense and experience, we can assume that the arms are probably more often supported during sitting time than in upright position. In Paper III, we are starting to explore whether the use of a second accelerometer on the thigh, which will give information about when a person is sitting or upright, can be an alternative to better describe the physical load on the upper arm, when performing whole-day measurements of physical load in different occupations.

In Paper IV we further assessed if whole-day measurements with accelerometers is related to neck or shoulder pain and if such an association may be modified if arm elevation during sitting time is excluded.
Aim

The overall aim of the thesis was to investigate methods that occupational health ergonomist could use for assessing physical load at work, with a focus on the neck and upper extremities.

In Paper I, the aim was to examine the intra- and inter-observer reliability and criterion validity of the BAsIK observation protocol for assessing working technique in cash register work (Appendix 1).

In Paper II, the aim was to examine the inter- and intra-observer reliability of risk assessments performed by OHS ergonomists without the use of any explicit observational method.

In Paper III, the aim was to explore the difference between upper arm elevation measured with inclinometers during work and leisure in different occupational groups. Within the study population, there were some occupational groups that had work tasks that forced workers to work with highly elevated arms, while other groups did not have such tasks.

In Paper IV, the aim was to determine the association between inclinometry-assessed arm elevation at work and neck shoulder pain within a population of blue-collar workers.

In both Paper II and IV, a further aim was to explore how the results were modified if arm elevation during sitting time was excluded.
Methods

Paper I and II

In Paper I, two experienced OHS ergonomists independently used the BAsIK observation protocol to assess 17 videos of cash register work on two occasions each. The videos were about 15 minutes long. In order to evaluate the criterion validity of the protocol, their assessments were compared with meticulous video-based analyses performed by researchers and with video tracking technique.

In Paper II, 21 experienced OHS ergonomists independently assessed the risk of MSD from 10 video sequences of varyingly repetitive work tasks. The video sequences were 2-6 minutes long. The risks were assessed for the neck, shoulders, elbows and wrists. The risk was assessed on a 3 point scale: low risk, moderate risk and high risk. The ergonomists assessed the risk based on their own experience and knowledge and without the use of an explicit tool. A second assessment was performed by 9 OHS ergonomists to evaluate intra-observer reliability.

Paper III and IV

In both Paper III and IV, inclinometers were used over 2-4 days to measure upper arm elevations and time spent sitting among blue-collar workers. This was done during both work and leisure in Paper III and during work only in Paper IV. The inclinometers were attached to the workers’ dominant upper arm, hip and back. A custom-made algorithm, Acti4, was used to identify sitting periods (99) based on the inclinometer data.

In Paper IV, the workers were asked to rate the worst pain they had experienced in their neck/shoulder during the past month. This was done at baseline and then through a short questionnaire that was sent to them via their mobile phones. The workers answered the questionnaire every month during a 12-month period after the inclinometer measurements.
In Paper III, a Danish population of 86 female and 111 male workers was used (NOMAD) (100,101). The workers within this population were categorized into 13 different occupational groups depending on their occupation and main work tasks.

In Paper IV, a Danish cohort of 58 transportation workers, 120 cleaners and 476 manufacturing workers was used (DPHACTO) (102,103).

Statistics

Paper I and II
Reliability was calculated as the proportion of assessments that were in agreement, in percent. To take the agreement due to chance into account, proportion agreement was combined with Kappa statistics.

In both papers, the combination of a proportional agreement larger than 0.7 and a Kappa value larger than 0.4 was considered to show acceptable performance.

Paper I

Reliability
In Paper I, assessments of two ergonomists were compared and the response alternatives were primarily on 2-point scales: positive vs. negative. For this situation, Cohen’s kappa (104) is suitable. However, Cohen’s kappa may be low even if the observers agree, but when there is a high or low prevalence of positive or negative ratings (105). This problem was taken into account in Paper I by using a prevalence- and bias-adjusted kappa PABAK.

Criterion validity
In Paper I, the ergonomists’ ratings on the 2-point scales were compared with detailed video analysis performed by 1-2 researchers from the project group. The outcome of the detailed video analysis was frequencies of events or proportion of time measured on continuous scales. These results, from the detailed analysis, were plotted against the ergonomists’ ratings on the 2-point scale. The two distributions were compared using Wilcoxon signed rank test. Questions for which the two distributions differed significantly (p<0.05) in the expected direction were considered to have acceptable criterion validity.

