Journal of Sound and Vibration (1998) 215(4), 965–976
Article No. sv981677

A REVIEW OF THE BIOMECHANICS AND EPIDEMIOLOGY OF WORKING POSTURES
(IT ISN'T ALWAYS VIBRATION WHICH IS TO BLAME!)

M. L. MAGNUSSON
Iowa Spine Research Center, The University of Iowa, Iowa City, IA 52242-1088, USA
AND
M. H. POPE
Iowa Spine Research Center, The University of Iowa, Iowa City, IA 52242-1088, USA

(*Accepted 7 April* 1998)

Many vibrational environments also subject the worker to awkward, asymmetric and prolonged postures. This paper reviews the epidemiological, biomechanical and physiological factors involved in working postures which could lead to musculoskeletal problems. Too little or too much sitting leads to low back pain. Sedentary postures, including driving, also lead to a higher risk of a herniated disc. In sitting the pelvis rotates and higher pressures exist in the disk. A backrest inclined to 110° or more and with a lumbar support will reduce the disk pressure. Jobs involving excessive force application will be more apt to cause muscular and ligamentous damage. However, these excessive demands can occur in whole body vibration environments too. Neck, shoulder and arm problems are usually related to posture but can occur in WBV environments. Knee problems, in the standing worker, may be due to a flexed knee posture in an attempt to attenuate vibrations. Excessive postural demands on the neck, shoulder and arm will lead to higher muscle forces and higher joint forces. Recommendations are given to reduce risk of disability.

1. INTRODUCTION

There is no single posture that can be comfortably maintained for long periods of time. Any prolonged posture will lead to static loading of the muscles and joint tissues and, consequently, can cause discomfort. The human being's natural behaviour is to change posture often. Even during sleep, there is a need for posture adjustments. At the workplace, standing and sitting are the two basic forms of postures. These two postures have their specific advantages and disadvantages for mobility, exertion of force, energy consumption, circulatory demands, coordination, and motion control. Workers who are in a WBV environment are often also subjected to postural stress, whether they are seated or standing. In this paper we will deal with the epidemiology and biomechanical studies of musculoskeletal problems associated with the workplace.

2. EPIDEMIOLOGY

2.1. THE LUMBAR SPINE

Magora found that both too much and too little sitting or standing were related to a high incidence of low back pain (LBP) [1]. An increased risk of prolapsed lumbar disk has been reported among persons who have had sedentary occupations for several years [2].

0022–460X/98/340965 + 12 $30.00/0

Some studies on the epidemiology of low back pain, unspecific for diagnoses, have found that both sedentary occupations and occupations with very heavy loading increase the risk for low back pain [3, 4]. This paradox may be explained by prolapsed disks being related to sedentary occupations, or prolonged driving, while other disorders, such as muscle strain and ligamentous injury, are associated with heavy work. In fact, jobs involving manual materials handling have been reported not to be associated with an increased risk of prolapsed disk. This may be due to the fact that lumbar disks are very resistant to compressive loads and that such loads can fracture the vertebral endplate before causing damage to the disk [5]. Muscle strain and ligamentous injury can also occur in WBV environments (i.e., the construction worker operating in an asymmetric posture, at the controls of a bulldozer).

Several studies, most of which are retrospective, have indicated an increased risk for back pain in people with predominantly seated working postures [1, 6–9]. They also show that prolonged sitting aggravates back pain in people with ongoing symptoms. There seems to be an increased risk of low back problems from prolonged sitting in a vibrational environment, such as the professional driving of vehicles [10]. Kelsey and Hardy, in an epidemiologic survey, stated the evidence that driving of motor vehicles increases the risk of prolapsed lumbar disks [11]. They suggest the combination of vibration and prolonged sitting, with little freedom to change posture, as plausible causative factors. Bent-over postures seem to carry an increased risk for low back pain [8, 12]. Frymoyer *et al.* found both bending and twisting to be significantly related to low back pain [13]. Both can be involved in certain jobs involving driving.

2.2. THE NECK, SHOULDER AND ARM

In most epidemiological studies on neck and shoulder pain, the exposure has been defined by job title rather than job characteristics, such as an objectively quantified load or a detailed description of working postures, arm and head movements, materials handled, and work organization. This makes epidemiological studies difficult to interpret.

In the only study that specifically addressed the relationship between musculoskeletal pain in the upper extremities and working posture, nearly 40% of the patients visiting the occupational health clinic were diagnosed with a non-traumatic musculoskeletal disorder [14]. Almost 70% of the patients with shoulder pain stated that they worked with their hands at or above shoulder level.

