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Roland Kadefors
National Institute for Working Life, Göteborg, Sweden

Static workload in the extreme
A review of musculoskeletal disorders in manual welders, and an evaluation model for welding work

1 Introduction

1.1 Background

The work relatedness of musculoskeletal disorders has been subject to much scientific study. It has been estimated that approximately 2,500 scientific papers relevant to the subject have been published (National Research Council/Institute of Medicine 2001). There are several reasons for this high level of interest. The conditions are prevalent; on the other hand, the nature of many of the types of disorders is complex. They occur in occupational groups as well as in the general population; age, gender and individual disposition are common confounders; and the mechanisms are not well understood. There is controversy around these issues. However, there is general agreement that certain conditions in physical work exposure stand out as posing particularly high risks for a variety of disorders in different parts of the musculoskeletal system. Such situations include (NRC/IOM 2001) awkward working positions, high force demands, high repetitivity, and exposure to vibration.

From the point of view of physical strain at the workplace, it is of note that exposure to static work does not manifest itself in these and other surveys as a major cause behind the development of work related musculoskeletal disorders. Nevertheless, static workload is considered ergonomically unsound. It is accompanied by fatigue, pain, and tremor and impaired motor performance (Laurig 1970). It is one of the conditions that have been in focus in the development of the international ergonomics standards within the ISO and CEN efforts (e.g., ISO 11226 ”Ergonomics – evaluation of static working postures“ and EN 1005-4 ”Evaluation of working postures and movements in relation to machinery“); still the linkage to workers´ health is weak. The driving force behind the interest of the standardisation bodies with respect to limiting static workload seems to be to avoid fatigue and support performance rather than to secure health at the workplace.

Taking into account this general background, it is of interest to study the musculoskeletal health of occupational groups with particularly high exposure to static work. For this purpose, manual welding provides a good model. The aim of this paper is to review scientific literature providing information on the pattern of musculoskeletal disorders in welders, and to discuss the implications following the presentation of evidence. The hypothesis is that welders run a higher risk to acquire musculoskeletal disorders due to high static workload than do other workers, where the exposure is characterised as being more dynamic, but still at high physical effort.

1.2 Manual welding

Welding technologies are commonly employed in construction and metal manufacturing industry. Even though robotisation has taken over much of the traditional unqualified stereotype welding production, manual welding remains an essential activity in many companies (Boekholt 2002). It engages a large number of personnel in the industrialised world; for instance in Germany alone, it is estimated that approximately 400.000 persons work full or part time in manual welding operations (Deutscher Verband für Schweissen und verwandte Verfahren, quoted by Zschiesche 2005).

To become a qualified welder requires years of training. The quality demands are extremely high in many types of production, e.g., in welding of pressure vessels or gas containers. From an operational point of view, welding is characterised by high precision demands with respect to positioning of the tip of the welding electrode in relation to the joint of the work piece. Depending on the welding method, the welding torch plus cable may weigh between 1.0 (TIG, Tungsten Inert Gas welding) and 4.0-7.0 kg or even more (MIG, Metal Inert Gas welding, flux core welding). In stick welding (MMA, Manual Metal Arc welding,) which still constitutes a majority of manual welding work, melting of an electrode takes about 1.5 minutes, then some changing of welding rod, rinsing, and inspection, all dynamic work at rather low muscular effort, takes place. In the case of semi-automatic welding (MIG/MAG), the electrode wire is fed continuously though the torch, which means that there is technical provision for continuing welding for as long as required production wise. This may mean several minutes of uninterrupted static hand and arm positioning. For a professional welder, arc time per day (the effective time of daily exposure to static work) is usually less than 25% of a working shift, corresponding to two hours per day (Boekholt 2002).

Semmer (1976) has shown that the physical load on the circulatory system in welders is moderate, albeit differs somewhat between welding methods. It is localised muscular effort rather than general physical workload that poses the main problem from an ergonomics point of view.

Lowe et al. (2001) studied localised muscle fatigue and pain/discomfort in seven trunk and upper extremity muscles of ship-yard welders carrying out welding in confined spaces. It was found that there were more fatigue effects in shoulder muscles in stick electrode welding compared to flux-core arc welding. It was estimated that the welding operations required an exertion level of 25-35% of maximal voluntary contraction, entailing an endurance of 2-3 minutes.