The detailed analysis for one of the questions in BAsIK was performed by tracking upper arm velocity in the horizontal plane using a video-tracking technique (88).

The procedure for each question is presented in Paper I, Section 2.5.1 and Table 3.
Paper II

Reliability
In Paper II, there were 21 observers who assessed the work tasks once and 9 who assessed the work tasks twice. The risk ratings represented an ordinal scale (low, moderate and high risk). Therefore, the linearly weighted kappa (106) was calculated. This kappa was pairwise averaged over all pairs (107).

Paper III
In Paper III, the difference in percentage of time with arm elevated > 60° at work compared to leisure was calculated using linear mixed models. The work exposure for each occupational group was compared to the average of all workers’ leisure exposure. In the analysis, we adjusted for age, height, and neck or shoulder pain. The confidence intervals were adjusted using Dunnett’s post hoc test to account for multiple comparisons.

Paper IV
In Paper IV, workers who had a strong fluctuating or severe persistent pain over the 12-month follow-up period were defined as cases. Their arm elevation was compared to a reference group with no or very low pain using logistic regression. The analyses were made with and without adjusting for age, influence at work, support at work, heavy load at work and sex. We suspected that workers with neck/shoulder pain at baseline might avoid working with their arms elevated. If this were true, then a possible association between arm elevation and neck/shoulder pain would have been reversed. Therefore a sensitivity analysis was performed. In this analysis, all workers who had pain that affected their ability to perform their most demanding work tasks and also had dominating pain in the neck or shoulders were excluded.
Results

Paper I

All questions in the BAsIK observation protocol were considered to have acceptable intra-observer reliability. Only 3 of 10 questions were considered to have acceptable inter-observer reliability Table 3.

Table 3. Inter-rater reliability for each of the questions in the BAsIK protocol in terms of prevalence- and bias-adjusted kappa (PABAK)

<table>
<thead>
<tr>
<th>Question</th>
<th>Prop</th>
<th>PABAK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Which posture does the cashier have during the observed time?</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Does the cashier work mostly with tense and/or raised shoulders?</td>
<td>0.41</td>
<td>-0.18</td>
</tr>
<tr>
<td><strong>Does the cashier take the chance to take short breaks and relieve or move his/her shoulders for more than 2 s?</strong></td>
<td><strong>0.82</strong></td>
<td><strong>0.64</strong></td>
</tr>
<tr>
<td><strong>Does the cashier work with smooth and gentle movements?</strong></td>
<td><strong>0.71</strong></td>
<td><strong>0.41</strong></td>
</tr>
<tr>
<td>Does the cashier wait for the groceries until the conveyor belt has fed them as close as possible to the scanner before grasping them?</td>
<td>0.47</td>
<td>-0.06</td>
</tr>
<tr>
<td>Does the cashier lift groceries unnecessarily when scanning?</td>
<td>0.47</td>
<td>-0.05</td>
</tr>
<tr>
<td>Does the cashier work with small wrist movements and straight wrists while scanning?</td>
<td>0.65</td>
<td>0.29</td>
</tr>
<tr>
<td>Does the cashier release the groceries as soon as possible after scanning?</td>
<td>0.59</td>
<td>0.18</td>
</tr>
<tr>
<td>Is the cashier’s face continually directed to the side (20° or more) when scanning many groceries that come in quick succession</td>
<td>0.47</td>
<td>-0.06</td>
</tr>
<tr>
<td>Does the cashier have his/her hand outstretched towards the receipt printer in anticipation of printing?</td>
<td>0.65</td>
<td>0.29</td>
</tr>
</tbody>
</table>

Questions with prop >0.7 and PABAK >0.4 are marked with boldface text
In total, 3 of 10 items were considered to have acceptable criterion validity. These questions were:

- Quality of movement (Does the cashier work with smooth, gentle movements?)
- Rotating the head (Is the cashier’s face continually directed to the side 20° or more when scanning many groceries that come in quick succession? Yes, No, rarely or never)
- Receipt handling (Does the cashier have his/her hand outstretched towards the receipt printer in anticipation of printing? No, rarely or never, Yes.)

