The importance of hand activity and arm posture for shoulder muscular activity

Experimental and field studies

Håkan Sporrong

Göteborg 1997

The importance of hand activity and arm posture for shoulder muscular activity-

experimental and field studies

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I Influences of handgrip on shoulder muscle activity
Sporrong H, Palmerud G, Herberts P
Eur J Appl Physiol 71:485-492,1995

II Hand grip increases shoulder muscle activity
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Sporrong H, Sandsjö L, Kadefors R, Herberts P
Appl Ergonomics, submitted

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J Orthop Res, submitted

Abstract

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EMG was measured from the supraspinatus, infraspinatus, deltoid, trapezius, romboid and levator scapulae. IMP from the supraspinatus muscle was measured in paper V. In the field study (IV), the myoelectric activity from the trapezius muscle, and the position of arms and back, were measured using portable devices (MyoGuard and Intometer).

In study I of intermittent hand activity, there was a significant increase in supraspinatus activity in humeral flexion from and above 60°. In study II of static hand activity, the supraspinatus and the infraspinatus muscles increased their activity significantly in flexion in the elevated arm positions. In study III, light hand activity (precision) increased the EMG activity in all six shoulder muscles. In the field study (IV), the workers, to a high percentage of the time, had their arms in elevated positions, and the muscular rest time (defined as a percentage activity of a reference contraction) was small. In study V, concentric activity resulted in a higher IMP/torque ratio in all arm positions above 40° of abduction compared to eccentric activity.

It is concluded that handgrip exertion increased the shoulder muscle activity, especially that of the supraspinatus muscle and in the most elevated arm positions. In these positions the effect of concentric activity yielded a higher IMP per torque compared to eccentric. The findings have implications for work place organization in industries with manual labor at or above shoulder level.

Key words: biomechanics, EMG, hand activity, IMP, shoulder

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The following abbreviations are used:

CSA = cross sectional area
CTD = cumulative trauma disease
EMG = electromyography
FW = fine wire
IMP = intramuscular pressure
MCI = microcapillary infusion
MVC = maximal voluntary contraction
OR = odds ratio
RMS = root mean square

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Contents

INTRODUCTION

Background. Shoulder pain from muscles, tendons and joints is a common reason for sickleave (Maeda 1977, Herberts et al 1981, Hagberg 1987). Occupational demands are therefore important issues to consider. In a study on welders (Herberts and Kadefors 1976) the frequency of shoulder tendinitis was high. However, shoulder tendinitis has not been extensively studied in relation to occupation and there are few population based studies on shoulder tendinitis. In a study by Petersson (1984) it was shown that ruptures of the rotator cuff were present in more than 50% of the subjects older than 60 years. These ruptures may have been caused by tendinitis.

The majority of the epidemiological studies have focused on neck-shoulder pain, mostly myalgesic pain syndromes of the trapezius muscle (Hagberg 1984, Hagberg and Sundelin 1986, Veiersted 1994). It seems, however, evident that trauma or overuse of the shoulder may lead to dysfunction requiring medical attention (Belzer and Durkin 1996). In a questionnaire concerning musculoskeletal discomfort, 81% of dentistry personnel had experienced musculoskeletal problems during the last 12 months (Augustsson and Morken 1996). About half of the employees claimed to have had pain in the neck, and the same frequency was registered for shoulder discomfort and back pain. The incidence of shoulder injuries in the work place has risen significantly over the past 10 years (Curtis and Wilson 1996). The cost for illness due to pain in the musculoskeletal system was calculated to be 70 billion SEK in Sweden in 1991 (Hansen 1993), a greater part of this sum constituting losses in industrial production. Twenty-five to thirty percent of this cost was estimated by Hagberg (1996) to originate from disorders in the neck-shoulder region, in a work concerning prevention of neck-shoulder illness. Investigations of how employees experience their work and work environment show that complaints due to heavy or longlasting loading constitute one of the biggest work environment problems. In Sweden, over 70% of all reported work-related illnesses have been associated with excessive loading. This type of problem often leads to long sickleaves or disability pensions, with great socioeconomic consequences for the individual and the society (Nachemsson 1991). Aarås (1994) showed that an improvement in the workplace design may lead to a decrease in sickleave due to musculoskeletal pain, and that this may be accomplished without a decrease in productivity. Schibye and collaborators (1995) showed in a study of sewing machine operators that myalgic shoulder and neck symptoms were reversible, and could be influenced by reassignment to other work tasks.

Terminology. An isometric contraction is muscle tension developed without a change in muscle length. Concentric and eccentric contractions are characterized by muscle fiber shortening and lengthening, respectively. The intramuscular pressure (IMP) at rest is a measure on the volume load of a muscle (Styf and Körner 1986). IMP during isometric muscle contraction and during dynamic muscle contraction are measures on force generation from a specific muscle (Körner et al 1984, Aratow et al 1993, Crenshaw et al 1995, Styf et al 1995). EMG is a measure on the electromyographic activity generated in a muscle, and is also a measure (indirect) on force generation from the muscle studied (de Luca and Forrest 1973, Aratow et al 1993). Torque is a measure on the tensile force from all agonistic muscles acting over a joint, and on the moment arms. The pennation angle is the angle between the muscle fibers and the tendon.

Etiology. There are several types of loading that are considered harmful:

1) an occasional but extremely high load, for instance during one heavy lift.

2) repeated loads of moderate or high intensity.

3) longlasting loads of low or moderate intensity

a) static load. The muscle contraction is maintained for a period of time but the muscle length and the joint angle are kept the same.

b) unilateral repeated movements with one extremity. This entails that some muscles are activated repeatedly, which may increase the risk for disorder and pain.

Concentric activity is the result of tension produced in the contractile tissues of the muscle, whereas during eccentric contraction the increased force production is the result of the noncontractile (connective tissue) and contractile tissues working together. The increased muscle soreness during eccentric activity may be indirect evidence for the extremely high connective tissue loading that occurs during maximal conditions of eccentric work (Hancock and Hawkins 1996).

Occupational risk factors were described in a review article by Sommerich and coworkers (1993). Risk factors for pain in the shoulder are working with the hands held above shoulder level (Bjelle et al 1979, 1981, Herberts et al 1984), working with the upper arm slightly elevated in abduction (Kuorinka and Viikari-Juntura 1982, Arborelius 1986, Hagberg and Wegman 1987), increased load in the hand (Sigholm et al 1984), vibration (Kihlberg et al 1993, Stenlund et al 1993, Hales and Bernard 1996), and incorrect position of neck (Harms-Ringdahl and Ekholm 1986). Repetitive work is also considered a risk factor (Kilbom 1994, Campbell Semple 1991), although a recent study suggested that repetitive upper extremity motions in the workplace are not hazardous (Hadler and Hill 1997). For myalgia, there are also psychosocial risk factors (Theorell et al 1991, Bongers et al 1993, Johansson and Rubenowitz 1994), such as stress (Veiersted 1994). However, there are no known psychosocial factors regarding tendinitis. Some studies state that psychosocial factors play a minor role in shoulder pain than in low back pain (Johansson et al 1992).

In a recent study, the hypothesis was proposed that shoulder-neck pain is a family-learnt illness behaviour (Hasvold and Johnsen 1996).

Anatomy and biomechanics. The shoulder (Fig.1) is the most mobile joint in the human body due to the relative lack of bony restraint (Perry 1988). The shoulder joint consists of four different joints: the gleno-humeral (between the upper arm and scapula), the acromio-clavicular (at the lateral end of the clavicula), the sterno-clavicular (between the breast bone and the clavicula) and the scapulothoracal (between the scapula and the chest wall). The shoulder complex consists of 21 muscles (Högfors et al 1987), 12 of which control the glenohumeral joint. Some of the muscles are large and superficially located, such as the trapezius, deltoid and pectoralis major. Others are relatively smaller and deeply located. Among these are the muscles of the rotator cuff which include the subscapularis (located anterior of the gleno-humeral joint), the supra- and infraspinatus and the teres minor (situated cranial and dorsal to this joint). The gleno-humeral muscles can, according to Perry (1988), be divided into arm elevators (the deldoid and supraspinatus), joint stabilizers (the rotator cuff muscles) and peripheral movers (pectoralis major, latissimus dorsi and teres major). The shoulder muscle function is however complex. Arm abduction is accomplished not only by the deltoid and supraspinatus muscles but also by the rest of the rotator cuff muscles (Otis et al 1994, Sharkey et al 1994).

The stability of the shoulder is partly accomplished by these shoulder muscles, and partly by ligaments and capsular structures surrounding the joint. The rotator cuff muscles center the humeral head in the congruent glenoid fossa through the midrange of motion, when the capsuloligamentous structures are lax (Bigliani et al 1996). In the intact shoulder, the subscapularis muscle is the least important anterior stabilizer. When the stability from the capsuloligamentous structures decrease, the biceps becomes more important than the rotator cuff muscles (Itoi et al 1994). The function of the shoulder muscles and interaction between them are only partly known. To better understand the complex shoulder function, several biomechanical models of the shoulder have been presented (de Luca and Forrest 1973, Arborelius 1986, Dul 1988, Veeger et al 1991, Högfors et al 1987, 1991, Karlsson and Peterson 1992, van der Helm and Veenbas 1994).

