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Improving technical methods for assessment of workplace ergonomic exposure

CAMILLA DAHLQVIST
DIVISION OF OCCUPATIONAL AND ENVIRONMENTAL MEDICINE | LUND UNIVERSITY

My passion in life is horses. Luckily, I have a work situation where at the end of the working day I can devote myself to it. Many others may have to give up passions, due to pain in muscles and joints caused by their physically demanding work. This thesis is my contribution to try to change this, by improving technical objective methods for measuring the physical workload in the upper part of the body. The methods may be used e.g. as a part of the systematic work environment work to achieve a satisfying work environment that prevents development of musculoskeletal disorders among employees.

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Improving technical methods for assessment of workplace ergonomic exposure

Camilla Dahlqvist

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Abstract
Background: Repetitive work, work performed in awkward and constrained postures and work with excessive or sustained muscular load is common in many occupational settings. Such work is known to be risk factors for developing musculoskeletal disorders in the neck/shoulder region and in arms and hands. One method that can be used to assess the exposure to these risk factors is technical recordings that rely on sensors attached directly to a subject. However, there is a commonly held belief that the methods are time consuming, require expensive equipment and also demand technical knowledge to perform and are therefore not suitable for all. *Aims*: To simplify the inclinometry method in order to make it easier to use for different actors in the work environment field, and to refine the surface electromyography (sEMG) method of the forearm extensor muscles for more accurate estimates of recorded muscular load. *Methods*: For the inclinometry method in the laboratory, one model of the new generation of triaxial accelerometers with integrated data loggers (GC inclinometer) were validated against traditional ones (LT inclinometer). Also the deviation angles of two simplified reference postures for upper arms from a standard reference posture were evaluated. For the field study, self-recordings of upper arm elevations were evaluated by analysing each recording twice; once with a simplified reference posture and once with a standard reference posture. For the sEMG method in the laboratory, the electrical activity of right forearm extensor muscles was recorded from four electrode pair positions during two maximal voluntary contractions (MVC; hand grip and resisted wrist extension). In the field study, the electrical activity was recorded using two electrode pair positions and the two MVCs during one working day of hotel room cleaning. Each recording was analysed twice; once with hand grip as reference contraction and once with resisted wrist extension as reference. *Results*: For the inclinometry method in the laboratory, all group mean absolute differences of simulated work tasks and body parts between the two inclinometers were less than 2.5°. In the field study, the upper arm elevations during work (50th percentile) were almost identical (group mean difference of 0.2°) for the two analyses using different reference postures. For sEMG in the laboratory, resisted wrist extension showed 1.2 – 1.7 times higher EMG amplitudes and lower coefficient of variation than hand grip. In the field study, the workload during cleaning was lower when using resisted wrist extension as the reference than when using hand grip. The workload (99th percentile) was overestimated in two subjects when hand grip was used as reference contraction. *Conclusions*: For the inclinometry method, the obtained data from the GC inclinometers were fully comparable to the data from the LT inclinometers. The simplified reference posture deviated somewhat from the standard reference, but the effect of this deviation on group recordings of work was negligible. The hotel room cleaners managed to perform self-recordings of upper arm elevations and velocities. For the sEMG, the use of resisted wrist extension may be a more accurate maximal effort of forearm extensor contraction than using hand grip. Problems associated with poorly activated forearm extensors can be overcome by using resisted wrist extension as reference.

Key words
Work-related musculoskeletal disorders, physcial workload, risk assessment, inclinometry, sEMG, upper arm elevation and velocity, hand grip, resisted wrist extension, hotel room cleaning

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MADE IN SWEDEN

To my family

Table of Contents

Acknowledgements 8
List of papers 10
Populärvetenskaplig sammanfattning på svenska 11
Abstract 13
Abbreviations 15
List of figures 16
List of tables 16

Introduction 17

Work-related musculoskeletal disorders (WMSDs) 17
Risk factors for developing WMSDs 17
Physical load at work 18
Repetitive work 19
Awkward postures 19
High muscular load 19
Sustained muscular load 20
Systematic work environment work 20
Assessment of physical workload 21
Self-reporting 21
Observational methods 22
Objective technical methods 22
Validity 26
Precision and accuracy 27
Reliability 28
Repeatability 28
Hotel room cleaning 28

Aim 31

Materials and Methods 33

Subjects 33
Inclinometry 34
Study design 34
Methods 35
ERSRP - evaluation of the repeatability of the standard reference posture 35
Data processing and analyses 36

sEMG 37
Study design 37
Methods..38
Data processing and analyses 39
Statistical analyses...40
Results with comments 43
Inclinometry 43
GT inclinometer versus LT inclinometer 43
Simplified reference posture versus standard reference posture 44
Within-subject variation of the simplified and standard reference postures 45
The protocol and the subjects´ perception of self-recording 47
Variation in workload between days 48
sEMG 50
Maximal voluntary contractions and electrode positioning 50
Correlation between MEF and MVE 50
Muscular load during work 51
Physical workload in hotel room cleaning 53
Inclinometry 53
sEMG 53
Comments 53
General discussion 55
Methodological considerations...57
Inclinometry 57
sEMG 57
Methodologically and clinically relevant differences 58
Estimation of sample size and power calculation 58
Inclinometry 61
sEMG 61
Electrode positioning 61
MVCs 62
Gender aspects...62
Recording strategies 63
Technical methods in practice and in research.......................................64
Changing the reference contraction? 64
Practical implications 65
Conclusions 67
Recommendations 67
Future research..69
References 71

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List of papers

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I. Dahlqvist C, Hansson G-Å, Forsman M. Validity of a small low-cost triaxial accelerometer with integrated logger for uncomplicated measurements of postures and movements of head, upper back and upper arms. Applied Ergonomics 2016; 55:108-116.

II. Dahlqvist C, Nordander C, Granqvist L, Forsman M, Hansson G-Å. Comparing two methods to record maximal voluntary contractions and different electrode positions in recordings of forearm extensor muscle activity: Refining risk assessments for work-related wrist disorders. Work 2018; 59:231-242.

III. Dahlqvist C, Nordander C, Forsman M, Enquist H. Self-recordings of upper arm elevation during cleaning – comparison between analyses using a simplified reference posture and a standard reference posture. BMC Musculoskeletal Disorders 2018; 19:402.

IV. Dahlqvist C, Enquist H, Löfqvist L, Nordander C. The effect of two types of maximal voluntary contraction and two electrode positions in field recordings of forearm extensor muscle activity during hotel room cleaning. International Journal of Occupational Safety and Ergonomics. In press.

Populärvetenskaplig sammanfattning på svenska

I många yrken är det vanligt att man får ont i muskler och leder i bland annat nacke, skuldror, rygg, armar och händer. Orsaken till besvären kan vara att arbetet är tungt (ihållande belastning på musklerna och/eller tunga lyft med höga skjuta/dra krafter), att arbetet utförs i vridna, låsta eller böjda arbetsställningar och/eller att det är samma rörelser som upprepas om och om igen. Enligt Arbetsmiljöverkets statistik över besvär orsakade av arbetet hade ungefär 15 procent av de sysselsatta kroppsliga besvär till följd av arbetet under första kvartalet av 2016. För att minska risken för att drabbas är det viktigt att göra riskbedömningar och vid behov genomföra nödvändiga förändringar. Det finns flera olika risbedömningsmetoder man kan använda, som till exempel självrapportering, observationsmetoder (en observatör bedömer arbetet i fråga) och tekniska mätningar av fysisk belastning. Alla metoderna har för- och nackdelar, där till exempel självrapportering är bra att använda i stora grupper. Observationsmetoder är ofta lätta att använda och tolka, men resultaten varierar mellan olika observatörer. Tekniska mätningar däremot, är objektiva och har fördelen att ge exakta siffervärden på arbetsställningar och rörelser samt muskelbelastning i till exempel övre delen av kroppen. Den allmänna uppfattningen om tekniska mätningar är dock att de kräver dyr utrustning, tekniskt kunnande och är tidskrävande, och används därför mestadels bara av forskare och ett fåtal praktiker.

Syftet med den här avhandlingen var att förbättra två av de tekniska mätmetoder som vår forskargrupp använder för att mäta fysisk belastning. För inklinometri-metoden (mätning av arbetsställningar och rörelser i huvud, rygg och överarmar) var syftet att förenkla den så att fler kan använda den. För elektromyografi-metoden (mätning av muskelbelastning i underarmarna) var syftet att förfina den för att få ett mer korrekt mått på muskelbelastningen under arbete.

Fyra studier genomfördes, två i laboratorium och två ute i fält på olika arbetsplatser i städbranschen. I den första studien jämfördes en billig och lättanvänd inklinometer mot vår traditionella inklinometer. Dessutom jämfördes två enkla referenspositioner (nolläge) för överarmarna mot en standardreferens. I fältstudien för inklinometri undersöktes det om arbetstagare själva kan mäta sin arbetsbelastning i överarmen. Kvalitén på dessa jämfördes med kvalitén på mätningar som forskare gör genom att analysera varje mätning två gånger; en gång med den förenklade referenspositionen som referens och en gång med standardreferensen. I laboratoriestudien för elektromyografi jämfördes två olika maxkontraktioner (handledsextension mot motstånd och handgrepp) och fyra olika elektrodplaceringar för underarmsmusklerna (extensorerna) med varandra, i form av amplitud och repeterbarhet av den elektriska signalen. I fältstudien studerades hur muskelbelastningen under städning skiljde sig åt när man använde de två olika maxkontraktionerna som referenskontraktion vid två av de fyra elektrod-placeringarna.

Resultaten för inklinometri-metoden i laboratoriestudien visade att gruppmedelvärdet för den absoluta skillnaden mellan den billiga och lättanvända inklinometern och den traditionella inklinometern var mindre än 2.5 grader. I fältstudien visade resultaten att arbetsställningarna i överarmen under städning var nästan identiska mellan de två analyserna med olika referenspositioner. För elektromyografi i laboratoriestudien visade handledsextension mot motstånd 1.2 – 1.7 gånger högre elektrisk signal och bättre repeterbarhet än handgrepp. I fältstudien var muskelbelastningen under städning lägre när handledsextension mot motstånd användes som referenskontraktion än när handgrepp användes. Arbetsbelastningen överskattades för två individer när handgrepp användes som referenskontraktion, vilket troligen berodde på att dessa individer inte aktiverade extensorerna maximalt vid handgrepp.

Konklusionerna för avhandlingen är att mätdata från den billiga och lättanvända inklinometern var fullt jämförbara med mätdata från den traditionella inklinometern. Den förenklade referenspositionen skiljde sig något från standardreferensen, men effekten av denna var försumbar vid mätning på en grupp av individer. Lokalvårdarna kunde själva mäta arbetsställningar och rörelser i överarmen. Resultaten för elektromyografi antydde att handledsextension mot motstånd var en bättre metod än handgrepp för att uppnå en maximal kontraktion av extensorerna i underarmarna. Problemen med dåligt aktiverade extensorer under maxkontraktionen kan undvikas genom att använda handledsextension mot motstånd istället för handgrepp.

Abstract

Background: Repetitive work, work performed in awkward and constrained postures and work with excessive or sustained muscular load is common in many occupational settings. Such work is known to be risk factors for developing musculoskeletal disorders in the neck/shoulder region and in arms and hands. One method that can be used to assess the exposure to these risk factors is technical recordings that rely on sensors attached directly to a subject. However, there is a commonly held belief that the methods are time consuming, require expensive equipment and also demand technical knowledge to perform and are therefore not suitable for all. *Aims:* To simplify the inclinometry method in order to make it easier to use for different actors in the work environment field, and to refine the surface electromyography (sEMG) method of the forearm extensor muscles for more accurate estimates of recorded muscular load. *Methods:* For the inclinometry method in the laboratory, one model of the new generation of triaxial accelerometers with integrated data loggers (GC inclinometer) were validated against traditional ones (LT inclinometer). Also the deviation angles of two simplified reference postures for upper arms from a standard reference posture were evaluated. For the field study, self-recordings of upper arm elevations were evaluated by analysing each recording twice; once with a simplified reference posture and once with a standard reference posture. For the sEMG method in the laboratory, the electrical activity of right forearm extensor muscles was recorded from four electrode pair positions during two maximal voluntary contractions (MVC; hand grip and resisted wrist extension). In the field study, the electrical activity was recorded using two electrode pair positions and the two MVCs during one working day of hotel room cleaning. Each recording was analysed twice; once with hand grip as reference contraction and once with resisted wrist extension as reference. *Results:* For the inclinometry method in the laboratory, all group mean absolute differences of simulated work tasks and body parts between the two inclinometers were less than 2.5°. In the field study, the upper arm elevations during work (50^{th} percentile) were almost identical (group mean difference of 0.2°) for the two analyses using different reference postures. For sEMG in the laboratory, resisted wrist extension showed 1.2 – 1.7 times higher EMG amplitudes and lower coefficient of variation than hand grip. In the field study, the workload during cleaning was lower when using resisted wrist extension as the reference than when using hand grip. The workload (99^{th} percentile) was overestimated in two subjects when hand grip was used as reference contraction. *Conclusions:* For the inclinometry method, the obtained data from the GC inclinometers were fully comparable to the data from the LT inclinometers. The simplified reference posture deviated somewhat from the standard reference, but the effect of this deviation on group recordings of work was negligible. The hotel room cleaners managed to perform self-recordings of upper arm elevations and velocities.

For the sEMG, the use of resisted wrist extension may be a more accurate maximal effort of forearm extensor contraction than using hand grip. Problems associated with poorly activated forearm extensors can be overcome by using resisted wrist extension as reference.

Abbreviations

CI – confidence interval

CR – coefficient of reliability

CV – coefficient of variation

GC inclinometer – Gulf Coast Data Concept inclinometer

ICC – intraclass coefficient

IZ – innervation zone

LT inclinometer – Logger Technology inclinometer

MEF – maximal exerted force

MVC – maximal voluntary contraction

MVE – maximal voluntary electrical activity

OHS – occupational health service

RVC – submaximal voluntary contraction

RVE – submaximal voluntary electrical activity

SD – standard deviation

sEMG – surface electromyography

WMSDs – work-related musculoskeletal disorders

List of figures

Figure 1. Systematic work environment work. 21
Figure 2. Two scenarios of static load. 24
Figure 3. Electrode pair positions for paper II and IV. 38
Figure 4. The two maximal voluntary contractions. 39
Figure 5. Variation in the simplified and the standard reference postures. 45
Figure 6. The individual upper arm velocity during work, from paper III. 49
Figure 7. The correlation between MEF and MVE, short version from paper IV. 51
Figure 8. Motor point (MP) and Innervation zone (IZ). 62

List of tables

Table 1. Examples of reported associations between adverse physical workload in various body regions and WMSDs in neck and upper extremities. 18
Table 2. Examples of factors that affect the validity for the two technical methods in this thesis. 27
Table 3. Study design, overview. 33
Table 4. Parametric and non-parametric tests for differences in percentage of time above 30° and 60° between GC and LT inclinometers. 40
Table 5. Group means of right upper arm elevations recorded with the GC and LT inclinometers, and group means of the differences between these. 43
Table 6. Group means of upper arm elevations and the percentage of time >30° during work for the simplified and the standard reference analyses. 46
Table 7. Group mean differences and group mean absolute differences of upper arm elevations between the simplified and the standard reference analyses. 47
Table 8. The within-subject variation of upper arm elevation and velocity between working days, from paper III. 49
Table 9. The group means of MEF and MVE at two electrode pair positions in paper II and IV. 50
Table 10. The maximal excerted force (MEF), the maximal voluntary electrical activity (MVE) and the muscular load (%MVE) of hotel room cleaning, from paper IV. 52
Table 11. Physical workload in hotel room cleaning during one working day. 54
Tabel 12. Post-hoc power calculations for methodologically and clinically relevant differences. 60

Introduction

Work-related musculoskeletal disorders (WMSDs)

Taken together, WMSDs constitute the most common occupational disease in the European Union [1]. Along with high monetary costs for the society, WMSDs imply severe consequences for the individual, in terms of pain and disability [2, 3]. WMSDs are injuries and disorders in the locomotor system (i.e. skeleton, muscles, tendons, ligaments, cartilage, nerves and discs). These disorders cover a wide range of inflammatory and degenerative diseases such as tendonitis, tenosynovitis, myalgias and entrapment syndromes [4, 5, 6]. The most prevalent problems are backache and muscular pains (the shoulders, the neck and upper/lower limbs) [1].

Risk factors for developing WMSDs

The risk factors for developing WMSDs include a number of different loads such as awkward and constrained postures, repetitive work (velocity) and excessive and/or prolonged muscular load. Examples of associations between body region, adverse physical load and specific WMSDs are shown in Table 1. Wrist velocity and forearm muscle activity show associations with diagnoses in the whole upper part of the body, such as tension neck syndrome, neck pain and shoulder pain. This is due to the nature of the work. As an example, assembly work such as putting together parts for a gearbox is often hand-intense (high velocity), and to be able to see properly, the subject must bend his head forward. Thus, as an indirect consequence of the hand-intense work, the subject is at risk for developing pain in the neck. This thesis focuses on reliable and cost-effective methods to ascertain work postures and velocities in the upper arms as well as muscular load in the forearms.

Also psychosocial work conditions such as high work demands and low job control have been associated with musculoskeletal disorders [7, 8, 9]. Other aspects of work may also affect the development of musculoskeletal disorders such as genetics, lighting, vibrations, temperature and noise [10, 11, 12, 13]. Furthermore, leisure time activities may play a role [14].

Table 1. Examples of reported associations between adverse physical workload in various body regions and WMSDs in neck and upper extremities.

Exposed body region	Adverse physical workload				
				Sustained muscular load	
	Velocity	Awkward postures	High muscular load	Static muscular load	Lack of muscle recovery
Neck	Shoulder pain [15]	Thoracic outlet syndrome [15] Neck pain [16]			
Shoulder muscle (Trapezius)			Subacromial impingement syndrome [17]	Cervical syndrome [15] Frozen shoulder [15] Supraspinatust endonitis [15] Infraspinatus tendinitis [15]	
Upper arm	Bicipital tendonitis [15] Infraspinatus tendonitis [15]	Tension neck syndrome [15] Subacromial impingement syndrome [18] Supraspinatus tendonitits [19] Shoulder pain [20]			
Forearm muscles (Extensors)				Neck pain [15] Infraspinatus tendonitis [15]	Pain in elbow/hand [21] Carpal tunnel syndrome [21]
Wrist	Tension neck syndrome [15] Shoulder pain [15] Carpal tunnel syndrome [21, 22] Lateral epicondylitis [23] Medial epicondylitis [21]	de Quervain´s disease [24] Lateral epicondylitis [21] Radial styloid tenosynovitis [25]			

Physical load at work

The physical loads during work are of both physiological and biomechanical nature. The physiological loads involve the respiratory and cardiovascular systems. An important measure is oxygen consumption in relation to the maximal oxygen uptake capacity per kg body weight (VO_{2max}) where 30 % of the VO_{2max} is acceptable for prolonged physical work without breaks [26]. The biomechanical loads are the forces that act on the body, which are a combination of posture, the body's mass and changes in directions and/or velocities (accelerations) of the body. The magnitude of the force that is required to create a movement of a body part (force moment), can be calculated by multiplying the perpendicular distance from the point where the force acts to the center of the body part, by the body part's mass. As an example, the force moment on the neck when the head is forward bended to approximately 60° from the upright body is calculated by multiplying the perpendicular distance from the neck to the center of the head by the mass of the head. In this thesis, physical load is defined as the biomechanical load, i.e. the mechanical forces that arise in the body during work. Pertinent aspects of this load include postures, velocities and muscular load and are assessed in amplitude, duration and frequency dimensions.

Repetitive work

Repetitive work means that the same work cycle is repeated over and over again throughout the work day. In harmful repetitive work the cycle time is short and the pace is high. Therefore, in this context, repetitive work is characterised by a high velocity. In combination with a high force, the risks of developing WMSDs increase further. One consequence of monotonous movements for e.g. the forearm and wrists are different types of entrapment syndromes such as carpal tunnel syndrome. Due to the repetitive movements, the tendon sheaths may swell and because of the limited space in the carpal tunnel, the median nerve will be squeezed between the swollen tendons. The circulation deteriorates, leading to numbness and pain [27].

Awkward postures

An awkward posture is a position where limbs and joints deviate extensively from their neutral position. Awkward postures can create large force moments on the joints and tendons and the muscles operate less efficiently. Examples of awkward postures are working with elevated arms above a certain degree, or working with a bent and/or twisted neck [19, 28, 29].

High muscular load

High muscular load is often described as heavy lifting, carrying heavy loads and pulling and pushing of heavy loads. Using hand-held tools such as chain saws and screwdrivers also often requires a considerable amount of force. Dose-response relationships between different diagnoses in the neck/shoulder region and muscular load of trapezius, as well as relationships between diagnoses in elbow/hands and muscular load of extensor muscles, have been reported [15, 21]. Strength training has been reported to improve e.g. the peak force of trapezius, along with muscle fibre growth and an increased capillarisation of the muscle [30]. Furthermore, it has also been shown that strength training increases the maximal activity of the trapezius, which in turn increases shoulder strength in women with trapezius myalgia [31]. An improved strength decreases the relative workload which may indirectly increase pain reduction.

Sustained muscular load

Sustained muscular load is often described as a low-intensive load during long time periods without short breaks [32, 33]. There is no interruption in the muscle fibre activation and this leads to an exhaustion of the fibres. One hypothesis that has been suggested to explain the pathomechanisms of sustained muscular load is the Cinderella hypothesis (first up and last to bed) and concerns muscle fibres with low recruitment threshold levels [34]. These fibres may be active throughout every contraction, and thus vulnerable to such load. Sustained tension may lead to energy depletion and accumulation of phospholipases in the muscle fibres, which damage the cell membranes [35]. This in turn leads to leakage of algesic substances (e.g. Substance P) which have been shown to be elevated in subjects with trapezius myalgia [36].

Systematic work environment work

Systematic work environment work refers to the employers' work to investigate the work environment, to implement changes and to follow them up, in order to achieve a satisfying work environment and to prevent accidents and disorders among the workers (Figure 1).

Surveillance – The physical, organisational and social working conditions should be investigated. Observational methods, questionnaires and technical methods are useful tools to examine the physical workload. It is of interest to perform clinical examinations [37], both to explore the prevalence of pain among the employees, and to detect individuals that are about to develop pain, and take actions for them. Furthermore, it is also important to investigate how the work is organised, such as job content and job rotation. Other aspects that are of importance are e.g. physical properties such as risk of falling/slipping, lighting conditions and if it is a hot/cold and/or a noisy environment.

Risk assessment – Based on the surveillance, an assessment of the impact of the work on WMSDs is performed.

Actions – The actions may be carried out in different ways depending on the risk. It could be implementation of organisational changes such as duration of work tasks, or implementation of technical measures, such as a new tool.

Control – The changes that have been decided should be controlled to investigate that they have really been implemented, and that they have had the desired effect. If the changes have not helped or if they have created new risks, a new surveillance should be carried out. Also surveillance shall be carried out recurrently and at each change of the work process.

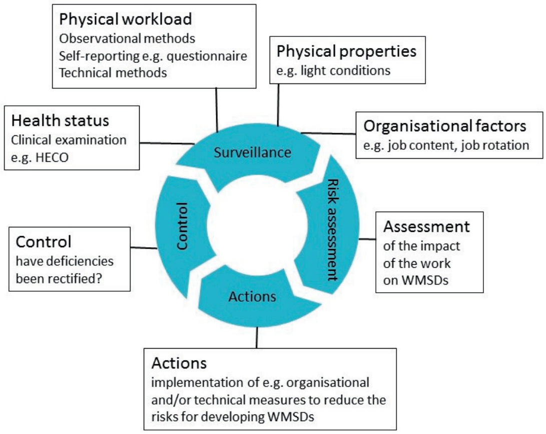

Figure 1. Systematic work environment work.
Adopted from the Swedish Work Environment Authority.

Assessment of physical workload

Self-reporting

Self-reporting is a practical tool when assessing the physical workload in large study groups. Commonly used procedures are interviews, questionnaires and/or diaries. A disadvantage with this method is that overestimation of the workload is common among individuals with pain [38]. Such overestimation leads to incorrect associations between the workload and WMSDs.

Observational methods

There are a huge number of different observational methods available. Several of them, such as the "Quick Exposure Check" (QEC) and the "Rapid Upper Limb Assessment" (RULA) are general, to suit many different types of jobs and include both the neck, shoulders, forearms and hands, and assess the applied force, static load, awkward postures and repetitive work. Others, such as the "Hand Activity Level" (HAL), includes only the forearm and hand and assess the force and repetitive work. Sometimes the methods are too general to give valuable information. In such cases, branch-specific methods are used, e.g. "Kitchen Intervention Work Load Assessment" (KILA), which is a tool for kitchen work [39] and "Movement and Assistance of Hospital Patients" (MAPO), which assesses patient handling [40]. Observational methods are often easy to use and interpret and roughly estimates postures during work. However, the results vary between observers and the different methods often give differing results when assessing the risk of developing WMSDs [41, 42, 43].

Objective technical methods

Objective technical methods provide exact numerical values of both postures and velocities during work [44, 45, 46, 47]. With technical methods it is possible to measure the muscular load [48] and to record the workload during several days [49]. They are also well suited for measuring exposure before and after changes in working techniques or when new technical appliances are implemented [50, 51]. Furthermore, as visual assessment of velocities and of force and/or exertion intensity often show a low reliability [42], technical methods may be used as a part of a risk assessment. Moreover, the risk factors for developing WMSDs have been known for a long time, but the knowledge about the quantitative exposure-response relationships are still limited. With an increased use of technical methods this knowledge could be enhanced.

The general opinion about technical methods is that they are time-consuming, require expensive equipment and technical knowledge to perform and are therefore not suitable for different actors in the work environment field. To increase the use of technical methods both among different actors in the work environment field such as the occupational health service (OHS) and among researchers, more user-friendly and less time-consuming methods are needed, both in terms of low-cost and easy-to-use equipment and easier and less time-consuming measuring procedures.

Inclinometry

An inclinometer is a sensor that measures the inclination (the angle relative to the line of gravity) of different body parts. It most often consists of a triaxial accelerometer that registers force-signals of gravity and accelerations in three orthogonal axes (X, Y and Z). However, to obtain the recorded accelerometer data as an angle relative to the line of gravity, to describe postures and movements during work, two transformations are performed [52]. The first is a transformation from the accelerometer co-ordinate system to the body-segment co-ordinate system. This is achieved by recording of two reference positions, upright and forward. With these references, the co-ordinates of any vector in the body segment co-ordinate system can be calculated from the accelerometer co-ordinate system. The second transformation is from the body segment co-ordinates to spherical co-ordinates, giving the magnitude (r), inclination (θ) and direction (φ) of the acceleration vector. This means that for e.g. the head, θ represents the extent of inclination and φ represents the direction of inclination. Thus, in the upright position, $\theta = 0°$ (the North Pole of the sphere); in the forward bending position, $\theta = 90°$ and $\varphi = 0°$; and standing on the head, $\theta = 180°$ (the South Pole of the sphere) [52]. If the upright position (the reference posture) is not adopted, an error in the calculated posture estimates may be introduced, as it cannot be assumed that one of the axes will be parallel with the line of gravity when mounted on a body part. The recorded inclinations are presented as percentiles of the angular distribution. Also the angular velocity is presented, which is the derivative of the angle.

For the upper arms, also the percentage of time when the arm is elevated more than 30°, 60° and 90° is presented. These levels are based on that they are fairly easy to assess with observational methods. However, the measures are difficult to use as a predictor for WMSDs, as they give no information about the elevation distribution below these levels. For example, a cashier spends the whole day sitting at the checkout desk with elevated arms above 30° about 20 % of the working day. This means that the rest of the time (80 %), the elevation is below 30°. But how are the arm elevations distributed during this time? She may spend all of it at 0°, or at 29°. From the pathomechanistic perspective, the scenario at 29° means that she spends the whole day at a harmful level [53], which is not reflected when only % time above 30° is derived.

Electromyography

Surface electromyography (EMG) is used to measure the muscles' response to stimulation from the nervous system, and registers the electrical voltage changes (action potentials) that propagates along the muscle cell membrane due to this stimulation. The muscle contracts, and by deriving the amplitude of the action potential signal, and relating it to the electrical activity registered during a maximal voluntary contraction (MVE), or activity during a sub-maximal voluntary contraction (RVE), an estimate of the applied force can be obtained in terms of % of MVE. The estimates are traditionally presented as the static (10^{th} percentile of the amplitude probability distribution function, APDF), median (50^{th} percentile) or peak

(90th percentile) loads. The static load however, gives little information about the exposure on low-threshold motor units, which are presumably, as described above, exposed during long time periods, i.e. as long as the muscle is active at all. Instead, other measures may be used to describe the deleterious exposure: Veiersted *et al.* have for example proposed a method for determining very short periods of inactivity (EMG gaps), and have shown that a high number of gaps per minute is associated with lower risk of neck/shoulder pain in a one-year prospective study [54, 55]. Furthermore, Østensvik *et al.* have shown that sustained low-level muscle activity (SULMA) periods, defined as continuous muscle activity above 0.5% of the MVE, longer than 10 min per hour was positively correlated, and predominantly short periods were negatively correlated, to complaints in the neck region [56]. In addition, muscular rest (% of time for muscle recovery) is defined as the percent of time when the muscle activity is below a certain level of the MVE, which often is set to 0.5 % MVE [57, 58]. Lack of muscle recovery in the forearm extensor muscles has been shown to be associated with pain in elbow/hand [21]. The shortcoming of using only the static load as a predictor for WMSDs is illustrated in Figure 2, where two scenarios are presented. For both, the 10th percentile (the static load) is 3 %MVE. However, in the first case (solid line), there is no muscular rest, whereas in the second case (dashed line) the muscular rest is 5 % of time.

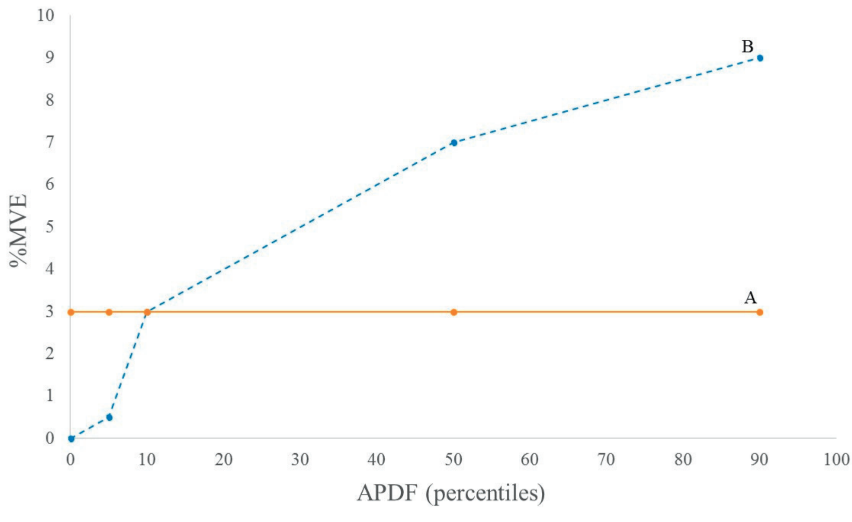

Figure 2. Two scenarios of static load.
A) Static load of 3 %MVE with no muscular rest (solid line) and B) Static load of 3 %MVE with muscular rest of 5 % time (dashed line).

The recorded EMG amplitudes are influenced by e.g. skin conductance and subcutaneous thickness and should therefore be normalised to a reference contraction. This can be obtained in a variety of different postures and loads, e.g. a maximal voluntary contraction (MVC) or a sub-maximal voluntary contraction (RVC). For the forearm extensors, a commonly used reference contraction is a maximal voluntary power grip (here referred to as hand grip) in a mid-pronated (i.e. neutral) forearm posture [47, 59, 60]. However, when using this contraction for normalisation of EMG recordings, our research group sometimes see higher EMG amplitudes during work than those obtained with the hand grip. Furthermore, in a laboratory setting we found that the muscle activity during work, expressed as %MVE, showed an intra-individual coefficient of variation (CV) that was 33 % [61]. An alternative contraction could be resisted wrist extension as this may provide a better approximation of the magnitude of maximum activation of the forearm extensor muscles than hand grip, and therefore such approach should be investigated. Furthermore, during the years we have placed the EMG electrodes on the most prominent part of the extensor muscles. It has been suggested that this position should be avoided, as this is where the innervation zone (IZ) is likely to be [62, 63]. Moreover, previous studies have also shown that the EMG amplitude varies depending on the electrode position [64, 65]. Hence, there is also a need to study different electrode positions on the forearm.