Welding may take place in a variety of postures, ranging from welding downhand in optimal working zone, to welding overhead, kneeling or squatted. However, irrespective of posture, the high precision demands requires postural stabilisation, particularly of the hand and arm, which means that the stabilising muscles of the shoulder are active to a high degree for as long as the welding task continues (Sporrong et al. 1998).

2 Musculoskeletal disorders and complaints in welders

2.1 Epidemiological studies

In The Work Environment 2001 (Annual Report, Swedish Official Statistics), "welders and flame cutters" stand out in terms of heavy exposure and health effects in several respects. For instance, welding constituted one of the 20 occupations where more than half the population reported being "worn out after work" (54%). High prevalence of pain in the musculoskeletal system every week was reported:

- Lower extremity: 38.3%
- Upper back: 29.1%
- Lower back: 18.5%
- Shoulder and arm: 37.0%
- Wrist: 23.9%.

These figures were significantly higher than what was found in the general male working population, with the exception of the upper and lower back, where about the same prevalence was found also in the general population.

In terms of exposure to physical load, welding rated number 8 of all occupations reporting exposure to heavy lifting daily of materials weighing 15 kg or more (39%). Flexed or twisted postures were reported by 49% of the welders (rating 9 of all occupations), whereas 40% of them reported work with the hands at or above shoulder level (rating 7).

This statistical overview indicates that it is primarily in the extremities and in the shoulder that welders report musculoskeletal pain to a higher degree than do workers in general. This observation agrees with the results of the literature review to follow.

Based on questionnaire data, Torell et al. (1988) reported on the 12-month prevalence rate of complaints from the musculoskeletal system in a group of 79 welders, compared with control groups of platers and hull fitters. It was found that musculoskeletal disorders were common in all three groups, but that welders had significantly higher prevalence of problems in the shoulder and neck than had the controls. The prevalence rates were (controls in brackets), neck 59(36,41)%; shoulder 58(40,39)%; elbow 22(20,33)%; knees 53(54,46)%; back 69(65,76)%. It should be noted that also the platers and hull fitters did carry out some welding work, although only to a limited extent.

In the Swedish national register of occupational accidents (the ISA system) also occupational diseases are included. For each occupation, relative risk was calculated for men and women separately (Report of the Health Risk Study Group to the Swedish Commission of Working Conditions, 1990). Among women, female welders rated 5 among all types of work. Male welders had rating 17. There was an overrisk among male and female welders concerning disease in the musculoskeletal system generally. Specifically, male welders had overrisks in the neck (rating 8), back (rating 17), and shoulder/arm (rating 15). Female welders had rating 7, 8, and 9, respectively, also indicating significant overrisks.

In a retrospective cohort study in 550 Dutch shipyard welders, Wanders et al. (1992) reported on the medical wastage in comparison with control groups of shipwrights and engine fitters. It was found that the welders left their job with a disability pension 20 % more often than did the controls. The most common medical diagnoses centered on respiratory, cardiovascular, musculoskeletal and mental disorders. With respect to permanent disability due to disorders in the musculoskeletal system, this study did not demonstrate an overall overrisk for welders compared to controls (90% confidence interval 0.9-1.5). Nevertheless, the contribution of musculoskeletal diseases to the total amount of medical wastage was high: about 20% in both welders and controls.

With respect to prevalence of symptoms in the hand, Hagberg et al. (1990) reported on a questionnaire study, comparing various occupational groups, including welders, to a reference group of engineers. The relative risks for various symptoms were calculated. It was found that welders had a relative risk (RR=10) for numbness, wrist pain, and finger pain. They also had a high relative risk for general weakness in the handgrip.

Burdorf et al. (1998) studied the prognostic value of pain in the musculoskeletal system in welders with respect to sickness absence the following year, and found that those experiencing symptoms of this kind had a higher risk of subsequent sickness. They reported that neck or shoulder pain and pain of the upper extremities contributed significantly to neck and shoulder absence (relative risk RR=3.35, confidence interval 1.73-6.47), and to upper extremity absence (RR=2.29, confidence interval 1.17-4.46).