Hagberg and Wegman, in a metaanalysis, found significant odds ratios above 1·0 for cervical spondylosis in meat carriers, dentists, miners, and heavy workers, suggesting high loading on the cervical spine as the causal exposure [15]. Extreme forward flextion of the cervical spine was suggested as the causative factor for cervical syndrome in civil servants [16]. The assumed causative factor for tension neck syndrome is static contraction of the neck and shoulder muscles to counteract the weight of the head [17]. Thus, the greater the angle of the neck flexion, the greater the load in the muscles and joints. A high odds ratio was found in keyboard operators, which may reflect the exposure of a static load on the upper trapezius muscle as measured by EMG [18]. Neck and shoulder pain was found, in conjunction with LBP, in a study of bus and lorry drivers by Magnusson *et al.* [19]. A significantly higher frequency of cervical spine disorders based on clinical examination was found in forest machine operators [20] and in tractor drivers [21]. An increased number of radiologically defined pathological changes in railway operators was found in one study [22]. Johanning compared subway operators with switch board operators in the subway and found that drivers more often reported neck problems than the switch board operators [23]. This indicates that the combination of vibration and posture is an important factor as both groups had similar vibration exposure.

In a study that included machine operators, carpenters, and office workers, it was found that working in twisted or bent postures increased the occurrence of neck and shoulder symptoms, an association that was most evident for machine operators [24].

Many studies suggest shoulder muscle "overload" as being the major cause for the increasing incidence of "occupational" shoulder pain [25–29]. A clear relationship between exposure groups and chronic tendinitis has been demonstrated in three studies [14, 27, 30]. One of the common exposure factors was long periods of time with the arm in an abducted or flexed position. Burt *et al.* found an 11% prevalence of shoulder symptoms in newspaper employees, and the symptoms were associated with the amount of time spent typing at computer terminals. This was thought of as time spent in a static sitting posture with arms unsupported [31]. Note that many driving environments do not offer support to the arms. Hagberg and Wegman demonstrated an association between elevated work heights and prevalence of rotator cuff tendinitis and found an Odds Ratio (OR) of 11 for work at shoulder height compared with work below that level [15].

Awkward postures of the wrist, for example, working with the wrist not straight, repetitive forceful work, and vibration, are risk factors for cumulative trauma disorders affecting the wrist [32].

2.3. HIP AND KNEE

Work that involves much loaded knee bending carries an increased risk for osteoarthritis of the knee, OR 2.2, [33] and there is a 2–3 times greater risk for male shipyard workers, farmers, construction workers, and firemen [12, 34, 35, 36]. There seems to be a clear increased risk for developing osteoarthrosis of the hip among farmers; the relative risk ranging from 9·7 to 12·4 in different studies [37, 38]. Severe osteoarthrosis is associated with prolonged standing at work and heavy lifting. The relative risk for disability pensions because of osteoarthritis of the hip in men over 59 years was 12·4 (6·7–23·0) for those with high exposure to physical load compared to those with low exposure [39].

In the standing posture, when subjected to WBV, the subject will usually adopt a flexed knee stance to attenuate the vibrations [40]. This will result in higher contact stresses in the knee, particularly the patellofemoral joint. Although some attenuation occurs in the knee in an extended posture, significant vibration amplitudes are measureable at the hip [41].

3. STUDIES OF POSTURAL STRESS ON THE MUSCULO-SKELETAL SYSTEM

The seated posture is determined by both the design of the seat and the task to be performed. The height and inclination of the seat, the position and shape of the backrest, and the presence of armrests influence the seated posture. Since all postures become uncomfortable and may be a risk factor for LBP if maintained too long, the chair should permit alterations in posture [42]. A "semi-sitting" posture is often desirable to facilitate changes between standing and sitting when performing different tasks. The authors have encountered this posture in many bench work jobs. However, a bent forward position is a common seated working position, adopted by many drivers and even required in some (i.e. helicopter pilots). It is also seen when desk work is being performed and in light mechanical work that demands high precision, such as dentistry, jewelry, and watchmaking. Leaning backwards positions are preferred at rest but also in such tasks as car driving.

3.1. THE LUMBAR SPINE

When sitting, the pelvis rotates backward and the lumbar lordosis decreases [43–47]. The disk pressure in a seated unsupported upright posture measured at the L3 level is 40% greater than the value obtained in upright standing [48]. Figure 1 shows the disc pressure in different postures in relation to the standing posture. This pressure corresponds to an approximate load of 700 N. The reduced lumbar lordosis, which creates an increased load moment and deformation of the disk itself caused by the lumbar spine flattening, is most likely a strong contributing factor for the increased disk pressure in unsupported sitting. Andersson and Örtengren performed an extensive series of experiments to establish the spinal load during sitting in different chairs and with different back supports [49–52]. These studies confirm that the disk pressure is significantly higher in unsupported sitting than in standing. The lowest pressure was found in the upright straight position. The disk pressure was influenced by several different support factors. Inclination of the backrest, as well as a lumbar support, resulted in decreased disk pressure. The disk pressure decreased with the amount of backrest inclination up to 110°. The effect of a lumbar support was more pronounced when the backrest inclination was small. Figure 2 shows the effect of back rest inclination on the disc pressure. The use of armrests also resulted in a decreased disk pressure.