Some studies have used a submaximal voluntary contraction (RVC). The advantages of using RVC as reference is that the component of variance due to normalisation (for recordings of light assembly work) has been reported to be little (4 % of the total variance) [66]. Furthermore, Hansson *et al.* have shown that normalisation to the electrical activity obtained during the submaximal voluntary contraction (RVE) improved sensitivity to differences between work tasks compared to MVE [57]. On the other hand, when assessing workload related to the individual's capacity, the maximal contraction is preferable [67] as this makes it possible to assess the relationship between workload and WMSDs.

Goniometry

Goniometers are mounted around a joint, for registration of motions in two directions. They can e.g. be used to record dorsal and palmar flexion of the wrists, and by using a neutral (anatomical) reference position, wrist postures (and wrist velocities) can be calculated [45].

Inertial measurement units (IMUs)

An IMU is an electronic device using a combination of an accelerometer, a gyroscope and a magnetometer. By integrating information from these complementary sensor types, the limitation of each individual type is compensated for, which allows to precisely assess orientations and movements. It can of course be used as an inclinometer and with the advantage of obtaining velocities directly from the gyroscope.

Near-infrared spectroscopy (NIRS)

NIRS is a spectroscopic method that uses the near-infrared region of the electromagnetic spectrum and provides information about the oxygen saturation of haemoglobin within the microcirculation, e.g. muscle tissue [68].

Intramuscular EMG

Needle or fine wire electrodes are inserted into the muscle, which record the activity in a very small area of the muscle. The recorded voltages may be some ten mV. The advantage with this method is that it is only the activity from the muscle of interest that is recorded, in opposite to surface EMG, where adjacent muscles may interfere.

Mechanomyography (MMG)

MMG is a non-invasive technique using accelerometers, which records low frequency skin surface vibration caused by muscle contraction. The MMG may provide a useful alternative to the electromyogram (EMG) for indication of the degree of muscle activation and for monitoring muscle fatigue, when sEMG is not feasible, e.g. in adverse environments contaminated by electrical noise [69]. It has a higher signal-to-noise ratio than the sEMG and thus can be used to monitor muscle activity from deeper muscles without using invasive measurement techniques.

Pulse

Pulse measurements are very useful when studying the impact of work on the respiratory and cardiovascular systems. It is also useful in hot environments as the pulse is affected not only by the physical load, but also the heat.

Validity

Validity is basically about the relevance of measurements, i.e. the degree to which a method really measures what it is meant to measure. Validity may be divided into sub terms.

Construct validity refers to the degree to which a test measures what it claims. For inclinometry and sEMG, inclinations relative to the line of gravity and the amplitude of the electrical activity are of interest, and indeed this is what these methods register (Table 2). Thus, the construct validity is high for both inclinometry and sEMG.

Criterion validity reflects to which extent a measure is related to an outcome, and can be divided into *concurrent* and *predictive* validity. Concurrent validity is demonstrated when a method correlates well with a previously validated method. It can also refer to the practice of concurrently testing two methods at the same time. Thus, the studies in paper I and III were concurrent validity studies.

The predictive validity of a method is good if it predicts future cases of an outcome. Inclinometry measures posture and sEMG measures force. High exposures in these parameters are established risk factors for WMSDs. Thus, inclinometry and EMG methods which are concurrent valid, should also be predictively valid. [15, 21]. The predictive validity has not been evaluated in this thesis.

Content validity refers to whether a measure represents all facts of a given construct. For inclinometry, inclinations relative to the line of gravity are recorded, but the method is not able to distinguish between e.g. arm abduction and arm flexion/extension and to determine if the arms are supported or not. Furthermore, the method cannot record head rotations in the upright position. For sEMG, the muscle contraction itself and its generated force is not registered.

Table 2. Examples of factors that affect the validity for the two technical methods in this thesis.

	Validity			
	Construct	Criterion		Content
		Concurrent	Predictive	
Inclinometry	Inclination vs the line of gravity	Comparison to traditional inclinometer	Association with the risk for complaints/disorders	Inclinometry cannot distinguish between arm abduction and arm flexion/extension
				Inclinometry does not register head rotation in the upright position
sEMG forearm	Amplitude of electrical signal	Comparison between two reference contractions	Association with the risk for complaints/disorders	The method registers activity only from the exensor muscles
				The method does not register the applied force

Precision and accuracy

To be able to adequately quantify exposure, the method in question must deliver a meaningful measure of the activity. The repeated measures of the same activity, with the method, should be accurate (their average is close to the true) and precise (the values are close to each other). But what is the truth for e.g. angles of arm elevation? In a study made by Jackson *et al.*, the human ability to correctly identify normal right angles (the "Goldmeier effect") was pointed out as the truth and was used to evaluate the accuracy of obtained angles recorded with two different types of inclinometers [70]. In another study made by Bernmark *et al.*, an optoelectronic measuring system was considered to be the truth [71], while it in a study made by Korshøj *et al.* was a magnetic tracking device [72]. However, in the case with e.g. the optoelectronic system, the reference points (reflective spherical markers applied on the skin to a body segment) of this system may not coincide with e.g. the long axis of the humerus, which should be considered as the real truth. As there is no "official" gold standard, comparison with existing approved/established equipment may be performed when evaluating the precision and accuracy of new sensors.

Reliability

A high reliability means that the result is the same in repeated measurements (test-retest reliability) and regardless of who is performing the measurements (inter-observer reliability). A high reliability is presumed for high validity but it does not guarantee a high validity, as other parameters such as to which degree a method really measures what is intended to measure, is included in this concept.

Repeatability

Repeatability is a measure of a method's precision. In the context of an experiment, repeatability measures the variation in measurements taken by a single person or instrument under the same conditions and in a short period of time, e.g. repeated measurements of the reference position for the upper arms.

Hotel room cleaning

Cleaning is a job with high physical demands. The work tasks are highly repetitive (e.g. vacuuming, polishing, wiping and mopping), involve awkward postures (e.g. cleaning the toilet and bathtub, making the bed and cleaning under the furniture's) and require high force exertions. Several studies around the world have reported a high prevalence of WMSDs among cleaners [73, 74, 75, 76]. It is predominantly females with a low socio-economic status that work as cleaners and they have little control over their work. They represent an invisible workforce as their work is undertaken outside standard working hours and often unnoticed by the rest of the workforce. They self-report a high workload and a high incidence of pain, especially in the neck/shoulder region and in the back, but also in the elbows, wrists, knees and feet. A high proportion of the cleaners take painkillers to be able to work and many of them also have sleeping problems due to the pain. Their problems are not always taken seriously. There are suspicions that their pain is due to other factors that are linked to their low socio-economic status. However, with objective technical methods it is easy to determine whether the workload is too high. The hotel cleaning industry is in major need for changes and it is therefore important to perform cost-effective risk assessments of the cleaning job, and to take actions based on these, to reduce the risks for developing WMSDs. Technical measurements can be used, as a part of the risk assessment, to objectively record the physical workload during cleaning.

Aim

To simplify the inclinometry method in order to make it easier to use for different actors in the work environment field such as the occupational health service (OHS), safety personnel, employers and employees by…

…comparing recorded data of work postures and velocities from a low-cost, easy-to-use triaxial accelerometer with integrated data logger (GC inclinometer) with data from our traditional inclinometer (LT inclinometer).

…evaluating the deviation of two simplified reference postures from a standard reference posture.

…exploring if employees can record their own physical workload of upper arm by themselves.

…evaluating if self-recordings of workload have the same quality as recordings performed by researchers.

To refine surface electromyography of the forearm extensor muscles for more accurate estimates of the recorded muscular load during work by…

…evaluating the EMG amplitude and repeatability of hand grip and resisted wrist extension, and four electrode pair positions, in recordings of for forearm extensor muscle MVCs.

…assessing the effects of hand grip and resisted wrist extension, and two of the four electrode pair positions, on field recordings of hotel room cleaning.

Materials and Methods

This thesis includes two laboratory studies and two field studies, all concerning technical recording with respect to physical load at work. An overview of the studies is shown in Table 3.

Table 3. Study design, overview.

	Subjects (N)	Gender	Type of study	Type of work	Technical method	Aim
Paper I	12	6 ♀ 6 ♂	Laboratory	Simulated work tasks	Inclinometry	To simplify the method
Paper II	12	6 ♀ 6 ♂	Laboratory	MVCs	sEMG forearm	To refine the method
Paper III	28	24 ♀ 4 ♂	Field	Hotel room cleaning, office cleaning	Inclinometry	To simplify the method
Paper IV	13	13 ♀	Field	Hotel room cleaning	sEMG forearm	To refine the method

Subjects

For the laboratory studies (paper I and II), the subjects were colleagues at the Division of Occupational and Environmental Medicine at Lund University. Both women and men (50/50) were included. For the field studies (paper III and IV), the subjects were employees working at nine different hotels and one cleaning company in the southern part of Sweden. Twenty-four (20 women and four men) of them worked as hotel cleaners and four (all women) worked as office cleaners. Five of the subjects participating in paper III also participated in paper IV. Twenty-five of the cleaners in paper III answered a questionnaire on musculoskeletal symptoms. Twenty-four (96 %) of them reported complaints/pain in at least one body region during the past seven days, where 22 (88 %) of these reported complaints/pain in more than one body region. There was a high proportion of immigrants among the subjects in paper III (and IV) who spoke English and Swedish of varying quality.

Despite this, the subjects were able to perform self-recordings of upper arm elevation and velocity, which indicates that the protocol was easy to follow.

An additional data collection was made for Evaluation of the Repeatability of the Standard Reference Posture (ERSRP). Twenty colleagues, 18 women and 2 men, at the Division of Occupational and Environmental Medicine participated. They performed their ordinary work tasks during one working day, with interruption for performance of the standard reference posture (4 times * approximately 5 minutes).

Inclinometry

Study design

In paper I, each of the twelve subjects performed four different five-minute simulated work tasks; simulated painting work, simulated computer work, simulated furniture polishing and rest with elevated, supported arms. The tasks were selected to represent different combinations of high/low angles and high/low velocities of the head, upper back and both upper arms and was used for comparison of data between the new inclinometers (GC) and the traditional inclinometers (LT). The subjects also adopted two simplified reference postures for the upper arms, to evaluate the deviation of these from a standard reference. The simplified reference postures were considered to be easier to adopt by the subjects themselves, as no chair and dumbbell were needed.

Paper III included two parts. In part one, 24 hotel cleaners and four office cleaners received a protocol with instructions on how to perform self-recordings of upper arm elevations. They started and attached a GC inclinometer to their upper arm, and adopted a simplified reference posture. Thereafter, a researcher instructed each of them to adopt the standard reference posture. The subjects wore the GC inclinometer continuously for 2 or 3 days. The cleaners noted starting and stopping times of work and lunch breaks for each day in a provided form. The protocol with instructions was continuously improved during the study. In part two, the researchers attached the GC inclinometer to the upper arm on each of 13 female hotel room cleaners and instructed them how to adopt the standard reference posture. The cleaners wore the GC inclinometer during one working day, accompanied by the researchers. In addition, GC inclinometers were attached to the head, upper back and left upper arm, to study the workload also for these body parts. The results are reported in the Results section; “Physical workload in hotel room cleaning”.

The data collection for the ERSRP was carried out in the laboratory at the Division of Occupational and Environmental Medicine.

Methods

Depending on mounting location along the arm, arm movements can result in varying rotation of the inclinometer in relation to the humerus. In paper I, one LT inclinometer was fixed to each of four GC inclinometers. With such approach, i.e. mounting the two types of inclinometers on top instead of e.g. along each other, the impact of skin movements and changes in muscle shape (soft tissue artefacts) that might occur during upper arm movements may be reduced. Moreover, the LT inclinometers were considered as the truth, as they have proved to have a mean absolute accuracy of 1.3° when validated in a rigid jig using graduated arcs [52]. But to be completely certain that validation against the real truth is performed, without bias from e.g. rotations and soft tissue artefacts, some kind of markers would have to be inserted into the bones, e.g. the humerus, to assess its exact position for e.g. 0°, 30°, 45°, 60°, 90°, 120°, 150° and 180°.

The standard reference posture for each upper arm (0° of elevation) was performed with the subjects seated, with the side of the body leaning towards the back of the chair, and the arm hanging vertical over the back of the chair, with a 2-kg dumbbell in the hand [77]. This proceeding has been used in a large number of studies [48, 78, 79, 80]. However, this standard reference posture require a chair and a dumbbell to adopt. To make this procedure easier to adopt, without the need of a chair and a dumbbell, we included two simplified reference postures (posture 1 and posture 2) in the study. For posture 1, the researcher instructed the subjects to stand upright, lean to the right (or left) with the arm hanging vertically towards the floor with extended elbow and fingers, and with the wrist in neutral position. Posture 2 was adopted as posture 1, but with relaxed fingers and hand.

In both part one and two of paper III, an updated version of the GC inclinometer from paper I was used. In part one, the subjects adopted the simplified reference posture (posture 2 from paper I) by themselves, and repeated it each morning. In addition, after the researcher had done a brief visual inspection of that the GC inclinometer had been attached properly, each subject was instructed to adopt the standard reference posture. With this approach, the within subject variation of the simplified reference posture in relation to the standard reference posture could be evaluated. Furthermore, by wearing the GC inclinometer continuously for two or three days, also the within subject variation of the workload between working days could be studied.

ERSRP - evaluation of the repeatability of the standard reference posture

One GC inclinometer was attached to each subject's right upper arm. The subject was then asked to perform five toe jumps, which were later on used for easier identification of the reference posture part of the recording when analysing the recording. The researcher then instructed the subject to adopt the standard reference posture. Thereafter, the subject was asked to perform the toe jumps again. The reference posture and the toe jumps were repeated another four times during the working day, with approximately 1 ½ h in between. The times when adopting the reference postures were noted. The deviation from the first standard reference posture was derived for each of the following four occasions.

Power calculation and sample size calculation

A sample size calculation was performed prior to the study, where relevant differences between repeated measures of the standard reference posture were judged to be acceptable up to 2°. As the differences between repeated measures of the reference postures were expected to be small, the SD was estimated to be about 2°. With these assumptions, 16 subjects were estimated to be needed for detection of a statistically significant difference of 2° with 80 % power.

Data processing and analyses

The data from the LT inclinometers in paper I were processed in EMINGO (a program for analysing field recordings of ElectroMyography, INclinometry and GOniometry), developed at Occupational and Environmental Medicine in Lund. The data were low-pass filtered (5 Hz) and calibration values generated at a previous recordings for +1 g and -1 g for all three axes for each inclinometer were used for calibration. The 1st, 10th, 50th, 90th and 99th percentiles of the angular distributions of head and back forward/backward inclinations and upper arm elevations were derived. Also the percentage of time with the arms elevated more than 30°, 60° and 90°, and the median of the forward/backward angular velocity distributions of head and back and the generalised angular velocity distributions for the upper arms were calculated.

In paper I and III, the signals from the GC inclinometers were pre-processed in MATLAB. The four GC inclinometers were synchronised to each other and digitally resampled to 20 Hz. The data files were then fused into one file and the remaining processing was made in the same way as the LT inclinometer files. Thus, the same percentiles of inclinations and percentages of time that was obtained for the LT inclinometers were also calculated for the GC inclinometers.

For paper I, this allowed us to assess the overall differences (the group mean of the absolute differences) and the systematic differences (group mean of GC minus LT) of the different measures between the two types of inclinometers. The correlations between pairs of inclinometers were also calculated, using the cross-correlation function [81]. Furthermore, the group mean of the deviation of posture 1 and posture 2 from the standard reference posture was calculated. Finally, the group mean absolute differences between analyses when using the standard reference posture as reference and when using the simplified reference posture (posture 2) as reference were calculated.

For paper III, the data were analysed twice, once using the simplified reference posture as reference (simplified reference analysis) and once using the standard reference as reference (standard reference analysis), for evaluation of the quality of the self-recordings. Group means of arm elevation were calculated for comparisons between the two analyses. In addition, for each subject the differences between the results derived from the two analyses, as well as the absolute differences were calculated. Thereafter, the group means of both the differences and the absolute differences were calculated. Furthermore, the difference between the simplified reference posture and the standard reference for each subject was calculated. The within-subject variation using the first and second simplified reference postures for 19 subjects were assessed. Also the within-subject variation of workload between the first and second working days for 22 subjects were calculated. These 22 recordings were divided into hotel housekeeping (cleaning hotel rooms) and hotel housekeeping+ (cleaning hotel rooms but also corridors, conference rooms, dining rooms and/or pool areas), and the workload under these working conditions were compared.

sEMG

Study design

In paper II, the electrical activity of the right forearm extensor muscles was recorded from four different electrode pair positions on three separate occasions. On each occasion, three MVCs of two different types, hand grip and resisted wrist extension, were performed.

For paper IV, the electrical activity of the right forearm extensors at two of the four different electrode pair positions from paper I was recorded during one working day of hotel room cleaning. Each of the 13 female subjects performed three efforts of each of the two MVCs from paper I, hand grip and resisted wrist extension before they started work. A researcher followed each subject during the working day and noted exact starting and stopping times of different work tasks and lunch breaks.

Methods

For paper II and IV, two Ag/AgCl electrodes were applied to the skin above the most prominent part of the forearm extensor muscles (extensor carpi radialis brevis and longus) [61]. Two additional electrodes were applied proximal to the original pair. Furthermore, for paper II, one more electrode was applied distally to the original pair. These arrangements allowed recordings to be made, as shown in Figure 3, from four pairs of electrodes in paper II and from two pairs of electrodes in paper IV.

The signals were amplified, filtered (in paper II; 10 – 400 Hz and in paper IV; 200 – 4800 Hz) and sampled at a rate of 1024 Hz. The signals were stored on a portable data logger using memory cards. After the recording, the data were transferred to a computer for analysis where the EMG signals were digitally band-pass filtered (30 – 400 Hz) and notch filtered (mains frequency, 50 Hz, and all its harmonics). The root-mean-square value was calculated for periods of 0.125 s, and the noise was subtracted in a power sense [82]. A moving window with a width of 0.5 s was used to find the highest EMG activity resulting from the three efforts of MVCs for each kind of contraction [82, 83].

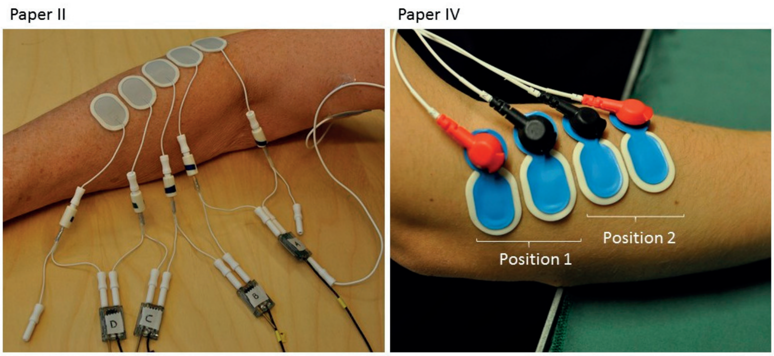

Figure 3. Electrode pair positions for paper II and IV.
For paper II, the electrodes were numbered 1 – 5 starting at the elbow. The signals were recorded from four pairs of electrodes (A – D). For paper IV, the electrodes were numbered 1 – 4 starting at the elbow, and the signals were recorded from two pairs of electrodes (position 1 and 2). Electrode pair A = position 1 and electrode pair C = position 2.

Maximal voluntary contractions (MVCs)

Resisted wrist extension – The subject sat on a chair without armrests with the elbow flexed and with the forearm pronated and supported on a table. The hand was inserted into a glove, which was attached to a sheet of plywood. A metal ring was attached to the underside of the plywood, through which the middle finger of the glove was passed. A non-flexible strap went through the ring which was attached to a force transducer on the floor. The hand was outside the table while the wrist was supported on the table (Figure 4). The wrist remained in the neutral position during the attempts of maximal extension, and care was taken to ensure that the plywood sheet remained horizontal.

Hand grip – The subject performed a maximal isometric grip around a Jamar dynamometer while seated with a backrest, with the right upper arm close to the body, with the elbow flexed at 90° holding the forearm and hand without support in a mid-pronated (neutral) position, and with the wrist slightly extended.

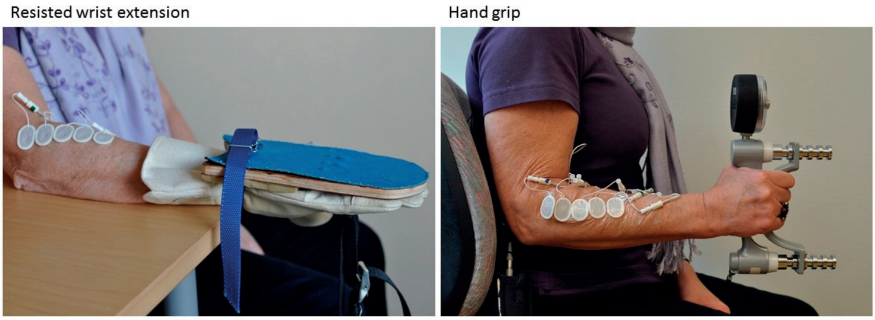

Figure 4. The two maximal voluntary contractions.
The two MVCs included in paper II and IV.

Data processing and analyses

In paper II, the mean EMG amplitude (µV) across occasions for each pair of electrodes and each type of MVC was calculated for each subject, as well as the group mean of these means. The standard deviation (SD) and the coefficient of variation (CV; SD/mean) for the MVCs were calculated for each subject for the three different occasions. The group mean of the CVs were then calculated. Furthermore, to derive a combined measure of goodness (the combination of high amplitude and low CV) the ratio between the group mean EMG amplitude and the group mean CV (group EMG_{amp}/CV) was calculated.

For paper IV, each recording made during cleaning was analysed twice; once using resisted wrist extension as the reference contraction and once using hand grip as the reference, which resulted in four separate results for each subject. The 90th and 99th percentiles of the amplitude distribution (expressed as %MVE) and muscular rest (% of time; EMG amplitude below 0.5 % MVE) during work were calculated for each subject and for the four sets of data. The highest maximal exerted force (MEF; Newton) recorded during the three efforts of each of the two MVCs was used to calculate the individual ratios and the group mean ratios between the two MVCs at both electrode pair positions. The ratios were also calculated for the MVE and the %MVE (99th percentile).

Statistical analyses

For all statistical analyses in all papers, a p-value <0.05 was used to indicate a statistically significant difference.

One-sample t-test

In paper I, comparisons between the group means of the inclination percentiles, the median angular velocities and the percentage of time above 30°, 60° and 90° for the four body parts and work tasks for the two types of inclinometers were performed with one-sample t-test, and 95 % confidence intervals (CI95) were calculated for the mean differences. As the data were not normally distributed, non-parametric tests may have been used. Therefore, binomial tests were later on performed, and are for some of the differences reported in Table 4 together with the corresponding t-tests. In fact, with the binomial test 15 out of the 24 tested differences were statistically different, for the t-test only 6. For example, for the left arm in computer work for the percentage of time >60° the binomial test showed a statistically significant difference (though very small) which was not shown with the t-test. One of the significant differences reported with the t-tests disappeared when using the binomial tests (percentage of time >30° for the left arm in furniture polishing). However, the differences that were shown to be significant were so small that they may be considered irrelevant.

Table 4. Parametric and non-parametric tests for differences in percentage of time above 30° and 60° between GC and LT inclinometers.
One sample t-test reporting mean difference with 95 % confidence interval (CI95). Binomial test reporting median difference between the 25th and 75th quartiles and the proportion of recordings with a difference ≤ 0 % of time. N = 12.

	LT inc	One-sample t-test		Binomial test		
		Mean (CI95)	p-value	Median (25th and 75th quartiles)	% ≤ 0	p-value
percentage of time >30°						
left arm furniture polish	45	-0.5 (-0.9 – -0.1)	0.02	-0.3 (-1.0 – -0.01)	75	0.1
percentage of time >60°						
right arm painting	8.5	-0.2 (-0.3 – -0.1)	0.005	-0.2 (-0.3 – -0.1)	92	0.006
left arm painting	34	-1.0 (-1.4 – -0.7)	<0.001	-0.9 (-1.6 – -0.6)	100	<0.001
right arm computer work	0.5	-0.00 (-0.02 – 0.02)	0.9	0.00 (-0.02 – 0.01)	75	0.1
left arm computer work	1.3	-0.06 (-0.16 – 0.04)	0.2	-0.00 (-0.05 – 0.00)	100	<0.001

Wilcoxon signed-ranks test

In paper III, as the data were not normally distributed, comparisons between group means of upper arm elevation for the two reference analyses were performed using Wilcoxon signed-rank test. In paper IV it was used for comparisons between the four sets of data (2 MVCs * 2 electrode pair positions).

Kruskal-Wallis one-way analysis of variance

Comparisons between group means of different types of cleaning in paper III were performed using Kruskal-Wallis one-way analysis of variance.

Mann-Whitney U-test

In paper III, Mann-Whitney U-test was used to perform post hoc analyses for p-values <0.05 of different types of cleaning.

One-way analysis of variance (One-way ANOVA)

In paper III, the within-subject SDs of the simplified reference posture and of the upper arm elevations and velocities between working days were calculated using one-way ANOVA. The SDs were then used to calculate the repeatability coefficients (CR). Furthermore, the mean squares between subject and within subject assessed from the ANOVA model were used to calculate the intraclass coefficients (ICC). The repeatability coefficient describes the absolute difference between two measurements on a subject which is expected to differ by no more than the reported value on 95 % of the occasions. For the reference posture a low repeatability coefficient is desirable. For the workload, a high repeatability coefficient is preferable, as this indicates a variation in workload between working days for each subject, which is recommended to reduce the risks for developing WMSDs [84]. The ICC is a measure of the proportion of the total variance that is attributable to differences between subjects, and the remaining differences are then within subjects.

The same procedure was repeated for the ERSRP.

Pearson´s correlation coefficient

As the residuals of the MEF and MVE in paper IV were normally distributed, the Pearson´s correlation coefficient, r, was used for correlation analyses between the MEF and the MVE for all four sets of data.

Linear mixed regression model

For paper II, the effect of MVC on the EMG amplitude was calculated using a linear mixed regression model, with a random intercept for each individual and with MVC and occasion included as fixed factors. The ICC for the two MVCs and the four electrode pair locations were calculated from the models fitted for each type of MVC separately.

Results with comments

Inclinometry

GT inclinometer versus LT inclinometer

Inclination, percentage of time and angular velocity

In paper I, the right upper arm elevations at all percentiles and the percentage of time >30°, >60° and >90° were almost identical for the two types of inclinometers. In Table 5, the 50th and 90th percentiles of right upper arm elevation and the percentage of time >30° for simulated painting work and simulated computer work for the two inclinometers and the differences between these are reported. The highest group mean absolute difference between the two types of inclinometers were seen for the left arm in simulated painting work at the 90th and 99th percentiles of arm elevation (2.4°). For each of all the other work tasks and body parts at all percentiles the differences were <1.7° (examples of the differences are reported in Table 5). The differences were smaller than e.g. the between-days and between-subjects variability of upper arm elevation in strictly standardised work tasks [77].

The group means of the absolute difference for the percentage of time above 30°, 60° and 90° of upper arms and all four work tasks were <1.3 %time (one example reported in Table 5).

Table 5. Group means of right upper arm elevations recorded with the GC and LT inclinometers, and group means of the differences between these.

Group means at the 50th and 90th percentiles and the percentage of time above 30° for the 12 subjects in paper I, as well as group means of the differences calculated for each subject.

	Painting			Computer work		
	GC	LT	difference	GC	LT	difference
	Mean (range)	Mean (range)	Mean (range)	Mean (range)	Mean (range)	Mean (range)
Percentile (°)						
50th	30 (25 – 35)	31 (26 – 35)	-0.4 (-1.1 – 0.2)	28 (18 – 43)	28 (18 – 42)	-0.2 (-1.4 – 0.3)
90th	58 (40 – 97)	57 (42 – 94)	-0.03 (-1.2 – 2.9)	35 (21 – 52)	34 (21 – 52)	-0.1 (-1.1 – 0.3)
Percentage of time						
>30°	51 (35 – 71)	52 (37 – 72)	-1.0 (-3.4 – 0.4)	44 (0 – 100)	44 (0 – 100)	-0.4 (-2.0 – 0.4)

The group means of the absolute difference of the median angular velocity for each of the four work tasks and the four body parts were <5.0 °/s, with the highest difference for the left arm in rest with elevated, supported arms. This difference is most likely due to a higher noise level in the GC inclinometers than in the LT inclinometers. As the activity were very low in the rest task, this noise became "visible" in the output signal. However, as most occupations have a higher degree of activity than the rest with elevated, supported arms, this phenomenon may have a limited impact on field recordings of physical workload. Furthermore, with the updated version of the GC inclinometer (used in paper III) with higher resolution and lower noise performance this problem is minimised.

Sample by sample correlation and difference

The correlation between paired signals for each of all of the work tasks and body parts were >0.98, except for the rest with elevated, supported arms, where the group mean correlations ranged between 0.91 and 0.98. The reason for this is discussed above. Further, the sample by sample group mean absolute differences were <2.5° for all work tasks and body parts. The cross correlation value is a measure of how well two signals follow each other and the absolute difference is a measure of how far the signals are from each other. Thus, the signals from the two types of inclinometers coincided well (except for the rest with elevated, supported arms) and were close to each other.

Simplified reference posture versus standard reference posture

For posture 2 (simplified reference posture) in paper I, the group mean of the differences in relation to the standard reference posture were 5° (range 1 – 8°) for the right arm and 9° (range 5 – 12°) for the left.

In paper III, the group mean of the differences between the two reference postures of right arm for day 1 was 9° (range 1 – 21°), which was somewhat higher than the difference between the reference postures in paper I. This difference is likely due to the fact that the simplified reference posture in paper I was adopted by instructions and corrections from a researcher, in contrast to the simplified reference posture in paper III, where the reference was adopted by the employees themselves.

For the ERSRP, the group mean of the first occasion was 4° (range 1 – 17°). This was less than half of which was seen for the simplified reference posture in paper III.

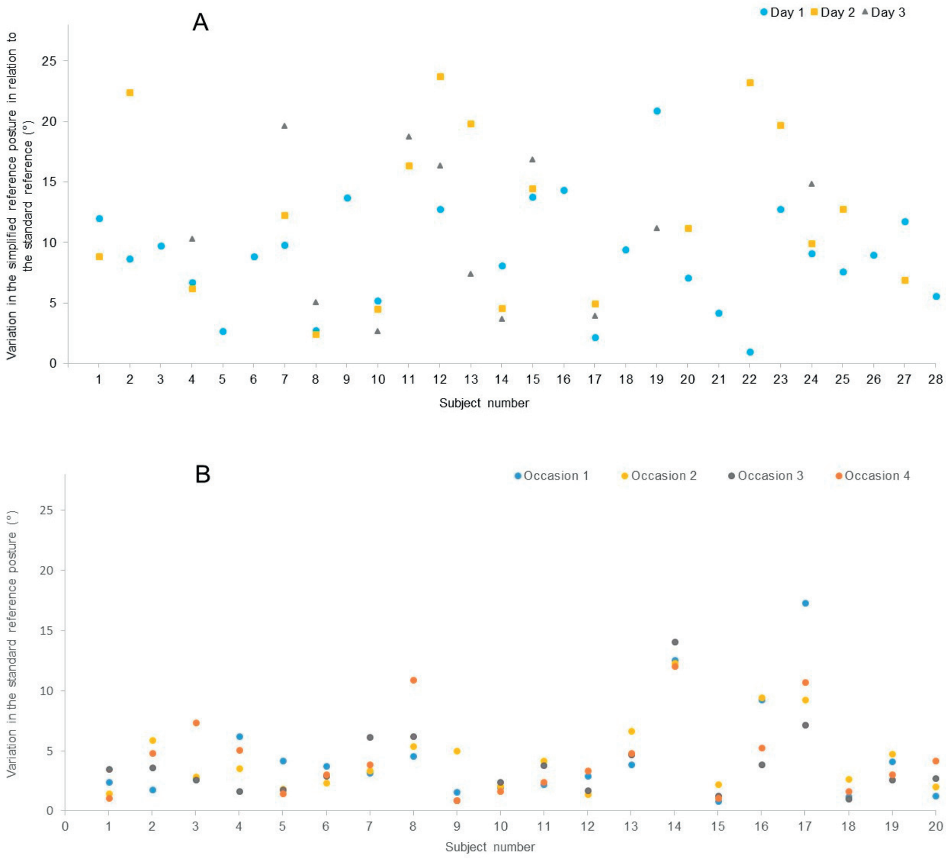

Figure 5. Variation in the simplified and the standard reference postures.