The only questions considered to have both acceptable inter-observer reliability and criterion validity were “Quality of movements” and “Working posture.” Posture was not assessed for criterion validity, but it was evident that whether the person was standing or sitting could be assessed.

Paper II

When the 21 ergonomists assessed the videos the first time, all three, high, moderate and low risk assessments were represented in 59 of the 70 risk ratings of neck and upper extremities (10 work tasks X 7 body parts). The weighed kappa ranged from 0.20-0.40 for intra-observer reliability and 0.12-0.32 for inter-observer reliability (Table 4).

According to our criteria (proportional agreement > 0.70 and kappa > 0.4), neither intra- nor inter-observer reliability was considered acceptable for risk assessment of the neck or upper extremities.
Table 4. Intra- and inter-observer reliability for the risk assessments in terms of proportional agreement (prop) and weighted kappa averaged over pairs ($\kappa_w$).

<table>
<thead>
<tr>
<th></th>
<th>Intra-observer reliability</th>
<th>Inter-observer reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Prop</td>
<td>$\kappa_w$</td>
</tr>
<tr>
<td>Neck</td>
<td>0.59</td>
<td>0.35</td>
</tr>
<tr>
<td>Right shoulder</td>
<td>0.53</td>
<td>0.30</td>
</tr>
<tr>
<td>Left shoulder</td>
<td>0.57</td>
<td>0.38</td>
</tr>
<tr>
<td>Right elbow</td>
<td>0.50</td>
<td>0.23</td>
</tr>
<tr>
<td>Left elbow</td>
<td>0.64</td>
<td>0.40</td>
</tr>
<tr>
<td>Right wrist</td>
<td>0.51</td>
<td>0.20</td>
</tr>
<tr>
<td>Left wrist</td>
<td>0.54</td>
<td>0.28</td>
</tr>
</tbody>
</table>

**Paper III**

The mean percentage of time with upper arm elevation above 60° during leisure was 10.4% (SD 7.2) for all workers. None of the 13 assessed occupational groups had a statistically significant higher exposure than this level during work, when the total time was considered (Table 5). When arm elevation during sitting time was excluded, the mean leisure exposure was lowered to 2.3% (SD 1.3). Without arm elevation during sitting at work, the domestic cleaners, construction workers, garbage collectors and manufacturing workers had a statistically significantly higher percentage of time with arm elevation above 60° than the mean leisure exposure for all occupations.
Table 5. Upper arm elevation among the 13 different occupational groups at work and for all workers at leisure, in percentage of time with the arm elevated above 60°. The figures are presented with and without arm elevation during sitting.

<table>
<thead>
<tr>
<th></th>
<th>During both sitting and non-sitting</th>
<th>Arm elevation during sitting excluded</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td><strong>During work</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Assemblers</td>
<td>29</td>
<td>2.4 (1.5)</td>
</tr>
<tr>
<td>CAD/CAM (office workers)</td>
<td>15</td>
<td>2.4 (1.5)</td>
</tr>
<tr>
<td>Cleaners (aircraft cleaning)</td>
<td>14</td>
<td>7.5 (5.0)</td>
</tr>
<tr>
<td>Cleaners (domestic cleaning)</td>
<td>9</td>
<td>6.0 (2.9)</td>
</tr>
<tr>
<td>Construction outdoor workers (pulling, digging cable and pipes)</td>
<td>11</td>
<td>11.9 (5.5)</td>
</tr>
<tr>
<td>Construction workers machine operator (excavator)</td>
<td>8</td>
<td>11.8 (4.7)</td>
</tr>
<tr>
<td>Construction workers (combination of the two above)</td>
<td>16</td>
<td>12.6 (5.1)</td>
</tr>
<tr>
<td>Construction workers, paviors</td>
<td>8</td>
<td>11.7 (6.7)</td>
</tr>
<tr>
<td>Garbage collectors</td>
<td>19</td>
<td>9.1 (5.3)</td>
</tr>
<tr>
<td>Managers and health professionals</td>
<td>10</td>
<td>2.7 (1.1)</td>
</tr>
<tr>
<td>Manufacturing workers (finishing tasks)</td>
<td>36</td>
<td>9.8 (5.2)</td>
</tr>
<tr>
<td>Manufacturing workers (form building tasks)</td>
<td>7</td>
<td>8.3 (3.0)</td>
</tr>
<tr>
<td>Social and health care workers</td>
<td>13</td>
<td>3.8 (1.2)</td>
</tr>
<tr>
<td><strong>During Leisure</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All occupation groups during leisure</td>
<td>197</td>
<td>10.4 (7.2)</td>
</tr>
</tbody>
</table>