With respect to neck pain, Eklund and Gunnarsson (1992) referring to ISA statistics, reported that welders had a relative risk RR=2 to acquire neck injuries. They identified dynamic biomechanical loading due to visors as a major cause behind this type of pain.

2.2 The clinical pattern

In a clinical and experimental investigation of tendonitis of shoulder muscles (Hagberg and Wegman 1987), it was found that high relative risk (RR=10) was present in three categories of workers: shipyard welders, plate workers and pooled groups with work above shoulder level.

Herberts et al (1976) found in a clinical-epidemiological study of 131 shipyard welders that there was a prevalence rate of 18% of supraspinatus tendonitis, a non-bacteriological inflammatory reaction in the shoulder rotator cuff. This was significantly higher than in a group of white-collar controls, but the prevalence of this disorder did not differ significantly from that of shipyard plate workers (again, the platers also carried out some welding work). However, the welders were significantly younger when they acquired the disease (Herberts et al. 1981). It was concluded that welding work accelerates the inflammatory process. It was further demonstrated that the supraspinatus muscle was particularly strained in welding work at or above shoulder level (Kadefors et al. 1976; Herberts et al. 1984; Järvholm 1990).

The high prevalence rate of musculoskeletal symptoms among welders was further emphasized in a clinical-epidemiological study of a group of 58 welders by Törner et al. (1991). All subjects investigated had clinical aberrations in the musculoskeletal system. Symptoms in the last seven days included 38% from the neck, 42% from the shoulder, 40% from the low back, and 20% from the knees. Diagnoses that were more significantly common in the welders than in the control groups (fishermen and clerks) included shoulder muscle atrophy (mm. supraspinatus and infraspinatus), and contractures in the hand (Dupuytren's disease). The static load on the shoulder in the welders was suggested as a probable cause behind the differences in the shoulder disease pattern in welders and fishermen.

Nauwald reported (1980) on a clinical investigation of knee-joint changes in 120 ship-yard welders. He found a high prevalence of pathological abnormalities. In this group, 69% had spontaneous pain in the knees. The pain was in most cases load-dependent. There was a clear tendency towards an increased prevalence in welders above the age of 45. Patella and bursa syndromes were the most common diagnoses. Exposure to kneeling work was identified as a major cause behind the problems.

3 Discussion and conclusions

3.1 The risk pattern

The number of scientific studies on work-related musculoskeletal disorders in welders is limited. The studies are of different design and quality. However, a critical look at the evidence available with respect to musculoskeletal complaints and disorders in welders gives rise to the following conclusions:

(a) musculoskeletal symptoms are prevalent in welders;
(b) welding work entails an increased risk for shoulder pain mainly due to inflammatory reactions in the rotator cuff;
(c) the occasional findings of disorders in the neck, the hand, the low back or the lower extremities warrant further study.

Based on these observations, a discussion on work-relatedness of musculoskeletal disorders in welders should focus on shoulder disorders in the first place. Table 1 summarises the papers providing data on shoulder disorders in welders.

3.2 Physiological considerations

There is reason to assume that it is the static character of the work that presents the elevated risk. It was emphasised above that welding requires a high degree of postural stabilisation, which makes the load on the rotator cuff muscles significant already at moderately elevated arms and low level of hand load.

It is of note that the clinical aberrations identified in the studies reported in welders do not affect the muscles themselves, but rather associated tissues, in particular tendons. This pattern is in contrast to the nature of shoulder and neck disorders found in subjects exposed to say, light assembly or computer work. Here exposures often result in diagnoses such as myalgia or tension neck syndrome, affecting muscle tissue (Juul-Christensen et al. 2005). Even though the background to such ailments is complex in these occupational groups, a prevailing model for the aetiology of muscular pain is based on metabolic crisis and