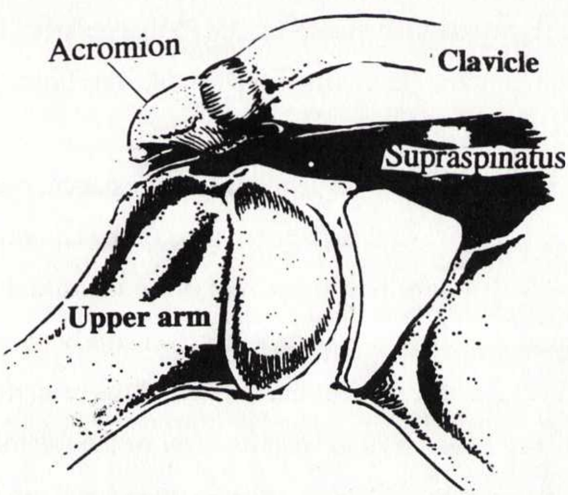


Fig.1 The anatomy of the shoulder.

Shoulder pain. There are at least two different clinical conditions to consider regarding work-related shoulder muscle pain. *Tendinitis* is a rather well defined clinical condition. The symptoms are pain when lifting the arm, especially in abduction, pain in rotation outwards against resistance (impingement sign), sub-acrominal pain and decrease of pain after administration of local anaesthetic into the subacrominal space (impingement test).

The causes of tendinitis are several. Progressive impairment of the blood supply to the rotator cuff, is probably a factor that contributes to degeneration with increasing age (Herberts and Kadefors 1976). Studies have shown that the supraspinatus tendon has a zone (the critical zone) of a vascularity, which was not be seen in the rest of the rotator cuff (Rathburn and McNab 1970). The circulation of the tendon is further impaired by the humeral head compressing the tendon against the coracoacrominal arch (Herberts et al 1984). This compressive effect, by the humeral head, is increased in working situations where the arm is elevated. Overhead work entails also that the hypovascularity of the supraspinatus tendon is likely to be accentuated by high intramuscular pressures (IMP) that reduces blood flow to the muscle and tendon (Herberts et al 1984, Järvholm et al 1988a,b).

Sometimes there is an anatomical basis for tendinitis, for instance, reduced height of the subacrominal space, and the shape or slope of the acromion as can be visualized on x-ray. Bigliani and Morrison (1986) identified three different types of acromions (type I-III) in a cadaver study. Seventy percent of the rotator cuff tears occurred in the hooked shape of acromion (type III). These circumstances can lead to wear and tear of the rotator cuff as a result of mechanical conflicts. Rahme (1994) studied patients with unilateral impingement syndrome with plain radiography. He found an increased predominance of patients with narrow subacrominal space on the affected side. In a study during prolonged arm abduction, a 14 % increase in the thickness of the supraspinatus muscle was noted (Jensen et al 1994), which would increase the risk of symptoms related to this muscle if the subacrominal space was limited. Tennis players have thicker supraspinatus muscles on their dominant side than on the non dominant side, (Edshage et al 1995), which probably increases the risk of mechanical conflicts and of developing shoulder pain on the dominant side. Typical findings of wear of the supraspinatus tendon are often observed at surgery. Tendinitis can further on lead to rotator cuff rupture of the degenerative type, and the main wear is mostly located at the supraspinatus tendon (Neer 1972). In older people, the frequency of rotator cuff rupture is high (Pettersson 1984).

In summary, there is a complex interaction between reduced vascularity and mechanical impingement behind the occurrence of supraspinatus tendinitis.

Neck-Shoulder myalgia (trapezius myalgia) is another common pain syndrome in the shoulder-neck region (Hagberg 1984). This syndrome is however more diffuse and therefore known under several other names, such as myofascial pain syndrome, or myofasciit. The etiology of this syndrome is still poorly understood, although there are several theories. The energy theory states that the reason for this syndrome is a selective lack of ATP in some muscle fibers (Foster et al 1986). Another theory states that mechanical damage to the muscle may cause degenerative processes in the muscle tissue, that lead to a change in the calcium level in the muscle. Pain is related to the calcium level (Edwards 1988). A third theory states that the so-called type I muscle fibers are overloaded and cause pain (Hägg 1988). These fibers are used at low activity levels and are supposed to be activated in static work conditions. Central steering mechanisms that cause an increased muscle relaxation level may also explain myalgia. Veiersted (1994) showed that inability to relax shoulder muscles was a risk factor for developing this syndrome. Chronic pain patients have less ability to perceive muscle contraction correctly; they tend to underestimate the actual levels of muscle contraction (Flor et al 1992). The frequency of EMG gaps, which is equivalent to a totally relaxed muscle, is decreased in people with myalgia. A feedback device that signals to a person when the gap frequency at rest is too low, was recently presented (Hägg 1997). This device can be used for prophylactic measures.

Psychosocial factors are also of importance in myalgic pain conditions (Theorell et al 1991). These factors generate an increased general muscle tension and an increased muscle activity level at rest, as shown by Veiersted (1994).

Ergonomic considerations. A better understanding of shoulder function and the mechanisms for developing shoulder pain is essential for the prevention of work-related shoulder pain, as well as for the rehabilitation of these conditions. Differences in experimental methods, and a lack of consensus about etiological parameters and how to model the joint axes of the human arm, make the results difficult to compare (Buckley et al 1996). Burdorf and coworkers (1997), in a study on tank terminal workers, showed that the assessment strategy chosen in a particular study strongly influences random measurement error of physical load, and that inappropriate strategies may mask true associations between physical load and musculoskeletal complaints.

Several studies have supported the claim that there is an increased risk for developing shoulder pain due to working with elevated arms, and that added load in the hand increases the shoulder load. In heavy industrial work situations, male gender and tendinitis predominate. However, in light monotonous work situations, female workers and myalgia disorders predominate (Herberts et al 1984). Most work tasks entailing elevated arm positions involve not only holding a tool in the hand, but also working actively with the hand in a static or dynamic manner. The effect of this added hand activity on the shoulder muscles is not well known. This was the reason for studies I-III, which are experimental studies. With respect to the laborotary tests being representative of occupational work, it is more relevant to study intermittent tests in which variation of limb movements is possible (Hermans and Spaepen 1997). This is why the field study (IV) was performed, in order to allow the subject to work freely with his/her ordinary tasks, while the shoulder muscle activity and arm positions were recorded. In study V the effects of different contraction modes on pressure in the supraspinatus muscle and on the shoulder torque were measured in different arm positions. The findings would be relevant not only for occupational shoulder pain but also for athletic training, as well as for rehabilitation after injuries and diseases (Styf et al 1995, Sirota et al 1997). Eccentric training increases the force in eccentric activities, while concentric training increases the force in both contraction modes (Amiridis et al 1997).

In summary the purpose of the present work was to elucidate the effects on shoulder muscle activity of a number of possible derogatory factors: dynamic and static handgrip exertion, precision demands and concentric/eccentric muscular activity. The addition of these effects to static postural loading, was studied.

REVIEW OF THE LITERATURE

Verne T. Inman was one of the first to use electromyographic signals (EMG) to analyse muscle function. His article "Observations of the function of the shoulder joint", published in 1944, is still appreciated and was published for a second time in 1996. For elucidating shoulder and arm movements, Inman used both x-ray and insertion of pins into the bones of subjects. He stated that movement in the shoulder joint is complex, since the shoulder consists of four different joints. As a person lifts the arm, the first part of the movement is to a large extent performed in the joint between the scapula and the chest wall. Above 30° abduction or 60° flexion, there is a ratio of 1 to 2 between the movement in this joint and the joint between the upper arm and scapula. This ratio is however influenced in persons with impingement or rotator cuff syndrome, where arm abduction has a larger scapulothoracic component than for normal shoulders (Deutsch et al 1996). For lifting the arm more than 120°, lateral rotation of the upper arm is essential and so is also a capacity for the clavicular bone to rotate. For maximum elevation, the movement occurs in a plane anterior to the plane of the scapula (An et al 1991). Inman also stated that the pressure and friction of the upper arm against the glenoid reaches its summit at 90° abduction, as other research groups have since confirmed (Poppen and Walker 1978). Inman divided the shoulder muscles into abductors or flexors (the deltoid, pectoralis major, supraspinatus), depressors (subscapularis, infraspinatus and teres minor), scapular rotators (upper trapezius, levator scapulae, serratus anterior), and teres major with a stabilizing function. Investigations done in more recent years have emphasized that muscles in the shoulder must not be regarded as single muscles, but rather that each muscle can be divided into several different functional units, with different modes of action. This is the case for the deltoid muscle (Michiels and Bodem 1992), the trapezius muscle (Jensen 1995), the subscapularis muscle (Kadaba et al 1992).