Electromyographic studies of the erector spinae musculature have shown similar activity levels in standing as in unsupported sitting [50, 51, 53, 54]. There is a general agreement that the myoelectric activity decreases in sitting when the back is slumped forward, the arms are supported, when a backrest is used, and when leaning backwards [43, 47–57]. The parameter that has the major influence on myoelectric activity is the backrest inclination. Figure 3 shows the effect of back rest inclination on electromyographic activity of the spine muscles. In one of the studies by Andersson *et al.*, it was shown that when the backrest–seat angle was increased, the muscle activity at all levels of the back decreased

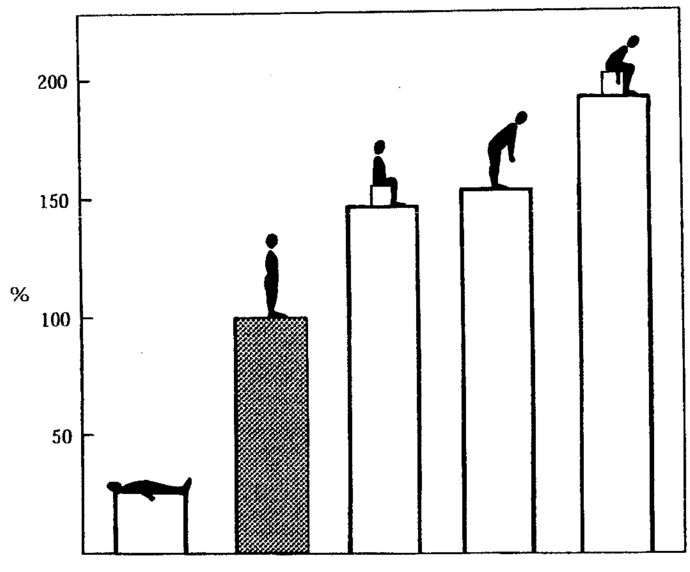

Figure 1. The relative loads on the third lumbar disk for various body positions in living subjects in relation to the upright standing posture, depicted as 100%. (Adapted from Nachemson, 1975).

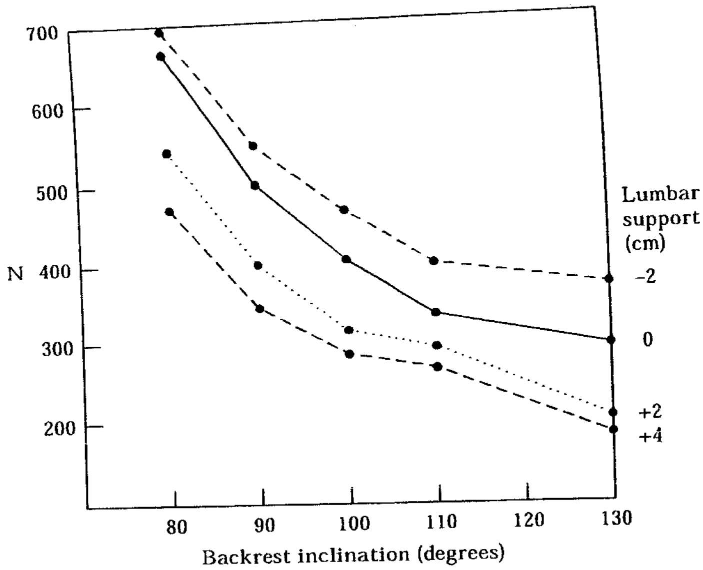

Figure 2. The disk pressure decreases when the backrest inclination is increased and when a lumbar support is used. (Adapted from Andersson *et al.*, [50]) Key to lumbar support height (cm): –●–, –2; —●—, 0; ···●···, +2; ——●——, +4.

[49]. When the backrest inclination was greater than 100°, the effect of further inclination decreased, however. A lumbar support had only a minor influence on muscle activity, whereas it was of great importance on the disk pressure. An inclined backrest of 120° was proven favourable in terms of less height loss during vibration [58]. The muscular activity of the spinal musculature increases when the knees are bent more than 90°, whereas

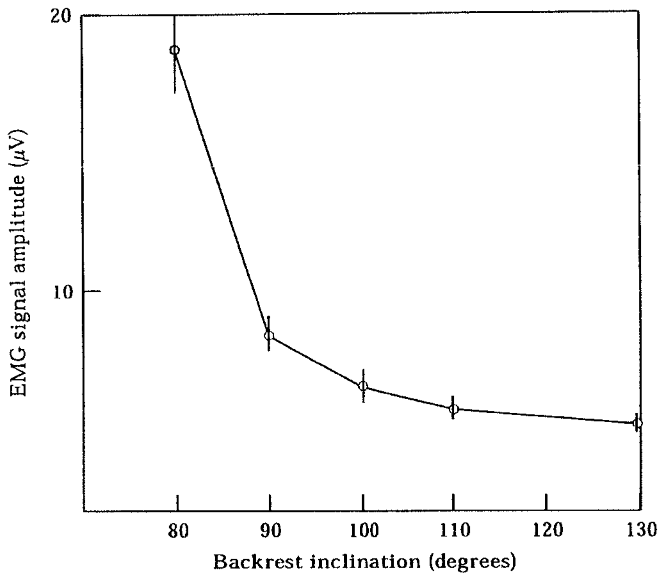

Figure 3. The myoelectric activity (EMG) decreases when the backrest inclination is increased.