A) Variation between days for the simplified reference posture (paper III) in relation to the standard reference posture adopted at day 1

B) Variation between four occasions of the standard reference posture (ERSRP) in relation to the standard reference posture.

Within-subject variation of the simplified and standard reference postures

The within-subject SD was 5.6° (CI95 3.7 – 7.5°) for the simplified reference posture, with a CR of 16° and an ICC of 0.2. The differences between the simplified reference posture and the standard reference posture for each of the 28 subjects in paper III on days 1, 2 and 3 are shown in Figure 5A.

For the ERSRP, the within-subject SD was 1.8° (CI95 1.5 – 2.1), with a CR of 5° and an ICC of 0.7. Thus, the repeatability was higher for the standard reference posture. The variation for each of the 20 subjects for 4 occasions are shown in Figure 5B.

As the within-subject variation was rather poor for the simplified reference posture with a high CR and a low ICC, a recording of upper arm elevations analysed with the simplified reference posture at only one occasion should be interpreted with caution. The standard reference posture has a higher repeatability than the simplified one, and is thus more reliable.

The group means of upper arm elevations and the percentages of time >30° >60° and >90° during work were very similar between the simplified reference analysis and the standard reference analysis for both paper I and III (Table 6).

Table 6. Group means of upper arm elevations and the percentage of time >30° during work for the simplified and the standard reference analyses.
Paper I = Group means of the simulated work for the 12 subjects. Paper III = Group means of cleaning (across 2-3 working days) for the 28 subjects .

	Simplified reference analysis		Standard reference analysis	
	Paper I	Paper III	Paper I	Paper III
Percentile (°)	Mean (range)	Mean (range)	Mean (range)	Mean (range)
50^{th}	54 (16 – 155)	30 (20 – 47)	54 (13 – 150)	30 (22 – 38)
90^{th}	68 (19 – 157)	64 (45 – 91)	68 (21 – 153)	64 (50 – 86)
Percentage of time				
>30°	55 (0.2 – 100)	49 (27 – 78)	56 (0 – 100)	49 (34 – 63)

In paper I, the group mean of the difference in workload (simulated work) at the 50^{th} percentile of upper arm elevation between the simplified reference analysis and the standard reference analysis was 0° (Table 7). The group mean of the absolute difference was 3°. For the percentage of time >30°, the group mean difference was -1.4 % and the mean absolute difference was 6 %.

In paper III, the group mean of the difference in workload (average of 2-3 working days of cleaning) at the 50^{th} percentile of elevation was 0.2°. The group mean of the absolute difference was 4°. For the percentage of time >30°, the group mean difference was 0.3 %, and the group mean absolute difference was 9 %. The differences seen at the 50^{th} and 90^{th} percentiles of upper arm elevation between the two analyses were at the same size as the between-days and between-subjects variability of upper arm elevation during strictly standardised work tasks [77].

The group mean of the absolute difference for the percentage of time >30° for upper arms between the two analyses were rather large in both paper I and III. This clearly shows that a minor difference between two reference postures have a large impact on this measure. Therefore, together with the fact that it gives no information about the distribution of upper arm elevations beyond the specific level, it may not be suitable to use to describe the physical load during work when using the simplified reference posture as reference.

The differences between the two analyses were smaller than the differences between the two reference postures for both paper I and III, which may be explained by the triangle inequality; the difference between two distances of one of each of two different reference points and one certain elevation point on the unit sphere is smaller than the distance between the two reference points. Thus, differences seen between different reference postures are always smaller than the differences seen between analyses of workload. See a more explicit explanation in paper III.

The simplified reference posture is sufficient on a group level for recording of upper arm elevation.

Table 7. Group mean differences and group mean absolute differences of upper arm elevations between the simplified and the standard reference analyses.
Paper I = Group means of the simulated work for the 12 subjects. Paper III = Group means of cleaning (across 2-3 working days) for the 28 subjects .

	Paper I	Paper III
	Mean (range)	Mean (range)
Mean difference (°)		
50th	0.0 (-7 – 7)	0.2 (-7 – 10)
90th	-0.1 (-8 – 7)	-0.2 (-12 – 8)
percentage of time >30°	-1.4 (-64 – 20)	0.3 (-18 – 21)
Mean absolute difference (°)		
50th	3.0 (0.1 – 7)	4.2 (0 – 10)
90th	3.1 (0 – 8)	4.2 (0 – 12)
percentage of time >30°	6.2 (0 – 64)	9.3 (0 – 21)

The protocol and the subjects´ perception of self-recording

The protocol in paper III was tested in an occupation with a high proportion of immigrants, where the subjects spoke English and Swedish but with varying quality. Despite this, they were able to follow the instructions in the protocol and performed self-recordings of upper arm elevation and velocities. This indicates that the protocol was easy to follow and may be used by most employees. The protocol includes three parts:

1) Starting the GC inclinometer.
2) Attaching the GC inclinometer to the upper arm.
3) Adopting the simplified reference posture.

No subjects were excluded due to an incorrect placement of the GC inclinometer. Still, the protocol was improved during the ongoing study. The changes appeared to make it easier for the subjects to follow the instructions, as the help needed decreased with improved versions. However, the protocol was not improved systematically and the changes made were not evaluated in a systematic manner.

Instead, the changes were made based on how comfortable and secure the subjects seemed to be when they attached the GC inclinometer and adopted the simplified reference posture. According to the questionnaire which the subjects answered after their participation, all subjects except one were positive to the self-recording. The latest version of the protocol is attached at the end of this thesis (Appendix).

Variation in workload between days

With the new approach of self-recordings, allowing three recording days, the within-subject variation in workload between days could easily be studied. The CRs and ICCs of the 50^{th} and 90^{th} percentiles of upper arm elevations and the median angular velocity for hotel room cleaning and hotel room cleaning+ are reported in Table 8. For hotel room cleaning, the within-subject variation was low, with a CR of 1.6° for the 50^{th} percentile of upper arm elevation, which indicates that the work is repetitive and monotonous. The individual variations of upper arm velocities between days are shown in Figure 6. Several of the subjects had almost identical velocities during their different working days. For hotel room cleaning+, the within-subject variation was somewhat higher with a CR of 4.8°, and thus more varied than hotel room cleaning. The difference between the two types of cleaning were more obvious for the median angular velocity, where hotel room cleaning had a CR of 13 °/s while hotel room cleaning+ had a CR of 33 °/s. Thus, hotel room cleaning+ is more advantageous than the hotel room cleaning, as variation in workload is beneficial from the viewpoint of preventing WMSDs [84]. Furthermore, the group mean velocity was 18 °/s lower in hotel room cleaning+. In addition, both hotel room cleaning and hotel room cleaning+ showed upper arm velocities above the action level for preventing WMSDs suggested by our department (discussed below in the Results section; “Physical workload in hotel room cleaning”).

Table 8. The within-subject variation of upper arm elevation and velocity between working days, from paper III.
The group mean, the within-subject SD (° or °/s; 95% confidence interval, 95CI), the coefficient of repeatability (° or °/s; CR) and the intraclass correlation coefficient (ICC) of upper arm elevations at the 50th and 90th percentiles of the angular distribution and the median angular velocity (°/s) between working days for 22 subjects. Self-recordings of hotel room cleaning (cleaning hotel rooms) and hotel room cleaning+ (cleaning hotel rooms and other tasks such as cleaning corridors). The standard reference posture was used as reference.

Percentile	Hotel room cleaning (n=11)				Hotel room cleaning+ (n=11)			
	Group mean (° or °/s)	Within-subject SD (95CI)	CR (° or °/s)	ICC	Group mean (° or °/s)	Within-subject SD (95CI)	CR (° or °/s)	ICC
50th (°)	29	0.6 (0.3 - 0.9)	1.6	0.98	28	1.7 (0.9 - 2.5)	4.8	0.86
90th (°)	64	1.5 (0.8 - 2.2)	4.1	0.97	62	4.4 (2.3 - 6.4)	12	0.80
velocity (°/s)	81	4.7 (2.5 - 6.9)	13	0.93	63	12 (6.4 - 18)	33	0.66

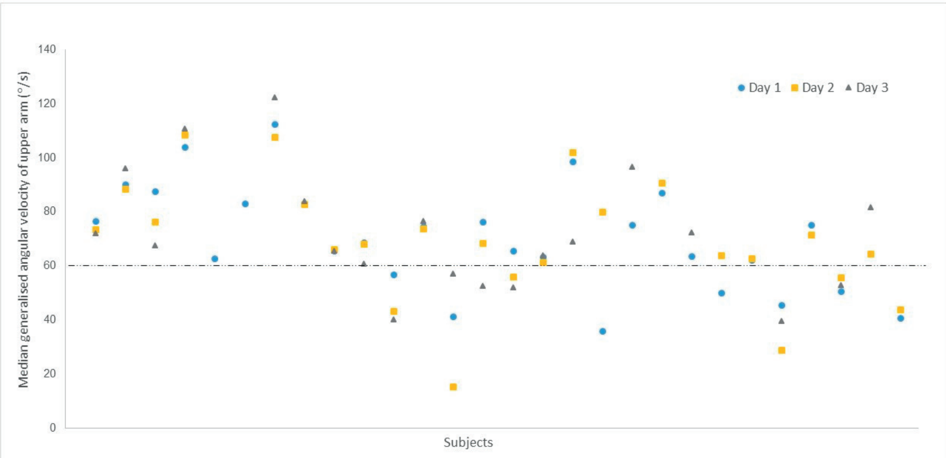

Figure 6. The individual upper arm velocity during work, from paper III.
The median generalised angular velocity during work for the 28 subjects for day 1, day 2 and day 3. The dashed line is the action level for the prevention of WMSDs.

Maximal voluntary contractions and electrode positioning

In both paper II and IV, the highest group mean MVEs were, for both electrode pair positions (1 and 2), found for resisted wrist extension (Table 9). In paper II, these values were 1.7 and 1.4 times higher than for hand grip. In paper IV, corresponding values were 2.3 and 1.8. The variation in resisted wrist extension over the three occasions (paper II), in terms of the group mean CV was 14 % for both electrode pair positions. For hand grip it was 22 – 23 %. The highest group mean MVE/CV ratio (combined measure of goodness) over the three occasions was derived for resisted wrist extension. The repeatability, in terms of ICC, was moderate (values between 0.50 and 0.75) for both contractions and both electrode pair positions.

The group mean MVEs for the two contractions varied considerably with electrode positioning (Table 9). This is likely due to skin movements, arm positions, influence of surrounding muscles and the distance from the IZ [85, 86, 87].

Table 9. The group means of MEF and MVE at two electrode pair positions in paper II and IV.
For paper II the group mean of the means across three occasions of the maximal exerted force (MEF, Newton) and the group mean of the means across three occasions of maximal voluntary electrical activity (MVE; µV), the coefficient of variation (CV; %), the MVE/CV ratio and the intraclass correlation coefficient (ICC) is reported. For paper IV the group mean of highest value of the MEF is reported.

Contraction	Electrode position	Paper II					Paper IV	
		MEF (Newton)	MVE (µV)	CV (%)	MVE/CV	ICC	MEF (Newton)	MVE (µV)
Resisted wrist extension	1	90	718	14	51	0.70	72	846
	2		628	14	46	0.62		439
Hand grip	1	408	431	22	20	0.62	288	372
	2		470	23	20	0.68		241

Correlation between MEF and MVE

In paper IV, the correlation between the MEF and MVE was lower at position 1 ($r = 0.07$, $p = 0.8$; Figure 7) than at position 2 ($r = 0.62$, $p = 0.02$). The values for hand grip were $r = 0.01$ ($p = 1.0$) at position 1 and $r = 0.33$ ($p = 0.3$) at position 2. As the muscle activity is used as a proxy for muscle exertion during work, a high correlation between MVE and the applied force when performing the MVC is desirable. However, as described above, the MVE is influenced by e.g. electrode position and subcutaneous thickness, which affects the correlation. For the resisted wrist extension at position 2, a R^2 of 0.39 was seen between the MVE and the MEF.

Thus, 39 % of the variance in MVE could be explained by the MEF. The corresponding value for hand grip was only 11 %. No correlations were found for position 1 for none of the MVCs.

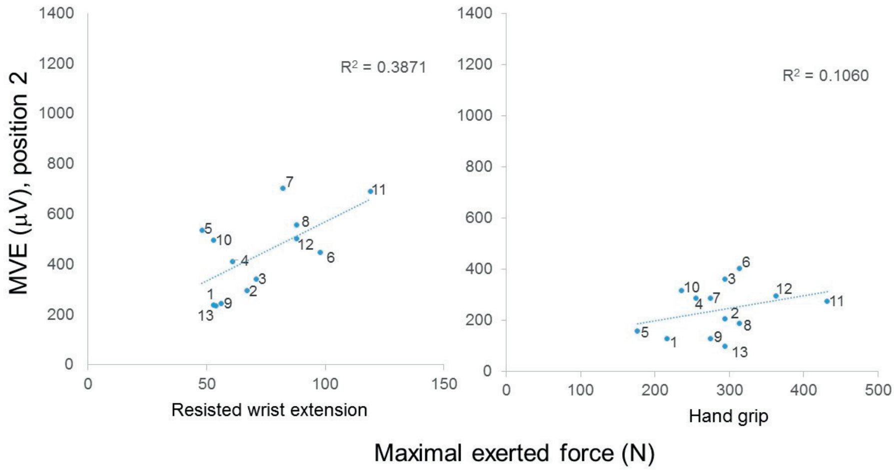

Figure 7. The correlation between MEF and MVE, short version from paper IV.
The maximal voluntary electrical activity (MVE; µV) versus the maximal excerted force MEF; Newton) for resisted wrist extension and hand grip at electrode pair position 2.

Muscular load during work

The group mean %MVE (99th percentile) at both position 1 and 2 were lower when resisted wrist extension was used as reference contraction than when hand grip was used (Table 10). The %MVE at the 99th percentile was above 100 % for two subjects at position 2 when using hand grip as the reference. These subjects (number 5 and 8) had hand grip MVEs that were among the lower values, while their MVEs for resisted wrist extension were among the highest. Moreover, their ratios of the MEF between the two contractions were the same as for the other subjects, while their MVE ratios were among the two highest. It seems like they activated their extensor muscles to a lesser extent than the others during the hand grip. This resulted in an overestimation of the muscular workload when hand grip was used as reference contraction. It is not possible to determine if a subject activates the extensor muscles maximally by analysing the hand grip force and MVE only. Therefore, the MVE ratio between resisted wrist extension and hand grip may be used to distinguish individuals who fully activate their extensor muscles from those who do not. The MVE ratios for the two subjects who had a %MVE above 100 % were >3.0. No consistent effect of electrode positioning was found.

Table 10. The maximal excerted force (MEF), the maximal voluntary electrical activity (MVE) and the muscular load (%MVE) of hotel room cleaning, from paper IV. Ratios between resisted wrist extension and hand grip. (N = 13).

	Maximal voluntary contractions									**Workload**			
	MEF (Newton)			MVE (µV)						%MVE (99th percentile)			
subject	Resisted wrist extension	Hand grip	Ratio	Resisted wrist extension		Hand grip		Ratio		Resisted wrist extension		Hand grip	
				Position 1	Position 2	Position 1	Position 2	Position 1	Position 2	Position 1	Position 2	Position 1	Position 2
1	54	216	0.25	441	237	255	129	1.7	1.8	35	41	60	76
2	67	294	0.23	799	296	271	206	2.9	1.4	46	57	128	83
3	71	294	0.24	735	341	430	360	1.7	0.9	24	44	41	41
4	61	255	0.24	1358	411	407	286	3.3	1.4	30	42	98	60
5	48	177	0.27	760	536	251	159	3.0	3.4	49	39	149	131
6	98	314	0.31	634	449	639	404	1.0	1.1	44	53	44	59
7	82	275	0.30	1229	705	447	288	2.7	2.4	32	29	88	71
8	88	314	0.28	939	559	389	188	2.4	3.0	34	49	82	146
9	56	275	0.20	727	244	361	129	2.0	1.9	33	52	66	98
10	53	240	0.22	1337	496	532	316	2.5	1.6	34	49	85	77
11	119	431	0.28	890	691	239	276	3.7	2.5	47	37	176	92
12	88	363	0.24	745	502	384	294	1.9	1.7	40	38	77	65
13	53	294	0.18	409	238	235	97	1.7	2.5	40	38	69	93
Mean	72	288	0.25	846	439	372	241	2.4	2.0	37	44	90	84
SD	21	64	0.04	304	162	123	96	0.77	0.73	7.6	7.9	40	29

Physical workload in hotel room cleaning

Inclinometry

Postures and movements of head, upper back and both upper arms, as well as the muscle activity and time for recovery of the right forearm extensors for 13 female hotel room cleaners during one working day are reported in Table 11. The group means of the 50th and 90th percentiles of forward bending of the head were 30° (range 18 - 43°) and 60° (range 49 – 72°), respectively. The 90th percentile of upper arm elevation was 61° (range 47 – 75°) and the median angular velocity was 92 °/s (66 – 129 °/s). This is the highest female group mean of upper arm velocity that we have recorded so far, during nearly 30 years of research. When comparing with the action levels for the prevention of WMSDs, proposed by our research group, the hotel room cleaners exceeded four of the five action levels that are proposed for inclinometry [88]. For the median angular velocity of right upper arm, the action level (60 °/s) was exceeded by all subjects [89].

sEMG

The muscular load in the forearm extensors at the 50th and 90th percentiles was 17 % of MVE (range 9 – 30 % of MVE) and 46 % of MVE (range 23 – 76 % of MVE), respectively. For the 90th percentile, also this group mean is the highest that we hitherto have recorded among all female occupational groups. When comparing with the action levels, both the 50th and the 90th percentiles were exceeded.

The time for recovery was 1 % of time (range 0 – 4 % of time). The proposed action level is 5 % of time. All subjects had a time for recovery below this level, i.e. the time when the extensor muscles had possibilities to rest was too short.

Comments

Hotel room cleaners have a very high physical workload, both in terms of postures, velocities and muscular load. They exceeded seven of the nine action levels that we have proposed for inclinometry and sEMG of the forearm. When the exposure is higher than the action levels for postures, velocities and muscular load, the risks for developing WMSDs are high. For time for recovery it is the opposite; an exposure below the action level implies a high risk for developing WMSDs.

In summary, hotel room cleaners have a very high risk for developing WMSDs. There is a need for preventive actions. Our suggestion is that the work pace is lowered by reducing the number of rooms that are included in a hotel room cleaner's working day, to decrease the risks for developing WMSDs. The staff should be offered regular medical examinations regarding ergonomically demanding work. With such approach, it is possible to take actions for the employee or group of employees which are about to develop disorders/pain in muscles and/or joints. The workplace is recommended to use the Occupational Health Services (OHS) which can perform the medical examinations and continuously perform assessments of the work. They should also educate the cleaning staff in ergonomics. The self-recording method is a suitable tool to use to check if the preventive actions, i.e. a reduced number of rooms has had the desired effect on the work pace.

Table 11. Physical workload in hotel room cleaning during one working day.
The workload in the right side of the 13 subjects included in paper IV, compared to the action levels for the prevention of WMSDs, proposed by the division of Occupational and Environmental Medicine, Lund.

[a] High risk of disorders at higher exposure.

[b] High risk of disorders with shorter time for recovery.

[c] Applies if the arms are unsupported against for example a table.

		Hotel room cleaning	Action levels for the prevention of WMSDs
	Percentile	Mean (Min - Max)	
Postures (°) [a]			
Head			
inclination	10th	0 (-11 – 8)	-10°
	50th	30 (18 – 43)	25°
	90th	60 (49 – 72)	50°
Back			
inclination	50th	19 (11 – 32)	
	90th	59 (43 – 74)	
Upper arm, right			
elevation	50th	28 (21 – 38)	30°
	90th	61 (47 – 75)	60°
Velocity (°/s) [a]			
Upper arm, right	50th	92 (66 – 129)	60 °/s
Muscle activity [a]			
Forearm extensors, right			
activity (%MVE)	50th	17 (9 – 30)	10 %MVE
	90th	46 (23 – 76)	30 %MVE
Time for recovery [b]			
Forearm extensors, right			
(% time)		1	5 % of time

General discussion

The aims of this thesis were to simplify and refine two objective technical methods for assessment of ergonomic exposure. Simplification aims to make the inclinometry method easier to use for different actors in the work environment field (paper I and III), and refinement aims to improve the sEMG method of the forearm extensors in order to achieve more accurate estimates of muscular load during work (paper II and IV). The methods have been used during many years of research, where strictly standardised protocols have been used. This has made it possible to collect such amount of data, that exposure-response relationships between several physical exposures and WMSDs have been established [15, 21]. However, the equipment used in those studies have been quite expensive, and the proceedings for attaching and calibrating the equipment have been rather complicated and time-consuming. As objective technical methods have several advantages in comparison with e.g. observational methods, such as exact numerical values of postures, movements and muscular load during work, and possibilities to record the workload during several days, it is valuable to make them easier to use to make them exploitable to the public. The process to simplify a technical method and maintain as high quality as possible, has a number of challenges. They lie on different echelons of the method, where some are easier to alter than others, such as e.g. the instructions in the protocol, in comparison to e.g. the size of a certain equipment.

For the inclinometry method, the new equipment had to be inexpensive. A suitable alternative was one sensor of the new generation of accelerometers that have been on the market for about a decade, which had a price of about €95. Thus, the equipment for a complete set were 5 * €95 (four accelerometers attached to the head, upper back and both upper arms and one used for events), which was about 1/15 of the price for the traditional equipment (LT inclinometers). It went faster to attach these new devices (GC inclinometers) as they have no cables and have an integrated data logger, in contrast to the LT inclinometers. For these, a separate logger must be worn in a belt and the inclinometer cables that are connected to the logger have to be taped to the skin. As the GC inclinometers include a battery, they are a little bit bigger than the LT inclinometers, which of course is a disadvantage when they are attached to e.g. the forehead, especially when using them to record the workload in occupations in the service sector. Furthermore, it has been reported that the batteries sometimes expand in hot and humid climate (personal communication with researchers in Central America), and the lithium battery will eventually be totally depleted (after a couple of hundred charges). The validation study (paper I) showed that the GC inclinometers reported data that were almost identical to that of the LT inclinometers. They were also easier to handle than the LT inclinometers without cables and external logger, but above all they were cheaper. Therefore, to provide a sensor to the public which reports data that are very close to one with high accuracy, we compromised on the size and the problems with the battery.

The requirement for the simplified reference posture was that it could be adopted without any dumbbell and chair for use at any workplace, and that employees' themselves could adopt it. It was also desirable with a high repeatability. The simplified reference postures (postures 1 and 2) that were evaluated in paper I were chosen after quite a lot of pre-testing. Many of the tested variants, such as leaning forward to 90° with the arms hanging vertically towards the floor, or holding the arm flexed to 90° with the upper arm close to the body, were rejected due to too deviating angles (up to three times as high as those from postures 1 and 2) in relation to the standard reference posture. In paper I, the simplified reference posture (posture 2) was adopted by instructions and corrections from a researcher. Thus, as the simplified reference posture was intended to be used by workers themselves, it needed further evaluation in a study where workers adopted it. It also deviated from the standard reference to such magnitude that it was judged to need further validation in field recordings of physical workload. In paper III, where the simplified reference posture was adopted by the subjects themselves, the repeatability of the simplified reference posture was low (CR 16°). This may be due to the difficulties to reproduce the same position without support from an object such as a chair. However, when using it as reference in the 28 field recordings of cleaning, it gave values of upper arm elevations that were very close to those when using the standard reference posture as reference. Therefore, we compromised regarding the within-subject variation, and recommend it for use in group recordings of upper arm elevations. For single recordings the standard reference posture may be used as this is more reliable (CR 5°).

For the sEMG method, the main focuses were to explore why some subjects show EMG amplitudes during work that are higher than those obtained during the MVC (hand grip) and to improve the within-subject variation of the MVC. Resisted wrist extension was a suitable alternative as this may be one of the more obvious manners to activate the extensor muscles. The glove that was used to perform the resisted wrist extension MVC was not optimal as it was one size, without padding and had to be tightened hard around the wrist. It was a challenge in the field recordings (paper IV) to place the subject in the right sitting position, tighten the glove and to carefully adjust the strap as quickly as possible to keep the calibration time to a minimum without compromising on accuracy.

Methodological considerations

A strength in this thesis is that the inclinometry and sEMG methods were evaluated both in the laboratory and in field studies of real work. It was mostly female cleaners that were recruited in the field studies (33 of 37), and therefore a selection bias may be suspected. However, we do not believe that women and men perform e.g. the hand grip contraction differently, or that women and men manage to follow the instructions in a protocol differently. Therefore, we find the results from the field studies to be applicable to both women and men.

Inclinometry

As there is no gold standard for inclinometry, we chose to evaluate the GC inclinometer against a previously validated one with high accuracy, during simulated work tasks. The work tasks in paper I were chosen due to the content of different combinations of both high and low elevations and velocities. This allowed us to detect potential random or systematic errors. However, the recording time could have been a bit longer, as the movement pattern was not strictly repetitive, except for the rest with elevated supported arms. The validation could have been carried out in field recordings, but since it was two inclinometers on top of each other for each body part, these were suspected to interfere with the subject's performance during real work. Thus, the validation was carried out in the laboratory.

The self-recording method was tested in field recordings of cleaning, an occupation with high proportion of immigrants. The subjects spoke Swedish and English of varying quality. They thus needed instructions that were easy to follow. We believe that by developing the protocol in such a group of subjects, we had an opportunity to bring out a protocol that almost anyone will be able to use. The approach of making changes during the ongoing study seemed to be successful, as the help needed decreased with improved versions. We believe that the current protocol is ready for use. It would be interesting to investigate if the self-recording method could be sent out per mail, with the receiver performing it without a researcher nearby. For such a study, it would be possible to include many more subjects, as the only time required for the researcher would be to send out a package including the protocol and a GC inclinometer, and to analyse the data.

sEMG

Our research group have chosen to record the extensor muscle activity as a proxy for the forearm muscle exertion during work. Another strategy could be to record the muscle activity of the forearm flexors. However, in a study made by Greig *et* *al*., the extensor carpi ulnaris muscle showed the highest activation of the seven extensor and flexor forearm muscles studied, followed by extensor digitorum and extensor carpi radialis [90]. One of the three extensors had the highest activation of all muscles in about 2/3 of all exertions (357 efforts). The findings support the notion that the extensors are heavily loaded during manual tasks [91]. Based on these facts, Greig *et al*. suggested that the forearm extensors should be included when collecting EMG to estimate demand in the forearm.

Another approach could be to record the forearm muscle activity using a through-forearm setting. In a study made by Takala *et al*., the through-forearm setting showed the lowest variation in EMG activity compared to five other electrode positions [65].

The equipment to perform resisted wrist extension was not designed to be adapted to different hand sizes and therefore not so comfortable. It should also be easier to adjust, as the time for preparing the subject is critical. It may be more correct to perform resisted wrist extension in the functional position of the hand to achieve a higher force, but as the action potential is equally large regardless of the muscle length, we do not believe that this is significant for the conclusions. However, as the muscles move in relation to the electrodes between different postures, a functional hand position (somewhat dorsally flexed) in comparison to a straight wrist during the MVC might be more relevant, as this is a common work posture.

Methodologically and clinically relevant differences

We judge that from 30° of upper arm elevation and above, a difference of 5° is clinically relevant (Table 12). For the median angular upper arm velocity a difference of 10 °/s is relevant. For static work, already a difference of 5 °/s is relevant, as such difference is better from the view of the risk for developing WMSDs.

Estimation of sample size and power calculation

Power calculations should be performed before a study for estimation of sample size. This was not done in the studies included in this thesis. Instead, the size of the studies were determined due to economic and practical issues. Based on the results observed in the present thesis it is valuable to reflect on the study size needed in future projects to detect the observed effects with reasonable statistical power. In paper I, the difference for e.g. the right arm during simulated painting (50^{th} percentile) between the simplified reference analysis and the standard reference analysis was 0.7° with a mean SD of 4° (Table 12). To detect such a small difference with 80 % power, 513 subjects would have had to be included. However, we believe that an acceptable difference between the analyses using the simplified reference posture and using the standard reference is 2°. To detect a difference of 2° with 80 % power, 63 subjects should be included (assuming an SD of 4°). Still, the present results indicate that the difference, on group level, between the two reference posture methods is negligible.

In paper III, there was a difference of 19 °/s in upper arm velocity between hotel room cleaning and hotel room cleaning+. With the number of subjects included there was 68 % power to detect this difference as statistically significant. In fact, p was <0.05. We consider 10 °/s a clinically relevant difference between occupations. To detect such a difference between two situations, 49 subjects in each occupational group should be included if the SD is 17 °/s, as in the present study.

Tabel 12. Post-hoc power calculations for methodologically and clinically relevant differences.

Paper		Power calculation							
		Mean 1	Mean 2	SD (average)	N/group	Power	N with power of 0.8		N with power of 0.8
	Comparison between methods							**Methodologically relevant difference**	
I	LT and GC (simulated painting; right upper arm elevation, 50th percentile)	30.5°	30.3°	3.5°	12	0.03	4 808	2°	49
I	Analysis using simplified ref and analysis using standard ref (simulated painting; right arm elevation, 50th percentile)	30.1°	30.8°	4.0°	12	0.06	513	2°	63
III	Analysis using simplified ref and analysis using standard ref (three working days; right upper arm elevation, 50th percentile)	29.7°	29.5°	5.1°	28	0.03	11 872	2°	103
	Comparison between workloads							**Clinically relevant difference**	
III	Hotel room cleaning and hotel room cleaning+ (three working days; right upper arm elevation, 50th percentile)	30°	28°	4.3°	10	0.18	73	5°	12
III	Hotel room cleaning and hotel room cleaning+ (three working days; right upper arm velocity, 50th percentile)	82 °/s	63 °/s	17 °/s	10	0.68	14	10 °/s	49

Inclinometry

Inclinometers have been shown to have a high precision and accuracy when fixed in a rigid jig using graduated arcs [52]. However, as they cannot be fixed to the human skeleton, they may be susceptible to methodological errors, due to changes in position relative to the underlying bone during movements (soft tissue artefacts). This emphasize the importance of consistency in how a tool is used, e.g. the mounting of the inclinometer and how the reference posture is adopted. It has been reported an underestimation of at least 10° of upper arm elevations at angles greater than 90° when using LT inclinometers compared to "meticulous assisted observation" [70]. However, our research group has reported a group mean difference >1° at instructed arm elevations of 90° [92]. Thus, the strictly standardised procedure for mounting the inclinometers and how to adopt the reference posture (and forward direction) suggest that methodological errors can be reduced, and ensure consistency in precision.

sEMG

Electrode positioning

It is recommended to avoid the IZ when applying electrodes for sEMG, as this will reduce the EMG amplitude and also make it sensitive to small skin movements [62, 63]. Therefore, our research group were interested in examining if our traditional electrode pair positioning coincided with the IZ. Prior to the laboratory study in paper II, we assumed that the IZ was the same as the motor point (MP). Thus the MP in one of the forearm extensor carpi radialis muscles were localised. However, we later understood that the IZ and the MP were two different concepts [93]. Anatomically, the MP corresponds to the site where motor neurons enter muscles (Figure 8). Operationally, the MP is the site where a muscle contraction at a minimal electrical stimulation intensity is achieved [94]. For the forearm extensors this point is at the site where the index or the middle finger extends repeatedly. The IZ corresponds to the anatomical site where clusters of neuromuscular junctions are located [95]. The results from paper II indicated that when using resisted wrist extension as reference, the electrode pair position closest to the elbow, in terms of high amplitude and low CV, was the best option. The results also indicated that our traditional position was at risk of being over the IZ. However, when taking the correlation between the MEF and MVE in paper IV into account, the position closest to the elbow (position 1) was doomed to be less adequate than the traditional position (position 2). Therefore, we recommend to use position 2 when recording the muscular workload of the forearm extensors, despite the drawbacks from positioning the electrodes over the IZ.