**Bold figures** indicate statistically significant lower exposure during work compared to the mean leisure exposure for all groups. **Highlighted figures** indicate statistically significant higher exposure during work compared to the mean leisure exposure for all groups.
Paper IV

When the total work time was considered, transportation workers were exposed to upper arm elevation $> 60^\circ$ during work to a higher degree than cleaners and manufacturing workers. When arm elevation during sitting time was excluded from the analysis, there were no differences between the three occupations Table 6.

Table 6. Upper arm elevation during work in percentage of time with the arm elevated above $60^\circ$

<table>
<thead>
<tr>
<th></th>
<th>During both sitting and non-sitting</th>
<th>Arm elevation during sitting excluded</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transportation workers</td>
<td>58 10.2 (6.5)</td>
<td>4.2 (4.3)</td>
</tr>
<tr>
<td>Cleaners</td>
<td>120 5.5 (2.4)</td>
<td>4.0 (1.4)</td>
</tr>
<tr>
<td>Manufacturing workers</td>
<td>476 6.0 (3.7)</td>
<td>4.3 (3.1)</td>
</tr>
</tbody>
</table>

The odds ratios that were adjusted for potential confounders for severe neck or shoulder pain was 0.96 (95% CI 0.91-1.03) per one percentage point increase in total work time with arm elevation $> 60^\circ$. Without arm elevation during sitting time, the odds ratio was 0.98 (95% CI 0.89-1.07). In the sensitivity analysis, when all workers who had pain that affected their ability to perform their most demanding work tasks and also had dominating pain in the neck or shoulders (n=147) were excluded, the adjusted odds ratio for severe neck or shoulder pain was 1.00 (0.93-1.07).

Additional analysis

To further explore whether physical load differs when the arms are elevated during standing versus sitting, an additional analysis was performed. In DPHACTO, the workers were asked to rate, on a scale from 1-10, how physically demanding they normally consider their present work to be. Their answers to this question were plotted against the exposure to upper arm elevation above $60^\circ$ during total time, during sitting time and during non-sitting time at work. A local regression line (LOESS) was drawn in each of the scatter plots (Figure 5).

The results indicated that there was no correlation between upper arm elevation during sitting time and self-reported physical demands (Figure 5b). In
non-sitting positions, the higher the percentage of time the arm was elevated, the higher the worker rated that physical demands of his/her work (Figure 5c).

*Figure 5. Workers’ ratings of how physically demanding they considered their work (Y-axis) plotted with local regression line against the percentage of time with the arm elevated above 60° (X-axis) during a) the whole workday, b) during sitting time and c) during non-sitting time at work.*
In this thesis, three different methods OHS ergonomists could use for assessing physical load on the neck and upper extremities were investigated. The first two methods were based on visual observations. In Paper I, a branch-specific tool was used in which the load was operationalized into aspects of working technique. In Paper II, ergonomists assessed the risk of MSDs in the neck and upper extremities without guidance from any operationalized variables. In Paper III and IV, arm elevation data from whole-workday measurements, made with inclinometers, were investigated.

In Paper I, the inter- and intra-observer reliability and criterion validity were examined when two OHS ergonomists used the BAsIK protocol to assess working technique in cash register work. The intra-observer reliability was considered acceptable for all 10 questions in the protocol. The inter-observer reliability was deemed acceptable for 3 out of 10 questions: 1) whether the cashiers worked in standing or sitting position, 2) whether the cashiers took micro-breaks when possible, and 3) whether the cashiers worked with smooth and gentle arm movements. The other 7 questions were not considered to have acceptable inter-observer reliability. The criterion validity was considered acceptable for 3 out of 10 questions: 1) whether the cashiers worked with smooth and gentle arm movements, 2) whether the cashiers worked continuously with a rotated head, and 3) whether the cashiers’ arm was outstretched towards the receipt printer in anticipation of printing. Thus the only question that showed both acceptable inter-rater reliability and criterion validity was the one asking whether the cashiers worked with smooth and gentle arm movements. This is of interest, because the acceleration of a limb movement is directly related to the forces acting on the tissues. There are also studies indicating that the speed of a movement is related to MSDs (21,59,108).