Table 1: Epidemiological and clinical studies of shoulder disorders in welders

Author(s) and year	Character	Subjects	Control group	Main findings
Herberts et al. (1981)	Clinical and epidemiological study	Shipyard welders	Platers	Supraspinatus tendonitis, prevalence n.s. Welder cases significantly younger than control cases
Hagberg and Wegman (1987)	Clinical and epidemiological study	Welders	Mixed working population	RR 10 shoulder tendinitis in welders
Torell et al. (1988)	Cross-sectional questionnaire study	Shipyard welders	Platers and hull fitters	Higher prevalence of shoulder and neck complaints in welders
Törner et al. (1991)	Clinical and epidemiological study	Licensed welders	Fishermen	Shoulder muscle atrophy significantly more common in welders
Wanders (1992)	Retrospective cohort wastage study	Shipyard welders	Shipwrights and engine fitters	20% overrisk in welders for premature pension
Burdorf et al. (1998)	Epidemiological prospective study	Oil and offshore welders	Metal workers	Prevalence of shoulder and neck pain, slightly higher in welders but not significant (p=0.07)

necrosis of low-threshold motor-units (Sjøgaard et al. 2002). This type of diagnoses has not been reported widely in welder populations.

Tendonitis does not occur only as a result of exposure to static work: for instance, hand intense work may cause inflammatory reactions in the finger tendons (e.g., Putz-Anderson 1988). However, in the shoulder, due to the anatomical conditions both force induced wear and compartment pressure mechanisms are present. From the point of view of static workload, ischemia due to high intramuscular pressure (IMP) may be the most significant aspect in the present context, since it has clinical as well as ergonomic projections. It has been shown (Järvholm et al. 1988) that at intramuscular pressures exceeding approximately 40 mmHg (5.3 kPa) the blood supply is arrested, and at approximately 20 mmHg recovery from fatigue is severely impaired. These levels of pressure are attained at different contraction levels, depending on the anatomy of the muscle (Järvholm et al. 1991). In the supraspinatus compartment, the blood supply to a poorly vascularised zone of the tendon is affected. It has been suggested that static work (e.g., welding) in the long run initiates inflammatory processes in the compartments of the rotator cuff, causing tissue swelling, necrosis and pain. It should be noted that welding is most commonly carried out without arm support, which means that continuous activation is needed in postural muscles and in muscles in the shoulder and arm. In the shoulder, the rotator cuff muscles are activated as soon as the arm is lifted, but the activity increases as the hand is elevated.

Based on the IMP model, it is possible to define under what conditions intramuscular pressure levels exceeding 40 mmHg occur in the shoulder muscle complex. Palmerud et al. (2000) have demonstrated that humeral flexion/extension, elbow flexion and hand load influence the IMP of shoulder muscles. They have shown under what conditions an IMP exceeding 40 mmHg can be avoided in the major shoulder muscles. This in fact may give rise to recommendations as to acceptable postures and hand loads in static work engaging the shoulder. We shall come back to this provision here in a following paragraph.

3.3 Ergonomic considerations

The recommendations in ergonomics literature to limit exposure to static work are based on physiological and psychophysical considerations. As emphasised in a previous paragraph, static muscle contractions at high effort cause sensation of fatigue and pain; they limit endurance and they impair motor performance. Localised muscle fatigue manifests itself at the electrophysiological level in the amplitude and the frequency domains (Laurig 1967). In the pioneering works by Rohmert (1960) it was shown in skeletal muscle that muscular activation exceeding approximately 15% of maximal voluntary effort limited endurance, and that the relation between endurance time and activation level was exponential. Keeping a constant force at 50% of maximal effort may be sustained for only a couple of minutes, whereas introduction of pauses extends endurance significantly (Laurig 1981).

In ergonomics, it is not considered good practise to let workers be exposed to exhaustion. Regulatory instruments, standards and guidelines take into account also psychophysical reactions to exposure. For instance, the so-called NIOSH Guideline for Manual Lifting (Waters et al. 1993), which focuses on prevention of low back pain, is in part based on acceptability of test subjects to different provocations (postures, load mass, repetition). Ratings according to the Borg CR-10 scale (Borg 1982) have also been applied in a similar context. For instance, it has been suggested that exposure to static work should not exceed 20% of the endurance time, this in order to avoid CR-10 ratings exceeding 5 ”strong discomfort“ (Dul et al. 1993).

In the following paragraphs, different sources of scientific evidence are put together to form a basis for recommendation of good practise in the design of manual welding work in order to alleviate the risk for evoking shoulder complaints and disorders in this occupational group.