As the forces from the individual rotator cuff muscles are impossible to measure in vivo, biomechanical models have been developed. Hughes and An (1996), using a shoulder model, found the highest rotator cuff muscle forces during maximal internal rotation (subscapularis) and external rotation (infraspinatus, teres minor and supraspinatus) exertions. They concluded that ergonomic efforts to prevent rotator cuff disease should include reduction of internal rotation of the arm, and that abduction of the arm may not produce the greatest loads on the supraspinatus tendon. Analyses of arm elevation may thus underestimate the potential loads on the rotator cuff. However, these results are not in agreement with the findings of Sigholm and coworkers (1984), where it was found that the load of the shoulder was not dependent upon upper arm rotation. There are planar analyses of arm abduction (de Luca and Forrest 1973, Poppen and Walker 1978) as well as 3-dimensional analyses (Karlsson and Peterson 1992, van der Helm and Veenbas 1994). Sapega and Kelley (1994), in a review article, described different aspects of strength testing in the shoulder. They concluded that some ideal test positions, postures described to give the greatest force output in subjects, (Hageman et al 1989, Söderberg et Blaschak 1987), may be potentially injurious in patients with shoulder disease. In the presence of joint or soft tissue inflammation, muscle testing may have a limited value bacause pain results in reflex muscle inhibition. Isometric testing should perhaps be the preferred mode of testing in patients and isokinetic in healthy subjects.

The scapular plane is suggested for testing the rotators and abductors. This plane has anatomically and biomechanically advantageous characteristics that minimise stress to the capsuloligamentous- tendinous complex (Johnston 1937). Malanga and collaborators (1996) compared two recommended test positions for isolating the supraspinatus muscle function, one with the elbow extended, the shoulder in full internal rotation, and the arm in the scapular plane and the other with the elbow extended, the arm abducted 100°, and externally rotated. They concluded that either position can be used for strengthening the supraspinatus, but neither position selectively isolates the supraspinatus.

Several studies describe the prevalence of shoulder pain among different worker groups, (Bjelle et al 1979 et 1981, Hagberg and Wegman 1987, Stenlund et al 1993). Silverstein (1985) found a prevalenc of 7.8% of shoulder cumulative trauma disease (CTD) in a population of industrial workers, with an odds ratio (OR) of 5.4. The shoulder-neck region in cleaners and sweepers is subjected to a hazardous exposure from work (Hagner and Hagberg 1989). It has been reported in two different studies that ship yard welders had OR of 11 and 13 (Herberts et al 1981, 1984). McCormack and coworkers (1990) reported an increased frequency of shoulder tendinitis in manufactyring workers (OR=2.4). Luopajärvi and coworkers (1979), reported an increased risk in female assembly packers (OR=2.6). Different types of athletes may also have an increased risk of shoulder pain, such as swimmers (Kennedy et al 1978). Any repetitive microtrauma, particularly those involving sport activities requiring repetitive overhead use of the arm, may cause shoulder pain (Biasca and Gerber 1996). This is the case in the athletic throwing shoulder, where subtle instability or imbalance of shoulder muscle activity often is the cause of impingement symptoms in young athletes. In older subjects, rotator cuff injuries due to anatomic changes are often more frequent (Arroyo et al 1997).

Studies on the impact of work breaks, have been done by Mathiassen and Winkel (1996). The results suggested that a limitation in the daily duration of assembly work may be more effective at minimizing acute fatigue in the shoulder-neck region, than reduced work pace or increased break allowance. Mathiassen (1993) described the effect of different lengths of pauses during work on the shoulder-neck region. He found that the recovery of strength, EMG amplitude and cardiovascular responsiveness was not complete one hour after shoulder-neck exercises; there were even tendencies toward lack of recovery after 4 hours. He also suggested that the perception of muscular fatigue fails to monitor important physiological deviances arising during prolonged isometric exercise. Thus, exercise may be voluntarily continued in spite of the simultaneous development of adverse physiological responses. These findings coincide with the results of Byström and collegues (1991) concerning the effects of micropauses (10 sec). They found that these short breaks from work may create an increased risk of musculoskeletal disorders, by giving the worker a subjective sense of relief but not giving the muscle a chance to recover from fatigue.

A reference book of work-related musculoskeletal disorders was presented in 1995 (Hagberg et al), and the problem of prevention of work-related shoulder-neck illness was later discussed by Hagberg (1996). Different aspects of shoulder pain, from an ergonomic point of view, have been presented in several publications during the past years. Sigholm (1987) showed that hand dependecy was greater for the rotator cuff muscles than for the larger shoulder muscles (deltoid), and that the shoulder load was not dependent upon the upper arm rotation. Järvholm and coworkers (1990) measured intramuscular pressure in four shoulder muscles and found the highest pressure in the supraspinatus muscle. They also found that the pressure in this muscle, in arm levels above 30° abduction, exceeded the pressure where muscle blood flow was impeded (Järvholm et al 1988b, Järvholm 1990).

Rahme and coworkers (1993) presented a study of the subacrominal impingement syndrome. Rahme (1994) elucidated the pathogenesis of pain from this syndrome, and identified the predictors of surgical outcome. He found that a normal capacity to place the hand at the neck, hand in neck maneuver, before surgery, predicted a good result after surgery. Stenlund (1992) described shoulder tendinitis and arthrosis in the acromioclavicular joint, and their relation to occupational factors and sports. He found, in a cross-sectional study of brick layers, that 33% had signs of shoulder tendinitis on the left side and 40% on the right side. He also found an increased risk for shoulder tendinitis in workers that had previously been extremely active in sports.

Lindman and coworkers (1991) showed, with muscle biopsies, that patients with chronic trapezius myalgia had unspecific morphological changes in the muscle compared to healthy subjects. It was suggested that there might be an imbalance between the capillary supply to the muscle and muscle fiber type, and that this imbalance might be of significance in the development of a chronic myalgia. Vasseljen (1995) studied work-related shoulder-neck pain and exposures. He found, in a case-controlled study with EMG recordings from the trapezius muscle, that the cases performing manual activity showed higher muscle activity and fewer muscular pauses than the controls. The cases also had higher muscle activity at rest (Vasseljen and Westgaard 1995:1). These results coincide with earlier findings of Veiersted (1994). Dimberg (1991) presented the symptoms in an industrial population. He found that working with vibrating tools was an important factor for pain in the neck and arm, as did Stenlund and colleagues (1993).

Jensen (1991) described, in a thesis on isometric contractions of small muscle groups, the morphology of the supraspinatus muscle and IMP in this muscle on different depths (Jensen et al 1995). She found that the resting intramuscular pressure was independent of the measuring depth, whereas in contraction, the pressure increased with increasing depth. It was suggested that the combination of a high intramuscular pressure and local vasodilatation during and after isometric contractions may affect the microcirculation, due to leucocyte plugging in the capillaries. This could thus explain the relationship between sustained isometric contractions and pain development.

Biomechanical work on force distribution has been done by Karlsson (1992) and Laursen (1996).

Summary and hypotheses

Earlier studies have revealed an increased risk of shoulder pain in work with arms in elevated arm positions. The hypothesis behind this study is that additional aggravating circumstances exists in these work positions. It is hypothesized that

- intense hand activity increases the activity of shoulder muscles
- precision hand activity increases the activity of shoulder muscles
- construction work, during ceiling fitting, is performed with elevated arms and with a high mean shoulder muscle activity
- concentric and eccentric activity of the shoulder results in different values of pressure in the supraspinatus muscle and shoulder torque in elevated arm positions.

Aims of the thesis

- to establish how the load on different muscles in the shoulder depends upon the physical demands from the work, and to elucidate possible pain mechanisms originating from these structures.

- to develop a method which can describe the work situation from data collected at the workplace in order to evaluate the risk for chronic work-related disorders.

Specific aims

1. to describe the influence of hand activity on shoulder muscle activity and the extent to which the various shoulder muscles are affected. (I,II,III)

2. to further describe how hand activity as well as arm position influence shoulder muscle activity (I,II,III).

3. to analyze if this influence varies according to the type of manual activity (intermittent or static) or degree of hand activity (high or low intense activity), (I,II,III).

4. to measure, at the workplace, the actual extent to which construction workers use their arms in the elevated positions, during ceiling fitting, and to compare these results with the workers perceived estimation (IV).

5. to measure the muscle activity from the trapezius muscle, during ceiling fitting, as an indicator of total shoulder load,and to correlate the results with the recordings of arm posture (IV).

6. to map the exposure pattern of shoulder load over time in a field investigation among construction workers with a documented work situation with elevated arms (IV).

7. to compare the effects of concentric and eccentric muscular activity on IMP in the supraspinatus muscle and the shoulder muscle torque (V).

SUMMARY OF PAPERS

STUDY I.

Aim: to find out if intermittent hand activity increases shoulder muscle activity, and the extent to which the various shoulder muscles are affected and the influence arm positioning has on the shoulder muscle activity.