In Paper II, the intra- and inter-observer reliability was assessed when OHS ergonomists performed risk assessments for MSDs without an explicit method. 21 ergonomists assessed 10 videos of repetitive work once and 9 ergonomists assessed these videos again after at least 3 weeks. Neither the intra-nor inter-observer reliability was considered acceptable regarding their risk assessments for MSDs in neck or upper extremities.
In both Paper I and II, a kappa value higher or equal to 0.41 was considered acceptable. This criterion was chosen because it indicates “moderate agreement,” according to Landis and Koch’s table (104). However, this criterion is arbitrary and can be questioned, especially if an erroneous assessment has dramatic consequences. Then a more stringent criterion would have been chosen. However, this criterion was deemed to be a suitable trade-off from a practical point of view, when evaluating the physical load of a work task.

The inter-observer reliability scores were in general lower in BAsIK than in other examples of branch-specific methods (74,77) The reliability in Paper II was also lower than in many other risk assessment methods (42,109–111). However, reliability scores depend on the heterogeneity of the study sample. In Paper I, the aim was to identify relatively small differences between the cashiers who performed the same work task. Thus, the study sample was relatively homogenous. This might explain the low reliability scores for many of the questions in the protocol. In Paper II the work tasks were chosen to represent different risk levels. However, if the videos used in Paper II had been even more heterogeneous, with “more green” and “extreme red,” then the risk assessment would have been more evident and probably resulted in higher reliability scores.

There are several sources of variability that may contribute to uncertainty when visually assessing physical load and assessing the risk of MSDs.

First, the worker that is observed is of importance, as working technique on the same work task may differ between workers. However this is not the reason for the weak reliability in the two papers in this thesis. In Paper I, it was the differences between workers within the same work task that were of interest. In Paper II, differences between workers were kept constant, and the observers were presented with the same video of the same worker for each work task.

The second source of variability is when the observations are performed. Visual observations are normally made of a short episode during the workday. Earlier studies have shown that this approach is associated with unreliable results, given that the exposure may vary considerably over time (66). In the present work, the ergonomists observed videos that were between 6-15 minutes long. The variation in physical load during these minutes of observation was probably not the major issue explaining the low reliability, especially not in Paper II. However it might have been of some importance in Paper I. In Paper I, ten different questions were to have been assessed based on the 15-minute-long videos. One of the ergonomists assessed all 10 questions very quickly, within less than 2 minutes for one of the videos. This ergonomist might have missed important information in the video that the other ergonomists observed. One notion supporting this is that, for one of the videos, the ergonomists did not completely agree as to whether the cashier was sitting or standing. In this video, the cashier changed from sitting to standing during the video.
The third source of variability is that it may be difficult to visually assess movements and postures from videos. This has been discussed as being especially difficult for movements of small body parts (47). Studies have shown that the variability in observers’ ratings of postures increases when episodes of work are only partly visible (112).

The fourth source of variability is directly related to the observers: The observer’s own perception concerning how to translate the movements and postures into categories in the protocol or into risk estimates. This may be the major reason for the weak reliability in Paper II, where the ergonomists received no guidance in how to translate their observations into risk of contracting MSDs. In Paper I, physical load was operationalized through aspects of working technique. This gave the observers some guidance, such as whether an event happened “for the most part,” or “rarely or never,” but still it is possible for observers to interpret the response categories differently, especially when the assessed work is on the boundary between two categories. This problem has been referred to as the boundary zone problem (74,113). This fourth source of variability may explain why inter- but not intra-observer reliability was low for many of the questions in Paper I.

A solution to eliminate the second, third and fourth source of variability mentioned above is to instead use an objective method that measures physical load over a longer time period. Such method was investigated in Paper III and IV.

Arm elevation is one, among other, important factor that needs to be assessed when evaluating the risk for MSDs in the neck and shoulders. In Paper III and IV, data from whole-day measurements of upper arm elevation with inclinometers were investigated. In Paper III, the differences between upper arm elevation during work and leisure were assessed in the NOMAD population (100,101), consisting of 13 different occupational groups. In Paper IV, the association between upper arm elevation and neck or shoulder pain were assessed within the DPHACTO population (102,103), consisting of transportation workers, cleaners and manufacturing workers.