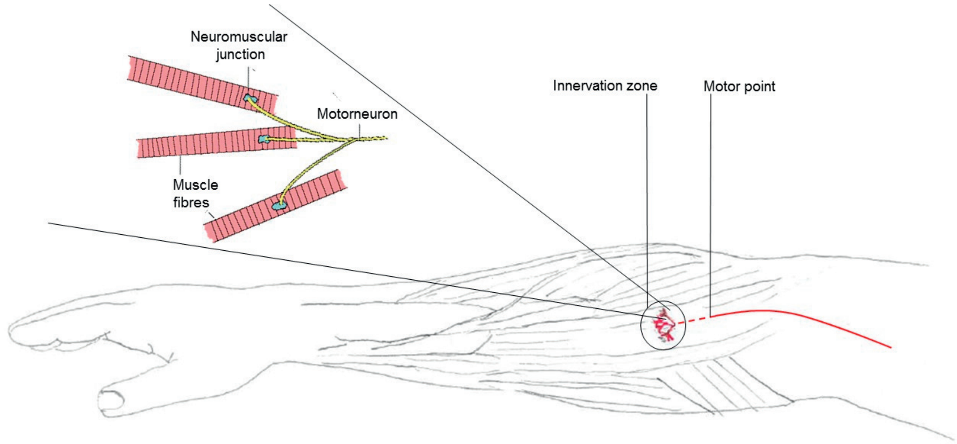

Figure 8. Motor point (MP) and Innervation zone (IZ).
MP = where the motor neuron enters the muscle and IZ = clusters of neuromuscular junctions.

MVCs

There is an ongoing discussion on how to normalise EMG recordings and a large number of strategies has been proposed, such as using the peak or mean EMG from the task under investigation, resisted flexor or extensor moment tasks, isometric maximal voluntary contractions (e.g. hand grip) or dynamic strength exercises (push-ups and chin-ups) [96, 97, 98, 99]. The chosen normalisation strategy is dependent on the purpose of the study, e.g. if the purpose is to reduce inter-individual variability, then the peak or mean EMG from the task under investigation may be used. If the study aims to assess the external load, an RVC is preferable. If the purpose is to compare muscle exertions between subjects in relation to their strength, an MVC should be used. Different normalisation strategies make it difficult to compare the workload between studies, which in turn complicates the progress to strengthen the exposure-response relationship between muscular load and WMSDs.

Gender aspects

Women have higher risk for developing WMSDs than men [100, 101]. One explanation is due to differences in muscle fibre characteristics, which explain gender differences in strength and fatigue resistance [102]. Also differences in motor variability have been suggested, where a high motor variability may be a mechanism for preventing chronic symptoms [103]. Furthermore, women use a higher proportion of their muscular capacity than men when they perform the same work tasks [100]. Women are also on average of smaller height, and thus probably more often work with their hands above shoulder height. It has been reported that the tendons of women are more sensitive to overstretch [104] and that women have more flexible joints around their shoulder joint [105]. It has been proposed that men and women have different exposure to risk factors, due to the gender segregation of the labour market [106]. However, the difference in prevalence remains when men and women from the same occupational class [101], or with the same work tasks [100] are compared. Technical methods are suitable for investigation whether there are differences in workload between women and men. sEMG is an important method for assessing the risk for developing WMSDs, as the muscle exertion is difficult to assess with e.g. observational methods. Normalisation to the activity during a MVC is necessary, instead of RVC, as the applied force in relation to the individual capacity, otherwise would be lost.

Recording strategies

The self-recording method implies that anyone can perform a recording of upper arm elevations and velocities. However, to be able to correctly interpret the derived elevations and velocities, information about the recorded work is important such as the type of work, different work tasks, and starting and stopping times of work and breaks. It is also important to provide information about how the work is performed, e.g. if the arms are supported on a surface, as this is considered to be less demanding than unsupported arms. During the years of research, we have usually had a policy to include twelve subjects from each occupation and the workload has been recorded during one working day. With the self-recording method, this can easily be increased, both the number of subjects and days. It is important that it is full-day recordings if it is a varied work or if the workload is intended to be compared with the suggested action levels for the prevention of WMSDs. The included subjects should perform the same work tasks for a lower inter individual variation [107]. For repetitive work, it is generally enough to record the workload during a part of the working day. Furthermore, the results from women and men should be presented separately, as women generally have e.g. a higher muscular load than men, see the “Gender aspects” section.

Technical methods in practice and in research

One important aspect of technical methods in practice is the balance between simplicity and quality. When the methods become easier to perform (e.g. simplified reference posture) the quality may go down (uncertainty in exposure). Therefore, it is of relevance to discuss the purpose of the recordings, and ask if it is to get an idea of how the workload is at a specific workplace, or if the purpose is to achieve recordings with high accuracy, such as when interventions are performed or when a thorough evaluation of a certain occupation is performed. In practice it is probably more valuable to record the exposure on many subjects as a part of the systematic work environment work, to assess the physical workload at a workplace. In research, to create a job-exposure matrix, or to establish exposure-response relationships between workload and WMSDs (with the purpose to eventually bring out limit values of physical exposure), both a high accuracy and a high number of subjects is wished for.

Another aspect of technical methods in practice is that the researchers who develop easy-to-use technical methods may not always know what the practitioners (e.g. the OHS) need and want, and the practitioners maybe do not know what they can ask for. Therefore, it could be valuable to offer them e.g. a tool like the self-recording method and have a dialogue with them, and if necessary adjust it so that it suits their needs. They might have a wish to e.g. use it on single individuals, which would mean that the instructions had to be changed to include instructions for the standard reference posture instead of the simplified reference posture.

Most research groups have their own ways how to record physical workload, with different ways how to e.g. adopt reference postures and directions, and how to perform the reference contraction for forearm sEMG. This makes it difficult to compare data from different studies. However, there are ongoing work to establish common ways how to perform technical recordings of physical workload in the EU [108]. Such guidelines, e.g. how to adopt the reference postures for upper arms, would give opportunities to compare and merge data from several countries. This would give a great contribution to the exposure-response relationships and thus a large step towards succeeding in establishing limit values of physical exposure.

Changing the reference contraction?

Even though the results from paper II and IV indicate that resisted wrist extension gives more accurate estimates of muscular load of the forearm extensors than hand grip, we still have not decided to replace the hand grip contraction. If we change it, comparisons to previous studies would be lost. One way to overcome this is to perform both MVCs and report data that has been normalised to both. However, this would extend the time it takes to prepare a subject for a whole-day recording of physical workload, which may make employers reluctant to permit recordings at their workplace. Furthermore, the time for analysing the data would increase, which is in the opposite direction to what we strive for. The current equipment also need improvements, e.g. better fitting and less tightening to the wrist. Moreover, it should be made of a material that can be properly cleaned. The discussion is ongoing.

Practical implications

This thesis has provided different actors in the work environment field such as the OHS and researchers with a low-cost, easy-to-use objective technical method for recording of work postures and velocities of head, upper back and both upper arms. It has also provided a self-recording method of upper arm elevation and velocity for continuous recording during several days. In addition, user-friendly software to analyse the recorded data obtained with the GC inclinometers have been developed. This means that two low-cost and easy-to-use complete methods for ascertainment of physical exposure at work are available for the public. The methods, especially the self-recording method, makes it possible to increase the use of technical methods both among practitioners and researchers, but also among employers and employees. In practice, the method can be used e.g. as a part of risk assessments and/or when interventions are performed. The methods in combination with action levels for prevention of WMSDs provide practitioners and employers with a method of assessing the risk of developing WMSDs among employees, which is an important improvement of prevention. In research, the exposure-response relationships between workload and WMSDs may be easier to determine if an increasing amount of researchers will use the methods.

The findings in this thesis suggest that resisted wrist extension should be used as reference contraction instead of hand grip for better estimates of the recorded workload of the forearm extensor muscles. However, as hand grip has been used in many previous studies, comparisons to these would be lost. To overcome this, both contractions could be performed and reported. Another approach could be to report data which have been normalised to hand grip and exclude subjects with a MVE ratio above a certain level (3 in paper IV). A somewhat lower %MVE could then be expected on group level (10 %) compared to previous studies as they likely include subjects with an overestimated workload.

Conclusions

The low-cost, easy-to-use GC inclinometers reported data of work postures and velocities that were fully comparable to data from our traditional inclinometers.

The simplified reference posture deviated somewhat from our standard reference. However, the effect of this deviation on group recordings of workload was negligible. Thus, self-recordings, on a group level, had the same quality as recordings performed by researchers.

Hotel room cleaners managed to start and attach the sensor to their upper arm and to adopt the reference posture by following instructions in a protocol with photos.

For normalisation of sEMG of the forearm extensors, resisted wrist extension showed higher MVE and lower CV than hand grip.

Some cleaners did not fully activate their forearm extensor muscles during hand grip, resulting in an overestimation of workload when using hand grip as the reference.

Problems associated with poorly activated forearm extensors can be overcome by using resisted wrist extension as the reference instead of hand grip.

The ratio between the MVE and CV was highest at the electrode pair closest to the elbow, but no consistent effect of electrode positioning on field recordings of workload was found.

Recommendations

Self-recordings should be evaluated on group level, with the assumption that it is the same work tasks and a high similarity in work performance for all individuals.

For single recordings of upper arm elevations, the standard reference posture should be used as reference posture, as this is more reliable.

In combination with action levels for prevention of WMSDs, different actors in the work environment field may use self-recordings for e.g. risk assessment of physical workload and/or when interventions, e.g. an improved working technique is implemented.

Future research

Another important exposure with a high risk of WMSDs is wrist velocity. This exposure is often associated with a high physical workload in the whole upper part of the body (see Introduction section “Risk factors for developing WMSDs”). Thus, wrist goniometry is also an important method for recording of physical load at work. However, the current equipment is very expensive and not durable. Therefore it is not an option for the public. There is a need to develop and evaluate a low-cost alternative. The evaluation could take place in the laboratory and include the current goniometers, the new equipment and one another reliable recording method such as an optoelectronic measuring system.

Inflammation is important in the development of WMSDs. Therefore, it would be very interesting to further study the content of inflammatory biomarkers in serum in subjects with WMSDs [109], with the purpose to develop a method (including blood sampling and analysis) to find individuals already in their onset of developing WMSDs. Such method may prevent further injury, and might also contribute to a greater acceptance of WMSDs as a work injury when assessing the work ability for disability pension for those individuals that already have developed WMSDs. This method in combination with the self-recording method where the workload on many subjects is easily recorded, should increase the knowledge about the relationship between physical exposure, WMSDs and the pathomechanisms involved.

There are several industries with a high physical workload that should be investigated. Warehousing is one and with the increasing e-business, this is an industry with an increasing number of employees. It is often seasonal employments (e.g. Christmas) with bad working conditions such as heavy lifting and handling loads at a high work pace. We believe that objectively recorded physical exposure that can be compared with action levels have a greater impact on employers, unions and authorities than subjective ergonomic assessments. This should be studied with a qualitative approach, e.g. in warehousing.

We have a database of physical exposure from nearly 60 different occupations. Hitherto, we have studied each exposure of workload separately. Combined exposures such as wrist velocity and forearm extensor muscle exertion, sample by sample, would provide us with valuable information to add to the exposure-response relationship between workload and WMSDs.

We have for the most part of our studies performed cross-sectional studies. To be able to study the causality between workload and WMSDs, prospective studies should be performed. A prospective study within warehousing would be adequate, to study the workload (see above) and for increased knowledge about causality.

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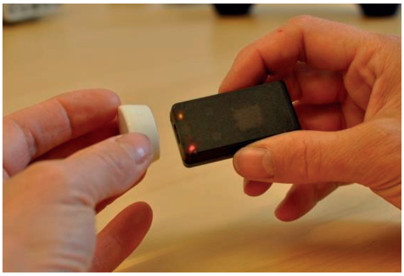
Appendix

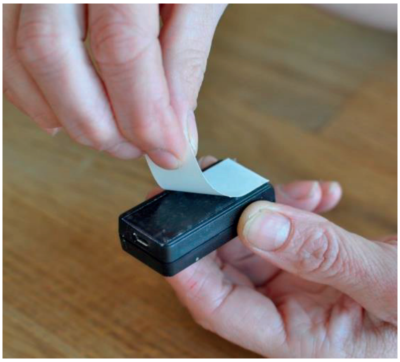
Instructions for self-recording of upper arm elevation and velocity

Please read these instructions carefully before you put the sensor on.



1. Start the sensor

Touch the USB connector with the magnet. A yellow and a red lamp start to blink. Remove the magnet immediately. Make sure the sensor is operating: the yellow lamp should be blinking all the time, and the red lamp now and then.



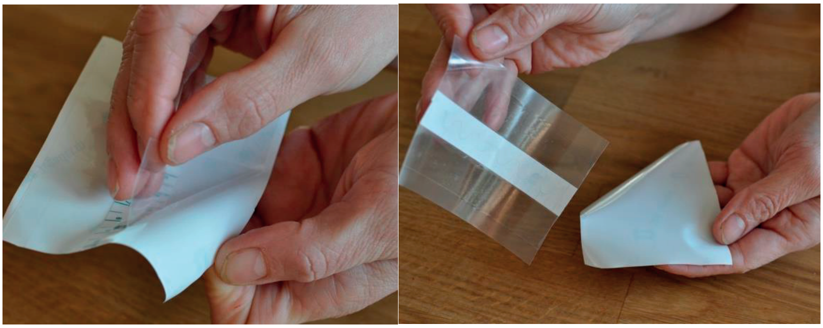
2.

Remove the white paper strip from the back of the sensor.

3. Attach it

Attach the sensor to your arm as shown in the picture.

Version 4
2019-03-27



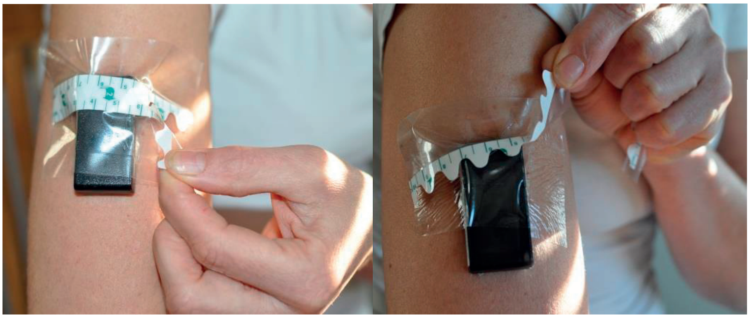
4.

Remove the white backing from the clear plastic film.

5.

1. Place the plastic film over the sensor.

2. Press the plastic film firmly along the sides and ends of the sensor.



6.

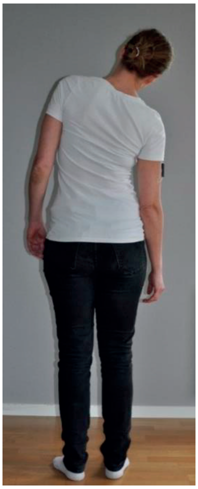
Grab one of the white strips on the film to remove one half of the covering plastic film. Then remove the other half, leaving only a thin plastic film.

7.

The thin plastic film should cover the whole of the sensor and part of the arm. Please, use more plastic films if you have not managed to cover the area shown in the picture.

8. Toe jumps

You will now perform **5 toe jumps**. Jump up and down 5 times.



9. Zero position

Immediately after the toe jumps, you should stand in **the zero position.** Follow these instructions carefully:

1. Lean to the right and hold your arm by your side, as shown in the picture. Extend the elbow.

Hold this position for 20 seconds.

2. **IMPORTANT** - Write down the exact time (hh:mm:ss) in the protocol under day 1.

MULTIDAY MEASUREMENT OF POSTURES AND MOVEMENTS OF RIGHT UPPER ARM

DAY 1

5 toe jumps + zero position + 5 toe jumps at time:......................

WORK STARTS at time:...

DAY 3	8-9	9-10	10-1[illegible]	12-13	13-14	14-15	15-16
Hotel room							
Facilities							
Övrigt							

LUNCH STARTS at time:..............................

LUNCH ENDS at time:..............................

WORK ENDS at time:..................................

If you have cleaned rooms today:

How many departure?.........

How many stay?...........

10. Toe jumps again

Perform **5 toe jumps** once again. Jump up and down 5 times.

You are now ready to start work.

Please note the starting and stopping times of work, the lunch and the breaks in the supplied form. The sensor should remain on your arm for the whole study period. Do not remove it during showering or when you go to bed.

If the sensor falls off, please note the date and time here:

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You should not replace it.

If you **feel any pain**, or if your **skin starts to itch,** or **turns red** around the sensor**, remove it immediately**. **Please note the date and time here:**

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Please feel free to give me a call or send me a text message if you have any questions.

Kindly,

Forename Surname, Institution, **phone xxxxxxxx, mobile phone xxxxxxxx**

Paper I

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Validity of a small low-cost triaxial accelerometer with integrated logger for uncomplicated measurements of postures and movements of head, upper back and upper arms

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ABSTRACT

Repetitive work and work in constrained postures are risk factors for developing musculoskeletal disorders. Low-cost, user-friendly technical methods to quantify these risks are needed. The aims were to validate inclination angles and velocities of one model of the new generation of accelerometers with integrated data loggers against a previously validated one, and to compare meaurements when using a plain reference posture with that of a standardized one. All mean ($n = 12$ subjects) angular RMS-differences in 4 work tasks and 4 body parts were <2.5° and all mean median angular velocity differences <5.0 °/s. The mean correlation between the inclination signal-pairs was 0.996. This model of the new generation of triaxial accelerometers proved to be comparable to the validated accelerometer using a data logger. This makes it well-suited, for both researchers and practitioners, to measure postures and movements during work. Further work is needed for validation of the plain reference posture for upper arms.

1. Introduction

Physical workload such as excessive and/or prolonged muscular load, repetitive work and work in awkward and constrained postures, are known risk factors for developing work-related musculoskeletal disorders (WMSDs) in the neck/shoulder region and in arms and hands (da Costa and Vieira, 2010; European Agency for Safety and Health at Work, 2010; National Institute for Occupational Safety and Health (NIOSH), 1997; National Research Council (NRC), 1999; Nordander et al., 2009; Staal et al., 2007). As an example, the 3rd European survey on working conditions (ESWC) from 2000, displayed that 37% of the workers in the European Union, who reported repetitive hand or arm movements at least 25% of the work time, reported muscular pain in neck/shoulders (Paoli and Merllié, 2001). Even though the risk factors have been known for a long time, there is limited knowledge about the quantitative exposure-response relationships and therefore regulations are difficult to implement. Still, some guidelines based on observations and expert ratings for reduction of WMSDs have been implemented. One example is the threshold limit value (TLV) based on Hand Activity Level (HAL) and peak hand force, used for control of workplace exposures in order to prevent disorders in hand, wrist and forearm (American Conference of Governmental Industrial Hygienists (ACGIH), 2001).

Some exposure-response relationships have been found in studies where technical measurements were used. Nordander *et al.* have shown a relationship between prevalence of reported complaints in elbow/hand the past seven days and technical measurements of wrist movements, where the slope of the regression line (β) for wrist angular velocity vs. complaints during the past seven days was 0.6%/(°/s) (Nordander et al., 2013). Another example is a study about work related shoulder disorders, where a duration increment of 1% of the daily working hours with the upper arm elevated more than 90° was associated with an OR of 1.23 for supraspinatus tendinitis (Svendsen et al., 2004). Such quantitative relationships are necessary for interpreting the measured exposure as risks for WMSDs.

Since technical measurements give numerical values in generic units, e.g. degrees (°) and °/s, of postures and movements, they are

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well suited for measuring exposure before and after changes in content and/or duration of work tasks and changes in the use of work stations, as well as when interventions, e.g. improved working techniques or use of new technical appliances, are implemented (Arvidsson et al., 2012; Forsman et al., 2012; Lindegård et al., 2012; Rislund et al., 2013).

Observational methods have been considered to be cheaper and easier to use than technical measurements (Winkel and Mathiassen, 1994), and have often been used to identify the risk factors for WMSDs. However, quantitative generic information is difficult to achieve with observational methods and no single method appears to have a clear advantage over any other (Takala et al., 2010). Further, different observational methods for categorizing the risks for musculoskeletal complaints often give various results (Chiasson et al., 2012; Kjellberg et al., 2015). In a recent study, comparing observations and inclinometer measurements, Trask *et al.* concluded; "Since observations were biased, inclinometers consistently outperformed observation when both bias and precision were included in statistical performance" (Trask et al., 2014). Moreover, dynamic work is best quantified with technical measurements (De Looze et al., 1994; Spielholz et al., 2001).

The general opinion about technical measurements is that they are time consuming, require expensive equipment and also demand technical knowledge to perform, and are therefore not suitable for actors in the work environment field, such as the occupational health services (David, 2005; van der Beek and Frings-Dresen, 1998). These actors need systematic and objective methods for their risk assessements that are user-friendly and cost effective (Kwak et al., 2011; Swedish Work Environment Authority, 2012), and until now, technical measurements have been considered to be too time-consuming and expensive. However, there are a number of low-cost (about $100–$300) technical devices available nowadays, used for monitoring human motions (Korshøj et al., 2014; Skotte et al., 2014; Yang and Hsu, 2010). This new generation of accelerometers with integrated data loggers would be an alternative to previous devices, since they do not have to be connected to a separate data logger. Still, the software for handling the data from some of these devices are rather time consuming and complicated, which makes the spreading to practioners limited. In addition to this study of validation, we have developed a protocol and user-friendly software, where the analysis process is fully automated as opposed to hitherto used software, and which give the same parameters of postures and movements as in scientific reports. The software for analysing data recorded with these new accelerometers is free to receive after contact with the authors (Forsman et al., 2015). With these improvements, actors in the work environment field will be able to use objective methods for ergonomic risk assessments. More feasible objective methods for measuring postures and movements during work may also extend the use of them among researchers, and thereby contribute to increase the knowledge about the relationship between exposure and WMSDs.

The main aim of the present study was to validate one model of the new generation of the small, low-cost and user-friendly triaxial accelerometers with integrated loggers by comparing the derived inclination angles and angular velocities against a previously validated traditional triaxial accelerometer using a data logger (Bernmark and Wiktorin, 2002; Hansson et al., 2001) in terms of accuracy and precision for using it as an objective method for measuring postures and movements during work. For further simplification of technical measurements, a second aim was to examine the methodological significance of a plain reference posture compared to our current, by comparing derived inclination angles and percentage of time above certain arm elevations when using plain reference postures, i.e. reference postures that are easy to perform, for which no extra material is needed, with corresponding data when using our current standardised reference posture where a dumbbell and a chair is used (Hansson et al., 2006).

2. Material and methods

2.1. Subjects

Twelve right-handed participants, six women and six men, participated in the study. For the women, the median age was 36 year (range 28–57), height 169 cm (156–172) and weight 61 kg (59–72) and corresponding data for the men were 39 year (21–57), height 180 cm (175–185) and weight 80 kg (70–110). The study has been approved by the Regional Ethics Committee in Lund (Dnr Etik:H15 2013/708), and all participants gave their written informed consent.

2.2. Study design

Each participant performed four different five-minute tasks in a random order with an approximate one-minute break between the work tasks. The tasks were: simulated painting work, simulated computer work, simulated furniture polishing work and rest with elevated, supported arms (Fig. 1). The tasks were selected to represent different combinations of high/low angles and high/low velocities and were used for comparison of data between the new accelerometers and the validated accelerometers. Each participant was instructed how the different work tasks should be performed. The participants also performed two plain reference postures for the upper arms (see below).

2.3. Methods

Postures and movements for the head, the upper back and both upper arms were collected using two different models of triaxial accelerometers. Four small, low-cost devices (5.0 × 2.4 × 1.3 cm) containing a triaxial accelerometer, 2 Gb memory for data logging, a female micro USB-connector and a rechearable battery (USB Accelerometer Model X8M-3 Mini, Gulf Coast Data Concepts, LLC, Waveland, MS, USA, "GC-inclinometer"[1]) and 4 validated accelerometers (Logger Teknologi HB, Åkarp, Sweden, "LT-inclinometer") in combination with a data logger (Logger Teknologi HB, Åkarp, Sweden) with a sampling frequency of 20 Hz (Hansson et al., 2001, 2003) were used. The sampling frequency for the GC-inclinometers was set to 25 Hz in an initiating text file. Four GC-inclinometers were tested for drift during 5.5 h and the maximum drift in any axis for the GC-inclinometers was 0.005 g, and the noise level, in the band 0–5 Hz, was 0.007 g. The mean absolute accuracy for the LT-inclinometers is 1.3° and the reproducibility is 0.2° (Hansson et al., 2001). The dynamic range is ±8 g for the GC-inclinometers and ±2 g for the LT-inclinometers.

One LT-inclinometer was fixed with double-sided adhesive tape, to each of the four GC-inclinometers. The GC-inclinometers were started one by one by holding a magnet near the USB-connector for 1 − 2 s. A LED verified that the logging had started. For synchronization of the 4 GC-inclinometers, the 4 pairs of inclinometers were put on a table and were rapidly pushed back and forth with one hand for 1 s. The time for the beginning of the pushing was noted. The pairs were then mounted, with double-sided adhesive tape, to the middle of the forehead just above the eyebrows, to the

[1] Inclination is the angle relative to the line of gravity and the term inclinometer is used when measuring postures of different body parts. This measurement may be done by using triaxial accelerometers that registers force-signals of gravity and acceleration.

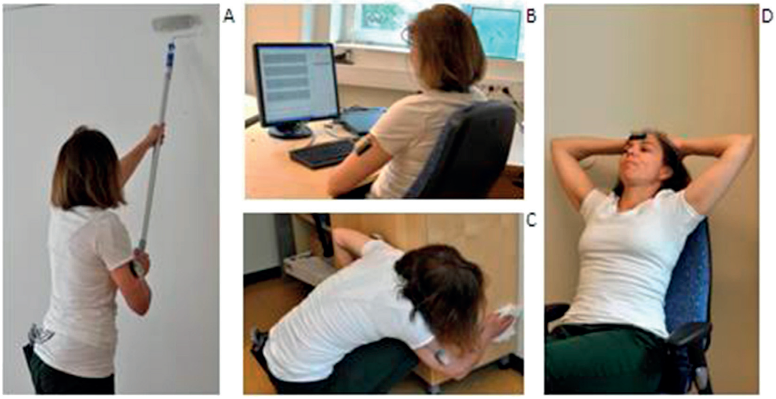

Fig. 1. The four different tasks. A = simulated painting work, B = simulated computer work, C = simulated furniture polishing work and D = rest with elevated, supported arms.

upper back to the right of the spine at the level of C7, and to both upper arms just below the insertion of the deltoid muscle (Fig. 2). These locations are commonly used, and the same as we use in our field measurements and it is likely that the inclinometers are not exactly parallel to e.g. the upper arm bone. By recording of a reference posture (defining 0° of inclination) the inclination may be calculated as the angle in relation to the reference posture (Hansson et al., 2006). All pairs were fixed with Tegaderm™ (3M Health Care, St Paul, MN, USA). After mounting, the LT-inclinometer logger was started and the time was noted.

Fig. 2. The placement and size of three of the four pairs of inclinometers including one inclinometer with an integrated data logger (GC-inclinometer) and one validated inclinometer (LT-inclinometer). The black inclinometer is the GC-inclinometer and the white inclinometer with a cable is the LT-inclinometer. The fourth pair is located on the left upper arm.

The measurements started with recording of 5 toe jumps and continued with the reference posture for the head and back (0° inclination), performed with the subject standing upright and looking straight ahead into a mirror. The forward direction was recorded with the subject sitting, leaning forward, looking at the floor. The reference posture for each upper arm (0° elevation) was performed with the subject seated, with the side of the body leaning towards the back of a chair, and the arm hanging perpendicular over the back of the chair, with a 2-kg dumbbell in the hand (Hansson et al., 2006). These reference postures and forward direction are the same as we use in our field measurements (Hansson et al., 2010). All postures during the recordings were calculated in relation to these reference postures. The recording continued with the performance of the 4 work tasks, followed by the performance of 2 alternative, plain reference postures (posture 1 and posture 2) for the upper arms, giving a total recording duration of approximately 40 min. Posture 1 was performed with the subject standing upright, leaning to the right (or left) with the arm hanging perpendicular towards the floor with extended elbow and fingers, and with the wrist in neutral position. Posture 2 was performed as posture 1, but with relaxed fingers and hand (Fig. 3). The instructor showed the subjects how these postures should be performed. The collected data from the two different inclinometer models were then transferred to a computer, one file containing the data from the LT-inclinometers and 4 files, transferred via the USB-connector, containing the data from the GC-inclinometers.

2.4. Data processing

The LT-inclinometer data were processed in EMINGO, a programme for analysing field recordings of ElectroMyography, INclinometry and GOniometry developed at Occupational and Environmental Medicine, Lund, Sweden: the data files are low-pass filtered (5 Hz), and calibration values generated at a previous recording (stored in a text file and used by the EMINGO programme during the analysis process) for +1 g and −1 g for all three axes for each inclinometer is used for calibration. The co-ordinates from the

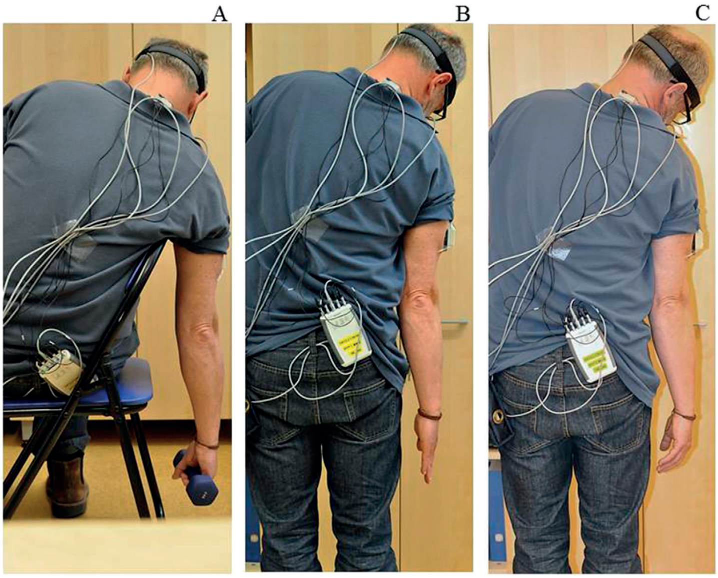

Fig. 3. The three different reference postures. A = standardised reference posture and 2 alternative, plain reference postures; B = posture 1 and C = posture 2.

inclinometers are transformed to the body segment and a second transformation is also performed where the co-ordinates of the body segment are transformed to spherical co-ordinates. These spherical co-ordinates represents, e.g. for the head, the extent and the direction of the inclination (Hansson et al., 2001, 2006). The reference postures, used for deriving angles in relation to them, for all body parts and forward directions for head and back were marked in the files. The start and end time for each of the 4 different work tasks were written in text files. The recordings were then analysed, deriving the 1st, 10th, 50th, 90th and 99th percentiles of the angular distributions of head and back forward/backward inclination and upper arm elevation, the percentage of time with the arms elevated more than 30°, 60° and 90°, and the median of the forward/backward angular velocity distributions of head and back and the generalized angular velocity distributions for the upper arms (summary measures). These measures were computed for the 4 work tasks.

The signals from the GC-inclinometers were preprocessed in MATLAB (version 8.2, MathWorks INC., Natick, MA, USA). The four GC-inclinometers were synchronized to each other by using the rapid pushing back and forth (or using the 5 toe jumps, for the 1 recording where the rapid pushing back and forth was forgotten) in the beginning of each file (see above), and then digitally resampled to 20 Hz. The data files were then fused into one file and the remaining processing was made in EMINGO and, as for the LT-inclinometers, previously generated calibration values were used. The first step was to inspect the recording visually, and if necessary, adjust the starting time of the GC-inclinometer recording so that the starting time for the pushing back and forth, or the toe jumps, coincided with the noted time. The GC-inclinometer recording was then processed and analysed in the same way as the LT-inclinometer recording, deriving summary measures and the median angular velocity for the 4 work tasks and the 4 body parts. To assess the overall differences and the systematic differences between the inclinometers, the mean root-mean-square differences (RMSDs), and the mean differences (GC minus LT), for the 12 participants between the summary measures from the LT-inclinometer recording and the summary measures from the GC-inclinometer recording were calculated for the 4 work tasks and the 4 body parts.

For calculation of the sample by sample Pearson's correlations and differences between the two inclinometer models, the low-pass filtered (5 Hz) data files generated in EMINGO with a frequency of 20 Hz and containing data of all samples of the recording of forward/backward inclination angles for head and back and elevation angles for upper arms were used. The comparison of data files originating from separate pairs of inclinometers was made in MATLAB, and the cross-correlation function was used (Bendat and Piersol, 2000; Jonsson et al., 2011). Hence, one of the signals was stepwise delayed, and for each delay a correlation factor was computed. The maximum correlation coefficient was then used for comparison of similarity. The correlation coefficient and the mean sample by sample RMSDs were calculated for the 12 participants for the 4 work tasks and the 4 body parts.