Materials and methods: In nine healthy subjects (mean age 27 years) EMG was recorded from four shoulder muscles (supra- and infraspinatus, trapezius (middle) and trapezius (descending part) on the dominant side. EMG was recorded using monopolar intramuscular wire electrodes, made of nickel-chromium alloy, and a silver/silver chloride surface electrode taped at the seventh cervical spinal process, which served as the indifferent electrode. Manual activity was performend in both the sagittal plane (flexion) and the scapular plane (abduction); the angles of the upper arm were 30°, 60°, 90° and 120°, giving a total of 8 positions. In all positions, the elbow was flexed 90°. The hand activity was intermittent, with a compression force of 30% and 50% MVC, lasting for approximately 10 seconds and with a frequency of about 0.5 Hz. The subject held a device weighing 600 g in his hand during the activity. Shoulder muscle activity with device in the hand and with arm in position, was compared to the shoulder muscle activity when dynamic handgrip exertion was added. The percentual changes in EMG activity were calculated. The mean values were analysed with Student's t-test.

Results: The changes in shoulder muscle activity were most pronounced in the supraspinatus muscle (Table 1). In the 90° and 120° positions, the supraspinatus activity increased 14.4 % and 10.4% in abduction and 15.1% and 17.0% in flexion, for the respective angles. Significant increases were found in the positions 60-120° flexion, and 120° abduction. In the infraspinatus muscle the changes were more subtle. The activity decreased significantly in the 30 and 90° positions of abduction. In the trapezius muscle no significant changes were noted since nearly all changes were lower than 5%. In the deltoid muscle, the activity increased significantly at 30° of abduction, whereas in the higher positions of flexion (90° and 120°) the activity decreased significantly, 8.7 and 12.5%, respectively.

Conclusions: A relationship exists between intermittent hand exertion and shoulder muscle activity, and in particular, the supraspinatus activity increases in elevated arm positions due to hand activity.

STUDY II.

Aim: To find out if static manual exertion influences shoulder muscle activity.

Material and methods: In principle, the same investigation was performed as in study I, but instead of intermittent hand activity over 10 seconds, a static manual exertion of 30 and 50 % of MVC was executed. Nine healthy subjects (age range 24 -34 years) participated, and these were the same as in study I. The same four muscles (supra- and infraspinatus trapezius and deltoid) were examined. The percentual changes in EMG activity, with and without added hand exertion, was assessed with a non parametric test (Fisher's test for pair comparisons).

Results: As in study I, the percentual changes of activity were largest in the supraspinatus muscle (Table 2). Significant ($p<0.05$) increases in activity were noted in 120° abduction (14%) and in 60° (10%), 90° (20%), and 120° (12%) flexion. The changes regarding the infraspinatus muscle were more subtle, but in flexion the activity increased in all positions, with only significant increase in the 120° position (20%). In the trapezius muscle, no significant alterations in activity were noted. In the deltoid muscle, significant decreases in activity were noted in 90° (7%) and 120° (13%) abduction.

TABLE.1 The percentual changes in muscle activity in three shoulder muscles in 16 arm positions due to hand activity. Digits positioned somewhat to the left are from study II, digits somewhat to the right are from study I. (Trapezius changes are not accounted for as the changes were small and all were insignificant).

	Supraspinatus		Infraspinatus		Deltoid	
A30	-1	-2	-1	-8	+5	+15
A60	+6	+4	0	-4	-4	0
A90	+16	+14	-2	-6	-7	-7
A120	+14	+10	+6	-1	-13	-6
F30	+7	0	+6	0	+1	+2
F60	+10	+6	+2	+1	+2	+2
F90	+20	+15	+7	+2	-14	-9
F120	+12	+17	+21	+3	-6	-13
30% 30	-1	-6	0	-7	+1	+2
30% 60	+1	+2	+1	-5	+11	0
30% 90	+6	+13	-3	-3	-9	-6
30% 120	+7	+18	+5	+1	-15	-8
50% 30	+5	+4	+7	-1	+5	+15
50% 60	+6	+8	+7	+3	-6	+3
50% 90	+16	+16	+2	-1	-14	-9
50% 120	+24	+9	+20	+1	-4	-10

TABLE 2. Stating the *significant results* in study I and II. Digits are percentual changes in activity. Digits positioned somewhat to the left are from study II, digits somewhat to the right are from study I. (Significance in study I is when the whole 95% confidence interval is located above zero change of activity or below. Significance in study II is when $p<0.05$ (Fishers test)).

	Supraspinatus		Infraspinatus		Deltoid	
A30	-	-	-	-8	-	+15
A60	-	-	-	-	-	-
A90	-	-	-	-6	-7	-7
A120	+14	+10	-	-	-13	-
F30	-	-	-	-	-	-
F60	+10	+6	-	-	-	-
F90	+20	+15	-	-	-	-9
F120	+12	+17	-	-	-	-13
30% 30	-	-6	-	-7	-	-
30% 60	-	-	-	-	-	-
30% 90	-	+13	-	-	-9	-
30% 120	-	-	-	-	-15	-8
50% 30	-	-	-	-	-	+15
50% 60	-	-	-	-	-	-
50% 90	+16	+16	-	-	-	-9
50% 120	+24		+20	-	-	-10

Conclusion: A relationship between static manual exertion and shoulder muscle activity exists. This connection with static manual exertion resembles the influence of intermittent manual activity on the shoulder. The most predominant increases in shoulder muscle activity in elevated arm positions, were found in the supraspinatus muscle.

Comments to studies I+II: The results in both studies are rather similar and emphasize that it is the stabilizing muscles of the shoulder, the supraspinatus muscle in particular, that increase their activity due to hand activity. However, during static hand activity, the difference between the influence of low and high intensity hand activity on the shoulder, is greater than during intermittent hand activity.

STUDY III.

Aim: to investigate the effects of light manual exertion (precision work) on the shoulder muscles, in simulated work postures that imitate real work positions.

Material and methods: Ten healthy subjects (mean age 34 years) participated. Seven shoulder muscles were investigated using EMG, with both intramuscular electrodes in the supraspinatus, infraspinatus, trapezius, levator scapulae and rhomboid major muscles, and surface electrodes over the deltoid muscle, both anterior and middle parts. The subjects held a light stick in hand and performed a precision task for 10 seconds. The task was to move the tip of the stick along a path carved out of a metal piece in front of the subject, while keeping the arm position constant. The arm positions were chosen to resemble real work positions. The upper arm was flexed 30°, 45°, 60° and 90°. The elbow was flexed 0°, 60° or 90°. The percentual changes in myoelectric activity were calculated, and the changes were assessed with a non-parametric test (Fisher's test for pair comparisons).

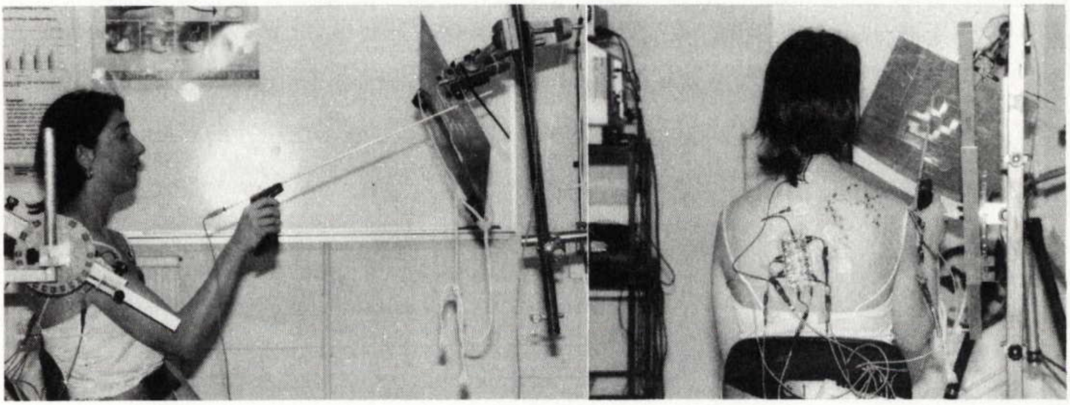


Fig.2 Side- and backviews of a subject holding the stick in hand.

Results: The EMG activity increased in almost all positions and for all shoulder muscles (Table 3). The percentual increase was largest in the trapezius muscle, the rotator cuff and the levator scapulae muscles. The p-values are shown in Table 4.

Table 3. Relative changes in myoelectric activity in percent (mean values) in 7 shoulder muscles as a consequence of precision activity in 5 armpositions. (F-shoulder angle, f-elbow angle)

	F30f90	F45f60	F60f90	F90f0	F90f90
Trapezius	67	33	57	13	-5
Deltoid ant.	16	7	13	6	-2
Levator scap.	16	38	25	30	33
Romboid maj.	49	9	8	5	6
Deltoid middle	29	17	12	11	4
Supraspinatus	41	12	23	14	60
Infraspinatus	23	25	20	31	22

Table 4. p-values in corresponding positions (Fisher´s test, Bradley).