In both Paper III and IV, we explored how the results might be modified if we excluded upper arm elevation during sitting time. We did this because we thought upper arm elevation during sitting time might be performed with supported arms to a higher degree, and arm elevation with support does not impose a force moment on the shoulder.

The results from Paper III showed that none of the 13 assessed occupational groups had a higher percentage of time with arm elevation at work than leisure. We knew, however, that some of the occupational groups were exposed to work tasks that forced the workers to elevate their arms. A large proportion of arm elevation derived from sitting time, especially so during leisure. When arm elevation during sitting was excluded from the analysis, domestic cleaners, construction workers, garbage workers and manufacturing workers had a
larger proportion of time with the arms elevated above 60° during work than during leisure.

The results from Paper IV showed that upper arm elevation per se was not associated with neck or shoulder pain in the DPHACTO population. This was in contrast to earlier studies in which an association between arm elevation and shoulder pain (29,30) and neck pain (108) has been observed. However, the exposure in the studied DPHACTO population (transportation workers, cleaners and manufacturing workers) was considerably lower than in the studies in which an association between arm elevation and shoulder pain has been observed. Our results are partly in line with the study by Nordander, where the studied population also had a relatively low exposure to arm elevation. In that study, no association was found between arm elevation and shoulder pain, but there was an association with neck pain (108).

Arm elevation above 60°, without support, for more than 10% of the workday has been suggested as a reasonable threshold, above which ergonomists should consider such work to be a risk factor for neck or shoulder disorders (98). The mean percentage of time with arms elevated above 60° during leisure was at the suggested risk threshold of 10%. In Paper IV, the mean exposure to arm elevation above 60° was also as high as the 10% level within the occupational group that had less pain in the studied population (transportation workers). These results indicate a problem when using whole day measurements of arm elevation with inclinometers for risk assessment purpose. From a whole day measurement solely we cannot know if the arms are supported or not. Based on the present data, we cannot explain the high exposure to arm elevation during sitting at leisure and among transportation workers. We can only guess that a large proportion of sitting time is performed with the arms supported by an armrest or perhaps on the steering wheel. To what extent this can impair the validity of using whole-day measurements of arm elevation when evaluating the risk of neck or shoulder pain needs to be further investigated. Our results indicate that if the 10% proposed time limit were to be applied, it might be warranted to exclude arm elevation during sitting time – at least when assessing work tasks performed in non-sitting positions. This is to some extent also supported by the additional analysis performed in this thesis on the DPHACTO material. This analysis showed that the workers’ own perception of how physically demanding their work was increased with duration of arm elevation during non-sitting time, but not with increased arm elevation during sitting time.

**Practical implications and future work**

The results from this work show that subjective assessments of repetitive work without a specific tool are not consistent between observers. We therefore recommend ergonomists to a larger degree employ systematic observational methods when possible. The reliability of a method may further be increased
by using repeated assessments. If the work task are video-recorded, then several ergonomists can assess the same work task. There are studies indicating that this is a cost effective way of assessing physical load at work (114). Within an OHS organization, this may be achieved by a collaboration between several ergonomists. Such approach needs to be evaluated in future studies.

A visual observation that only covers a short period of the workday may also be inaccurate because of the limited sample. Some important variables in an assessment may instead be measured with technical devices. If ergonomists choose to use inclinometers over the full day to assess arm elevation, then they cannot determine whether or not the measured arm elevation is supported or loaded. Thus they cannot be sure whether the arm elevation leads to an increased load for the shoulder. These two problems could be solved by using whole-day measurements with inclinometers and visual observations together in concert. We have tried this methodology in a pilot study to evaluate exposure to forward bending in a garbage collector (115). The worker wore a portable camera on his chest during the whole workday together with an inclinometer that measured back posture. The video was synchronized with the inclinometer. The inclinometer indicated each situation when the worker leaned forward and then the corresponding video sequence of this situation could be assessed. The method was quick and feasible to use, but needs to be tested further on a large scale.

Another solution, to the problem with whole day measurements of arm elevation, might be to develop and validate smart algorithms that can determine whether or not upper arms are supported or loaded.