For comparison between the standardised reference posture and postures 1 and 2 for the upper arms, the recordings from the GC-inclinometers were used. Inclination angles for postures 1 and 2 were derived for evaluation of the deviation of these postures from the standardised reference posture. In the next step, the same recording was used twice; one time with the standardised reference posture as the reference and one time with one of the new postures as the reference. New summary measures with one of the new postures as reference were derived, and the differences between these summary measures and those obtained with the standardized reference posture were calculated.

2.5. Statistical analysis

The statistical analysis was conducted in IBM SPSS Statistics Version 22 (SPSS, Chigago, IL, USA). A p-value of <0.05 (two-tailed) was considered significant. Comparisons between group means were performed using t-test and a confidence interval of 95% (CI95).

3. Results

3.1. Angular distributions

The mean RMSDs between the GC-inclinometers and the LT-inclinometers for the 12 participants are shown for the 4 work tasks and the 4 body parts at 1st, 10th, 50th, 90th and 99th percentiles of the angular distributions in Table 1. The highest mean RMSDs, 2.4°, were seen for the left arm in simulated painting work at the 90th and 99th percentiles of the angular distribution. All other tasks and body parts at all percentiles of the distribution, gave a mean RMSD <1.7°. There were statistically significant differences (GC minus LT) for i.a. the left arm in simulated painting work, where the differences for the 90th and 99th percentiles were −2.4° (CI95 -3.1° − -1.6°) and -2.4° (CI95 -3.1° − -1.7°), respectively.

3.2. Percentage of time

The mean RMSDs of the percentage of time between the GC-inclinometers and the LT-inclinometers for the 12 participants for the 4 work tasks and for upper arm elevation above 30°, 60° and 90° were <1.3%time (Table 1). There were small, but statistically significant differences (GC minus LT) for 7 of the 24 differences, e.g. for the right and left arm elevation above 60° in simulated painting work, where the mean differences were, for the right arm elevation -0.2%time (CI95 -0.3%time − -0.1%time), and for the left -1.0%time (CI95 -1.4%time − -0.7%time).

3.3. Angular velocity

The mean RMSDs of the median angular velocity distribution between the GC-inclinometers and the LT-inclinometers for the 12 participants for the 4 work tasks and the 4 body parts were <5.0 °/s. There were statistically significant differences (GC minus LT) for most of the different body parts and work tasks, with the highest difference for the left arm in rest with elevated, supported arms, with a mean of 5.0 °/s (CI95 4.8 °/s − 5.2 °/s). The median velocities for the LT-inclinometers ranged from 1.2°/s for the head in rest with elevated, supported arms to 108°/s for the right arm in simulated furniture polishing.

3.4. Sample by sample correlations and differences

The mean and minimum cross correlation coefficients and the mean sample by sample RMSDs between the GC-inclinometers and the LT-inclinometers for the 12 participants are shown for the 4 work tasks and the 4 body parts in Table 2. The mean correlations for the 4 work tasks and the 4 body parts were >0.98, except for rest with elevated, supported arms where the mean correlation across body parts ranged between 0.91 and 0.98. This work task was very static, the median angular velocities were <5 °/s (not in table), resulting in low minimum correlations for back and both upper arms (range between 0.58 and 0.78, Table 2). Further, the mean sample by sample RMSDs were <2.5° for all work tasks and body parts. An illustration of a representative correlation between a single pair of inclinometers derived from a

Table 1
Mean RMS differences (°) for the 12 participants at the 1st, 10th, 50th, 90th and 99th percentiles (°) of the angular distributions and the percentage of time (%time) above 30°, 60° and 90° for right and left arm, between the GC-inclinometers and the LT-inclinometers, for the 4 work tasks and the 4 body parts. The angles and the percentage of time for the LT-inclinometers are given within brackets.

Percentile	Painting				Computer work				Furniture polishing				Rest with elevated, supported arms			
	Head	Back	R arm	L arm	Head	Back	R arm	L arm	Head	Back	R arm	L arm	Head	Back	R arm	L arm
1st	1.5 (−38)	0.5 (−6)	0.3 (10)	0.2 (6)	1.3 (−7)	0.4 (5)	0.3 (22)	0.2 (17)	1.3 (1)	1.0 (9)	0.1 (3)	0.3 (23)	1.2 (−45)	0.5 (−20)	1.7 (132)	0.7 (136)
10th	1.3 (−31)	0.3 (−1)	0.3 (17)	0.2 (18)	1.0 (3)	0.4 (9)	0.3 (25)	0.2 (21)	1.1 (18)	1.0 (16)	0.2 (8)	0.4 (35)	1.3 (−43)	0.4 (−19)	1.5 (133)	0.6 (137)
50th	1.0 (−3)	0.4 (10)	0.4 (31)	0.7 (46)	1.0 (11)	0.5 (13)	0.3 (28)	0.4 (26)	1.2 (46)	1.0 (28)	0.3 (22)	0.6 (56)	1.2 (−40)	0.4 (−16)	1.4 (135)	0.6 (139)
90th	1.1 (30)	0.5 (28)	0.7 (57)	2.4 (94)	0.9 (22)	0.5 (17)	0.3 (34)	0.6 (35)	1.2 (61)	0.8 (43)	0.5 (43)	0.9 (85)	1.2 (−35)	0.4 (−13)	1.4 (138)	0.6 (142)
99th	1.2 (52)	0.5 (45)	1.0 (79)	2.4 (108)	0.9 (33)	0.6 (21)	0.4 (49)	0.9 (48)	1.2 (71)	0.6 (52)	0.5 (61)	1.1 (101)	1.3 (−31)	0.4 (−12)	1.3 (139)	0.8 (144)
Percentage of time																
>30°			1.1 (51.8)	0.6 (68.4)			0.4 (44.2)	0.6 (44.8)			0.7 (29.6)	0.3 (89.7)			0.0 (100.0)	0.0 (100.0)
>60°			0.2 (8.5)	1.0 (34.4)			0.0 (0.5)	0.1 (1.3)			0.1 (3.0)	1.2 (42.7)			0.0 (100.0)	0.0 (100.0)
>90°			0.2 (2.0)	1.3 (16.0)			0.0 (0.1)	0.0 (0.6)			0.0 (0.0)	0.5 (7.7)			0.0 (100.0)	0.0 (100.0)

Table 2
Mean and minimum (min) cross correlation coefficients and the mean and maximum (max) sample by sample RMS differences (RMSDs; °) for the 12 participants for the 4 work tasks and the 4 body parts.

	Painting				Computer work				Furniture polishing				Rest with elevated, supported arms			
	Head	Back	R arm	L arm	Head	Back	R arm	L arm	Head	Back	R arm	L arm	Head	Back	R arm	L arm
Correlation																
mean	0.999	0.997	0.996	0.999	0.995	0.987	0.989	0.994	0.998	0.992	0.982	0.998	0.977	0.944	0.907	0.945
min	0.997	0.995	0.991	0.995	0.980	0.972	0.957	0.986	0.997	0.974	0.954	0.996	0.920	0.776	0.578	0.764
RMSD (°)																
mean	1.8	0.9	1.3	2.0	1.3	0.7	0.7	0.7	1.6	1.5	2.4	1.2	1.4	0.6	1.6	0.8
max	3.1	1.3	2.3	3.2	3.5	1.1	1.4	1.3	3.3	2.0	4.6	1.6	3.4	1.2	3.4	1.8

measurement of forward/backward inclination angles for head is shown in Fig. 4. In this example, the correlation between the signals was 0.997 and the sample by sample RMSD was 2.6°.

3.5. *Reference postures for upper arms*

For the right arm and the 12 participants, the mean RMSDs in relation to the standardised reference posture were, 5.8° (SD 2.0°, range 2.4° − 9.9°) for posture 1, and 5.3° (SD 2.5°, 1.0° − 8.0°) for posture 2. For the left arm, the corresponding differences were, 8.3° (SD 3.2°, 2.8° − 14.0°) for posture 1, and 8.5° (SD 2.5°, 4.9° − 12.1°) for posture 2.

The differences for posture 1 and 2 in relation to the standardised reference posture were very similar. Posture 2 was considered to be the easier one to perform, since the hand was relaxed and was therefore chosen as an alternative reference posture. The mean RMSDs between the results when posture 2 was used as reference posture and the results when the standardised reference posture was used as reference posture for the 12 participants are shown for the 4 work tasks and for both upper arms at 1st, 10th, 50th, 90th and 99th percentiles of the angular distributions and for the percentage of time above 30°, 60° and 90° in Table 3. The mean RMSDs of the angular distributions were more than twice as high for the left arm than for the right arm in rest with elevated, supported arms. Further, the overall mean RMSD across work tasks was 3° for the right arm and 4° for the left. Corresponding differences between the GC-inclinometer and the LT-inclinometer (Table 1) was 0.7° for both right and left arm. There were no statistically significant differences for any of the percentiles for the 4 work tasks of right arm, e.g. the rest with supported, elevated arms, with a difference of -1.0° (CI95 -2.9°– 1.0°) for the 99th percentile. Contrary, for the left arm, the higher percentiles for 3 of the work tasks and all percentiles for rest with elevated, supported arms were statistical significant. The highest mean difference for this task was seen for the 99th percentile; -6.0° (CI95 -8.1°– -3.9°). Moreover, the mean RMSDs for the percentage of time above 30° in simulated computer work for both upper arms for the recording when posture 2 was used as reference, were approximately 25% of the time percentages measured with the recording when the standardised reference was used. The corresponding differences between the GC-inclinometers and the LT-inclinometers (Table 1) was approximately 1% of the time percentages.

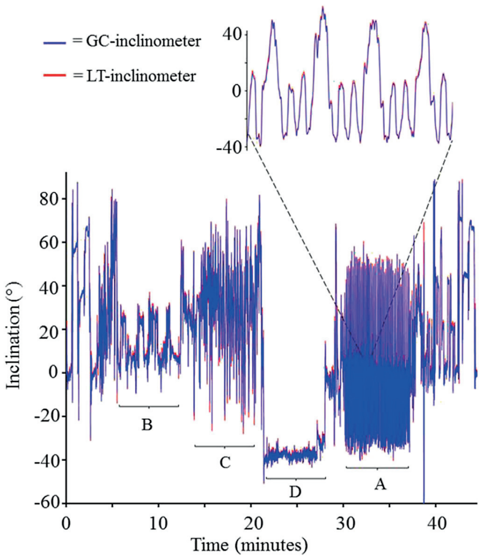

Fig. 4. Signals from a single pair of inclinometers, including one LT-inclinometer and one GC-inclinometer, mounted on the head on one of the twelve subjects. The signals show the angles during work simulation and are selected from 48 measurements obtained from 4 separate pairs of inclinometers/participant from 12 participants. The blown up part is half a minute of the recording. The red signal = LT-inclinometer and the blue signal = GC-inclinometer. A = simulated painting work, B = simulated computer work, C = simulated furniture polishing work and D = rest with elevated, supported arms. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

4. Discussion

In this study of validating a small, low-cost and user-friendly accelerometer with integrated datalogger against a validated accelerometer during different work tasks, the mean RMSDs between the two devices were similar for percentiles of inclination angles (<2.5°) and for the percentage of time above certain arm elevations (<1.5 %time). Further, the mean RMSD of the median velocity was also similar (<5 °/s). Compared to the standardized reference posture, the plain reference posture showed rather high overall mean RMSD across work tasks in percentile values, 3° for the right arm and 4° for the left one, in relation to the overall RMSDs across work tasks between the two devices (0.7° and 0.7°, respectively).

Inclinometers in general, determine their tilt angle relative the vector that is the sum of gravity and the dynamic accelerations; during more rapid motions this vector does not coincide with gravity, and a principal error is introduced. It was concluded in a study by Bernmark and Wiktorin, that the LT-inclinometer was not influenced by dynamic accelerations at slow (0.1 Hz) rates of arm swings; the curves from the LT-inclinometer and the optoelectric measuring system "coincided". For very fast (0.75 Hz) arm swings, the curves differed more; the LT-inclinometer was "influenced by

Table 3
Mean RMS differences (RMSDs; °) at the 1st, 10th, 50th, 90th and 99th percentiles (°) of the angular distributions, and the mean RMSDs of the percentage of time above 30°, 60° and 90° for the 12 participants and the 4 work tasks for right and left upper arms, between the recording with posture 2 as reference and the recording with the standardised reference posture as reference. The values for the GC-inclinometer recordings with the standardised reference posture as reference are given within brackets.

	Painting		Computer work		Furniture polishing		Rest with elevated, supported arms	
	Right arm	Left arm	Right arm	Left arm	Right arm	Left arm	Right arm	Left arm
Percentile (°)								
1st	3.7 (10.2)	1.6 (6.5)	4.3 (21.8)	3.3 (17.2)	1.0 (2.5)	4.0 (23.7)	2.7 (131.2)	6.4 (135.1)
10th	3.6 (16.6)	2.9 (18.2)	4.2 (24.9)	3.6 (21.1)	1.4 (7.5)	4.7 (34.9)	2.7 (132.6)	6.4 (136.7)
50th	3.5 (30.1)	4.6 (45.5)	4.1 (27.8)	4.2 (26.0)	1.8 (21.6)	5.2 (55.8)	2.6 (134.7)	6.4 (138.8)
90th	3.7 (56.7)	4.8 (92.1)	4.1 (34.0)	4.9 (34.9)	2.2 (42.9)	4.3 (84.4)	2.6 (137.8)	6.5 (141.8)
99th	3.1 (79.3)	4.8 (105.9)	3.4 (49.3)	4.7 (46.9)	2.1 (60.3)	4.6 (101.0)	2.6 (139.4)	6.5 (143.7)
Percentage of time								
>30°	10.6 (50.8)	5.1 (68.3)	10.9 (43.8)	11.5 (44.3)	3.8 (29.0)	3.3 (89.9)	0.0 (100.0)	0.0 (100.0)
>60°	1.0 (8.3)	4.4 (33.3)	0.1 (0.5)	0.2 (1.2)	0.3 (2.8)	11.5 (42.7)	0.0 (100.0)	0.0 (100.0)
>90°	0.4 (2.0)	3.0 (14.7)	0.0 (0.1)	0.1 (0.5)	0.0 (0.0)	1.9 (7.4)	0.0 (100.0)	0.0 (100.0)

dynamic accelerations [that] altered the direction of the total acceleration and caused a deviation from the vertical line" (Bernmark and Wiktorin, 2002). Also, in a recent study, Korshøj *et al.* concluded that the root-mean-square error (RMSE) values of inclination, at slow (0.125 Hz) and intermediate (0.25 Hz) frequencies, and for most of the simulated work tasks, between a triaxial accelerometer and a magnetic tracking device were "in close agreement". However, the inclination estimated by the triaxial accelerometer at high (0.5 Hz) frequency deviated from the reference measurements, where RMSE values up to ~10° were noted (Korshøj et al., 2014). In the current study, the frequency of large movements was highest for the simulated painting work and was estimated to 0.25–0.5 Hz.

It has been suggested that the mounting of the inclinometers may introduce a methodological error, such as underestimating upper arm elevation. This may be due to that the relative position of the inclinometer to the underlying bone, will change throughout the range of motion, to different extents at different arm elevations, i.e. soft tissue artifact. In a recent study, Jackson *et al.* showed an underestimation of about 10° at instructed arm elevations of 90° (Jackson et al., 2015). However, our experience shows a difference of <1° at instructed arm elevations of 90° (Hansson, 2015). In the current study, we followed the same instructions for arm elevations of 90° as in those 80 measurements that Hansson referred to in his Letter to the editor (Hansson, 2015). These instructions differ from those performed in Jackson *et al.* The arm elevations of 90° in Jackson and coworkers study was performed with the arms abducted, while the arm elevations in the current study (and in all our studies), were performed with the arms abducted, but somewhat flexed (20°–30°). There were also differences in the performance of the reference posture. Jackson and coworkers asked their subjects to sit, leaning to the right with the arm hanging vertically, while the subjects in the current study were asked to sit, with the side of the body leaning towards the back of a chair, and the arm hanging perpendicular over the back of the chair. Other methodological errors may also be introduced when using different sampling frequencies and filters when processing accelerometer data and calculating the summary measures.

As the signals from the GC-inclinometers and the LT-inclinometers of compared inclinometers were sampled and stored separately, with only manual synchronization, there were differences in the times arriving from the noted start times, which was used to define the time interval for the computation of the summary measures. Further, the reference postures for the GC- and LT-inclinometer recordings were marked separately in the two different inclinometer recordings, and were therefore not exactly the same. When comparing the start times for the toe jumps, the time differences between the two recordings for the 12 subjects were <1.2 s. This maximal time difference is negligible for the summary measures, since the work task durations were about 300 s. This maximal time difference is also well below the 5 − 7 s that the reference postures were held. Thus, the time differences have, if any, only a marginal impact on the summary measures and the reference postures.

The different work tasks were selected to accomplish a wide range of postures and movements. With these tasks, the GC-inclinometers were tested in different combinations of high/low angles and high/low velocities in order to find out if they influenced the overall differences. The mean RMSDs for the 12 subjects for the 4 work tasks and the 4 body parts were <1.7° for the angular distributions, except for the left arm in the simulated painting work, where the left arm showed mean RMSDs of 2.4° for the high percentiles (90th and 99th; Table 1). When scrutinizing the data, this task and this body part showed a combination of high angles and high velocity (71 °/s). Other combinations, e.g. high angles and low velocity, i.e. the left arm in rest with elevated, supported arms, showed a lower mean RMSD, on average 0.7° for the high percentiles. An additional combination, e.g. low angles and high velocity (108 °/s) was seen for the right arm in the simulated furniture polishing, where the mean RMSD was 0.5° for the high percentiles. High angular velocities in combination with high angles at the same time resulted in deviating values for the high angles when measuring with the GC-inclinometer compared to the LT-inclinometer.

The GC-inclinometers showed significant differences of the inclination and the median angular velocity compared to the LT-inclinometers for some occasions, where the most conspicuous were seen for the high percentiles of the inclination for the left arm in simulated painting work and for the median angular velocity for the left arm in rest with elevated, supported arms. Still, the differences for the percentiles across tasks and body parts between the GC-inclinometers and the LT-inclinometers, are smaller compared to methodological errors, e.g. soft tissue artifacts (10°). The differences are also below relevant differences that can be seen between occupational groups; it was shown in an earlier study by *Hansson* et al., that the head flexion and the arm elevation varied between 9° and 63° and 49° − 124°, respectively, in 43 types of work (Hansson et al., 2010). Further, the present differences of the arm elevation are also less than the between-days and between-subjects variability (3.4° and 4.0°, respectively) that has been seen during strictly standardized work tasks (Hansson et al., 2006).

The correlations between paired readouts in the present study were >0.98, except for one work task. The lower correlations for rest with elevated, supported arms across body parts are most likely due to the very low activity. The noise in the separate devices was "visible" in the output signals and since the noise behaves irregularly in comparison to each other, the co-variation became low. Still, the absolute error was low also for this case, <2.5° (c.f. Table 2). The RMSD and the cross-correlation values complement each other. The RMSD is a measure of how far away the output signals are from each other while the cross-correlations is a measure of how well they follow each other. In 3 of the 4 tasks, there is a high cross-correlation value (>0.98) and a low RMSD (<2.5°) for all body parts. The reason for a lower cross-correlation in the 4th task, the rest with elevated, supported arms, is discussed above.

The overall mean RMSDs between the percentile values derived using the plain reference posture and the percentile values derived using the standardized reference, across work tasks, was 3° for the right arm and 4° for the left one (derived from Table 3). These differences are four times higher for the right arm and almost six times higher for the left, than the corresponding differences between the GC-inclinometer and the LT-inclinometer, across work tasks (derived from Table 1). Further, the percentage of time above 30° elevation, differed considerably between the plain reference posture and the standardized reference posture for both arms during the computer work (Table 3; 11 %time and 12 %time, respectively). These differences are most likely due to that this work was carried out in a small range of elevations of approximately 20° – 50°, which includes the 30° elevation cut off. The differences between the plain reference posture and the standardized reference posture in the current study was 5° for the right arm and 8° for the left one. The methodological significance of a plain reference posture had implications on the percentage of time above certain elevations for this type of work task. Furthermore, the left arm showed considerable, and statistically significant, differences between the two reference postures for all higher percentiles of all 4 work tasks, which indicate a non-negligible difference between the two reference postures.

In addition to this study, we developed a protocol and a user-friendly software for analysing the recorded data obtained with the new accelerometers that has been tested by practitioners (Forsman et al., 2015). The software has the same calculation algorithms as EMINGO and the protocol is basically: "Attach 1 to 4 inclinometers, start each of them when the subject is in the reference posture position (of that body part). Ask the subject to do 5 jumps and note the time at the first jump. Also note other times, as those of different tasks, and breaks. Ask the subject to hold the arms in a 90°-abduction, and to bow forward once". After the recording, the accelerometers are connected to a computer. In the user-friendly software, the user is asked to write the start time for jump and start and stop time for work. The accelerometers are synchronized, and the reference postures for the different body parts are automatically taken as the first couple of seconds of each recording. The software finds the start of the jumps, analyses the recording, and immediately presents postures and movements of the recorded workload in figures and in tables (in an Excel file). The procedure for measuring and analysing data with this protocol and software is less time consuming and more user-friendly than for the validated accelerometers. The estimated time for mounting, and starting recordings including reference posture measurements, is about 3 – 5 min, where the corresponding time for the validated accelerometers, with cables and an external logger, is about 12 – 15 min. The system (accelerometers, protocol and software) give actors in the work environment field, because of the low costs and usability, opportunities to objectively measure the workload in different occupations. This may increase the quality of their risk assessments. The system may also give clearer support for prioritizing actions and clearer evaluations of implemented changes than observation methods do. The new accelerometers are also better suited than the validated ones in certain types of work, e.g. work that is carried out in confined spaces e.g. plumbing; there are no cables that may get stuck and there is no external data logger that may be in the way.

5. Conclusions

This model of the new generation of accelerometers with integrated data loggers proved to be fully comparable to a previously validated traditional triaxial accelerometer using an external data logger. With this new generation of accelerometers, in combination with the software and protocol, actors in the work environment field now have a cost effective, user-friendly and scientifically based objective method available for their risk assessments. The new accelerometers are also well-suited for researchers to measure postures and movements during work. However, different types of new accelerometers may have different properties regarding drift and noise level, which can contribute to methodological errors. Therefore we recommend testing other accelerometers concerning noise level and drift before use. Further investigation is needed in a larger material for validation of the plain reference posture for the upper arms.

Conflicts of interest

The authors declare no conflicts of interest.

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Paper II

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Comparing two methods to record maximal voluntary contractions and different electrode positions in recordings of forearm extensor muscle activity: Refining risk assessments for work-related wrist disorders

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Abstract.
BACKGROUND: Wrist disorders are common in force demanding industrial repetitive work. Visual assessment of force demands have a low reliability, instead surface electromyography (EMG) may be used as part of a risk assessment for work-related wrist disorders. For normalization of EMG recordings, a power grip (hand grip) is often used as maximal voluntary contraction (MVC) of the forearm extensor muscles. However, the test-retest reproducibility is poor and EMG amplitudes exceeding 100% have occasionally been recorded during work. An alternative MVC is resisted wrist extension, which may be more reliable.
OBJECTIVE: To compare hand grip and resisted wrist extension MVCs, in terms of amplitude and reproducibility, and to examine the effect of electrode positioning.
METHODS: Twelve subjects participated. EMG from right forearm extensors, from four electrode pairs, was recorded during MVCs, on three separate occasions.
RESULTS: The group mean EMG amplitudes for resisted wrist extension were 1.2–1.7 times greater than those for hand grip. Resisted wrist extension showed better reproducibility than hand grip.
CONCLUSIONS: The results indicate that the use of resisted wrist extension is a more accurate measurement of maximal effort of wrist extensor contractions than using hand grip and should increase the precision in EMG recordings from forearm extensor muscles, which in turn will increase the quality of risk assessments that are based on these.

Keywords: Technical risk assessment, electromyography, normalization, resisted wrist extension, hand grip

1. Introduction

Many occupations require excessive and/or prolonged muscular load, which in combination with

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repetitive work, may result in a high frequency of work-related wrist disorders [1–3]. The frequency is especially high for females in the assembly industry, and therefore, interventions in the physical work stations and in work organisations are needed, to decrease the risk for development of musculoskeletal disorders. The interventions are based on risk assessments, and it is important that the assessments are valid and reliable. Many observational risk assessment methods have been developed [4, 5]. However, visual assessments, as well as self-assessments of force and/or exertion intensity often show a low reliability [4]. It has been recommended that technical measurements should replace visual assessments when feasible [6], and surface electromyography (EMG) is a technical method that could be used to obtain quantitative measures of the forces exerted by the hand. One example of an observation method where the force assessment component can be replaced, is the ACGIH threshold limit value (TLV) for hand activity level [7]. The ACGIH hand activity level includes levels of force and repetitiveness (used to assess the risk of developing disorders in the hand, wrist or forearm), and EMG has been suggested for reliability reasons to determine the peak force when assessing the hand activity level, to be compared with the TLV in hand intense work. Furthermore, a direct association between the amplitude of muscular activity from EMG measures and pain has been demonstrated in several studies [3, 8–10]. Moreover, a low frequency of so called EMG gaps (short time periods with muscular rest) and/or a small time proportion with muscular rest, are associated with work-related musculoskeletal complaints [8, 11, 12].

The amplitude of EMG recordings differs between and within subjects carrying out the same working task [13, 14]. The difference between subjects may depend on technique, strength and skinfold thickness [15]. Therefore, large differences are seen between male and female workers performing the same working tasks [16, 17]. The difference in measurements made on one subject from one day to the next may also be influenced by the reproducibility of the electrode positioning, especially if the electrodes are positioned close to the innervation zone. Furthermore, to enable comparison of the muscular activity between subjects, EMG recordings are generally normalized to a reference contraction [18, 19]. Reference contractions can be obtained in a variety of postures and at different loads, e.g. maximal voluntary isometric contraction (MVC). The highest electrical activity obtained during the MVC is generally referred to as the maximal voluntary electrical activity (MVE) and the muscular load during work is then expressed as a percentage of the MVE. Work is often carried out in a variety of arm postures at different loads, and it is desirable that the reference contraction and the electrode position are appropriate during all these conditions.

Variation may be observed in the reference contraction of an individual when measured on different days. In fact, when evaluating the reproducibility of EMG measurements in a laboratory setting, we found that the muscular activity during work, expressed as %MVE in the right forearm extensors (*Mm. extensor carpi radialis* (*longus et brevis*); ECR), showed a high intra-individual coefficient of variation of about 33%. The corresponding variation in non-normalized data was 16%. For MVE during the contractions themselves, the coefficient of variation was 29% [14]. Thus, normalization itself introduces a variation.

Although the *resisted wrist extension* may be the most obvious manner to activate the extensor muscles, many research groups, including ours, elicit the MVC of the forearm muscles with a power grip (here referred to as the *hand grip*) in a mid-pronated (i.e. neutral) forearm posture [20–22]. This grip can be used for simultaneous MVCs for both the flexor and the extensor muscles. However, we occasionally see higher EMG amplitudes during industrial work than those obtained during the MVC performed with the maximum hand grip. We also see higher EMG amplitudes for some subjects when they perform a maximal active range of motion of the wrist in flexion-extension (maximal wrist extension) compared to when performing the MVC with the hand grip. These observations indicate that the muscles are not always fully activated during the reference contraction. Also the *resisted wrist extension* has been used as reference contraction for normalizing the forearm extensor muscle activity [17, 23–25]. However, we have considered this contraction to be more inconvenient to perform in work place recordings than the *hand grip.* Thus, there is clearly a need to re-evaluate the reference contractions.

Additionally, in some professions, such as dental hygienists [26, 27], a high force pinch grip is frequent. The impact of pinch grip on EMG from the forearm extensors has been discussed [28]. It would therefore be interesting to register both maximal wrist extension and pinch grip, when using the resisted wrist extension and the hand grip for normalization.

The effect of electrode positioning on EMG amplitude is also significant. If a pair of electrodes is placed symmetrically above the innervation zone, the recorded amplitude will be reduced, and will also be sensitive to small movements of the skin [29, 30]. To improve our knowledge on the location of the innervation zone, it would be interesting to find the motor point, i.e. the point where the nerve enters into the muscle, as this presumably is proximal to the innervation zone.

The aim of this study was to compare the amplitude and reproducibility of two different methods of measuring MVCs of the forearm extensors, and to examine the effect of electrode positioning on recordings of forearm extensor muscle activity.

2. Methods

2.1. Study design and subjects

Twelve right-handed employees at our department, six women and six men, without ongoing upper extremity complaints, participated in the study (Table 1). The electrical activity of the right forearm extensors was recorded on three separate occasions, at least seven days apart. On each occasion, three MVCs of two different types of contraction (the *hand grip* and the *resisted wrist extension*), and three maximal activations of two different types (pinch grip and maximal wrist extension), were performed, each followed by a short rest of about half a minute. The instructor actively encouraged the subject to perform at their best and they were asked to sustain the maximum contraction/activation for about 5 seconds. The subject was seated and body movements were controlled during each test.

All participants were colleagues at our research division, and were informed about the study according to the Declaration of Helsinki. They were informed verbally about the procedures, that participation was voluntary and that they were free to discontinue at any time without explanation. They all gave their verbal consent.

2.2. Electromyography

Mm. extensor carpi radialis longus et brevis (ECR) were located, in the same way as we do in our work place recordings, in the right forearm by palpation, while the subject performed a voluntary contraction with the forearm pronated. The skin was cleansed with acetone and rubbed with emery cloth. Two Ag/AgCl electrodes (Ambu Neuroline 720, Ambu A/S, Ballerup, Denmark) were applied along the muscle fibres, on the skin above the most prominent part of the muscles, i.e. at approximately one third of the distance from the *epicondylus lateralis humeri* to the *processus styloideus ulnae* [14]. Three additional electrodes were applied, two proximally to the original pair, and one distally, as shown in Fig. 1. This arrangement of five electrodes (numbered 1 to 5 starting from the elbow) allowed measurements to be made from four pairs of electrodes, labelled A to D in Fig. 1. The active diameter of the electrodes was 6 mm, and the centre-to-centre distance 20 mm.

Table 1
Characteristics of the six female (F) and six male (M) subjects, their skinfold thickness and maximal exerted force for the two maximal voluntary contractions (MVCs) and one of the two maximal activations, presented as the mean and standard deviation (SD) of measurements made on three occasions

Subject	Sex	Age (year)	Height (cm)	Weight (kg)	Skinfold thickness (mm)	Force (N)		
						Contraction (MVC)		Activation
						Resisted wrist extension	Hand grip	Pinch grip
					Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
1	F	43	168	61	8.9 (0.6)	78 (2.5)	337 (15)	108 (6.2)
2	F	66	160	63	7.1 (0.1)	48 (6.0)	262 (15)	75 (6.0)
3	F	53	153	51	9.0 (0.3)	64 (3.1)	275 (0)	66 (5.8)
4	F	46	166	71	7.9 (0.3)	82 (4.9)	422 (0)	95 (7.6)
5	F	34	167	60	5.6 (0.4)	89 (2.1)	405 (25)	71 (2.9)
6	F	50	165	57	4.4 (0.2)	57 (4.9)	373 (26)	86 (2.5)
7	M	57	169	72	4.7 (0.4)	114 (4.9)	464 (12)	106 (5.8)
8	M	31	173	62	3.1 (0.1)	112 (3.2)	405 (25)	110 (4.6)
9	M	61	171	81	4.0 (0.3)	121 (4.4)	520 (10)	83 (4.0)
10	M	55	178	73	5.5 (0.2)	112 (1.7)	493 (6)	110 (4.6)
11	M	37	185	74	4.1 (0.1)	137 (8.1)	510 (20)	135 (0.0)
12	M	58	194	90	5.0 (0.2)	104 (7.4)	582 (54)	117 (8.5)

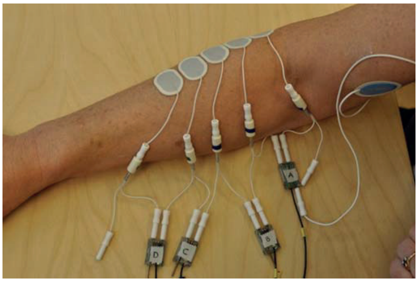

Fig. 1. Electrode positioning on the right forearm extensor muscles. The electrodes are numbered 1 to 5 starting at the elbow. The large blue electrode is the ground electrode. The signals were measured between pairs of electrodes (A-D).

The impedance was measured for each pair, and if the value was >15 kΩ, the electrodes were removed and replaced after repeated skin cleansing. The ground electrode was placed on the inside of the distal part of the upper arm.