Figure 4. The twisted posture in a vibrational environment stresses the entire spine by the extreme posture and the vibrational effect on the muscles and circulatory demands.

extension of the knees reduces the activity. This is probably due to the combined actions of various muscles that rotate the pelvis and thus influence the lumbar curve [46].

Forklift drivers, farmers and construction workers are exposed to long periods of twisted posture. Figure 4 shows the typical posture of a forklift driver. The twisted posture in a vibrational environment has been shown to cause increased energy consumption compared to twisted posture or vibration as single exposure variables [59]. Seated whole body vibration in a position that ensured muscular activity of the erector spinae muscles caused faster and more pronounced muscular fatigue in the lumbar erector spinae muscles when compared to the absence of vibration [60]. Both static sitting and seated whole body vibration caused increased height loss in subjects, suggesting increased spinal load [61, 62]. Some other studies, however showed the opposite [63, 64]. Considering the biomechanical aspects, i.e. the repeated mechanical compressive loading and the out-of-phase muscle activity [65], which adds load to the spine, it seems more likely that there is an increased spinal load from seated WBV. The contradictions in some studies are presumably due to differences in measurement methodology.

3.2. THE NECK

The load on the neck is correlated to the trunk and head position. The load moment is balanced by muscle forces and tension of the passive connective tissues. The very low muscle activity in both extreme flexed and extended postures indicates that the load moment is mainly counterbalanced by passive connective tissues, such as joint capsules and ligaments [16]. Very little muscle activity is demanded to keep the head in a normal upright position. The forward bending moment that is created by balancing the head requires only a low activity of the cervical erector spinae musculature. In the forward flexed position of the head, the major load will be carried by the C7-T1 joint. Compared to the normal upright position, the forward flexed position creates a 3·6 times greater load at this level [66]. Thus, flexion of the entire spine in the sitting posture increases the EMG activity in the cervical spine, trapezius, and thoracic erector spinae muscles. For even a 30° inclination angle from the vertical, the moment and corresponding muscle force values are 50% higher than the values achieved at 0°. The lowest activity is obtained when the trunk is leaning slightly backwards and the neck is vertical. It appears that the cervical extensor muscles may produce muscle fatigue symptoms quite quickly when head inclination angles become significant. This could be increased in a WBV environment. Chaffin, using EMG frequency shifts, found that the endurance time of young healthy females was considerably decreased when the neck inclination angle exceeded 30° [67]. In extreme head positions with the neck fully flexed, the extensor muscles of the cervical spine are not increased compared to the neutral upright head position, although the load moment of the C7-T1 motion segment is increased 3–4 times [16]. There is a considerable stress of the ligaments and joint capsules during extreme flexed positions of the cervical spine. The load on the cervical spine increases by wearing a helmet, especially if the helmet is equipped with equipment that increases the forward bending moment [68, 69].

3.3. THE SHOULDER AND ARM

The complex function of the shoulder joint, consisting of four separate joints and 15 muscles requiring a synchronized activity, makes the shoulder a very complicated biomechanical unit [10, 70, 71]. The calculation of joint reaction forces at the glenohumeral joint when the arm is elevated is a great problem because of the large number of muscles involved, the various force contributions of the different muscles, etc. Poppen and Walker [72] as well as Inman [70] found the glenohumeral joint forces at 90° of abduction to be close to body weight. Great muscle forces are thus necessary to keep the arm elevated, in particular in working postures where the hand is positioned at or above shoulder level and the arm is unsupported.

From an ergonomic point of view, it has become more important to detect the development of muscular fatigue, rather than focus on muscular force in order to prevent pain and injury. Local muscle fatigue is considered a limiting factor for monotonous and long lasting static work, although the work can be regarded as light. Muscle fatigue has been defined as failure to maintain constant force [73] due to a complex metabolic process. Chaffin [67] as well as Basmajian and De Luca [74] have defined localized muscular fatigue. Localized muscle fatigue can arise from sustained muscular work and is accompanied by motor decrement and pain confined to the muscle [67]. The main factor in local muscular fatigue is reduced blood flow in the contracting muscle, due to increased intramuscular pressure [75], and a consequent accumulation of metabolites. This vascular shortfall can appear when the relative force exceeds 15 to 20% of the maximum voluntary contraction (MVC) [76]. Spine muscles fatigued more and faster when, in a preloading condition (forward posture), vibration was added [60]. It is reasonable to assume that the shoulder muscles fatigue for the same reason in situations when the arm is unsupported and exposed to vibration.

Electromyographic studies have shown localized muscle fatigue in several of the shoulder muscles in work situations with the hand at or above shoulder level [77, 78]. Sigholm *et al.* found that the degree of upper arm elevation was the most important factor determining shoulder load, while upper arm rotation was of little importance and a hand weight was of less importance [79]. Hand weight was an important factor for the load on the supra- and infraspinatus muscles [30]. In overhead work, with the neck extended and the arms elevated, sometimes with a hand tool as extra load, there is a considerable muscular activity of the shoulder muscles to keep the arm in this position and at the same time an increased load moment on the neck, particularly at the C7-T1 level.