	F30f90	F45f60	F60f90	F90f0	F90f90
Trapezius	0.006	0.12	0.04	0.09	0.8
Deltoid ant.	0.3	0.13	0.03	0.6	0.5
Levator scap.	0.4	0.13	0.04	0.004	0.003
Romboid maj.	0.04	0.4	0.16	0.6	0.8
Deltoid middle	0.01	0.04	0.2	0.08	0.6
Supraspinatus	0.13	0.3	0.08	0.3	0.008
Infraspinatus	0.08	0.03	0.03	0.02	0.06

Conclusion: Light manual precision work increases the activity of all the tested shoulder muscles.

Comments to study III: The effects of precision hand activity on the shoulder, suggest a somewhat different mechanism for the influence on the shoulder, compared to the effects of hand activity of a higher intensity, as in studies I-II.

STUDY IV:

Aim: to get an apprehension of work postures and load on the shoulder, by registering trapezius muscle activity and back and arm positions on workers doing ceiling fitting, in a field study, and to investigate the workers own opinion of work postures using a questionnaire.

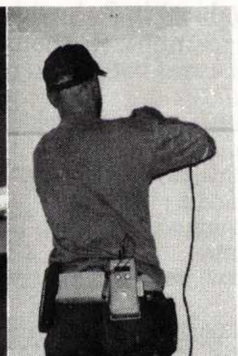


Fig. 3 and 4 The subject in two typical work situations.

Material and methods: The study consisted of two parts. First, the subjects answered a questionnaire, consisting of 72 questions, regarding the work situation from an ergonomic point of view. Sixteen workers participated in this part. In the second part of the study, measurements were made on eleven workers, with a mean age of 34 years, regarding the position of back and arms and the bilateral EMG activity from the trapezius muscles, during a 2 hour work period. During that time the worker fulfilled his ordinary tasks. The measured sequences included time for getting material and for change of work stations, but not for rests or meals. Both position and muscle activity were recorded with devices (MyoGuard and Intometer) that allowed a later off-line analysis. EMG was recorded using surface elctrodes. Both position - and EMG recordings were calibrated to well defined reference positions. The mean values and one standard deviation were calculated.

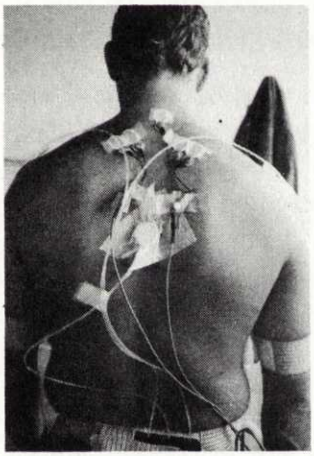


Fig 5 and 6. The worker from the backside with the mounted equipment for recording EMG and position.

Results: In the questionnaire, 38% of the workers claimed they had experienced pain from the right shoulder during the last 12 months, which they attributed to the work. From this group, 14% had been absent from work for more than 1 month due to shoulder pain . More than half of the workers claimed that they worked more than 3/4 of the time with their hands held above the shoulder level, and 19% claimed that they worked at least 1/4 of the time with their backs bent more than 60°.

Measurements:

Position results: 98% of the time was spent with the back in 0-30° (Fig.7). The mean angles between the upper arm and a vertical line were 49° (dominant arm) and 46° (non-dominant). For more than 1/3 of the working time the upper arm was bent 60°.

Muscle activity results : The EMG activity exceeded that of a specified reference contraction (arms positioned straight forward at shoulder level) in about 50 % of the registrations (Fig.8). The rest time, defined as the reference contraction with an additional 10% , was less than 10% of the working time. In Fig.8, the reference contraction is equivalent to an activity level of 100% on the x-axis. The curve shows the cumulative number of all observations. In about 20% of the observations, the muscular activity exceeded that of the reference contraction by a factor of 1.4.

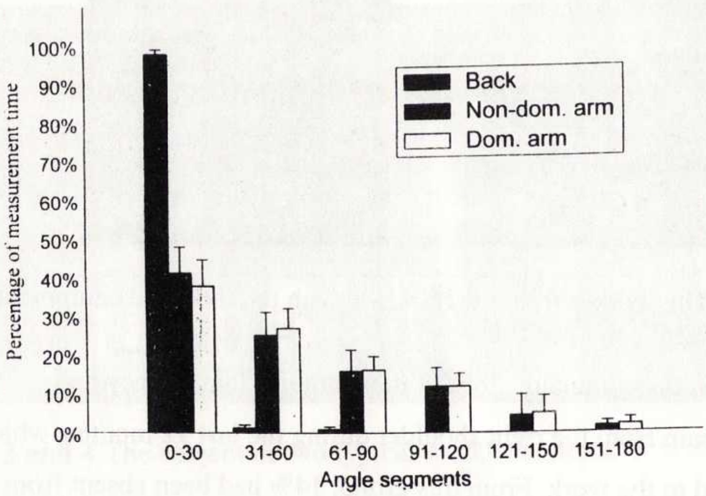


Fig 7 Position data showing the percentage of time spent in the different angle segments for back and both arms during the work sequence.

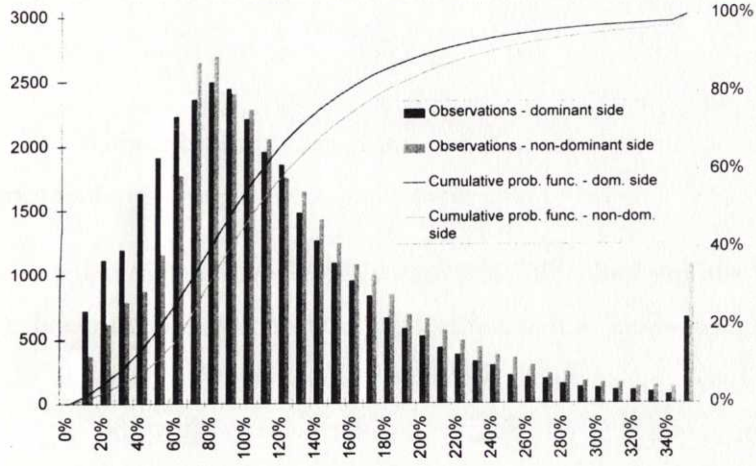


Fig 8 The EMG data from all subjects. X-axis shows muscle activity level, Y-axis (left) shows the number of observations made and Y-axis (right) shows the cumulative curve.

Conclusions: Ceiling fitting entails work that is performed using both arms to similar amounts, at high arm levels, and where muscular rest accounts for only a low percentage of the work time. The correlation between objective measurements and subjective answers in the questionnaire seems low.

Comments to study IV: The number of workers participating in the questionnaire was 16. Despite this, it seems that the prevalence figures are in accordance with the results of other similar but larger questionnaire investigations of similar jobs.

In studies I and II, it was shown that hand activity yielded an increase in supraspinatus activity in the elevated arm positions. Precision work in study III also resulted in an increased shoulder muscle activity. In study IV, the work tasks included these types of hand activity in elevated arm positions. It seems reasonable to assume that not only the elevated arm positions, but also the hand activity performed in these positions, may thereby result in shoulder disorders.

STUDY V.

Aim: To evaluate the effects of concentric, eccentric and isometric muscular activity on IMP in the supraspinatus muscle and shoulder torque.

Material and methods: Shoulder torque, EMG and pressure in the supraspinatus muscle were recorded during concentric, eccentric and isometric muscular activities, from nine healthy subjects (mean age 38 years). The contraction was isokinetic with a velocity rate of 60° per second. The range of movement was between 0° and 120°. The investigation was performed with the subject attached to a computerized ergonometer, which controlled position of the arm and torque. IMP was measured with a micro-capillary infusion technique, with an infusion rate of 1.5 ml/h. EMG was registered using a bipolar surface Ag/AgCl electrode, placed over the region of the supraspinatus muscle belly. The movement was carried out in the abduction plane, with the elbow flexed 90°. Mean values and standard deviation were calculated at each 10 degree increment of abduction. P-values were calculated using Student´s t-test. Linear regression analysis was done.

Results: Peak IMP and mean IMP did not differ significantly between concentric and eccenctric activity. Peak IMP ocurred at 115° (SD=15) in concentric activity and at 6° (SD=7) during eccentric, $p<0.001$. Peak torque was 40 Nm (SD=12) during concentric activity and 55 (SD=8) during eccentric, $p< 0.02$. Peak torque ocurred at 44° (SD=30) during concentric activity and at 74° (SD=14) during eccentric, $p< 0.05$.

The relationship between IMP and torque was 3.0 (SD=1.1) during concentric activity and 2.3 (SD=0.5) in eccentric, $p< 0.05$.

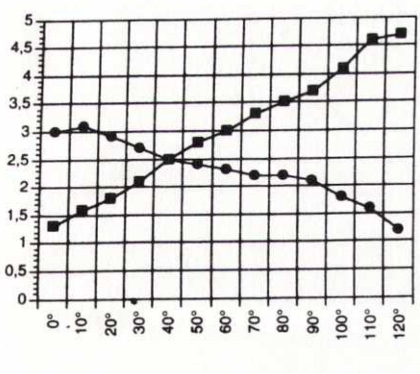
The correlation coefficient (r) between EMG from two shoulder muscles and IMP in the supraspinaus muscle during concentric activity was 0.98 and during eccentric activity -0.67.