After performance of the MVCs/activations described below, the positions of the electrodes were marked on the forearm with a felt-tip pen before they were removed. A line was drawn between the *epicondylus lateralis humeri* and the *processus styloideus radii*, and the shortest perpendicular distance between this line and each electrode was drawn. The distance from the epicondyle to the projection of each electrode on the line was measured, as was the distance between the epicondyle and the styloid.

The signals were amplified, filtered (10–400 Hz) and sampled at a rate of 1024 Hz, and stored on portable data loggers (Logger Teknologi HB, Åkarp, Sweden) using exchangeable flash-memory cards [31]. After collection, the data were transferred to a computer for quality assurance and analysis. The signal was band-pass (30–400 Hz) and notch filtered, i.e. 50 Hz and all harmonics. The root-mean-square value was calculated for epochs of 0.125 s, and the noise was subtracted in a power sense [32]. A moving window with a width of 0.5 s was used to find the highest EMG activity recorded during the three contractions and the three activations, for each kind of contraction and activation [32, 33].

2.3. Maximal voluntary contractions

2.3.1. Resisted wrist extension

The subject was seated with a backrest, with the upper arm close to the body, the elbow flexed and the forearm pronated and supported on a table, adjusted to a comfortable height. The hand was inserted into a glove that was attached to a sheet of plywood on the dorsal side of the glove. The middle finger of the glove went through a metal ring that was mounted on the underside of the plywood. A non-flexible strap went through the ring, which was attached to a force transducer on the floor. The hand was outside the table while the wrist was supported on the table (Fig. 2). The subject was asked to attempt to perform a maximal extension of the wrist, while the wrist remained in the neutral position, and care was taken to ensure that the sheet of plywood remained horizontal when the wrist extensors were maximally activated (Table 1).

2.3.2. Hand grip

The subject performed a maximal isometric grip around a Jamar hand dynamometer (Sammons Preston, Bolingbrook, IL, USA) while seated with a backrest, with the right upper arm close to the body, with the elbow flexed at 90° holding the forearm and hand without support, in a neutral position (Table 1, Fig. 2).

2.4. Maximal activations

For the pinch grip, the subject was seated with the arm unsupported and somewhat forward flexed at the shoulder, with the elbow flexed to approximately 90°, holding the forearm in a neutral position. The wrist was in a functional position (0–30° extension, 0–15° ulnar deviation, Fig. 2). The examiner handed a pinch dynamometer (North Coast Medical, Gilroy, CA, USA) to the subject who was instructed to grip it by the thumb and the second and third fingers, and press as hard as possible (Table 1).

For the maximal wrist extension, the subject was seated with the elbow supported by the table, flexed at 90° (forearm pronated and approximately 45° upwards). The wrist was at maximal dorsal flexion, and the subject was instructed to continue to extend the wrist as much as possible (Fig. 2).

2.5. Detection of the motor point

The motor point was detected using a transcutaneous electrical nerve stimulator (TENS, CEFAR Medical AB, Lund, Sweden). A carbon rubber electrode, 50 × 30 mm, was placed on the muscles on the flexor side of the forearm, and fixed with Mefix® (Mölnlycke Health Care AB, Gothenburg, Sweden). The extensor side was shaved, and covered with

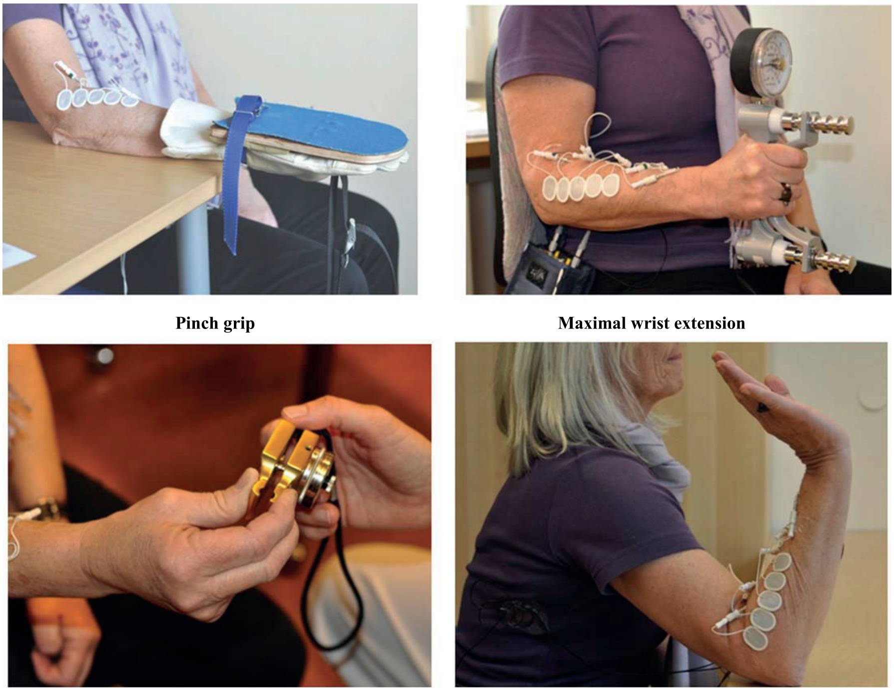

Fig. 2. The maximal voluntary contractions and maximal activations.

electrode gel. A smaller carbon rubber electrode (18 mm in diameter) was held in place on the skin over the muscle belly. The TENS was set to low-frequency stimulation, generating constant current trains of 8 square pulses with a repetition rate of 1.7 Hz. The amplitude was slowly increased while the electrode was slid up and down, as well as sideways, along the full length of the muscle. The point at which repeated extension of the index and/or the middle finger was observed at the lowest electrical stimulation was identified as the motor point. This point was marked, and the distance to the epicondyle was measured. Finally, the markings on the arm were photographed to allow subsequent quality checks.

2.6. Skinfold thickness

The thickness of the subcutaneous tissue was measured at the area between the electrodes forming pair C, using a skinfold calliper (Harpenden, British Indicators, West Sussex, UK), according to the manufacturer's instructions.

2.7. Data analysis

The quality review of the collected data revealed no anomalies, and all the data were analysed. Calculations were performed separately for each pair of electrodes and each type of MVC and maximal activation. After inspecting the data and finding it reasonable, the mean EMG amplitude (μV) across occasions was calculated for each subject, as well as the group mean of these means.

The standard deviation and the coefficient of variation (CV: standard deviation/ mean) for the MVCs were calculated for each subject for the three different occasions. We then calculated the group mean of the CVs. To derive a combined measure of goodness, i.e. the combination of high amplitude and low CV, the ratio between the group mean EMG amplitude and the group mean CV (group EMG_{amp}/CV) was calculated.

The effect of type of MVC on the EMG amplitude was calculated using a linear mixed regression model, with a random intercept for each individual and with MVC and occasion included as fixed factors.

A p-value below 0.05 was considered statistically significant. To investigate the retest correlation for the two different MVCs, the intra class correlation coefficients (ICC) were calculated from the linear mixed regression models fitted for each type of MVC separately. Values above 0.6 were considered good or excellent [34], indicating a low between-days variation within subjects. The MVC with the highest group mean EMG amplitude was selected. For each subject, the mean EMG amplitudes for the other MVC and the maximal activations were normalized to this, and expressed as %MVE. Then, the group mean EMG amplitudes for the maximal activations were normalized to both the *resisted wrist extension* and the *hand grip*, and expressed as %MVE. IBM SPSS Statistics Version 22.0 (SPSS, Chicago, IL, USA) was used for the statistical analyses.

3. Results

3.1. Maximal voluntary contractions

The highest group mean EMG amplitudes were, for all electrode pairs found for the *resisted wrist extension* (Table 2, Fig. 3). These values were 1.2–1.7 times higher than those obtained with the *hand grip*. The reproducibility in the *resisted wrist extension* over the three occasions, in terms of the group mean CV, was 14–15% for electrode pairs A, B and C, and 22–28% for the *hand grip*. For pair D, the corresponding values were 21% and 28%, respectively. The group mean CVs for force were 5% for the *resisted wrist extension* and 4% for the *hand grip* (derived from Table 1). The highest group EMG_{amp}/CV ratio (the combined measure of goodness) over the three occasions was derived for the *resisted wrist extension* in all electrode pairs. Concerning the reliability, in terms of ICC, values above 0.6 was found in pair A, B and C for the *resisted wrist extension*, and in pair A and C for the *hand grip* (Table 2).

When the mean EMG amplitudes for the *hand grip* was normalized to the mean EMG amplitude for the *resisted wrist extension* (expressed as %MVE of *resisted wrist extension*) for each participant in all four electrode pairs, a value greater than 100% was found for three subjects, two of the subjects in pair B and D and one in pair C and D (Fig. 4).

3.2. Maximal activations

The pinch grip gave 60–68 %MVE when normalized to the *resisted wrist extension*, and 74–100 %MVE when normalized to the *hand grip*. For the maximal wrist extension, 58–80 %MVE was registered when normalized to the *resisted wrist extension,* and 67–121 %MVE when normalized to the *hand grip* (Fig. 4).

3.3. Electrode positioning

The group mean EMG amplitudes for the two MVCs varied considerably with the electrode positioning (Table 2, Fig. 3). The lowest values were observed with electrode pair C (the pair used in our

Table 2

Group mean EMG amplitude (EMG_{amp}) from three separate occasions and group mean across these. Group mean CV (CV) and the ratio between the mean and CV (EMG_{amp}/CV) for the maximal EMG amplitudes for two different contractions (MVCs) obtained using four different pairs of electrodes in twelve subjects. Statistically significant differences in EMG amplitudes between MVCs, and intraclass correlation coefficients (ICC), calculated by linear mixed regression models

Contraction (MVC)	Electrode pair	EMG_{amp} (μV) occasion 1	occasion 2	occasion 3	mean	Significance	CV (%)	EMG_{amp}/CV	ICC
Resisted wrist extension	A	679	716	760	718	*** (A vs hand grip A)	14	51	0.70
	B	653	662	712	676	** (B vs hand grip B)	15	45	0.69
	C	608	653	623	628	*** (C vs hand grip C)	14	46	0.62
	D	779	805	938	841		21	40	0.46
Hand grip	A	353	435	505	431		22	20	0.67
	B	439	513	664	539		28	19	0.36
	C	415	496	500	470		23	20	0.68
	D	584	707	902	731		28	26	0.47

**$p < 0.01$, ***$p < 0.001$.

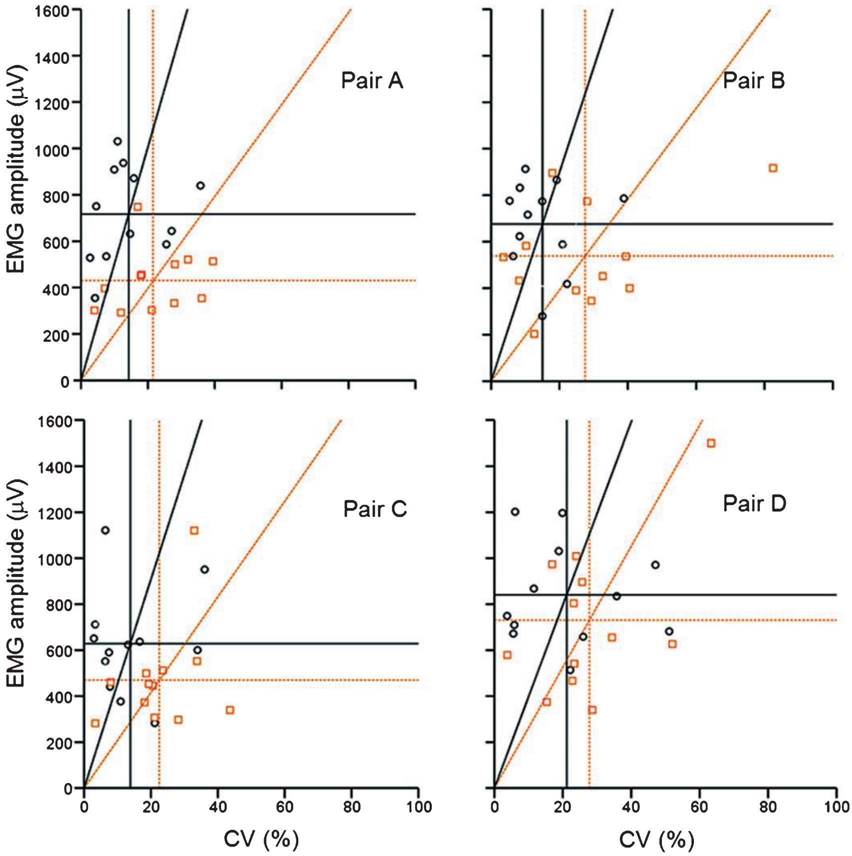

Fig. 3. Mean EMG amplitude versus CV for two types of contraction. The EMG amplitude was measured on three separate occasions using four pairs of electrodes in twelve subjects (○ and —— = the *resisted wrist extension*, □ and ······ = the *hand grip*). The horizontal lines represent the group mean EMG amplitude and the vertical lines the group mean CV for each type of MVC. The slopes of the lines through the origin represent the ratio between the group mean EMG amplitude and group mean CV for the twelve participants.

work place recordings) for the *resisted wrist extension* (Table 2), the pinch grip and the maximal wrist extension (data not shown), while the *hand grip* showed the lowest amplitudes for pair A (Table 2). The highest group mean EMG amplitudes were seen for pair D for the *resisted wrist extension*, the *hand grip* and the pinch grip, and for pair B for the maximal wrist extension. The highest group EMG_{amp}/CV ratio was seen for pair A for the *resisted wrist extension* and for pair D for the *hand grip*.

The electrode positions for participants number 7 and 8 varied >20 mm between sessions, i.e. the electrode pair positions were interchanged (Fig. 5). These participants also showed high CVs between sessions.

3.4. Motor point

The median distance from the *epicondylus lateralis humeri* to the motor point was 63 mm (range 50–73 mm), approximately ¼ (range 22–27%) of the distance between the *epicondylus lateralis humeri* and the *processus styloideus radii*. This was very close to electrode 2, the one used in pairs A and B (Fig. 5).

4. Discussion

In this comparison of two MVCs, and four electrode positions, the *resisted wrist extension* gave the

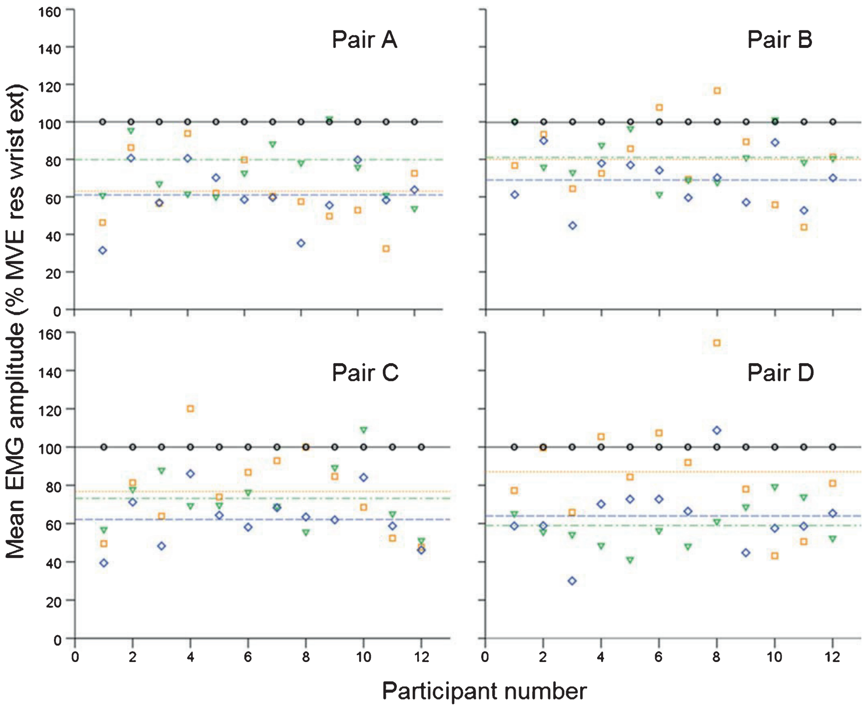

Fig. 4. Normalized mean EMG amplitudes. The EMG amplitude was measured on three separate occasions for two types of MVC and two types of maximal activation using four pairs of electrodes in twelve subjects. The mean EMG amplitudes for the *hand grip* (□ and ·······, the pinch grip (◇ and ----), and the maximal wrist extension (▽ and -·-·), have been normalized to the mean EMG amplitude for the *resisted wrist extension* (○ and —), and are presented as %MVE. The horizontal lines represent the group mean %MVE.

highest group mean EMG amplitude for all electrode pairs, and the group mean CV was lower for the *resisted wrist extension* than for the *hand grip* for all electrode pairs. Furthermore, the group EMG_{amp}/CV ratio was substantially higher for the *resisted wrist extension* than for the *hand grip* for all electrode pairs. ICC showed no substantial difference between the two contractions. Concerning electrode positioning, the highest group EMG_{amp}/CV ratio in the *resisted wrist extension* was observed for pair A, the most proximal position, and in the *hand grip* for pair D. The motor point was located approximately ¼ of the distance between the *epicondylus lateralis humeri* and the *processus styloideus radii*.

4.1. Maximal voluntary contractions

In the present study, 11 of the 12 subjects exhibited higher EMG amplitudes with the *resisted wrist extension* than with the *hand grip* (Fig. 4; electrode pair C). This differs from the results reported in a previous study, where both the *resisted wrist extension* and the *hand grip* were performed [23]. In that study, only 6 of the 11 subjects showed the highest EMG activity with the *resisted wrist extension*, while the rest of the participants showed the highest activity with the *hand grip*. Recalculation of the original data gave an MVE group mean of 114% when comparing the *hand grip* to the *resisted wrist extension*. In the present study, the corresponding value was 77%, which is in accordance with the results of a recent study by Meyland et al., who reported a value of 79% [17], approximately a factor of 0.8 for these studies. There is no obvious explanation for the difference between the present study and that carried out by Åkesson et al. However, in the study by Åkesson et al. the *hand grip* was performed with a supported forearm, which was not the case in the present study or that by Meyland et al.

The results in the current study are in good agreement with the results in a recent study by Ngo and

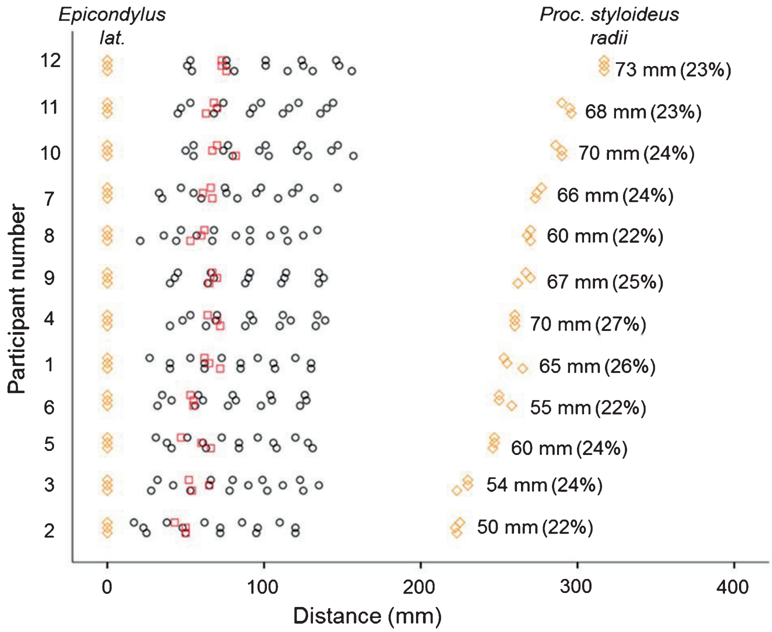

Fig. 5. Distances for right forearm. The distance (mm) from the *epicondylus lateralis humeri* (◇) to the electrodes (○), to the motor point (□) and to the *processus styloideus radii* (◇), measured on three separate occasions in twelve subjects. The digit given for each participant is the distance between the *epicondylus lateralis humeri* and the motor point. The ratio of the median distance between the *epicondylus lateralis humeri* and the motor point, and the distance between the *epicondylus lateralis humeri* and the *processus styloideus radii* is given in brackets.

Wells [35]. In their study, the ECR muscles also showed 1.3 times higher EMG amplitudes for the *resisted wrist extension* than the amplitudes obtained with the *hand grip*. The subjects in Ngo and Wells´ study performed the *resisted wrist extension* with the forearm in a mid-pronated (i.e. neutral) position, while the subjects in the current study performed it in a pronated forearm position; the results from these two studies indicate that the forearm position may be of less importance when performing the MVC with the *resisted wrist extension*. For practical reasons, in workplace recordings, the *resisted wrist extension* in a pronated position may be preferred; especially if also the activity from the trapezius muscles is recorded. Then, a force transducer anchored to a heavy metal plate on the floor, can be used for both muscles.

In general, the ratio between EMG amplitude and CV, was more than twice as high for the *resisted wrist extension* as for the *hand grip*, whereas ICC showed no substantial differences between the two MVCs. Altogether, the results of this study show that the *resisted wrist extension* may be preferred for normalization of the forearm extensor muscles.

4.2. *Electrode positioning*

The group mean EMG amplitude varied with the electrode position. The activity in the extensor muscles may differ considerably depending on the distance from the IZ, skin movements, arm position and the influence of surrounding muscles. Barbero et al. reported that the IZ could be located, starting from the *epicondylus lateralis humeri*, between 17% and 42% of the length of the forearm [36]. In the present study, lower amplitudes were obtained for most subjects with electrode pair C, compared to the other pairs of electrodes for one of the two MVCs and for both of the activations studied. It is possible that these lower amplitudes indicate the location of the IZ, and in agreement with that reported by Barbero et al. These facts, in combination with the highest ratio for the *resisted wrist extension* being found for pair A and for the *hand grip* with pair D, indicate that our present electrode pair position, pair C, is not optimal.

The highest EMG amplitudes were seen for pair D for the *resisted wrist extension*, the *hand grip* and the pinch grip. However, the reproducibility, in terms of CV, was low for these MVCs and for the activation. The reason could be that the electrodes constituting pair D are placed at the tapered and distal part of the extensor muscles, and very small changes in electrode positioning and a shortening of muscle length will result in higher CVs.

The motor point was located close to electrode 2, the electrode used in pairs A and B. This location, in combination with the lower amplitudes in pair C for one of the two MVCs and both activations, indicates that the IZ is located distally to the motor point and should not interfere with the signal given by electrode pair A. In fact, pair A seems to be located approximately half-way between the IZ and the attachment of the extensor muscles on the *humerus* and could therefore be a suitable alternative for electrode positioning.

Variation in electrode positioning may be one factor that influences the CV. We performed a sensitivity analysis by excluding the occasion with the most deviating positions for participant numbers 7 and 8, which reduced the CVs for both participants on average by 7% for the four electrode pairs and the MVCs and activations.

4.3. Limitations

The results presented in this paper are based on the EMG amplitudes obtained in the laboratory with well-defined arm postures during specific MVCs and maximal activations, in contrast to the working situation, where there is a wide range of arm posture and wrist angles. The relations between the tested electrode positions in this study may therefore be different under real working tasks. The number of participants in the study was also small. Despite these limitations, we believe that the results make an important contribution to the discussion on recording forearm EMG.

4.4. Practical implications

Since the *resisted wrist extension* showed a substantially higher EMG_{amp}/CV ratio in comparison to the hand grip, the *resisted wrist extension* may be used as MVC in new EMG studies, both in laboratory and in work place recordings. Although there is not yet any comparisons performed in work place settings, it seems as the *resisted wrist extension* should give a lower inter- and intra-subject variation in comparison to the *hand grip*. The present findings should increase the precision in the measurements, which would also increase the quality of risk assessments that are based on EMG measurements from forearm extensor muscles. This is increasingly important as technical development make measurements more feasible also for practitioners [37], and reliable risk assessments are needed for efficient preventions of work-related musculoskeletal disorders.

In EMG research, the method of normalization and use of MVC versus reference contractions has been a controversial issue for a long time. We have hitherto considered the *hand grip* to be as good as the *resisted wrist extension* for recording the MVE of the forearm extensors [23]. However, when normalizing to the *hand grip*, we sometimes see unexpectedly large differences in amplitudes between the right and left forearm extensors, even when the tasks are performed bimanually. We suspect that this phenomenon occurs when the subject only activates the flexors in one of the forearms, but both flexors and extensors in the other, when performing the *hand grip*. By using the *resisted wrist extension* instead of the *hand grip* this problem might be solved.

5. Conclusions

The best combination of reference contraction and electrode positioning, in terms of high EMG amplitude, low CV, high group EMG_{amp}/CV ratio and a good ICC, was found for the *resisted wrist extension* with electrode pair A. Hence, the *resisted wrist extension* may be used as MVC in new EMG studies, both in laboratory and in work place recordings.

This study also indicates that the motor point is located approximately ¼ of the distance from the *epicondylus lateralis humeri* to the *processus styloideus radii,* and that the innervation zone does not interfere with the signal recorded from pair A, i.e. the most proximal electrode positions. A factor of 0.8 can be used, at group level, for comparisons between forearm extensor muscle recordings using the *resisted wrist extension* and the *hand grip* as MVCs. Further studies should be performed during actual work in work place recordings, including different work tasks with several different arm positions, to evaluate the effect of the different ways to perform MVC, and the different electrode positions.

Acknowledgments

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Conflict of interest

The authors declare no conflicts of interest.

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Paper III

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RESEARCH ARTICLE Open Access

Self-recordings of upper arm elevation during cleaning – comparison between analyses using a simplified reference posture and a standard reference posture

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Abstract

Background: To reduce ergonomic risk factors in terms of awkward and constrained postures and high velocities, it is important to perform adequate risk assessments. Technical methods provide objective measures of physical workload. These methods have so far mainly been used by researchers. However, if written instructions how to apply the sensors and how to adopt the reference posture are provided, together with triaxial accelerometers, it may be possible for employees to record their own physical workload. The exposure in terms of e.g. upper arm elevations could then easily be assessed for all workers in a workplace. The main aims of this study were: 1) to compare analyses for self-recording of upper arm elevation during work using a simplified reference posture versus using a standard reference posture, and 2) to compare the two reference postures.

Methods: Twenty-eight cleaners attached an accelerometer to their dominant upper arm and adopted a simplified reference according to a written instruction. They were thereafter instructed by a researcher to adopt a standard reference. Upper arm elevations were recorded for 2 or 3 days. Each recording was analysed twice; relative to the simplified reference posture and relative to the standard reference posture. The group means of the differences in recorded upper arm elevations between simplified and standard reference analyses were assessed using Wilcoxon signed ranks test. Furthermore, we calculated the group mean of the differences between the simplified reference posture and the standard reference posture.

Results: For arm elevation during work (50th percentile), the group mean of the differences between the two analyses was 0.2° (range -7 – 10°). The group mean of the differences between the two references was 9° (range 1 – 21°). The subjects were able to follow the instructions in the protocol and performed self-recording of upper arm elevation and velocity.

Conclusions: The small difference between the two analyses indicates that recordings performed by employees themselves are comparable, on a group level, with those performed by researchers. Self-recordings in combination with action levels would provide employers with a method for risk assessment as a solid basis for prevention of work-related musculoskeletal disorders.

Keywords: Inclinometry, Zero position, Self-measurement, Physical workload, Angular velocity, Arm elevation, Hotel housekeeping

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Background

Many jobs involve repetitive work, prolonged muscular load and work performed in awkward and constrained postures. Such work are known to be risk factors for developing work-related musculoskeletal disorders (WMSDs) in the neck/shoulder region, arms, and hands [1–4]. To reduce these risks, it is important to perform risk assessments, and to implement organisational and technical measures when necessary [5]. The reliability of risk assessments is important as this affects the decisions made and the priorities afforded different interventions [6].

Several kinds of risk assessment methods are available, such as self-reporting, observational methods and technical methods, all of which have advantages and disadvantages [7]. For example, in self-reporting, which has the advantage of being practical in large groups, overestimation of the workload is common among individuals with pain [8]. Observational methods are often easy to use and interpret, and give a rough estimate of postures during work, but results vary between observers [9]. As observational methods have no common references, they tend to give different results when assessing the risk of developing WMSDs [10, 11]. Technical methods, on the other hand, provide exact numerical values for both postures and movements during work, i.e. upper arm elevation and velocity [12].

There is a commonly held belief that technical methods require expensive equipment, technical understanding and are time-consuming [13]. However, low-cost sensors for recording of elevations and velocities during work are now commercially available [14, 15]. These sensors have also made it feasible to measure the workload over several days [16]. Many studies have been performed previously in which the workload on a few individuals has been recorded during 1 day [17, 18]. With the advent of low-cost sensors, it is now possible to monitor the entire workforce over several days.

Measurements over extended periods of time are important in planning job rotation as a measure for the prevention of WMSDs [19]. Furthermore, measurements made over several days will give a better idea of the loads experienced on an average working day [20]. Such an average measurement is likely to be more strongly correlated with the prevalence of WMSDs than those from one-day recordings. So far, the number of technical recordings has been limited, mainly due to the need for researchers.

If self-recording of physical workload was possible, all the employees' workload at almost any workplace could be explored for several days. Such recordings would be invaluable when performing risk assessments. However, it would be necessary to develop easily understandable instructions so that the employees can attach the equipment and calibrate it, i.e. adopt a reference posture. The reference posture should have a high reproducibility, and this can be studied if recordings are performed over several days. The reference posture should also be easy to adopt, and without the need of extra material. Such a reference would rule out our standard reference posture, which we have used in many studies, as the latter requires a chair and a dumbbell [17, 21–23]. A self-recording method also requires a reliable method of identifying the reference, as this defines 0 degrees of inclination. Furthermore, the starting and stopping times of work and breaks should be noted, to distinguish between working time and leisure time.

One occupation with a high physical workload and a high risk of WMSDs is cleaning [24]. As an example, the prevalence of complaints and diagnoses in neck/shoulders has been reported to be 48% among female hospital cleaners working in a traditional work organisation [25]. Around the world there are many employees working as cleaners and it is important to perform risk assessments of their work in a cost-effective manner. Therefore, we would like to test the self-recording method in the cleaning industry.

The main aims of this study were: 1) to compare analyses for self-recording of upper arm elevation during work using a simplified reference posture versus using a standard reference posture, and 2) to compare the two reference postures. Other aims were to study the between-day repeatability in the simplified reference posture, and to assess the suitability of a protocol for self-recording. Furthermore, we aimed to compare the physical workload, the between-day repeatability of the workload, and to assess the risk of musculoskeletal disorders among different types of cleaning.

Subjects and methods

Study design

This was a field study including two parts. In part one (self-recordings), workers received a protocol with instructions on how to attach a triaxial accelerometer (GC inclinometer) to the upper arm, and how to adopt a reference posture. It was adopted by the cleaners themselves, without the need of extra material, and referred to as the simplified reference posture. A researcher then instructed each of them to adopt the standard reference posture. The workers wore the GC inclinometer continuously, both day and night, for 2 or 3 days. They repeated the simplified reference posture each morning and noted starting and stopping times of work and lunch breaks for each day in a provided form.

In part two (researchers' recordings), which was conducted on different days than the self-recordings, the researchers attached the GC inclinometer to the worker's right upper arm and instructed each subject to perform the standard reference posture. The researchers followed each worker during the one-day recording and noted exact starting and stopping times for work and breaks.

Subjects

Self-recordings

Twenty-eight subjects, 24 women and 4 men, participated in the study (Table 1). Their mean age was 43 years (range 22–58). Twenty-four of the subjects (20 women and 4 men) worked as hotel cleaners and 4 (all women) as office cleaners. Three of the 28 subjects were native Swedish speakers, while the other 25 spoke English and Swedish of varying quality. All the hotel cleaners cleaned hotel rooms (denoted hotel housekeeping). Some of them (eleven subjects) also had other tasks such as cleaning corridors, conference rooms, pool areas and/or dining rooms (denoted hotel housekeeping+). The office cleaners cleaned mainly offices, but also toilets, changing rooms, corridors and dining rooms.

Researchers' recordings

Fourteen right-handed female hotel cleaners participated in standard one-day recordings performed by professionals (Table 1). Their mean age was 42 years (range 22–57). They all cleaned hotel rooms. Five of these also performed self-recording, on separate occasions.

Materials

Triaxial accelerometers with an integrated data logger (USB Accelerometer Model X16-mini, Gulf Coast Data Concepts, LLC, Waveland, MS, USA, "GC inclinometer") with a sampling frequency of 25 Hz were used. This frequency is sufficient as it has been shown that 99.5% of the signal power for wrist (and it is not expected to be higher for the upper arms) was contained in the 0–5 Hz band in occupational repetitive work [26]. The size was 5 × 2.4 × 1.3 cm and they contained a 2 GB memory for data logging, a female micro USB-connector and a rechargeable battery [14]. The accelerometer was attached to the upper arm, just below the insertion of the deltoid muscle, with double-sided adhesive tape and fixed with plastic film (Tegaderm™, 3 M Health Care, St Paul, MN, USA) to secure them from falling off.