Conclusion

The results of this thesis indicate that, a single visual observation of a work sequence, without the use of an explicit method, is not a reliable means of evaluating risk of MSDs in neck and upper extremities due to repetitive work. The reliability of an assessment may increase when the load is operationalized into well-defined variables. When a branch-specific tool was used in which cashiers’ working technique was operationalized into defined variables, the intra- but not inter-observer reliability was acceptable.

When arm elevation is measured over the whole day, a large proportion of arm elevation may derive from sitting and leisure time.

Upper arm elevation per se, in terms of proportion of the whole workday with the arm elevated above 60°, was not a risk factor for neck or shoulder pain among the studied transportation workers, cleaners and manufacturing workers. This might be explained by the low exposure to arm elevation during non-sitting time in the assessed population.

This must be taken into account when evaluating the risk for MSDs in neck and upper extremities.
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Sammanfattning på svenska

För att förebygga belastningsbesvär behöver ergonomer praktiskt användbara, reliabla och valida metoder för att bedöma fysisk belastning i arbete. Ofta bedömer ergonomer arbetet visuellt utan att använda någon specifik metod.

Inom ramen för denna avhandling har en branschanpassad metod tagits fram för att bedöma arbetsteknik i kassaarbete (BAsIK observationsprotokoll).

Ett objektivt alternativ för att registrera arbetsställningar i armar över flera dagar kan vara att använda personburna inklinometrar. Dessa registrerar lutningen mot lodlinjen. Det behövs riktlinjer i hur data från sådana heldagsmätningar ska tolkas.

Syftet med denna avhandling var att undersöka och utforska metoder för att bedöma fysisk belastning i arbete, med fokus på nacke och övre extremiteterna.

I studie:
I, undersöktes BAsIK observationsprotokoll avseende reliabilitet och kriterievaliditet.
II, undersöktes reliabiliteten då ergonomer bedömde risk för besvär i Nacke och övre extremitet vid repetitivt arbete, utan att använda sig av någon specifik metod.
III, utforskes heldagsmätningar av överarmsvinkel med inklinometrar från en dansk population (NOMAD) n=197. Andelen tid med lyftade armar under arbete jämfördes med den genomsnittliga exponeringen under fritiden i 13 olika yrken.
IV, undersöktes sambandet mellan andel tid med lyftade armar uppmätt med heldagsmätningar med inklinometrar och smärta i Nacke/skuldra i en dansk population (DPHACTO) bestående av 654 arbetare.

Studie III och IV gjordes med och utan tid med lyftade armar under sittande med i analyserna eftersom vi misstänkte att arbete med lyftade armar under sittande ofta sker med understödda armar.

Intra- bedömaren reliabiliteten bedömdes vara acceptabel för alla frågor i BAsIK, men endast 3 av 10 frågor bedömdes ha acceptabel interbedömarreliabilitet, och 3 bedömdes ha acceptabel kriterievaliditet.
Varken intra- eller inter-bedömare reliabilitet bedömdes vara acceptabel då ergonomer bedömde repetitivt arbete utan någon specifik metod.

Trots att flera yrkesgrupper i studie III hade arbetsuppgifter som krävde att de arbetade med högt lyftade armar, var det ingen grupp som hade högre andel tid med lyftade armar > 60° på arbetet jämfört med den genomsnittliga andelen av tid med lyftade armar > 60° under fritid. Däremot då tid med lyftade armar under sittande perioder togs bort från analyserna, var det 8 av 13 yrkesgrupper som hade högre andel tid med lyftade armar > 60° under arbete jämfört med fritid.

Det fanns inget samband mellan andel tid med lyftade armar, uppmätt med heldagsmätningar med inklinometrar, och besvär i nacke/skuldra i den undersökta populationen i studie IV.

Resultaten indikerar att korta enskilda visuella bedömningar av ett repetitivt arbete utan en systematisk metod inte är tillförlitliga. En stor andel av tid med lyftade armar kan komma från sittande perioder. Vid låg exponering för arbete med lyftade armar verkar inte armlyft vara en enskild riskfaktor för smärta i nacke/skuldra.

Detta tillsammans, bör tas i beaktande vid riskbedömningar avseende besvär i nacke och skuldra.
References


Observation Protocol

General Aspects During Work

- **Posture**
  The standing posture puts less load on the shoulders than sitting. When standing, it is also easier for the cashier to move such that they are always positioned in the best way for the task at the checkout. It is therefore good to vary the working position between sitting and standing.