Kadefors *et al.* measured localized muscle fatigue of the shoulder muscles in three typical working situations and found localized muscle fatigue in both experienced and unexperienced welders in overhead work only [78]. In experienced welders, fatigue was confined to the supraspinatus muscle; whereas fatigue in inexperienced welders was abundant in several other muscles, suggesting a higher risk than normal to acquire tendinitis at the suspraspinatus tendon insert in overhead work [80].

Work tasks that demand continuous arm movement generate load patterns with a static component of the shoulder joint [28]. In an optimal seated work posture, the upper trapezius static load level is 2–3% of the MVC [18]. Optimal posture was defined as a vertical position or slightly backwards inclination of the spine, an approximately vertical position of the upper arm, and a work task at about elbow height without material handling (i.e., data entry work). In this position, intramuscular pressure was close to zero in the upper trapezius, supraspinatus, and infraspinatus muscles, suggesting normal blood flow in these muscles. Elevation of the shoulders without raising the arms may increase the load level on the upper trapezius to about 20% of MVC [26]. Any deviation of the arm from the vertical position increases the load on the upper trapezius and the rotator cuff muscles. Both EMG amplitude and intramuscular pressure (IMP) increase linearily with an increased shoulder torque [77]. The IMP and EMG amplitude are markedly reduced if a given shoulder torque is obtained during flexion instead of abduction. At an abduction of 30° (in a plane of 45° to the frontal plane) without a hand load, the IMP in the upper trapezius is only 15 mm Hg, while the corresponding value in the supraspinatus muscle is about 80 mm Hg. The blood flow in the supraspinatus muscle is significantly impeded at an IMP of about 40 mm Hg. Thus, the supraspinatus muscle is very vulnerable in work situations with elevated arms.

3.4. THE LOWER EXTREMITY

Leg support is important for the distribution and reduction of the load on the buttocks and the back of the thighs. The feet should therefore be permitted to rest firmly on the floor or foot support to avoid the weight of the lower legs being supported by the thighs resting on the seat. If there is pressure under the thighs close to the knees, it may create clinical problems in terms of swelling of the legs and pressure on the sciatic nerve. It has been shown that the volume of the legs increases by 4% during prolonged sitting. When a seat is too high, the feet do not reach the floor and the pressure on the thighs becomes uncomfortable [43, 47]. When the seat is too low, the small knee and hip angles soon become uncomfortable, and the pelvis rotates backward and flexes the spine [46, 7]. If adjustments are available the worker should be instructed how to use them.

4. CONCLUSION

No single posture can be maintained for a long period of time without considerable discomfort. LBP is found in both sedentary occupations and in drivers as well as those involved in manual materials handling. The seated posture leads to inactivity that may itself be injurious. Lack of motion leads to an accumulation of metabolites, which probably accelerates the degeneration of the disks and increases the probability of disk herniation. Drivers' postures can also lead to musculoskeletal problems in the neck, shoulder and arm. Hip and knee problems are also related to posture and can be exacerbated in a WBV environment. Studies of the seated posture indicate that backrest inclinations greater than 100° and a lumbar support reduce disk pressure and muscular activity. An inclination of

120° indicates less spinal load during vibration. Likewise neutral postures of the neck and upper extremities reduce musculoskeletal stress.

The advantages of the seated working posture are that it provides the stability needed for tasks with high visual demands and motor control. Furthermore, it is less energy consuming than standing, it puts less load on lower extremity joints, and it reduces the hydrostatic pressure on the lower extremity circulation. The disadvantages are the increased load on the back and neck, the risk for decalcification, and the low demands on the circulation.

Another factor to consider is that some stress is necessary to maintain the health of the skeleton. The weightless environment of space decreases bone mineral content (BMC). Experimental studies have shown a close relationship between BMC and static compressive strength in lumbar vertebral segments [81–83]. Thus a balance (not too much, not too little) is needed to maintain homeostasis without injury.

4.1. RECOMMENDATIONS

The following considerations about the workplace and work performance should be taken into account in all kinds of work as a measure of preventing musculoskeletal disorders or reducing the risk of impairment following an injury.

1. Provide the possibility for variation of sitting posture or variation between standing and sitting.
2. Avoid flexed, twisted, and hyperextended standing postures.
3. Avoid extreme postures of the head, especially neck flexion under WBV.
4. Avoid work with unsupported arms.
5. Provide a seat with sufficient inclination and a good back support. In a vehicle, good vibration damping characteristics.
6. Avoid driving or lifting in flexed or twisted postures. Avoid lifting directly after driving.
7. Avoid prolonged sitting in constrained or fixed postures without stretching.