Procedures

Standard reference posture

The researcher instructed the subject to sit on a chair and lean towards the backrest with the arm hanging vertically over the backrest, holding a dumbbell in the hand (Fig. 1a) [21].

Simplified reference posture

The subject followed the instructions in the protocol and leaned to the right with the arm alongside the body and with an extended elbow for about 20 s (Fig. 1b) [14].

Table 1 Anthropometric characteristics

	Self-recording			Researchers' recording		
	Height (cm)	Weight (kg)	BMI	Weight (cm)	Height (kg)	BMI
	160	50	20	160	50	20
	170	73	25	170	73	25
	172	61	21	172	61	21
	–	–	–	–	–	–
	169	70	25	169	70	25
	–	82	–			
	168	65	23			
	176	73	24			
	168	66	23			
	167	54	19			
	168	80	28			
	150	42	19			
	174	106	35			
	168	80	28			
	153	50	21			
	–	–	–			
	159	82	32			
	155	59	25			
	–	–	–			
	154	50	21			
	160	50	20			
	158	62	25			
	169	74	26			
	167	65	23			
	146	51	24			
	163	63	24			
	148	48	22			
	168	75	27			
				177	69	22
				160	50	20
				165	–	–
				162	–	–
				158	63	25
				160	61	24
				160	60	23
				157	52	21
				172	65	22
Mean	163	65	24	165	61	22.5
SD	8.4	15	4	6.5	8.0	2.1

Height, weight and BMI for the 37 subjects participating in the study. Twenty-eight subjects participated in the self-recording and fourteen subjects participated in the researchers' recording. Five subjects participated in both types of recordings
- missing data

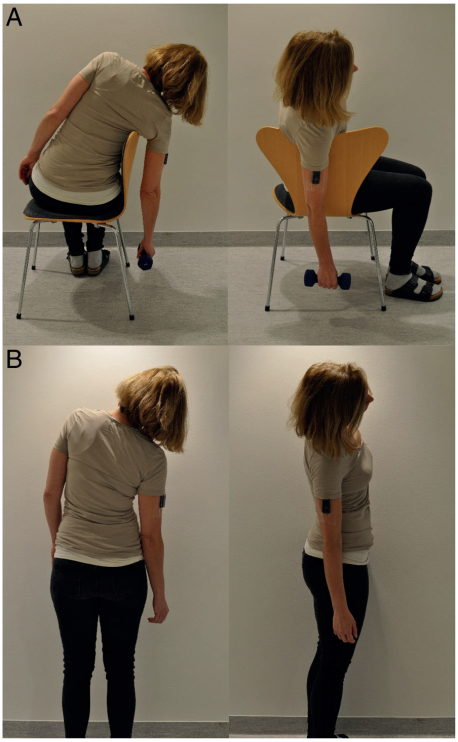

Fig. 1 a The standard reference posture, and (**b**) the simplified reference posture

The protocol

The self-recording method was tested in the cleaning industry. We made one Swedish and one English version of the protocol, as it is known to be a high proportion of immigrants among the employees [27]. Twenty-five subjects chose to use the Swedish version, while three subjects chose the English version. The protocol with instructions for using the GC inclinometer consisted mainly of pictures with short explanations how to attach the GC inclinometer and how to perform the simplified reference posture (see Additional file 1). The researcher noted that the first subjects seemed to have some difficulties in understanding the Swedish and English instructions properly, due to language barriers. Therefore, we improved the protocol in steps during the study. The first change (version 2) was to add instructions on how to start the GC inclinometer (which for the first subjects had been performed by the researcher), to obtain a complete instruction for self-recording of upper arm elevation and velocity. We also simplified the part on how to attach the inclinometer. The second change (version 3) was to add a second series of toe jumps after the simplified reference posture to improve our ability to determine which part of the recording corresponded to it. To make it easier for the subjects to perform the self-recording, minor changes were made throughout the study, such as highlighting the most important steps (starting the device and performing the simplified reference posture), numbering the various steps in the protocol and simplifying the language in the text boxes. Three versions of the protocol were used. Version 1 was used by four subjects, version 2 was used by five, and version 3 was used by 19 subjects. A few subjects needed help to start the GC inclinometer and some of them had to be reminded to adopt the simplified reference posture. However, the need for help decreased with improved versions of the protocol.

Self-recordings

Each subject was given a GC inclinometer and a protocol with instructions. Nineteen subjects (at twelve different times) individually followed the protocol and attached the GC inclinometer, performed five toe jumps and adopted the simplified reference posture by themselves. The toe jumps were later used to find this part of the recording. At one occasion, nine subjects were helped by their supervisor, due to lack of time. The supervisor started and attached the GC inclinometer, and instructed each subject how to perform the simplified reference posture. The supervisor had not used the protocol previously.

For each subject, the researcher did a brief visual inspection of that the GC inclinometer was attached properly. The researcher then instructed each of the subjects to perform the standard reference posture.

The subjects were instructed to perform the simplified reference posture every morning and to note the time for this and the starting and stopping times of work and lunch breaks in the provided form. They were instructed to apply more plastic film if needed and they were also told to remove the GC inclinometer if they experienced itching or irritation of the skin. Nineteen of the subjects wore the GC inclinometer for 3 days and nine subjects wore it for 2 days. At the end of the second or third working day, the researcher instructed the subject to perform the standard reference posture again, and then removed the GC inclinometer. In four cases the supervisor removed the GC inclinometer, and one subject removed it herself. The stop time was noted.

Researchers' recordings

Researchers experienced in technical methods attached the GC inclinometer to the subject's right upper arm, one subject at a time, on different days from the self-recordings. Each subject was instructed to adopt the standard reference posture for the right upper arm. The researchers followed each subject during their working day, noting the exact starting and stopping times for work, breaks, and different work tasks.

Questionnaire

To further assess the suitability of the protocol and the self-recording method, all subjects were asked, after the recording, to answer six questions about their perceptions of the self-recording.

Data processing and analyses

The data were processed with the EMINGO software suite, developed by the Division of Occupational and Environmental Medicine in Lund, Sweden using MATLAB (version 2016b, Math Works INC., Natick, MA, USA). The data were resampled at 20 Hz, anti-aliased, low-pass filtered (5 Hz), and visually inspected.

Self-recording

Upper arm elevations and velocities were recorded continuously but only the data on work were analysed. Lunch breaks were excluded according to the times noted in the provided form. The data were analysed twice; once using the simplified reference posture as reference (henceforth referred to as the simplified reference analysis) and once using the standard reference as reference (henceforth referred to as the standard reference analysis). The 1st, 10th, 50th, 90th and 99th percentiles of the angular distribution (°) and the percentage of time the arm was elevated above 30°, 60° and 90° were calculated. Furthermore, the median generalised angular velocity (°/s) was derived for each subject. 1 °/s = 0.017 rad s^{-1} and 1 rad s^{-1} = 57.3 °/s. Group means of upper arm elevations and velocities were calculated for comparisons between the simplified reference analysis and the standard reference analysis. Further, for each subject we calculated the differences between the results derived from the two different analyses, as well as the absolute differences (i.e. the non-negative difference, regardless of sign). Then the group means of the differences and the group means of the absolute differences were calculated.

Furthermore, for each subject, we calculated the difference between the simplified reference posture and the standard reference posture (°). In most cases we used the references from day 1. In one case, the GC inclinometer fell off during day 1. The subject attached it again, and the researcher (who was still there) instructed her, during her lunch break, to perform the standard reference posture again. Another subject appeared to have replaced the GC inclinometer upside down after it had fallen off during the morning day 1 (detected during data analysis), and therefore this part of the recording was discarded. For this subject, the standard reference posture from day 3 was used. The simplified reference posture from day 2 was used for both these subjects.

The first and second simplified reference posture were used to investigate the reliability of the reference. Nine of the subjects performed the simplified reference posture on one occasion only and were therefore excluded when analysing the within-subject variation of the reference.

The within-subject variation in workload between the first and second working days was also calculated among the hotel cleaners. Then, two recordings were excluded because the subjects removed their GC inclinometer while showering after day 1. They had replaced the device after showering, but did not repeat the simplified reference posture, and therefore, the data for the remaining days had to be rejected. The remaining 22 recordings were divided into hotel housekeeping and hotel housekeeping+, with eleven subjects in each group.

When comparing upper arm elevations and velocities between the specific types of cleaning (hotel housekeeping, hotel housekeeping+, and office cleaning), as well as when comparing with the researchers' one-day recordings of hotel housekeeping, the standard reference analysis was used. The four men were excluded from these calculations, to be able to compare them with previous and future recordings, where the results for women and men are separated [28].

Researchers' recordings

Upper arm elevations and velocities during the working day were analysed, lunch breaks excluded. The same measures as for the self-recordings were calculated; the percentiles of the angular distribution (°) and the percentage of time the arm was elevated above 30°, 60° and 90° were calculated for each subject. The median generalised angular velocity (°/s) was also derived, and group means of both elevations and velocities were calculated.

Statistical analyses

The statistical analyses were carried out with IBM SPSS Statistics Version 22 (SPSS, Chicago, IL, USA). The alpha level was set at 0.05. Comparisons between group means of upper arm elevations for the two reference analyses were performed using Wilcoxon signed ranks test. The within-subject variation was calculated using one-way ANOVA for the simplified reference posture and for the upper arm elevations and velocities during work. The 50th and 90th percentiles of upper arm elevation and the median generalised angular velocity were the dependent variables, and subject was the independent variable. To investigate the repeatability of the simplified reference posture and of the workload between working days, the repeatability coefficient (°) and the intraclass correlation coefficient (ICC) were calculated [29, 30]. We used ICC (1,1) i.e. one-way random effects model, absolute agreement, single measures. ICC estimates less than 0.5, between 0.5 and 0.75, between 0.75 and 0.9, and greater than 0.90 indicate poor, moderate, good, and excellent reliability, respectively [31]. The difference between the simplified reference posture and the standard reference posture of two following occasions, respectively, as well as upper arm elevations (50th and 90th percentiles) and the median angular velocity of two working days were the input variables in the model. Comparisons between group means of different types of cleaning were performed using Kruskal-Wallis one-way analysis of variance. Post hoc analyses for p-values < 0.05 was performed using Mann-Whitney U-test. The non-parametric tests were used since the data were not normally distributed.

Results

Simplified reference analysis versus standard reference analysis

Recordings of workload

The group means of upper arm elevation and the percentage of time above 30°, 60° and 90° during work were very similar between the simplified reference analysis and the standard reference analysis (Table 2). The upper arm velocity was identical (data not shown), as this is not dependent on the reference.

The individual differences between the simplified reference analysis and the standard reference analysis at the 50th percentile of arm elevation during work are shown in Fig. 2. The group mean difference was 0.2° (range -7 – 10°).

Table 2 Group means of upper arm elevations during work for the simplified and the standard reference analyses

	Simplified reference analysis Mean (range)	Standard reference analysis Mean (range)	p-value
Percentile (°)			
1st	5 (2 – 8)	5 (2 – 10)	0.68
10th	14 (7 – 21)	13 (8 – 20)	0.98
50th	30 (20 – 47)	30 (22 – 38)	0.98
90th	64 (45 – 91)	64 (50 – 86)	0.95
99th	109 (88 – 132)	110 (94 – 134)	0.30
Percentage of time			
> 30°	49 (27 – 78)	49 (34 – 63)	0.95
> 60°	13 (4 – 35)	12 (5 – 24)	0.95
> 90°	4 (1 – 10)	3 (1 – 8)	0.98

Group means (°) for the simplified reference analysis and the standard reference analysis at the 1st, 10th, 50th, 90th and 99th percentiles of upper arm elevation and the percentage of time above 30°, 60° and 90° for the 28 subjects during work. P-values for difference calculated with Wilcoxon signed rank tests

The group mean of the absolute differences in the 50th percentile of arm elevation was 4° (range 0 – 10°; Table 3), and for the percentage of time above 30° it was 9% (range 0 – 21%), for 60° 2% (0 – 11%), and for 90° 1% (0 – 3%).

Simplified reference posture versus standard reference posture

The differences (°) between the simplified reference posture and the standard reference posture on days 1, 2, and 3 for each subject are shown in Fig. 3. The group mean of the differences for day 1 (day 2 for two subjects) was 9° (range 1 – 21°). The individual arm position in the simplified reference posture relative to the arm position during the standard reference posture from day 1 (day 2 for two subjects) are shown in Fig. 4. They deviated in all directions (flexion, extension, adduction and/or abduction) without any obvious pattern.

Within-subject variation of simplified reference posture

The within-subject variation in the simplified reference posture was poor, with an ICC of 0.2 (Table 4). The repeatability coefficient was 16°.

The protocol

No subjects were excluded due to an incorrect placement of the GC inclinometer. Nevertheless, we improved the protocol during the study. These changes appeared to make it easier for the subjects to follow, as the help needed decreased with improved versions of the protocol. An additional change (version 4) was made after the analyses, with instructions not to replace the GC inclinometer if it falls off.

The protocol includes three parts (see Additional file 1):

1) Starting the GC inclinometer.
2) Attaching the GC inclinometer to the upper arm.
3) Performing the simplified reference posture.

Comparing different types of cleaning

Concerning self-recordings, the median upper arm velocity was higher in hotel housekeeping than in hotel housekeeping+ (82 vs 63 °/s; Table 5). There were no differences between self-recordings and researchers' recordings of hotel housekeeping (Table 5).

Five individuals participated in both the researchers' recordings and the self-recordings. The 90th percentile of upper arm elevation and the median generalised angular velocity for these individuals are shown in Figure 5. For them, the group mean difference for the 90th percentile of upper arm elevation between the researchers' recording on 1 day and the self-recording on several days, using the standard reference, was 1° (range -2 – 8°). The group mean difference for the upper arm velocity was -7 °/s (range -21 °/s – 2 °/s).

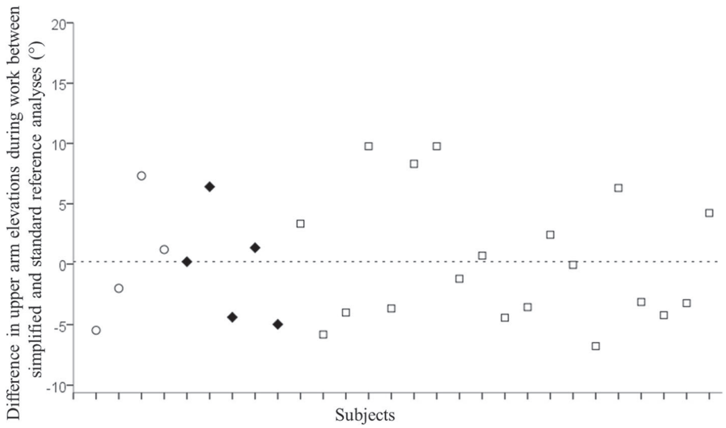

Fig. 2 Individual difference (°) between the simplified reference analysis and the standard reference analysis from day 1 at the 50th percentile of upper arm elevation during work for the 28 subjects. The dashed line indicates the group mean difference (0.2°). Version 1 of the self-recording protocol was used by four subjects (○), version 2 was used by five (◆) and version 3 was used by 19 subjects (□)

Within-subject variation in workload between days

The repeatability coefficient for hotel housekeeping was 1.6° with an ICC of 0.98 for the 50th percentile of upper arm elevation (Table 6). Corresponding values for hotel housekeeping+ were 4.8° and 0.86, respectively. The individual variations in upper arm velocities during the different working days are shown in Fig. 6.

The subjects' perception of self-recording

The subjects' perceptions are reported in Table 7. One subject answered "Bad" to one of the questions. All other answers were positive. Additionally, 87% of the subjects stated that the GC inclinometer had not interfered during work or leisure time during the three-day recording, and 96% were willing to wear the GC inclinometer again.

Table 3 Group means of the absolute differences of upper arm elevations during work between the simplified and the standard reference analyses

	Mean absolute difference (range)
Percentile (°)	
1st	1.8 (0.0 – 4.4)
10th	3.8 (0.2 – 9.1)
50th	4.2 (0.1 – 9.8)
90th	4.2 (0.0 – 12)
99th	4.7 (0.3 – 18)
Percentage of time	
> 30°	9.3 (0.2 – 21)
> 60°	2.3 (0.0 – 11)
> 90°	0.6 (0.1 – 2.9)

The group mean of the absolute differences (°; Mean absolute difference) at the 1st, 10th, 50th, 90th and 99th percentiles of the angular distributions (°) and the percentage of time above 30°, 60° and 90° for the 28 subjects during work, between the simplified reference analysis and the standard reference analysis

Discussion

On group level, the recordings of upper arm elevation during work using the simplified reference posture were almost identical to the same recordings using the standard reference posture. The subjects were able to follow the instructions in the protocol and performed self-recording of upper arm elevations and velocities for several days.

Simplified reference posture and standard reference posture

For recordings of arm elevations, it has been suggested that it is sufficient to attach an inclinometer with one of its axes aligned with the upper arm (humerus) without adopting a reference posture [15, 32]. However, since the humerus may not be parallel to the line of gravity, for example in subjects with voluminous upper arms (strong or obese), we believe that it is important to perform a reference posture to define 0° inclination. When using the standard reference posture the arm hangs out from the body (see Fig. 1a). Thus, this should be a minor problem. In the simplified reference posture the arm is closer to the body (see Fig. 1b). We therefore plotted the difference between the two reference postures from day 1 (Fig. 4) versus BMI. We saw no correlation, and do not suspect a major influence of BMI.

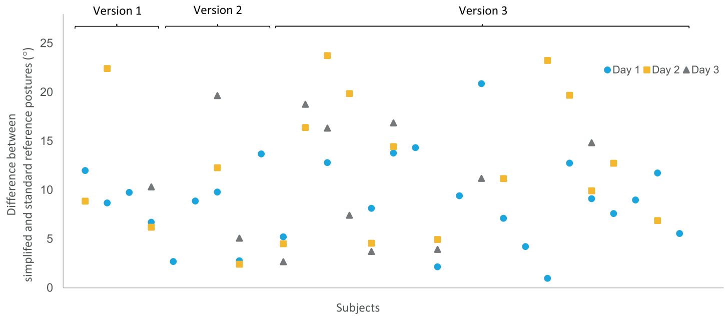

Fig. 3 Individual differences (°) between the simplified reference posture and the standard reference posture on day 1 (●), day 2 (■) and day 3 (▲) for all 28 subjects

For each individual, the difference in upper arm elevation during work between the two analyses was lower than the difference between the two references, and may be explained by the triangle inequality (see Fig. 7). The distance between the two reference points can be seen as the length of one side of a triangle (a). The distance between one of the reference points and a specific elevation point during work can then be seen as the length of a second side of the triangle (b), while the distance between the other reference point and the same specific elevation point can be seen as the length of the third side of the triangle (c). Thus, as the length of one side in a triangle is less than the difference (Δ) of the lengths of the two other sides, the difference between

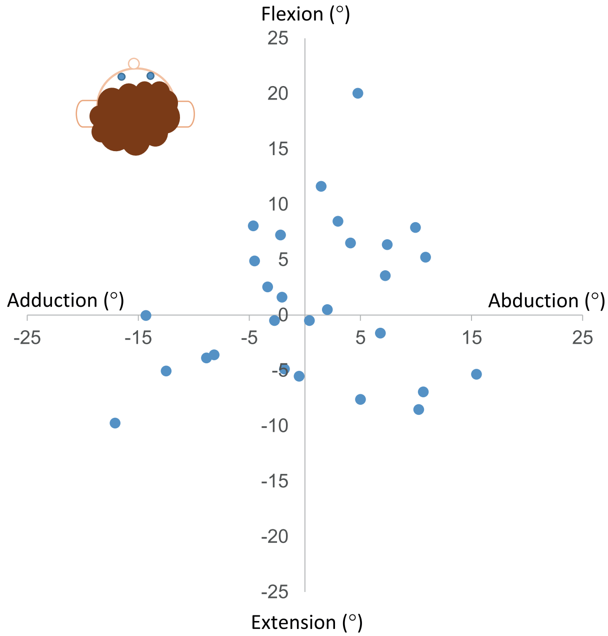

Fig. 4 Individual arm position in the simplified reference posture (●) relative to the arm position in the standard reference posture on day 1 (day 2 for two subjects) for the 28 subjects

Table 4 The within-subject variation of the simplified reference posture

Simplified reference posture			
Within-subject variation		Repeatability coefficient	ICC
SD	(95% CI)		
5.6	(3.7 – 7.5)	16	0.2

The within-subject variation (°; standard deviation (SD) and 95% confidence interval (95% CI)), the repeatability coefficient (°) and the intraclass correlation coefficient (ICC) of the simplified reference posture

the two reference analyses will be less than the difference between the two references (Δ = b − c < a). For an elevation point that is equally far from the two reference points, the triangle becomes isosceles and the difference between the two reference analyses will be zero (Δ = b − c = 0). If the elevation point is in line with the two references, the triangle becomes a line and the difference between the two reference analyses will be the same as the difference between the two references (Δ = b − c = a). In this study, the difference during work was never more than 10°, while the difference between the two references was up to 21°. In addition, the group mean difference during work was as low as 0.2° (range -7 – 10°). We therefore consider, on group level, the simplified reference posture sufficient for recording of elevations of the upper arm, given that it is the same work tasks and a low degree of freedom in work performance for all individuals [33]. In the current group of cleaners, the simplified reference posture deviated from the standard reference in a uniform pattern (i.e. in all directions, see Fig. 4). Consequently, deviations during work were balanced on group level. However, this may not be the case in other populations. A non-uniform deviation pattern will introduce a systematic error. Concerning upper arm velocity, the self-recording method can be used on individual level, as this measure is not dependent on the reference.

Within-subject variation of simplified reference posture

In a previous study of natural head posture recorded with inclinometer, the individual overall variability (standard deviation) was 1.6° [34]. In our study, the standard deviation of the within-subject variation was 5.6° for the simplified reference posture, i.e. somewhat higher. We speculate that this difference may be because it is more difficult to repeat an arm posture (without support) than a head posture, as in the latter the sight angle serves as a reference. The repeatability coefficient for the simplified reference posture was 16°. Thus, in 95% of measurements, the absolute difference between two simplified reference measurements on one subject is not expected to exceed 16°. Therefore, a recording of upper arm elevations analysed with the simplified reference posture at only one occasion should be interpreted with some caution.

The protocol and the subjects' perceptions of self-recording

The protocol was continuously improved during the study. Thereby, the problems that occurred during the study were resolved. Most importantly, if the GC inclinometer falls off it should not be replaced. Further, toe jumps are performed before *and* after the simplified reference posture. We believe that version 4 is easy to use. Still, for subjects that do not speak Swedish or English, one might consider to translate it into the language in question.

According to the questionnaire which the subjects answered after the study, all but one of the subjects were positive to self-recordings of upper arm elevations and velocities. Only one person answered "Bad" to the question "How did you experience to put on more plastic film?" Since eight subjects reported that it had not been necessary, we think this negative answer was due to language barriers, and this subject also meant that it had not been necessary.

Table 5 Group means of upper arm elevation and velocity during different types of cleaning

	Self-recordings during 3 days			Standard one-day recordings
	Hotel housekeeping (*n* = 9)	Hotel housekeeping+ (*n* = 11)	Office cleaning (*n* = 4)	Hotel housekeeping (*n* = 14)
	Mean (range)	Mean (range)	Mean (range)	Mean (range)
Elevation (°)				
50^{th}	30 (25 – 36)	28 (22 – 35)	33 (29 – 38)	28 (21 – 38)
90^{th}	65 (50 – 79)	62 (50 – 77)	64 (54 – 83)	61 (47 – 75)
Velocity (°/s)				
50^{th}	82[a] (53 – 114)	63[a] (37 – 89)	56 (37 – 75)	92 (66 – 129)

Group means at the 50^{th} and 90^{th} percentiles of upper arm elevation (°) and the median generalised upper arm angular velocity (°/s) during different types of cleaning when using the standard reference posture as reference. (Data from the four men are excluded). The generalised angular velocity is not dependent on the reference posture. Hotel housekeeping = cleaning hotel rooms, hotel housekeeping+ = cleaning hotel rooms and other tasks such as cleaning corridors. The standard recordings were performed by researchers. Differences calculated by Kruskal-Wallis analysis of variance. Post hoc analysis with Mann-Whitney U-test
[a] $p = 0.05$

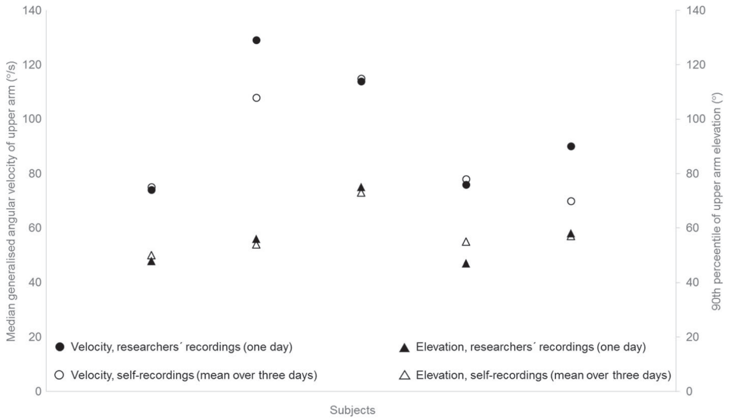

Fig. 5 Upper arm elevation and the median generalised angular **v**elocity of the upper arm for the five subjects who participated in both the self-recordings and the researchers' recordings. △ = upper arm elevation obtained with self-recording (using the standard reference posture). ○ = the median generalized upper arm velocity obtained with self-recording. ▲ = upper arm elevation obtained by the researchers' recordings. ● = the median generalised upper arm velocity obtained by the researchers' recordings

Risk of musculoskeletal disorders among cleaning staff

Our research group has performed technical measurements of upper arm elevations and velocities for about thirty years in about sixty different occupations. Most of these occupational groups have also been clinically examined using the standardised Health Surveillance in Adverse Ergonomics Conditions (HECO) method [35, 36] which quantifies the prevalence of WMSDs and diagnoses of the neck and upper extremities. Exposure-response relationships were obtained by compiling the data from the technical measurements and the clinical examinations, and we found strong associations between upper arm velocity and several diagnoses [2]. Based on this knowledge, we have recently proposed action levels for the prevention of WMSDs. The proposed action level for the median generalised angular velocity is 60 °/s [37]. This is well in line with the findings in a recent study by Dalbøge et al., where it was indicated that a median generalised angular velocity of the upper arm below 45 °/s was safe [38]. Based on previous studies [2, 39–42], we have proposed an action level of 60° for the 90^{th} percentile of upper arm elevation. The action level for elevation was exceeded in office cleaning, while the action levels for both elevation and angular velocity were exceeded in hotel housekeeping (both self-recordings and researchers' recordings) and hotel housekeeping+, indicating the need for preventive actions. Hence, it was highly relevant to test the self-recording method among cleaners.

Within-subject variation of workload between working days

The within-subject variation in upper arm elevation and velocity between working days in hotel housekeeping was low. This indicates that the work is monotonous and repetitive. The between days variation differed

Table 6 The group means and the within-subject variations of upper arm elevation and velocity between working days

Percentile	Hotel housekeeping (*n* = 11) Group mean (° or °/s)	Within-subject variation SD (95% CI)	Repeatability coefficient (° or °/s)	ICC	Hotel housekeeping+ (*n* = 11) Group mean (° or °/s)	Within-subject variation SD (95% CI)	Repeatability coefficient (° or °/s)	ICC
50^{th} (°)	29	0.6 (0.3 – 0.9)	1.6	0.98	28	1.7 (0.9 – 2.5)	4.8	0.86
90^{th} (°)	64	1.5 (0.8 – 2.2)	4.1	0.97	62	4.4 (2.3 – 6.4)	12	0.80
Vel. (°/s)	81	4.7 (2.5 – 6.9)	13	0.93	63	12 (6.4 – 18)	33	0.66

The group mean, the within-subject variation (° or °/s; standard deviation (SD) and 95% confidence intervals (95% CI)), the repeatability coefficient (° or °/s) and the intraclass correlation coefficient (ICC) of upper arm elevations (°; 50th and 90th percentiles of the angular distribution) and median upper arm velocity (°/s; Vel.) between working days for 22 subjects. Self-recordings of hotel housekeeping and hotel housekeeping+. Hotel housekeeping = cleaning hotel rooms and hotel housekeeping+ = cleaning hotel rooms and other tasks such as cleaning corridors. The standard reference posture was used as reference

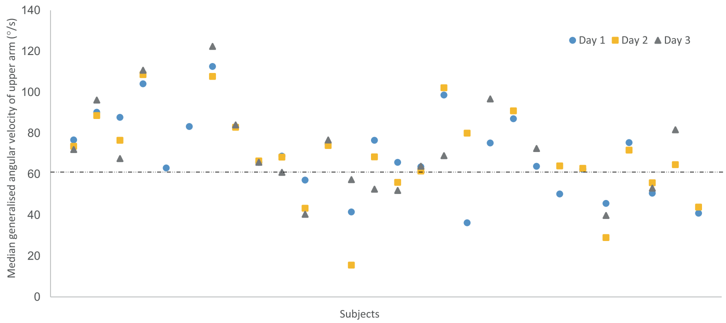

Fig. 6 The median generalised angular velocity of the upper arm during work for the 28 subjects for day 1 (●), day 2 (■) and day 3 (▲). The dashed line is the suggested action level for ergonomic workload

between hotel housekeeping + and hotel housekeeping, and one explanation could be that there were additional and more varied work tasks in hotel housekeeping+, such as for example cleaning corridors, conference rooms and pool areas.

Methodological considerations

To the best of our knowledge, this is the first time self-recordings have been made of upper arm elevation and velocity. This required a protocol explaining how to perform the self-recording. A strength of the study was that the protocol was tested and improved in an occupation with a high proportion of immigrants. Even if the subjects spoke poor Swedish and English, they were able to perform self-recordings. This indicates that the protocol is easy to follow and may be used by most employees. A weakness is that we did not improve the protocol systematically and did not evaluate the different steps of improvements in a systematic manner. Instead, we made changes in the protocol based on how comfortable and secure the subjects appeared to be when they attached the GC inclinometer and performed the simplified reference posture. On a visual inspection of Fig. 2 we did not see any improvement concerning the individual differences between the two analyses. Thus, we do not think that different versions of the protocol impacted on our data.

Considering recordings of upper arm elevation, we judge a difference of 5° to be clinically relevant. Prior to the study we did not know the distribution of the differences between the analyses with the two different reference postures. As this was about 5° for both the 50th and the 90th percentiles we would have needed 11 subjects to be able to detect a 5° difference between the two analyses with an 80% power. As 28 cleaners were included, we could detect a difference of 3°.