Table 5. Joint angle at peak IMP and joint angle at peak torque during concentric and eccentric muscular activity.

	IMP mmHg	SD	Abduction degrees	SD	Torque Nm	SD	Abduction degrees	SD
Concentric	135	57	115	15	40	12	44	30
Eccentric	134	60	6	7	55	8	74	14
p-value	n.s.		< 0.001		< 0.02		< 0.05	

Table 6. Mean values and one standard deviation of six parameters during concentric and eccentric muscle activity during the full range of motion (0°-120°).

	IMP mmHg	SD	Torque Nm	SD	IMP/Torque mmHg/Nm	SD	EMG uV	SD	EMG/Torque uV/Nm	SD	Work J	SD
Concentric	96	29	35	2.3	3.0	1.1	1045	208	31	6.8	73	27
Eccentric	97	26	46	6.1	2.3	0.5	917	287	21	7.2	98	33
p-value	n.s.		< 0.001		< 0.05		n.s.		< 0.02		n.s.	



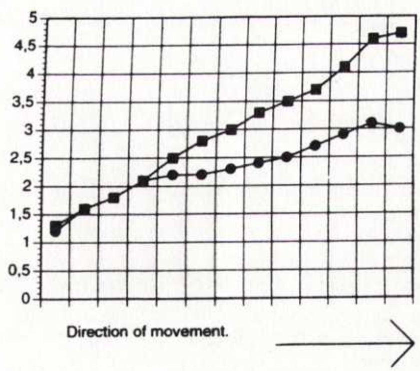


Fig.9 (left) The quotient mm Hg/torque in full ROM (0-120°) for eccentric (squares) and concentric (circles) activity.

Fig.10 (right) The corresponding curves in relation to the direction of movement.

Conclusions: Concentric activity resulted in lower peak torque, with no difference in IMP compared to eccentric activity. The peak levels for IMP and torque occurred at significantly different joint angles in concentric compared to eccentric activity.

Comments to study V: The joint angle at peak IMP occurred at a significantly longer muscle fiber length (low degree of arm abduction) during eccentric muscular activity compared to concentric activity. By applying the pennation angle theory, it is possible to predict high tensile forces of the supraspinatus tendon in these arm positions. Both the long moment arm and the low pennation angle, act in favor of force transmission from the supraspinatus muscle. The findings are relevant for biomechanical calculations and for training aspects of patients and athletes.

General discussion.

A. EMG, methodological considerations

In this work, both surface electrodes and intra muscular fine wire (FW) electrodes were used. There are advantages and disadvantages with both. In principle, it is possible to examine all muscles with the intramuscular technique, whereas deeper situated muscles are not suitable to examine with surface electrodes. For practical reasons and for minimizing the number of needle sticks the subject has to endure, a combination of the two electrode types is often necessary, if several muscles are to be investigated. In this work, both bipolar surface electrodes and unipolar FW electrodes were used.

Surface electrodes are used for superficially located muscles. Only the largest motor units are detectable at depths greater than 35 mm (Fuglevand et al 1992). Bipolar electrodes have a better ability to detect and eliminate electrical noise from the environment (Perry and Beckley 1981). The optimal interdetection spacing for bipolar electrodes has been reported in several studies (Jensen et al 1993, Lynn et al 1978). Basmaijan and deLuca (1985) recommended an interdetection spacing of 1 cm. Less space will entail that similar electrochemical events ocurring in the close-by muscle fibers, will be detected by both leads. These signals will thus be eliminated as they pass the differential amplifier, as the 60 HZ noise artifact is eliminated, and the amplitude of the signal will be reduced (Kelly et al 1997). Silver-silver chloride electrodes, which are considered to minimise motion artefacts produced by skin potentials (Webster 1984), where used in this work. These electrodes are thus useful in dynamic situations, as in studies IV and V. Surface electrodes record activity from the same depth and width, regardless of the size of the muscle. This means that if larger muscles are examined, the recorded activity represents a lower proportion of muscle fibers, than if smaller muscles were examined. In larger muscles, such as the trapezius and deltoid muscles, the EMG signal may not represent the activity of the whole muscle (Kamen and Caldwell 1996). As in study IV surface electrodes are preferred in view of the possible extrapolation to occupational studies, in which only this type of electrode can be used (Hermans and Spaepen 1997) .

The greatest advantage of intramuscular electrodes is the ability to reach deeper located muscles, e.g. the rotator cuff muscles. As in the case of surface electrodes, one limitation of FW electrodes is that the activity represents only a part of the muscle. It is probable that a greater part of the muscle activity is detected if a bipolar technique is used, but in this work on the shoulder, only relatively small muscles were investigated with the FW technique, and the judgement was that monopolar electrodes would be adequate. Kelly et al (1997) have shown that, if bipolar technique is to be used, two needle pricks for placement of each electrode pair are to be preferred rather than one. In this work a decision was made to limit the number of pricks as much as possible.

Placement of electrodes mostly followed the guidelines given by Basmaijan (1985). Jensen and coworkers (1993) recommended a position of electrodes 2 cm lateral of the midpoint between C7 and the lateral edge of the acromion, as a better point of measuring the upper trapezius muscle activity, than the so far mostly frequented midpoint. The amplitude will be reduced by 50% if electrodes are applied perpendicular rather than parallel to the muscle fibres (Vigreux et al 1979). Therefore, the latter method was chosen.

Several studies have shown that indwelling electrodes have lower test-retest reliability than surface electrodes (Komi et Buskirk 1970, Giroux et Lamogntagne 1990). Electrode placement is probably the greatest factor contributing to intersession fluctuation. Jonsson and Komi (1973) have shown that wire electrode migration is common during EMG studies, but is generally not greater than 1 to 2 mm. In this work, each subject was told to move the shoulder before the measurements started, thereby minimizing the possibility of electrode migration during the investigation.

In the present context we have chosen to normalize the EMG data for each electrode site and experimental session to the values recorded in a standardized reference position. Normalization faciliates the interpretation of data, since the effects of electrode position and individual variability are suppressed (Mathiassen et al 1996). The chosen reference position is estimated to correspond to 15-20 per cent of maximal voluntary effort in shoulder abduction; this makes it possible to judge if an experimental situation should be characterized as light, moderate or heavy, from an ergonomics point of view. However, individual factors such as physical fitness or obesity may influence the interpretation of results.

An alternative approach is to normalize to the EMG level recorded in maximal voluntary effort (Perry and Beckley 1981, Jonsson 1982). An attractive aspect in MVC normalization, is that the EMG levels may be interpreted in terms of muscle force exerted by the individual subject. However, there are several problems involved in the MVC approach. There is a large day to day variation (Sadomoto et al 1983), and a normalization based on only one MVC, differ to a large extent from the normalization values that are based on several MVC:s in different arm positions. The difference is caused by changes in the portion of the muscle within the viewing area of the electrodes, as well as changes in the length/tension relationship of the muscle with different joint angles, which would cause changes in the maximum EMG values (Mirka 1991). This makes in necessary to perform a complex calibration procedure at a series of external force outputs, in order to judge the relative muscle force produced accurately. It is also difficult to to be sure that it is the muscle being measured that is the one limiting the voluntary effort. Another problem is that it is difficult to motivate subjects to produce a truly maximal voluntary effort. The prime movement of the trapezius muscle is shoulder elevation, which is complcated to arrange for experimentally.

Since in the present context we were interested in relative effects only, we decided to use the reference contraction method. This choice expedited the experimental procedures greatly. It also meant that the subjects were less likely to be affected by any conceivably fatiguing muscle contractions.

Results of EMG measurements

In studies I and II, the effect of hand activity on the same four muscles were studied in the same arm positions. The results were similar in both intermittent and static manual exertion. In Table 1 and 2 the results from both studies are brought together.

Overall, the supraspinatus muscle was influenced the most by manual exertion. This muscle increased its activity significantly from and above 60° flexion. Previous studies showed that the supraspinatus is the most heavily loaded muscle in many working situations (Kadefors et al 1976, Malmqvist et al 1981, Herberts et al 1984). The localized muscle fatigue that occurs is accompanied by pain and motor decrement. Sigholm and coworkers (1984) have shown that the activity of the rotator cuff muscles vary with the magnitude of hand load.

In studies I and II the effect of hand activity on the infraspinatus muscle was less than on the supraspinatus. Only in the highest arm position and with a hand exertion of 50% MVC, was a significant increase noted in the infrapinatus. In arm abduction, the infraspinatus activity decreased significantly in two arm positions. Recent studies have shown a complex interaction in the stabilizing shoulder muscles (Perl et al 1992, Keating et al 1993), and that all rotator cuff muscles contribute to abduction (Sharkey et al 1994). The reason for the decreased infraspinatus activity, may be that an increased supraspinatus activity could relieve some load from this muscle. Otis and coworkers (1994) showed that both the infraspinatus and subscapularis muscles can contribute, not only to external and internal rotation, but also to elevation of the arm in the scapular plane. This could also explain the significant decrease in deltoid activity in the elevated arm positions. Sharkey and collaborators (1994) found, in a cadaveric study, that the deltoid force in lifting the arm was 41% less when the entire rotator cuff was activated, compared to when the deltoid was activited alone.