  1. Which posture has the person during the observed time?
     - [ ] The work is done sitting
     - [ ] The work is done standing
     - [ ] The work is done alternately sitting/standing

- **Tense Shoulders**
  Sitting high enough so that the belt conveyor is slightly below elbow height enables the cashier to work with lowered shoulders. This can reduce tension in the shoulders.

  ![a) Relaxed shoulders](image1) ![b) Tense/raised shoulders](image2)

  2. Does the cashier work mostly with tense and/or raised shoulders?
     - [ ] Yes
     - [ ] No

- **Micro-Breaks**
  Relaxation or variation can be achieved by taking advantage of short breaks. Short breaks include, for example, waiting for the receipt to be printed or waiting for a customer to pay. The breaks can be used to put forearms down on the conveyor and relax, or to stretch or gently move the shoulders.

  3. Does the cashier take the chance to take short breaks and relieve or move their shoulders for more than 2 seconds?
     - [ ] Yes, for the most part
     - [ ] No, rarely or never
When Scanning

**Quality of Movement**

The load on the body can be reduced by smooth, gentle movements.

4. **Does the cashier work with smooth, gentle movements?**
   - ☐ Yes, for the most part
   - ☐ No, he/she works mostly with quick or jerky movements

**Supply of Groceries**

Unnecessary lateral stretching can be avoided by letting the conveyor belt carry the groceries all the way. It is important that the checkout is correctly adjusted so that the groceries automatically stay as close to the scanner as possible. To determine whether the cashier stretches unnecessarily, one must first note where the groceries stop.

Example where the person grasps the groceries after the conveyor belt has fed them forward as far possible.

Example when the person grasps the groceries before the conveyor belt has fed them forward.

5. **Does the cashier wait for the groceries until the conveyor belt has fed them as close as possible to the scanner before grasping them?**
   - ☐ Yes, always or almost always
   - ☐ No
Lifting Groceries
Unnecessary lifting may be avoided by tilting or aiming the groceries at the scanner, thereby letting the conveyor belt move the goods. Small and lightweight goods (less than 500 g) may be easier to scan if they are lifted.

6. Does the person lift groceries unnecessarily when scanning?
   - Yes
   - No, rarely or never

Wrist Movements
Large wrist movements can be partly avoided depending on how the groceries are grasped.

One way to reduce the wrist movements may be to grasp the groceries with the fingertips and direct them toward the scanner by allowing the groceries to rotate in the hand instead of angling the entire wrist.

Small wrist movements and straight wrist are defined as movements that are less than 15 degrees from the wrist’s neutral position.

7. Does the person work with small wrist movements and a straight wrist when scanning?
   - Yes, for the most part
   - No
Release of Groceries

In general, the groceries can be released immediately after reading, allowing the conveyor belt to move them on. The exceptions are if the groceries are delicate, or if they have formed a pile.

8. Does the cashier release the groceries soon as possible after scanning?

☐ Yes, always or almost always when possible
☐ No

Rotating the Head

The placement of the scanner determines whether or not the cashier’s head has to be rotated. The scanner is sometimes placed diagonally in front of the cashier. This means that the cashier may need to keep their head turned towards the scanner for long periods. This is primarily a problem when many items to be scanned come in quick succession. When the groceries are to be weighed or handled in another way than scanning, the face is naturally directed forward, depending on the design of the checkout.

As many items need to be scanned in succession, static load due to twisting the neck can be reduced by:

• Positioning the cashier directly in front of the scanner
• Rotating the chair or standing facing the scanner
• From time to time during scanning, return to having the face directed straight ahead

Example where the cashier directs their face forward during scanning

Example where the cashier works with their face directed to one side more

9. Is the cashier’s face continually directed to the side (20 degrees or more) when scanning many goods that come in quick succession?

☐ Yes
☐ No, rarely or never

Receipt Handling

There may be an unnecessary static load on the shoulder if the arm is extended towards a receipt printer in anticipation of the receipt.

10. Does the cashier have his/her hand outstretched towards a receipt printer in anticipation of printing?

☐ No, rarely, or never
☐ Yes
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