Table 7 Questionnaire responses after the self-recording

	Bad	Rather bad	Rather good	Good
How did you experience to wear the GC-inclinometer during several days?			4 (17%)	20 (83%)
How did you experience to sleep with the GC-inclinometer on?			5 (22%)	18 (78%)
How did you experience to shower with the sensor?			3 (15%)	17 (85%)
How did you experience to attach more plastic film?[a]	1 (7%)		1 (7%)	12 (86%)
How did you experience to perform the toe jumps and the reference position each morning?			1 (5%)	21 (95%)
How did you experience to fill in the diary?			7 (32%)	15 (68%)

Distribution of questionnaire responses from 24 subjects after self-recording of upper arm elevation and velocity during 3 days. The response rate (proportion within brackets) are given for the different options
[a] eight subjects reported that this was not necessary

Conclusions

The small difference between the simplified reference analysis and the standard reference analysis indicates that recordings performed by employees themselves are comparable, on group level, with those performed by researchers. The subjects in this study were able to perform self-recording of upper arm elevations and velocities using the protocol provided. The simplified reference posture is sufficient on group level, with the assumption that it is the same work tasks and a high similarity in work performance for all individuals. The self-recording method can be used at an individual level

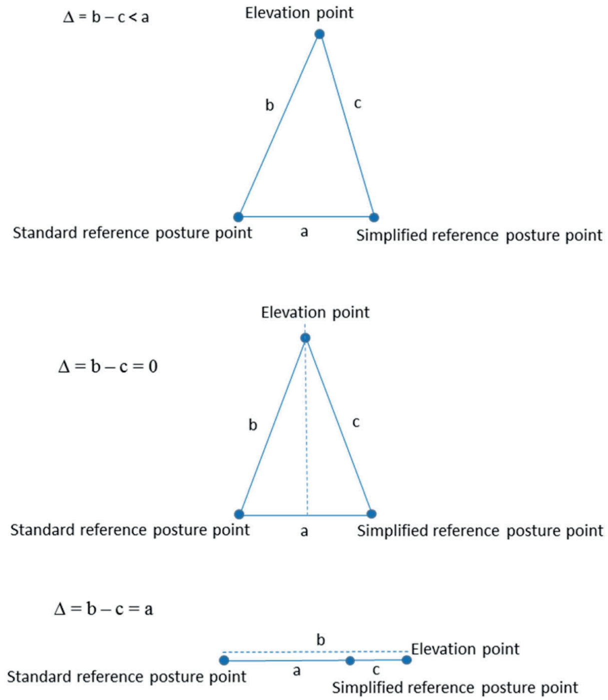

Fig. 7 The triangle inequality may be used to explain that the average difference in upper arm elevation between the two analyses was lower than the difference between the two reference postures. The upper triangle illustrates the case that is likely to occur most of the work time. In that case the difference $\Delta = b - c < a$, where a is the difference between the two reference posture points, and b − c is the difference between the two analyses. In the (unusual) middle case $\Delta = b - c = 0$; the elevation point is equally far from the two reference posture points, and in the (unusual) lower case, $\Delta = b - c = a$, the elevation point is in line with and outside the two reference posture points, and the difference between the two reference analyses will be the same as the difference between the two reference postures. So Δ is always less or equal to the difference between the two reference posture points

for recording of upper arm velocity. Self-recording could increase the use of technical methods when performing risk assessments and, in combination with action levels for the prevention of WMSDs, increase the accuracy of risk assessments. In addition, self-recording in combination with action levels would provide employers with a method of assessing the risk of developing WMSDs among employees, which would be an important improvement of prevention. Hotel cleaning implies a high risk of musculoskeletal disorders due to a high upper arm velocity.

Additional files

Additional file 1: The protocol (version 4) "Instructions for self-recording of upper arm elevation and velocity". (DOCX 1071 kb)

Additional file 2: Datasets of upper arm elevation using simplified and standard reference postures. (XLSX 26 kb)

Abbreviations
GC inclinometer: Gulf Coast triaxial accelerometer X16-mini; WMSDs: Work-related musculoskeletal disorders

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Availability of data and materials
The datasets used to calculate the group means of upper arm elevation and within-subject variations are included as a supplementary information file, see Additional file 2.

Authors' contributions
CD and CN were responsible for the concept and design of the study. CD was responsible for the data collection and performed the data analyses and the statistical analyses. CD drafted the manuscript. HE was responsible for development of the software for data analyses. CD, CN, MF and HE were

responsible for the interpretation of the results. CD, CN, MF and HE have contributed to, read, and approved the final manuscript.

Ethics approval and consent to participate
The study was approved by the Regional Ethics Committee in Lund (No. 2015/416). All subjects gave their written informed consent.

Consent for publication
The subject in Fig. 1 gave her written informed consent for publication.

Competing interests
The authors declare that they have no competing interests.

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Paper IV

The effect of two types of maximal voluntary contraction and two electrode positions in field recordings of forearm extensor muscle activity during hotel room cleaning

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Abstract
Purpose. To investigate the effects of using hand grip or resisted wrist extension as reference contraction, and two electrode positions, on field recordings of forearm extensor muscle activity. *Materials and methods*. The right forearm extensor muscle activity was recorded using two pairs of electrodes (over the most prominent part; position 2 and proximal to that; position 1) during one working day in 13 female hotel housekeepers. Each subject performed the two maximal voluntary contractions (MVCs), and the electrical activity obtained during these (the maximal voluntary electrical activity; MVE) was used for normalisation. Each set of recordings was analysed twice, once using hand grip as MVC and once using resisted wrist extension. *Results*. Resisted wrist extension showed higher group mean MVE than hand grip. Position 2 had higher correlation between MVE and force during the MVCs. The workload during cleaning was lower when using resisted wrist extension as the reference than when using hand grip (24 %MVE versus 46 %MVE; $p = 0.002$ at position 2) for the 90th percentile. The workload (99th percentile) was overestimated in two subjects when using hand grip as reference. *Conclusions.* Problems associated with poorly activated forearm extensors can be overcome by using resisted wrist extension as reference.

Keywords: hand grip; power grip; resisted wrist extension; MVC; MVE; EMG amplitude

Introduction

Surface electromyography (EMG) of the forearm muscles is one of the tools used to assess prolonged and forceful arm/hand exertions in e.g. industrial and manual work [1,2,3]. Such work is performed in a wide range of postures and with varying forces, and the forearm muscles can thus be involved to different degrees in different situations [4]. It may therefore be necessary to record the muscle activity from several forearm muscles to obtain a complete description of the forearm exertion during work. However, this may not be feasible in field recordings of physical workloads, as the time required to apply and calibrate the equipment may make employers reluctant to give permission for workplace recordings. Furthermore, analysing the vast amount of data collected would also be time-consuming [5]. Having to work with multiple measuring equipment may also interfere with the participants' mobility and comfort. A common strategy is to record the muscle activity in the extensor carpi radialis brevis and longus as a proxy for forearm muscle exertion during work [2,6]. Exposure–response relationships have been found between the peak load on these muscles (i.e. the 90th percentile of the amplitude distribution) and reported complaints in the elbow/hand during the past 12 months and past 7 days [7].

The recorded EMG amplitudes should be normalised to a reference contraction, as they are influenced by e.g. skin conductance and subcutaneous thickness [8]. A proxy for the applied muscle force relative to the subject's strength can be obtained by using the maximal voluntary contraction (MVC) as a reference and expressing the electrical activity obtained during work as a percentage of the electrical activity obtained during the MVC (the maximal voluntary electrical activity; MVE). A commonly used reference contraction is the maximal voluntary power grip (here denoted *hand grip*) in a mid-pronated forearm posture [2,9,10]. This grip can be used for both flexor and extensor muscles, but has been shown to give lower EMG amplitudes than, for example, maximal resisted flexor and extensor efforts [11,12]. This means that the extensor muscles are not fully activated during the hand grip, which may result in overestimation of the recorded workload.

The most appropriate way to perform a reference contraction of the forearm muscles has been discussed in several studies [11,12,13,14], although no consensus has yet been reached. For example, Ngo and Wells proposed that EMG amplitudes obtained during power gripping tasks should be normalised to resisted flexor and extensor MVCs, for better approximation of the magnitude of maximum activation of the forearm muscles. They also suggested that a hand grip could be performed to allow comparison with previous studies in which this has been used as a reference contraction [11].

Recommendations on the type and positioning of electrodes, signal processing and modelling were established for 27 different muscles by the European Concerted Action SENIAM (surface EMG for non-invasive assessment of muscles) in 1999 [15], but no such recommendations were established for the forearm. During nearly 30 years of research, our group has placed the EMG electrodes on the most prominent part of the extensor muscles. However, it has been suggested that this position should be avoided, as this is where the innervation zone is likely to be [16]. In addition, previous studies have also shown that the EMG amplitude varies depending on the electrode position [17,18,19]. There is therefore a need to study different electrode positions on the forearm.

We have previously found a variation in the EMG amplitude when recording the hand grip on different days. In a laboratory mock-up of an industrial setting, the coefficient of variation of the EMG recorded during the hand grip contraction was found to be as high as 29 % [6]. We occasionally also see higher EMG amplitudes during work than those obtained with the hand grip. Therefore, we compared the EMG amplitude and reproducibility of two different MVCs (*hand grip* and *resisted wrist extension*) and four electrode positions, and found the highest group mean EMG amplitude and the lowest CV for *resisted wrist extension* with the electrodes positioned closest to the elbow [12]. However, that study was conducted in a laboratory setting with recordings of MVCs. The present study was therefore carried out to investigate the effects of *hand grip* and *resisted wrist extension* on recordings of forearm extensor muscle activity at two electrode positions in whole-day field recordings during hotel cleaning.

1. Materials and methods

2.1. Study design and subjects

Thirteen right-handed female hotel housekeepers participated in the study. Their median age was 40 years (range 22–55), height 164 cm (157–177, data missing for one subject) and weight 62 kg (50–73; data missing for three subjects). The electrical activity of the right forearm extensor muscles was recorded by two pairs of electrodes at different locations during a normal working day for each subject. All subjects performed three efforts of each of two types of MVC (*hand grip* and *resisted wrist extension*, see below) before they started work. The researcher asked the subject to maintain each contraction for about 5 seconds and encouraged her to perform at her best. The subject sat on a chair and body movements were controlled during each attempt. Every other subject started with the *hand grip*, and the others started with the *resisted wrist extension*. All subjects cleaned hotel rooms. A researcher followed each subject during her working day and noted the exact starting and stopping times of different work tasks and lunch breaks. The study was approved by the Regional Ethics Committee in Lund (No. 2015/416). All subjects gave their written informed consent.

1.2. Electromyography

The extensor carpi radialis longus and brevis were located in the right forearm by palpation, while the subject performed a voluntary contraction with the forearm resting on a table, with a pronated forearm and an extended wrist. The skin was cleansed with alcohol and rubbed with emery cloth. We applied two Ag/AgCl electrodes (Ambu Neuroline 720, Denmark), to the skin above the most prominent part of the muscles, which was approximately one third of the distance from the lateral epicondyle to the styloid process of the ulna (position 2; Fig. 1) [6]. Two additional electrodes were applied proximally to the original pair (position 1; Fig. 1). In this way, recordings could be made at two positions for each subject. Position 2 is the location used in our previous studies of workload [2]. Positions 1 and 2 correspond to positions A and C, respectively, in the study by Dahlqvist et al. [12]. The centre-to-centre distance between the electrodes was 20 mm, and the active diameter of the electrodes was 6 mm.

The signals were amplified, filtered (200–4800 Hz) and sampled at a rate of 1024 Hz, and stored on 2 GB memory card in a Mobi-8 data logger (TMS International, Netherlands). After recording, the data were transferred to a computer for quality assurance and analysis. The EMG signals were digitally band-pass filtered (30–400 Hz) to remove electrical signals from the heart, and notch filtered (mains frequency, 50 Hz, and all harmonics). The root-mean-square value was calculated for periods of 0.125 s, and the noise was subtracted in a power sense [20]. A moving window with a width of 0.5 s was used to find the highest EMG activity resulting from the three efforts of MVCs for each kind of contraction [20,21].

1.3. Maximal voluntary contractions

1.3.1. Resisted wrist extension

The subject sat on a chair without armrests, with the elbow flexed and with the forearm pronated and supported on a table (Fig. 2a). The subject inserted her hand into a glove, on the dorsal side of which a piece of plywood was attached. A metal ring was attached to the underside of the plywood, through which the middle finger of the glove was passed. A strap was also passed through the ring and attached to a force transducer connected to a metal plate on the floor. The subject was asked to perform maximal extension of the wrist. Before the recording of the MVC, the strap was adjusted so the piece of plywood remained horizontal during the MVCs. The exerted force was registered for all three MVCs [12].

1.3.2. *Hand grip*

The subject performed a maximal isometric grip using a Jamar hand dynamometer (Sammons Preston, USA) with the elbow flexed at 90° with no support of the forearm or hand (Fig. 2b) [12].

1.4. Data analysis

The highest electrical activity resulting from the two types of MVC (MVE) was recorded at both electrode pairs. Each recording made during cleaning was analysed twice: once using *hand grip* as the reference contraction and once using *resisted wrist extension* as the reference, resulting in four separate results for each subject (2 MVCs x 2 positions). The 90th and 99th percentiles of the amplitude distribution (muscular activity during work, expressed as %MVE) and time for recovery (% of time; EMG amplitude below 0.5 % MVE) during work were calculated for each subject for the four sets of data. The group means were calculated for comparisons between the four sets of data using the Wilcoxon signed-rank test. The highest maximal exerted force (MEF; Newton) recorded during the three efforts of each of the two MVCs was used to calculate the individual ratios and the group mean ratios between *resisted wrist extension* and *hand grip* at both electrode positions. The ratios (*resisted wrist extension*/*hand grip*) were also calculated for the MVE and %MVE (99th percentile). The correlation between the MEF and the MVE for all four sets of data was calculated in terms of the Pearson correlation coefficient. The MEF was then the independent variable and the MVE was the dependent variable. The electrode position with the highest correlation coefficient for both types of contraction was used when plotting the MVE ratio versus the %MVE (99th percentile) when using *hand grip* as reference. SPSS version 24.0 was used for the statistical analyses. p <0.05 was used to indicate a statistically significant difference.

2. Results

3.1. Resisted wrist extension/hand grip ratios for MEF and MVE

The individual ratios of the MEF ranged from 0.18 to 0.31 (Table 1). The group mean ratio was 0.25. The group mean MVE for *resisted wrist extension* recorded at position 1 was 2.3 times higher than that for *hand* grip. The individual MVE ratios at position 1 ranged from 0.99 to 3.7. At position 2, the group mean MVE for *resisted wrist extension* was 1.8 times higher than that for *hand grip*, and the individual ratios ranged from 0.95 to 3.4.

2.2. *MEF versus MVE*

The correlation between the MEF and MVE recorded with *resisted wrist extension* was lower at position 1 (r = 0.07, p = 0.828; Fig. 3a) than at position 2 (r = 0.62, p = 0.023; Fig. 3b). The values for *hand grip* were r = 0.01 (p = 0.985) at position 1 (Fig. 3c) and r = 0.33 (p = 0.278) at position 2 (Fig. 3d).

2.3. *Muscular load and time for recovery during work*

The group mean %MVE (90^{th} and 99^{th} percentiles) was lower when *resisted wrist extension* was used as the reference contraction than when *hand grip* was used, at both electrode positions (Table 2). At position 1, the mean of ratios for the 99^{th} percentile was 0.48 95 % CI [0.36, 0.59], while the corresponding value at position 2 was 0.58 95 % CI [0.44, 0.71]. The %MVE was above 100 % in three subjects recorded at position 1 and in two subjects at position 2 when using *hand grip* as the reference.

The group means of the time for recovery were higher when *resisted wrist extension* was used as the reference than when *hand grip* was used, at both electrode positions (Table 2). The mean values of the ratios for the time for recovery at position 1 was 2.9 95 % CI [2.1, 3.7] and 2.3 95 % CI [1.6, 3.0] at position 2 (not in table).

2.4. *%MVE versus MVE ratio*

The two subjects with a %MVE (99^{th} percentile) above 100 % at position 2 when *hand grip* was used as the reference contraction had MVE ratios of 3.0 and 3.4. All other subjects had ratios below 2.5 (Fig. 4).

3. Discussion

Resisted wrist extension showed higher group mean MVEs than *hand grip* at both electrode positions. The correlation between the MEF and MVE was higher at position 2 than at position 1 for both *resisted wrist extension* and *hand grip*. At position 2, this correlation was higher for *resisted wrist extension* than for *hand grip*. When using *hand grip* as the reference, two subjects showed a %MVE above 100 % at position 2 during cleaning (99^{th} percentile). These subjects also had an MVE ratio between *resisted wrist extension* and *hand grip* greater than 3.0.

4.1. *MVE and MVE ratios for the two reference contractions*

Twelve of the 13 subjects exhibited higher MVEs with *resisted wrist extension* than with *hand grip*, which is in accordance with our findings in the laboratory setting, where this was the case in 11 of 12 subjects [12].

3.2. *Correlations*

We believe that the MVE, to some degree, reflects the MEF that is used when performing the MVC. However, several studies have shown that e.g. the subcutaneous thickness, electrode positioning and different arm positions also influence MVE [8,16,22,23], which of course will affect the correlation. In the current study, we found an R^2 of 0.39 between *resisted wrist extension* MVE at position 2 and the MEF. Thus, 39 % of the variance in MVE could be explained by the MEF. The corresponding value for *hand grip* was only 11 %. No correlations were found at position 1, which may be a consequence of electrode positioning. Therefore, in spite of the possible drawbacks resulting from positioning the electrodes over the innervation zone, we recommend position 2 for forearm extensor EMG recordings.

4.3 Muscular load during work and MVE ratios

When using *hand grip* as the reference, values of %MVE above 100 % were obtained for two subjects. Upon inspecting the data, we noted that these subjects (number 5 and 8) had *hand grip* MVEs for electrode position 2 that were among the lower values, while their MVEs for *resisted wrist extension* were among the highest. Furthermore, the ratios of the MEF between the two types of contraction for these subjects were the same as for the other participants, while their MVE ratios were the two highest. It thus appears that they activated their extensor muscles to a lesser extent than the others during the *hand grip*, resulting in overestimation of the muscular load during work when using *hand grip* as the reference. It is not possible to determine whether a subject activates the extensor muscles maximally by studying the *hand grip* force and MVE only. Instead, the MVE ratio for *resisted wrist extension* and *hand grip* can be used to distinguish individuals who fully activate their extensor muscles from those who do not.

4.4. Strengths and limitations

Differences in EMG amplitudes of the forearm muscles between different maximal efforts and/or with the arm in different positions have been reported in several previous studies [11,14,24]. However, these studies only compared the amplitudes during these specific maximal efforts in the laboratory, and it is difficult to estimate the consequences of different contractions in real working situations using such an approach. To the best of our knowledge, the present study is the first in which different reference contractions have been used and compared in field recordings of real work using different electrode positions. We recorded the muscular load in an occupation with very strenuous work tasks, and enabled us to reveal two subjects in which the workload was obviously overestimated due to poor activation of the forearm extensors in the *hand grip* contraction.

The main limitations of this study were the small number of participants, and the fact that only women were studied. Despite this, we saw differences in amplitude between the two types of reference contraction, and the results from our previous laboratory study were confirmed [12].

4.5. Practical implications

The results of this study show that the muscular load during work can be overestimated when using *hand grip* as the reference contraction for the normalisation of EMG data. Furthermore, the correlation between the MEF and the MVE was higher for *resisted wrist extension* than for *hand grip* at position 2. This suggests that *resisted wrist extension* may be used to normalise EMG data. However, *hand grip* has been used in many previous studies, and comparisons to these would be lost. One approach to overcome this could be to perform both *resisted wrist extension* and *hand grip* contractions and report both. Another approach could be to report data that have been normalised to *hand grip*, and exclude subjects with a MVE ratio above a certain level (3 in the current study). A somewhat lower %MVE could then be expected on the group level (41 %MVE instead of 46 %MVE in this study) compared with previous studies, as these are likely to include subjects with an overestimated workload.

5. Conclusions

Resisted wrist extension showed higher MVEs than *hand grip* for both electrode positions. A higher correlation was also found between the MEF and the MVE for *resisted wrist extension* than for *hand grip*, at position 2. When using *hand grip* as the reference, the muscular load during work was overestimated in two subjects. *Resisted wrist extension* may therefore be more valid for the normalisation of EMG recordings of muscular load during work. However, many studies have used the *hand grip* as reference. Therefore, both *resisted wrist extension* and *hand grip* could be performed and reported. To avoid overestimation when using *hand grip* as reference, subjects with an MVE ratio over a certain threshold (>3.0 in the current study) should be excluded.

Acknowledgements
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Conflict of interest
The authors declare that they have no conflict of interest.

Data availability statement
The authors confirm that the data supporting the findings of this study are available within the article.

Table 1. The maximal exerted force (MEF) and the maximal voluntary electrical activity (MVE) of the maximal voluntary contractions (*resisted wrist extension* and *hand grip*). Ratios between *resisted wrist extension* and *hand grip*. p for differences were calculated with the Wilcoxon signed-rank test ($N = 13$).

	Maximal voluntary contractions								
	MEF (N)			MVE (µV)					
Subject	Resisted wrist extension	Hand grip	Ratio	Resisted wrist extension		Hand grip		Ratio	
				Position		Position		Position	
				1	2	1	2	1	2
1	54	216	0.25	441	237	255	129	1.7	1.8
2	67	294	0.23	799	296	271	206	2.9	1.4
3	71	294	0.24	735	341	430	360	1.7	0.9
4	61	255	0.24	1358	411	407	286	3.3	1.4
5	48	177	0.27	760	536	251	159	3.0	3.4
6	98	314	0.31	634	449	639	404	1.0	1.1
7	82	275	0.30	1229	705	447	288	2.7	2.4
8	88	314	0.28	939	559	389	188	2.4	3.0
9	56	275	0.20	727	244	361	129	2.0	1.9
10	53	240	0.22	1337	496	532	316	2.5	1.6
11	119	431	0.28	890	691	239	276	3.7	2.5
12	88	363	0.24	745	502	384	294	1.9	1.7
13	53	294	0.18	409	238	235	97	1.7	2.5
				$p = 0.002$ (846 vs 372)		$p = 0.002$ (439 vs 241)			
Mean	72	288	0.25	846	439	372	241	2.4	2.0
				$p = 0.002$ (846 vs 439)		$p = 0.001$ (372 vs 241)			
SD	21	64	0.04	304	162	123	96	0.77	0.73

Table 2. The workload (%MVE; 90th and 99th percentiles) and time for recovery (% of time) during hotel housekeeping at two electrode positions (1 and 2) when using *hand grip* and *resisted wrist extension* as reference contractions. *p* for the differences were calculated with the Wilcoxon-signed rank test (N =13).

Subject	Workload													
	% MVE (90th percentile)				% MVE (99th percentile)						Time for recovery (% of time)			
	Resisted wrist extension		Hand grip		Resisted wrist extension		Hand grip				Resisted wrist extension		Hand grip	
	Position		Position		Position		Position		Ratio		Position		Position	
	1	2	1	2	1	2	1	2	1	2	1	2	1	2
1	18	23	31	42	35	41	60	76	0.58	0.54	3.0	1.9	1.5	1.0
2	24	32	67	47	46	57	128	83	0.36	0.69	2.3	1.1	1.2	0.7
3	13	25	22	23	24	44	41	41	0.58	1.06	6.6	3.6	3.4	3.8
4	15	23	49	32	30	42	98	60	0.30	0.70	3.4	0.9	0.7	0.6
5	26	23	79	76	49	39	149	131	0.33	0.30	3.9	4.1	0.8	1.0
6	24	32	24	35	44	53	44	59	1.00	0.90	3.5	1.9	3.5	1.7
7	15	16	42	39	32	29	88	71	0.36	0.41	5.5	5.0	2.2	2.2
8	18	25	42	75	34	49	82	146	0.41	0.34	5.5	2.9	1.9	0.7
9	17	30	34	56	33	52	66	98	0.50	0.53	4.1	2.0	1.8	0.9
10	18	29	46	46	34	49	85	77	0.40	0.64	3.0	1.0	0.8	0.6
11	25	19	92	47	47	37	176	92	0.27	0.40	3.0	3.7	0.7	1.7
12	19	21	37	35	40	38	77	65	0.52	0.59	1.8	2.0	0.9	1.1
13	18	20	31	50	40	38	69	93	0.58	0.41	5.1	4.4	1.8	1.0
	$p = 0.002$ (pos. 1 vs pos. 1)	$p = 0.002$ (pos. 2 vs pos. 2)			$p = 0.002$ (pos. 1 vs pos. 1)	$p = 0.002$ (pos. 2 vs pos. 2)					$p = 0.001$ (pos. 1 vs pos. 1)	$p = 0.002$ (pos. 2 vs pos. 2)		
Mean	19	24	46	46	37	44	90	84	0.48	0.58	3.9	2.7	1.6	1.3
	$p = 0.013$		$p = 0.875$		$p = 0.064$		$p = 0.650$				$p = 0.009$		$p = 0.152$	
SD	4.2	5.0	21	16	7.6	7.9	40	29	0.19	0.22	1.4	1.4	1.0	0.9

Figure captions

Figure 1. The positions of the electrodes (1 and 2) on the right forearm extensor muscles. LE = Lateral epicondyle.

Figure 2. Maximal voluntary contractions: (a) *resisted wrist extension*; (b) *hand grip*.

Figure 3. Maximal voluntary electrical activity (MVE) versus maximal exerted force (MEF) for 13 female hotel housekeepers: (a) *resisted wrist extension* at electrode pair position 1; (b) *resisted wrist extension* at electrode pair position 2; (c) *hand grip* at electrode pair position 1; (d) *hand grip* at electrode pair position 2.

Figure 4. The workload (% MVE; 99th percentile) during hotel room cleaning at electrode position 2 when using *hand grip* as reference contraction versus the ratio of the maximal voluntary electrical activity (MVE) for *resisted wrist extension* and *hand grip* for 13 female hotel housekeepers.

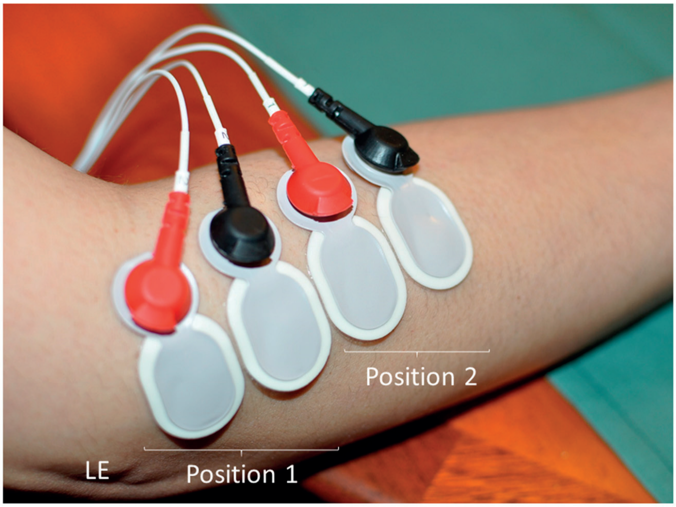


Figure 1

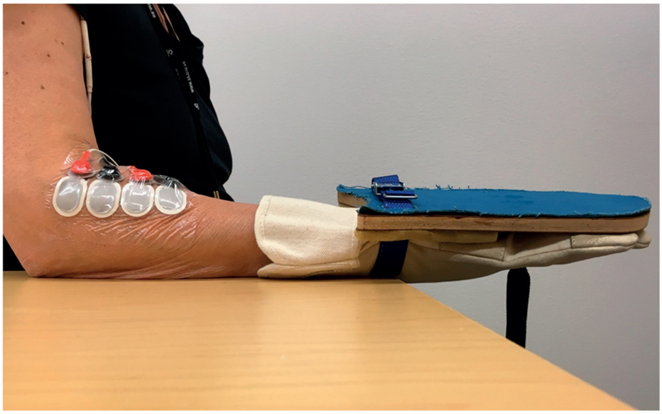


Figure 2a

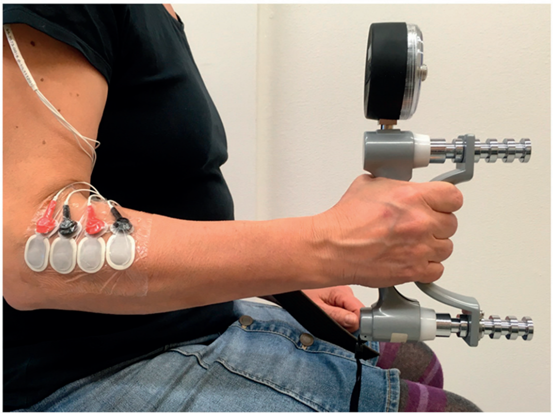


Figure 2b

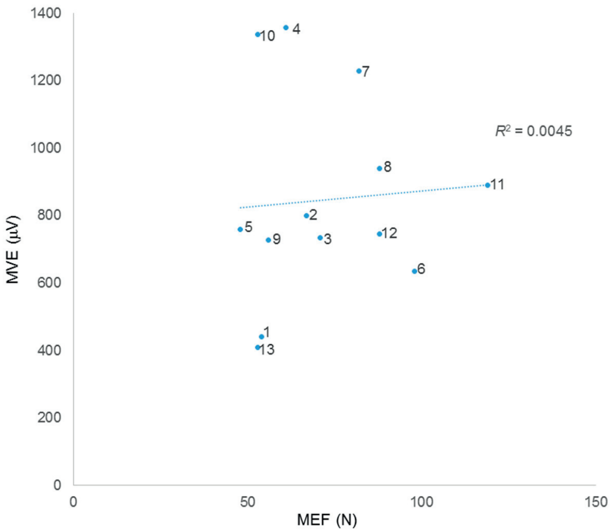


Figure 3a

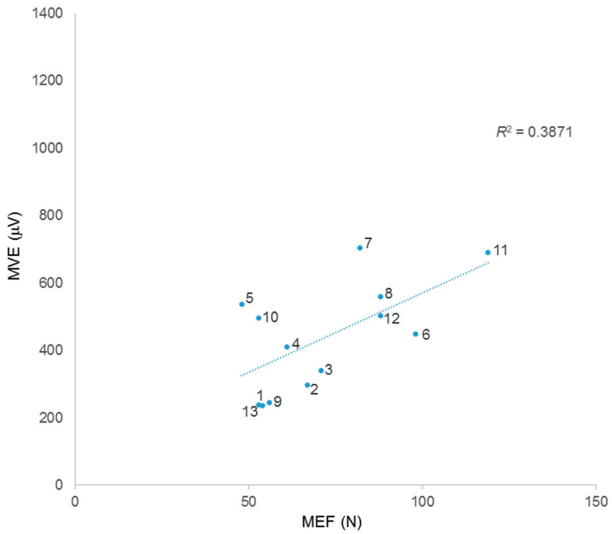


Figure 3b

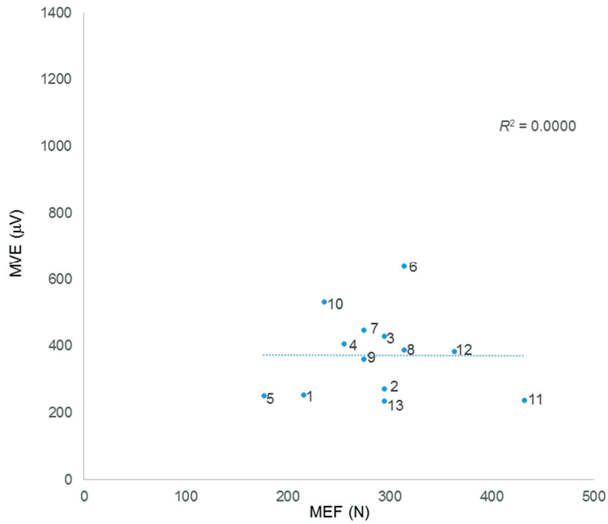


Figure 3c

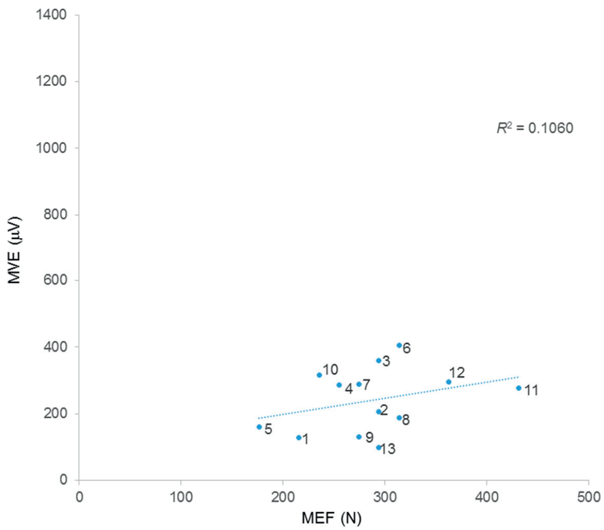
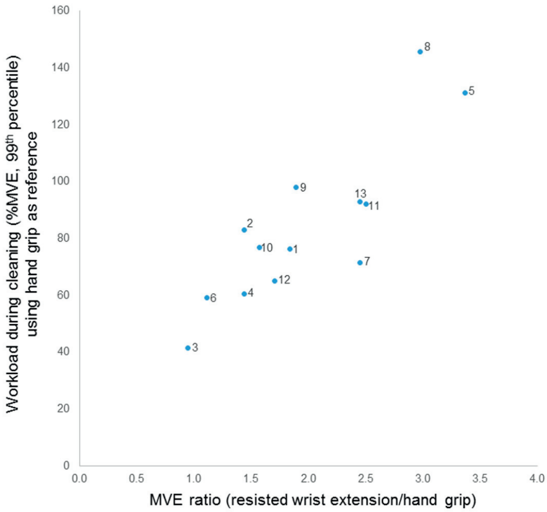


Figure 3d


160
140
120
100
80
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0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Workload during cleaning (%MVE, 99th percentile) using hand grip as reference
MVE ratio (resisted wrist extension/hand grip)
8
5
9
13
11
2
10
1
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12
4
6
3

Figure 4

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