In studies I and II, the changes in the trapezius muscle were small, and thus no significant differences were found. This demonstrates that, although the EMG activity of the trapezius muscle often is regarded as a general measure on the shoulder load (Hagberg and Sundelin 1986, Öberg et al 1995, Capodaglio et al 1996), this is not always the case. Palmerud and coworkers (1995) showed that subjects, to a large extent, could voluntarily reduce the trapezius muscle activity, transferring the load to synergistic muscles, while keeping the same arm position. This result suggested that there is a central regulation of trapezius muscle tone. Hand exertion of 50% MVC influenced as expected the shoulder more than 30% MVC; this was especially the case in static hand activity.

It should be noted that the changes in EMG activity in studies I-III are percentual. This entails that, to get an apprehension of the absolute changes, one has to estimate to what degree that particular muscle is active, in a certain arm position. In the elevated arm positions, the supraspinatus activity is high even without hand exertion. In these arm positions, the percentual change in supraspinatus activity is considerable due to hand activity. The influence of manual activity in these arm positions should therefore have clinical and ergonomic implications. One can speculate that this potentially harmful influence on the supraspinatus muscle-tendon complex can either directly cause chronic tendinitis or contribute to this disease by acceleration of degenerative processes, that are very common in this tendon (Petersson 1984).

The results from study III, describing the effects of precision work on the shoulder, differ from the results of studies I and II, where the effects of more intense hand activity on the shoulder muscles were described. In the precision task, the activity was measured from six shoulder muscles, and in nearly all muscles and positions, the activity increased. Milerad and Ericson (1994), in a study on dentists, also showed an increase in shoulder muscle activity during dentist precision work. Regarding the influence on the shoulder, it seems that in the case of hand precision, the mechanisms involved are somewhat different compared to more intensive hand tasks. It is speculated that in the case of precision, a stress component leads to a general increase in muscle tension, and that this is superimposed on the physical load, as suggested by Lundberg et al (1994). These findings correlate well with those of Veiersted (1994), where a decreased capacity to relax the trapezius muscle was found to be a risk factor for developing trapezius myalgia. Styf and Körner (1987) suggested that pain may induce coactivation of agonistic and antagonistic muscle groups, thus resulting in an inability to relax the muscles. However, pain provoked by psychosocial stress factors may not be mediated through increased muscle activity (Vasseljen and Westgaard 1995:2). In their study, no correlation was found between perceived general muscle tension and the EMG recordings from the upper trapezius in the cases with shoulder disorders. They speculated that the feeling of general tension represents a physiological activation response, that may or may not include muscle fiber activation. It seems, however, that most evidence suggests that stress factors result in increased muscle tension, as was the case in study III.

In study IV, which was a field study, the trapezius activity was measured during 2 hour working sequences during ceiling fitting. In a study by Malmqvist and coworkers (1981) on building workers, shoulder muscle fatigue was especially marked in the supraspinatus, and also in the trapezius muscle. The conclusion was, however, that in work tasks that are executed with elevated arms, in a high percentage of time, EMG from the trapezius muscle can function as a measure on shoulder load relatively well. For practical reasons, the EMG investigation was therefore limited to the trapezius muscle, in the field study. The trapezius muscle activity during work, was related to the activity during a reference contraction, that entailed a fairly high shoulder load. More than 50% of work time was spent at muscle activity levels above the reference level. Less than 10% of work time was spent at muscle contraction levels lower than that of the reference contraction . Both these findings indicate a high shoulder load during work. We must however remember, that high load per se is not always harmful. The potential injurious effects of the load on the shoulder depends on factors such as the duration, frequency and magnitude of the load.

In evaluating these results from the field study, it is important to register, that the subjects performed their ordinary tasks during the whole measuring period. Ceiling fitting consists of several different tasks, among these railing fitting, drilling, cutting of roof plates and mounting these. The measuring period included also short periods for getting material and changes of work stations, but included not breaks for meals or rest. According to the subjects own opinions, they were not influenced in their work by the measuring equipment. It is suggested that the results reflects the work conditions during ordinary ceiling fitting.

In study V, the measurements from surface electrodes reflecting activity from the trapezius and the supraspinatus muscles, are used to measure shoulder load. This is in accordance with earlier studies that have shown marked signs of fatigue in these two muscles in building workers (Malmqvist et al 1981). The overall findings coincided with earlier studies which have shown that EMG activity is more pronounced during concentric than eccentric activity (Bigland and Woods 1974). The correlation between EMG activity and shoulder torque generation was low. One reason for this is that the shoulder is a complex and very mobile joint, engaging several different muscles that all influence the shoulder torque. Aratow et al (1993), found in a dynamic study on muscles in the lower leg, that IMP provided a better index of muscle contraction force than EMG. The correlation between IMP and torque in study V was however also low. This reflects the complexity of the shoulder in contrast to the simpler mechanisms of the flexors and extensors in the lower leg.

The result that the shoulder peak torque occurs at different joint angles of abduction, for concentric versus eccentric muscle activity, could suggest that the agonistic co-activation of other shoulder muscles differs between the two contraction modes.

B. IMP, methodological considerations.

Intramuscular pressure during isometric contraction is considered to be a measure of the force output from that muscle (Körner et al 1984, Sejersted et al 1984, Sjøgaard et al 1986). By measuring the pressure, the contribution of an individual muscle to the force generation over a joint can be assessed. In this work, IMP measurements were made during dynamic conditions. The subject moved his/her arm between 0° and 120° during two seconds. Therefore, one prerequisite for IMP measurements is good dynamic properties of the recording system, which is the case with the microcapillary infusion technique (Styf and Körner 1986, Crenshaw 1994). The rise-time, defined as the time it takes for the signal to pass from

10% to 90% of its final value, varies between 35 and 70 msec with this technique (Styf and Körner 1986). Noninfusion techniques have poor dynamic properties (Sejersted et al 1984, Styf et al 1989) and are not suitable for IMP recordings during exercise. The microcapillary infusion technique for IMP recordings during exercise, has been decribed and evaluated by Styf and Körner (1986). Järvholm and coworkers (1988a) applied the method for IMP measurements in the supraspinatus muscle and reported very high pressures during arm abduction. The advantages and disadvantages with different tecniques for IMP measurements during muscular activity have been described in a review article (Styf 1995). A teflon catheter with a diameter of 1.05 mm was inserted through a venflon introducer, as parallel to the muscle fibers as possible, in order to minimize the risk of distorsion during muscle contraction. Järvholm and coworkers (1988a) investigated the effects of different infusion rates on IMP at rest, as well as during contraction. They showed that IMP was not affected significantly by infusion rates between 0.2 and 3 ml/h, however higher infusion rates increased IMP. In another study a comparison was made between IMP measurements with and without infusion (Styf et al 1989) . The results suggested that infusion is not necessary during short term pressure recordings if catheters are flushed initially. However non-infusion catheters occluded if pressures were measured without infusion. In this work an infusion rate of 1.5 ml/h at rest was used to avoid clotting problems.

IMP depends on the location of the catheter within the muscle. Pressure is a function of the depth of the catheter within the muscle, and increases as the centrally lying tendon is approached (Nakhostine et al 1993). Catheters should be placed to a depth that will allow the muscle fibers to shorten 20% of their resting length, without hitting the tendon. Otherwise the catheter may be bent, which may create partial occlusion and decreased dynamic properties of the pressure recording system (Styf 1995). In this work, the catheter was placed in a standardized way deep in the middle part of the supraspinatus muscle belly. Jensen and colleagues (1995) have shown that the depth of the catheter in the muscle and the complex anatomy in the region, strongly influence the recorded IMP values. In their study, IMP measurements showed wide regional heterogenity at the same measuring depth during contractions, which they attributed to the complex anatomy found in the supraspinatus region. By placing the catheter parallel to the muscle fibers, the change in catheter depth would be minimized during contraction. Additionally, by allowing the subjects to perform arm movements before the start of the measurements, the dislocation during contraction was minimized.

Results of IMP measurements

Earlier studies (Järvholm 1988b) showed that arm elevation above 30° abduction increases IMP to levels that impede blood flow to the supraspinatus muscle. In this work, IMP increased with increasing arm level during concentric activity. Unexpectedly, the IMP during eccentric activity was highest at the end of contraction, when the arm was at low levels. One can only speculate as to the reason for this. The supraspinatus muscle is a rather small muscle, enclosed by a tight fascia (Jensen 1995). It is surrounded by several other shoulder muscles with agonistic action. There is limited knowledge regarding co-activation of agonistic shoulder muscles. In study V, it seemed that the agonistic activity was different during concentric and eccentric muscle contraction. It is probable that these specific circumstances concerning the supraspinatus muscle might have influenced the results. The finding that IMP is high at the end of eccentric activity suggests that the supraspinatus muscle is heavily loaded in this arm position. Thus, eccentric activity in low arm positions may be harmful to the shoulder. Pope and collaborators (1997) found, in a population based study regarding the influence of occupational factors on shoulder pain, that work which involved stretching down to reach below the knee level doubled the risk of shoulder pain . The results in study V offer an explanation to that finding. It seems that these results may have both clinical and pathophysiological relevance, and have implications for prophylactic measures and rehabilitation, as well as for training of athletes.