REFERENCES

1. A. MAGORA 1972, *Industrial Medical Surgery* **41**, 5–9. Investigation of the relation between low back pain and occupation. 3. Physical requirements: sitting, standing and weight lifting.
2. J. L. KELSEY 1975 *International Journal of Epidemiology*. **4**, 197–205. An epidemiological study of the relationship between occupations and acute herniated lumbar intervertebral disks.
3. F. GYNTELBERG 1974 *Danish Medical Bulletin* **21**, 30–36. One year incidence of low back pain among male residents of Copenhagen aged 40–59.
4. A. MAGORA 1974 *Scandinavian Journal of Rehabilitation Medicine* **6**, 81–88. Investigation of the relation between low back pain and occupation. Six medical histories and symptoms.
5. H. F. FARFAN, R. H. HUBERDEAU and M. I. DUBOW 1972 *Journal of Bone and Joint Surgery* **54A**, 492–510. Lumber intervertebral disk degeneration.
6. L. HULT 1954 *Acta Orthopaedica Scandinavica* (*Supplement*) **16**, 7–117 The Munksfors investigation.
7. K. H. E. KROEMER and J. C. ROBINETTE 1969 *Industrial Medical Surgery* **38**, 115–125. Ergonomics in the design of office furniture.
8. J. S. LAWRENCE 1955 *British Journal of Industrial Medicine* **12**, 249–261. Rheumatism in coal miners. Part III, occupational factors.
9. R. E. PATRIDGE and J. A. ANDERSSON 1969 *International Rheumatism Congress Abstract*, 284. Back pain in industrial workers.
10. J. W. FRYMOYER, M. H. POPE and J. H. CLEMENTS 1983 *Journal of Bone and Joint Surgery* [*America*] **65**, 213–218. Risk factors in LBP, an epidemiological survey.
11. J. L. KELSEY and R. J. HARDY 1975 *American Journal of Epidemiology* **102**, 63–73. Driving motor vehicles as risk factor for acute herniated lumbar intervertebral disc.

12. R. E. Patridge and J. R. Duthie 1968 *Annals of the Rheumatological Disorders* **27**, 559–568. Rheumatism in dockers and civil servants. A comparison of heavy manual and sedentary workers.
13. J. W. Frymoyer, M. H. Pope, M. C. Costanza, J. C. Rosen, J. E. Goggin and D. G. Wilder 1980 *Spine* **5**, 419–423. Epidemiologic studies of low back pain.
14. A. Bjelle, M. Hagberg and G. Michaelsson 1979 *Scandinavian Journal of Work, Environment and Health* **5**, 205–210. Clinical and ergonomic factors in prolonged shoulder pain among industrial workers.
15. M. Hagberg and D. H. Wegman 1987 *British Journal of Industrial Medicine* **44**, 602–610 Prevalence rates and odds ratios of shoulder–neck disease in different occupational groups.
16. K. Harms-Ringdahl, J. Ekholm, K. Schüldt, G. Nemeth and U. Arborelius 1986 *Ergonomics* **29**, 1539–1552. Load moments and myoelectric activity when the cervical spine is held in full flexion and extension.
17. M. Hagberg 1984 *International Archives of Occupational and Environmental Health* **53**, 269–278. Occupational musculoskeletal stress and disorders of the neck and shoulder: a review of possible pathophysiology.
18. M. Hagberg and G. Sundelin 1986 *Ergonomics* **29**, 1637–1645. Discomfort and load on the upper trapezius muscle when operating a wordprocessor.
19. M. L. Magnusson, M. Pope, D. G. Wilder and B. Areskoug 1996 *Spine* **21**, 710–717. Are occupational drivers at an increased risk of developing musculo-skeletal disorders?
20. C. Hammar 1979 *Forest Health*, Boden, Sweden. The health status and adaption to work of forest workers in the Norrbotten County 1974–1978. (In Swedish).
21. E. Occhipinti, D. Colombini and S. Cantoni 1986 *Medina del Lavoro* **77**, 280–292. Alterazioni del rachide nei conducenti di automezzi pesanti (Spinal diseases in heavy vehicle drivers).
22. S. Arnautova-Bulat 1979 *Arhiv za higijenu rada i toksikologiju* **30**, 259–266. On the possible effect of vibrations on the spine of railwaymen.
23. E. Johanning 1991 *Scandinavian Journal of Work and Environmental Health* **17**, 414–419. Back disorders and health problems among subway train operators exposed to whole-body vibration.
24. S. Tola, H. Riihimäki, T. Videman, E. Viikari-Juntura and K. Hännineu 1988 *Scandinavian Journal of Work, Environment and Health* **14**, 299–305. Neck and shoulder symptoms among men in machine operating, dynamic work and sedentary work.
25. M. Hagberg 1988 *Arbetsmiljöfonden*, 1 Arbetsmiljöns betydelse för besvär i skuldra och halsrygg. (In Swedish).
26. M. Hagberg 1987 *Clinical concepts in regional musculoskeletal illness*. (N. M. Hadler, Editor pp. 191–200). Shoulder pain-pathogenesis. NY: Grune & Stratton.
27. P. Herberts, R. Kadefors and G. P. Andersson 1981 *Acta Orthopaedica Scandinavica* **52**, 299–306. Shoulder pain in industry: an epidemiological study on welders.
28. R. H. Westgaard and A. Aarås 1984 *Applied Ergonomics* **15**, 162–174. Postural muscle strain as a causal factor in the development of musculoskeletal illnesses.
29. S. Wiker, D. B. Chaffin, G. D. Langolf 1989 *Ergonomics* **32**, 211–237. Shoulder posture and localized muscle fatigue and discomfort.
30. P. Herberts, P. Kadefors, C. Högfors and G. Sigholm 1984 *Clinical Orthopaedics and Related Research* **191**, 166–178. Shoulder pain and heavy manual labor.
31. S. Burt, R. Hornung and L. J. Fine 1990 *NIOSH Health Hazard Evaluation Report* (HETA **89**, 250–2046).
32. B. Silverstein 1985 *Dissertation, The University of Michigan*. The prevalence of upper extremity cumulative trauma disorders in industry.
33. D. Felson, M. Hannan, A. Naimark, J. Berkely, G. Gordon, P. W. F. Wilson and J. Anderson 1991 *Journal of Rheumatology* **18**, 1587–1592.
34. H. Lindberg and F. Montgomery 1987 *Clinical Orthopaedics and Related Research* **214**, 235–236. Heavy labor and the occurrence of gonarthrosis.
35. E. Vingård 1991 *Doctorial thesis, Karolinska Institutet, Arbete & Hälsa*, **25**. Work, sports, overweight and osteoarthrosis of the hip.
36. B. Axmacher and H. Lindberg 1993 *Clinical Orthopaedics and Related Research* **287**, 82–86. Coxarthrosis in farmers.
37. P. Croft, D. Coggon, M. Cruddas and C. Cooper 1992 *British Medical Journal* **304**, 1269–1272. Osteoarthritis of the hip: an occupational disease in farmers.
38. B. Jacobsson, N. Dalén and B. Tjörnstrand 1987 *International Orthopedics* **11**, 311–313. Coxarthrosis and labour