3.4 An evaluation model for static work

The mechanisms behind musculoskeletal disorders in general, and shoulder-neck complaints in particular, are multidimensional. Posture plays an important role. Force and handling of objects are influential, as well as exposure time. However, it is not sufficient to consider only one of these factors at a time. For instance, an awkward static posture may be acceptable if it occurs once a day only, but not acceptable if it is combined with force development and occurs regularly during a working shift. Attempts have been made to devise models for development of musculoskeletal disorders, built on the three dimensions of posture, force, and time (Kumar 1994, Tanaka & McGlothlin 1993). Based on this conceptual framework and on previous developments in consumer technologies, the so-called Cube Model was introduced (Kadefors et al. 1994). This model, which sets out to operationalise ergonomic knowledge, is applied and further developed here for the specific purpose of welding work evaluation and design.

In the context of the Cube Model, for each one of the three basic dimensions of a cube, *force, posture* and *time*, *low demands, medium demands* or *high demands* may be defined. The criteria for choosing demand levels are in the model arbitrary, but it is essential that they be chosen so as to make possible to discriminate between acceptable and unacceptable work tasks from an ergonomics point of view. The criteria should reflect the user group concerned. Here the demand criteria are based on a mixed user group.

In principle, criteria setting in the cube model are based on published scientific evidence. This may mean direct reference to individual reports, or to scientific review studies. Also ergonomics standards developed within CEN and ISO may be applied whenever considered adequate. In the present context, it was decided to base the treatise on the evaluation model of work-related physical strain presented by Vink and Dul (1994). This source contains data on combinations of posture, handled mass, and time concurrently. The approach is relevant to the present focus (shoulder strain), and the situations covered are relevant to evaluation of welding work. However, the Vink model identifies only Acceptable and Conditionally Acceptable situations, adding plainly that "weight of more than 4 kg working in unsupported extreme joint deviations for longer than 30 minutes are always unsafe". For the purpose of qualifying this statement, also the intramuscular pressure criterion (40 mmHg) according to Palmerud et al. (2000) is applied.

In the present context, force development relates chiefly to handled mass. The criteria applied in Table 2(a) are drawn from Vink and Dul (1994). With respect to posture (Table 2(b)), the demand criteria according to Vink and Dul (1994) have been further developed to account for shoulder strain. The criteria angles in Table 2(b) have been drawn from the European standard, EN 1005-4. The time demand criteria presented in Table 2(c) are according to Vink and Dul (1994). They assume a work-rest quotient per cycle >1, which is the usual case in manual welding (Lowe et al. 2001).

In the model, each one of the 27 subcubes represents a combination of demands in the three dimensions. For each one of the subcubes it is possible to establish a *level of acceptability*. It has been found useful to define three levels according to the classification as applied in the ergonomics standardization documents (e.g., EN-1005-4):

a *Acceptable (A)*. – The health risk is considered low or negligible for nearly all healthy adults. No action is needed.

b *Conditionally Acceptable (CA)*. – There exists an increased health risk for the whole part of the user population. The risk shall be analysed together with contributing risk factors, followed as soon as possible by a reduction of the risks, i.e., redesign or if that is not possible, other suitable measures shall be taken.

c *Not Acceptable (NA)*. The health risk cannot be accepted for any part of the user population.

Table 2(a): Demand criteria: force (handled mass)

Demand level	Criteria	Comments
Low force demands	<1.0 kg at one handed lift	Relevant to TIG welding
Medium force demands	Between low and high demands	Normal range for welding operations
High force demands	>4 kg at one handed lift	Relevant to heavy current welding

Table 2(b): Demand criteria: posture

Demand level	Criteria	Comments
Low posture demands	Work with the hand in optimal zone (waist level, close to the body). Joints in neutral position. Upper arm flexed or abducted < 15º.	Normal in welding on small objects
Medium posture demands	In reach situations, with the upper arm flexed or abducted between 15º and 60º.	Occurs in all types of welding on medium size or large objects
High posture demands	Work with the hand above shoulder level or upper arm flexed or abducted > 60º.	Occurs in welding on large objects (e.g., containers, constructions, ship-yards)

Table 2(c): Demand criteria: time of exposure

Demand level	Criteria	Comments
Low time demands	< 30 minutes per day	Occurs when welding is interrupted by other activities
Medium time demands	Between 30 minutes and 4 hours per day	This range covers the majority of welding operations
High time demands	> 4 hours per day	May occur in extreme situations

Figure 1 shows the Cube Model adapted for evaluation of manual welding.