C. Measurements of position

The scapular plane was used in studies I and II. This plane is recommended by several authors for performing shoulder studies (Johnston 1937, Sapega and Kelley 1994) and also for post operative training (Hartsell and Forwell 1997) as this plane is more functionally relevant and less injurious to the rotator cuff. A subject, when asked to lift his/her arm, most often spontaneously moves the arm in this plane. In studies I to III, the position of the arm was maintained by the subject with the help of a guiding frame, positioned beside the subject. Previous to the study, a discussion took place whether to fix the arm in a locked position by some form of frame that would not allow the arm to change position. The fixed situation would probably influence the shoulder muscle activity, and therefore, this solution was abandoned. The ability of the subject to maintain the same arm position and to reposition their arm in an identical position, has been found to be fairly good (Peterson and Palmerud 1996). Small changes in arm position will not influence the results significantly. In studies I to III, only visual control was utilized for maintaining arm position.

In study IV, the Intometer instrument was used. This is a device that, by means of four pressure transducers and liquid-filled plastic tubes placed on the worker, can measure the position of both arms and the back of a subject (Bengtsson et al 1993). The position of the worker was related to reference positions at the start of the measurements. To secure the positions of the pressure transducers during work, reference positions were taken also at the end of the experiment.

In study V, the position of arm and speed of movement were controlled by a kinetic computerized ergonometer. The peak torque was reached at different joint angles during concentric and eccentric contraction. There are several reasons for this. Fitzpatrick and coworkers (1996) showed that the force production in working hand muscles is dependent upon the arterial perfusion pressure. Lifting the hand 45 cm above heart level produced a 22% decline in force output, while lowering the hand 45 cm below heart level caused an 8% increase in force output. These changes, which were greater if the work loads were higher, could thus explain a decrease in force output at higher arm levels. In study V, the peak torque was reached at 44° and 74° in concentric and eccentric muscle activity, respectively. Above those arm levels the torque fell. It seems reasonable to assume that above the heart level, the blood circulation to the arm and shoulder muscles is hampered, thus causing a decrease in force output. It is disputable whether or not this explanation is applicable during short contractions, as in this work. A biomechanical explanation to the decreased force at higher arm positions is also possible. In a position with the arm lowered, the moment arm for the supraspinatus muscle is long. While lifting the arm, the moment arm is shortened and the force output from the muscle is less. (Fig.11). It must however be realised, that the shoulder is very complex and several muscles with different moments arms are acting over the joint.

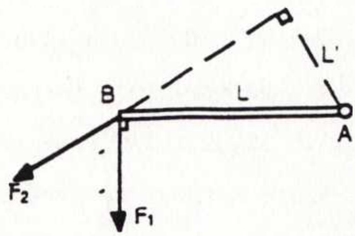


Fig. 11 The moment arm of the supraspinatus muscle in an elevated arm position (L´) compared to when the arm is in a low position (L). F_1 illustrates the tensile force from the muscle in the lowered arm position, and F_2 the tensile force when the arm is elevated.

D. Questionnaire

The correlation between the measurements of the positions of the arms and back, as done in study IV, and the results of the questionnaire concerning work postures, were not so good. The workers tended to over estimate the time spent in awkward positions. This finding is in accordance with the results of another study, where one conclusion was that the assessments in the questionnaire were not good for studying quantitative exposure-effect relationships (Viikari-Juntura et al 1996). They also found that the perception of musculoskeletal pain may bias the self-assessment of work load. Another important factor for the evaluation of results from a questionnaire, is the healthy worker effect. Workers with shoulder symptoms tend to change occupation and thereby distort the results of cross- sectional studies (Marcus and Gerr 1996). It is however important to realise, that the answers from a questionnaire, are to a large extent depending on how the questions are framed and asked, and that it is necessary with measurements to validate question formula and questionnaires.

E. Subjects

In this work no efforts were made to evaluate the results in view of different genders. Both sexes were included. Gender may,to some extent, influence the results. Some studies suggest that there is a difference between genders with respect to muscle morphology (Lindman et al 1991) and also to trapezius blood circulation (Larsson et al 1995). The difference between genders increases in dynamic compared to static exertions (Fothergill et al 1996). This may have some relevance in study V, where the exertion executed was dynamic. A possible gender effect should thus be stronger in study I (intermittent hand activity) as compared to study II (static). Muscle force is also lower in women (Mital and Sanghavi 1986). This could be explained by the smaller amount of muscle in women. It is shown that the force output of the quadriceps femoris muscle in the leg is correlated to the cross sectional area (CSA) of the muscle. There was, however, a lower force output in women even when the difference in CSA was accounted for (Kanehisa et al 1996). Women have a smaller hand size than men. It is shown that a relationship exists between hand size and hand strength (Kilbom et al 1993). Hand size may thus influence the results of the studies with hand held devices, as in study III.

Age is another factor of importance. In this work, the mean age of the participants was low (27 years in studies I and II, 32 years in III, 34 years in IV, and 38 years in V). Older people have a decreased peak torque, work and force (Gallagher et al 1996). In another study age was associated with a decrease in muscle strength but not in muscle endurance (Laforest et al 1990).

Lindström and colleagues (1997) have, in a study on knee extensors, shown that MVC and endurance level are significantly lower in older subjects. They conclude, however, that thigh muscles in older persons have, relative to their strength, similar properties as younger individuals with respect to muscle fatigue and endurance. Therefore it seems that the basic mechanisms are perhaps the same with different ages, but in view of the shoulder and the rotator cuff muscles, further studies need to be done to better clarify this assumption.

In the field study all workers were experienced, with a mean time of ten years in the profession. Thus the high muscular activity level during work, could not be explained by inexperience.

F. Future research

This and other studies (Viikari-Juntura et al 1996) showed that the results of questionnaires are unreliable. As a consequence, there is a need for better objective methods. There is also a need for better consensus about experimental methods and how to model the shoulder and the complex muscle activity (Buckley et al 1996) in order to make comparisons of results easier and more reliable. Vasseljen (1995) suggested that arm and trunk posture recordings have insufficient sensitivity to indicate risk for shoulder and neck complaints, at least in work with low to moderate biomechanical demands. Low correlation was found between postural recordings and upper trapezius muscle activity. Mathiassen (1993) found that the perception of muscular fatigue did not monitor other physiological parameters of ergonomic importance. These results suggest that, in order to to acquire a more representative measurement, as many factors should be analyzed in parallel as possible, e.g. muscle activity (EMG, IMP) and positions, as well as different physiological parameters.

The effects of work and work pauses have been examined in some studies (Sundelin and Hagberg 1989, Byström et al 1991, Mathiassen and Winkel 1996). Further studies to map the time necessary for the muscles to recover from different types of work and in different work postures, are of interest. The importance of training (a comparison between experienced and unexperienced workers) could also be of interest. Differences in muscle fatigue between trained and untrained welders have previously been demonstrated (Kadefors et al 1976). Training causes an increase in muscle endurance (Laforest et al 1990). Earlier studies have shown that dynamic muscle activity does not protect the shoulder muscles against fatigue in repetitive work as compared to static (Sundelin 1992).

The incidence and prevalence of shoulder tendinitis is not known, although it is a common clinical problem. There is a need for population based studies of tendinitis. Petersson (1984) has shown a high prevalence of tendinitis in elderly people. Many of these are, however, symptom free.

G. Conclusions

Our hypotheses were found to be true and the following conlcusions are well founded:

1. During an experimental work situation, hand activity resulted in an increased shoulder muscle activity, of which the supraspinatus muscle was affected the most.
2. During an experimental work situation, hand activity increased the supraspinatus muscle activity, in the more elevated arm positions.
3. Static and dynamic hand activity increased, during an experimental work situation, shoulder muscle activity in a similar way. Hand activity, with a high intensity, increased supraspinatus activity however more in the static situation, than in the dynamic. Precision hand activity increased the activity of all shoulder muscles.
4. Construction workers had, during ceiling fitting, their arms elevated more than 30° for longer than 50% of the investigated working sequence. The correlation of the measurements to the workers own estimation of work postures was low.
5. The exposure patterns of construction workers were mapped by video, questionnaire, protocol, and measurements of positions and muscular activity during work. During ceiling fitting tasks, the muscle activity from the trapezius, as an indicator of shoulder load, was high. Less than 10% of the work sequence was spent with muscles at rest level.
6. In an experimental situation, concentric shoulder muscle activity induced high pressures in the supraspinatus muscle, in elevated arm positions. Eccentric activity induced high levels of IMP, in the lower arm positions. Torque values were lower during concentric compared to eccentric muscular activity. The correlation between pressure in the supraspinatus muscle and surface EMG, from the trapezius and supraspinatus muscles, was high during concentric activity.

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