39. E. Vingård, L. Alfredsson, E. Fellenius and C. Hogstedt 1992 *Scandinavian Journal of Social Medicine* **20**, 31–36. Disability pensions due to musculoskeletal disorders among men in heavy occupations.
40. M. Pope, H. Broman and T. Hansson 1989 *Clinical Biomechanics* **4**, 195–200. The impact response of the standing subject—a feasibility study.
41. M. Pope, K. McLeod, M. Magnusson, M. Rostedt, T. Hansson and C. Rubin, 1996 *Proceedings of ORS, Atlanta, GA*. Transmission of whole body vibrations in the 10–40 Hz range into the hip and lumbar spine.
42. D. G. Wilder, M. H. Pope, J. W. Frymoyer 1988 *Journal of Spinal Disorders* **1**, 16–32. The biomechanics of lumbar disk herniation and the effect of overload and instability.
43. B. Åkerblom 1948 *Doctoral Thesis, Stockholm*. Standing and sitting posture.
44. G. B. J. Andersson, R. W. Murphy R. Örtengren and A. L. Nachemson 1979 *Spine* **4**, 52–58. The influence of backrest inclination and lumbar support on lumbar lordosis.
45. U. Burandt 1969 *Ergonomics* **12**, 356–364. Röntgenuntersuchung über die Stellung von Becken und Wirbelsäule beim Sitzen auf vorgeneigten Flachen.
46. J. J. Keegan 1953 *Journal of Bone and Joint Surgery* **35A**, 589–603. Alterations of the lumbar curve related to posture and seating.
47. H. Schobert 1962 *Sitzhaltung, Sitzschaden, Sitzmöbel*. Berlin-Göttingen-Heidelberg: Springer Verlag.
48. A. L. Nachemson 1981 *Spine* **6**, 93–97. Disk pressure measurements.
49. G. B. J. Andersson, B. Jonsson and R. Örtengren 1974 *Scandinavian Journal of Rehabilitation Medicine* (*Supplement*) **3**, 91–108. Myoelectric activity in individual lumber erector spinae muscles in sitting. A study with surface and wire electrodes.
50. G. B. J. Andersson and R. Örtengren 1974 *Scandinavian Journal of Rehabilitation Medicine* **6**, 115–121. Lumber disk pressure and myoelectric back muscle activity during sitting II. Studies of an office chair.
51. G. B. J. Andersson and R. Örtengren 1974 *Scandinavian Journal of Rehabilitation Medicine* (*Supplement*) **3**, 73–90. Myoelectric back muscle activity during sitting.
52. G. B. J. Andersson, R. Örtengren, A. Nachemson and G. Elfström 1974 *Scandinavian Journal of Rehabilitation Medicine* **6**, 104–114. Lumber disk pressure and myoelectric back muscle activity during sitting. I. Studies on an experimental chair.
53. S. Carlsöö 1963 *Writing desk, chair and posture of work*. Stockholm: Anatomiska Inst.
54. W. F. Floyd and P. H. S. Silver 1955 *Journal of Physiology* (*London*) **129**, 184–203. The function of the erectores spinae muscles in certain movements and postures in man.
55. B. Jonsson 1970 *Doctoral Thesis. Göteborg, Elanders*. The lumbar part of the erector spinae muscle: A technique for electromyographic studies of the function of its individual muscles.
56. A. J. S. Lundervold 1951 *Acta Physiologica Scandinavica* (*Suppl.*) **84**, 1–171. Electromyographic investigations of position and manner of working in typewriting.
57. B. Rosemeyer 1972 *Zeitschrift für Orthopädie* **110**, 514. Eine Methode zur Bechenfixerung im Arbeitssitz.
58. M. Magnusson, T. Hansson and M. H. Pope 1994 *Applied Ergonomics* **25**, 294–298. The effect of seat back inclination on spine height changes.
59. M. Magnusson, M. H. Pope, V. Lindell, M. Svensson and G. Andersson 1987 *Ergonomics* **30**, 55-60. The metabolic cost of various occupational exposures.
60. T. Hansson, M. Magnusson, H. Broman 1991 *Clinical Biomechanics* **6**, 173–178. Back muscle fatigue and seated whole body vibrations: an experimental study in man.
61. M. Magnusson, E. Hult, I. Lindström, V. Lindell, M. H. Pope and T. Hansson 1990 *Clinical Biomechanics* **5**, 137–142. Measurement of time-dependent height loss during sitting.
62. M. Magnusson, M. Almqvist, H. Broman, M. H. Pope and T. Hansson 1992 *Journal of Spinal Disorders* **5**, 198–203. Measurement of height loss during whole body vibrations.
63. R. Bonney 1988 *Clinical Biomechanics* **3**, 236–240. Some effects on the spine from driving.
64. I. Althoff, P. Brinkmann, W. Frobin, J. Sandover, K. Burton 1992 *Spine* **17**, 682–693. An improved method of stature measurement for quantitative determination of spinal loading: application to sitting postures and whole body vibration.
65. U. P. Arborelius 1983. *Forskningsrapport. Kinesiologigruppen, Anatomiska Institutionen, Karolinska Institutet*. (*in Swedish*). Effekt på rörelseorganen av belastningsreducerande åtgärder vid medeltungt stående materialhanteringsarbete och sittande monteringsarbete med små komponenter.
66. R. E. Seroussi, D. G. Wilder, M. H. Pope 1989 *Journal of Biomechanics* **22**, 219–229. Trunk muscle electromyography and whole body vibration.