It should be emphasized again that the present model, albeit thoroughly reasonable and relevant to the scope of the paper, are based on pieces of scientific evidence only. It is to be expected that the acceptability settings will be qualified as more scientific studies be invoked. It should be noted that a large portion of the most relevant scientific literature considers force demands from the point of view of individual capacity (e.g., Rohmert 1960). However, the practitioner is seldom in a position so as to be able to estimate the force capacity in an individual welder, whereas he may well be able to judge weights of equipment, and evaluate postures and time regimes.

Welding industry should take note of the scientific substance available in order to reduce the risk of manual

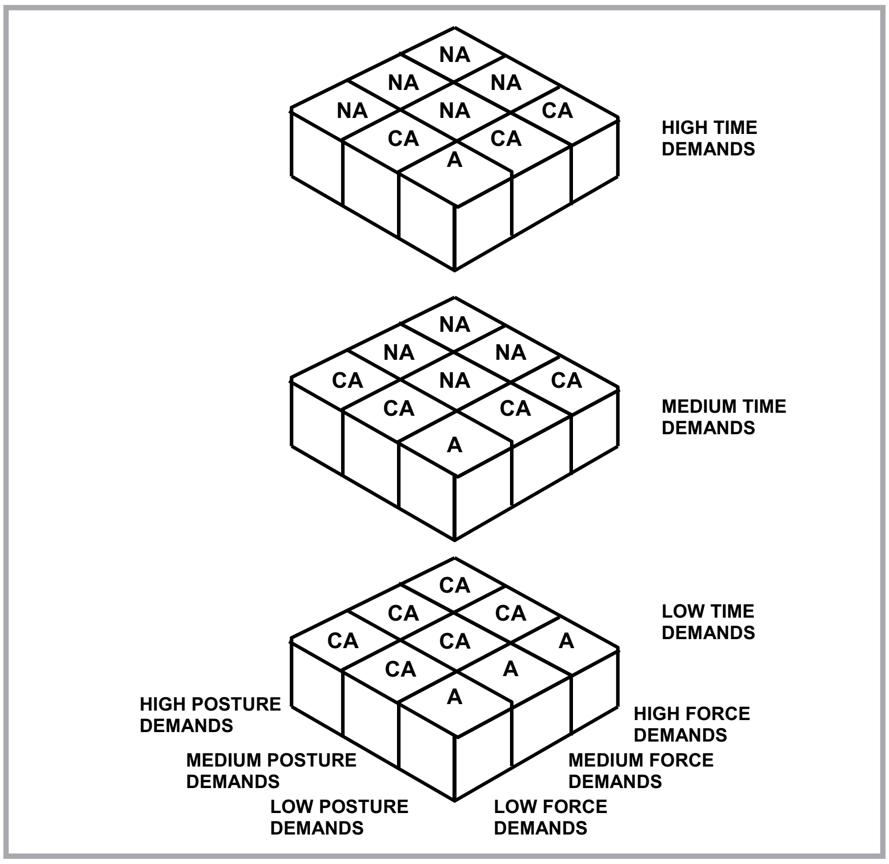

Figure 1: The Cube Model, adapted for manual welding. A = Acceptable; CA = Conditionally Acceptable; NA = Not Acceptable.

welders to acquire chronic shoulder pain as a result of sustained exposures to welding work in awkward positions. As always in ergonomics interventions, what is needed is a combination of technical and organisational measures. It has been shown (Kadefors 1997) that it is possible to design welding workplaces that will help reduce not only physical exposure, but provide integrated solutions alleviating the influence of a number of physical and chemical stressors. Organisational measures include giving room for competence development, enrichment and variation of the welder's work.

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Anschrift des Verfassers
Roland Kadefors Ph. D.
National Institute for Working Life
Box 8850
SE-402 72 Göteborg
E-Mail: roland.kadefors@arbetslivsinstitutet.se