67. D. B. CHAFFIN 1973 *Journal of Occupational Medicine* **15**, 346–354. Localized muscle fatigue: definition and measurement.
68. M. HAGBERG 1982 *Arbetarskyddsfonden rapport nr* 2. (in Swedish). Arbetsrelaterade besvär i halsrygg och skuldra.
69. S. TAMMINEN 1980 *Biomekanisk analys av gruvhjälmens belastning på nacke*. Examensarbete vid Arbetarskyddsstyrelsens kurs för företagsgymnaster. (in Swedish).
70 V. T. INMAN, J. B. SAUNDERS and L. C. ABBOTT 1944 *Journal of Bone and Joint Surgery* **26**, 1–30. Observations on the function of the shoulder joint.
71. N. K. POPPEN and P. S. WALKER 1976 *Journal of Bone and Joint Surgery* **58A**, 1–4. Normal and abnormal motion of the shoulder.
72. N. K. POPPEN and P. S. WALKER 1978 *Clinical Orthopaedics and Related Research* **135**, 165–170. Forces at the glenohumeral joint in abduction.
73. R. T. H. EDWARDS 1981 *Human muscle fatigue: Physiological mechanisms. Ciba Foundation Symposium* (Editors R. Porter and J. Whelan) **82**, 1–18. Pitman Medical: London. Human muscle function and fatigue.
74. J. V. BASMAJIAN and C. J. DELUCA 1985 *Muscles alive. Their functions revealed by electromyography*. Baltimore, MD: Williams & Wilkins.
75. R. T. H. EDWARDS, D. K. HILL and M. MCDONELL 1972 *Journal of Physiology* (*London*) **224**, 58–59. Myothermal and intramuscular pressure measurements during isometric contractions of the human quadriceps muscle.
76. L. LINDSTRÖM, R. KADEFORS and I. PETERSÉN 1977 *Journal of Applied Physiology* **43**, 750–754. An electromyographic index for localized muscle fatigue.
77. M. HAGBERG 1981 *American Journal of Physical Medicine* **60**, 111–121. Electromyographic signs of shoulder muscle fatigue in two elevated arm positions.
78. R. KADEFORS, I. PETERSÉN and P. HERBERTS 1976 *Ergonomics* **19**, 543–558. Muscular reaction to welding work: an electromyographic investigation.
79. G. SIGHOLM, P. HERBERTS, C. ALMSTRÖM and R. KADEFORS 1984 *Journal of Orthopedic Research* **1**, 3379–3386. Electromyographic analysis of shoulder muscle load.
80. P. HERBERTS and R. KADEFORS 1976 *Acta Orthopaedica Scandivavica* **47**, 381–387. A study of painful shoulder in welders.
81. P. BRINKMANN, N. JOHANNLEWELING, D. HILWEG and M. BIGGEMAN 1987 *Clinical Biomechanics* **2**, 94–96. Fatigue fracture of human lumbar vertebrae.
82. H. GRANHED, T. HANSSON and R. JONSON 1989 *Acta Orthopaedica Scandinavica* **60**, 105–109. The bone mineral content and ultimate compressive strength of lumbar vertebra of a cadaver study.
83. T. HANSSON, B. ROOS and A. NACHEMSON 1980 *Spine* **1**, 46–55 The bone mineral content and ultimate compressive strength in lumbar vertebrae.