Physical Limitations and Musculoskeletal Complaints Associated With Work in Unusual or Restricted Postures: A Literature Review

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ABSTRACT

Introduction. The vast majority of ergonomics research has addressed the demands of work in standing or sitting postures, and understandably so. However, many workers (for example, underground miners, aircraft baggage handlers, plumbers, agricultural workers, mechanics, and others) are often required to adopt postures such as kneeling, stooping, squatting, or lying down for significant periods of the work day.

Method. A literature search was performed using the ISI Web of Science database (for years 1980-2004). Articles retrieved from this search were evaluated in terms of relevance to assessing physical capabilities of workers in these postures and/or the musculoskeletal epidemiology associated with these postures.

Results. Work in unusual and restricted postures was associated with significantly higher rates of musculoskeletal complaints compared to workers not adopting these postures in epidemiology studies (Odds Ratios ranging from 1.13 to 13). Some studies suggested a dose-response relationship, with longer exposures leading to increased musculoskeletal complaints. Physical strength and psychophysical lifting capacity vary significantly as unusual or restricted postures are adopted, with lower lifting capacities evident in the kneeling, squatting, and lying positions.

Conclusions. Workers who adopt unusual or restricted postures appear to be at higher risk of musculoskeletal complaints and often exhibit reduced strength and lifting capacity. Research needs in this area include improved exposure assessment tools, studies of intervention effectiveness, adaptations of the body in response of work in unusual postures, and elucidation of

relevant injury pathways.

Impact on Industry: Workers who adopt unusual or restricted postures in their work often experience higher musculoskeletal injury rates. If awkward postures cannot be eliminated in the workplace, jobs should be designed in accordance with the reduced strength and lifting capabilities observed in these postures.

1. INTRODUCTION

The human body is remarkably adaptable and capable of performance in a wide variety of environments and circumstances. It cannot be said, however, that the body can perform equally well under all conditions. In fact, when faced with awkward tasks or environmental demands, the musculoskeletal system may endure substantial performance limitations. Such limitations are often evident when workers adopt unusual or restricted postures during performance of physically demanding work tasks. For the purposes of this discussion, the term “unusual posture” will be considered as any working posture other than typical standing or sitting positions. The term “restricted posture” indicates that these postures are forced upon workers due to limitations in workspace.

The vast majority of ergonomics research has focused on establishing design criteria for work involving standing (e.g., Waters et al., 1993; Snook & Ciriello, 1991) or sitting (e.g., Grandjean, 1988) postures, and understandably so. However, it must be recognized that there are numerous jobs (for example, underground miners, aircraft baggage handlers, plumbers, agricultural workers, mechanics, etc.) where workers operate in less desirable postures such as kneeling, stooping, squatting, and/or lying down (Haselgrave, Tracy, & Corlett, 1997). Unfortunately, experience has shown that many ergonomics techniques used to analyze or design standing or sitting workstations often do not adapt well to situations where unusual postures are employed (Gallagher & Hamrick, 1991). However, recent years have seen an increase in research examining the adaptations, limitations, and trade-offs associated with working in non-traditional work postures. The purpose of this article is to summarize current knowledge in this area, identify research needs, and to suggest methods of improving job design for workers who labor in unusual or restricted postures.

2. GENERAL CONSIDERATIONS

Workers typically enjoy the benefits of high strength capabilities and mobility when they assume a normal standing position. This stance permits many powerful muscle groups to work in concert when performing manual tasks. However, this muscular synergy can be seriously disrupted when unusual or restricted postures are employed. One need only imagine a lift performed while lying down on one's side to understand that many powerful muscles (i.e., those of the legs, hips, and thighs) will be unable to fully participate in the lifting assignment. Though these muscles may be activated and contract, they may not be in the position to generate forces that are of much use in accomplishing the task. Each unique postural configuration will result in its own set of strength limits. The number and identity of the muscles that can be recruited for the job will largely determine these limits (Dul, 1986).

Task performance in non-traditional work postures can also be affected by reduced mobility, stability, and balance. For example, when one is unable to stand on one's feet, mobility is dramatically reduced. This factor can have a significant impact on the method of task performance. Consider an asymmetric lifting task performed in standing versus kneeling postures. When a worker is standing, it is reasonable to request that they avoid twisting the trunk simply by repositioning the feet when asymmetry is present. However, the task of repositioning is considerably more difficult when kneeling (especially when handling a load), and workers are not inclined to take the time nor the effort to do this. Instead, the worker will opt for the faster and more efficient trunk twisting motion, at the expense of placing a sizable axial torque on the spine. Stability may also impact task performance in constrained postures. Workers may have to limit force application in certain postures in order to maintain balance. In this regard it is assumed for the purposes of this review that workers are working on a stable floor surface, and not operating on ladders or temporary platforms.

As mentioned previously, awkward work postures are often the consequence of restrictions in workspace, typically in vertical or lateral dimensions. For example, underground miners and aircraft baggage handlers often work in workspaces where the available vertical space does not allow upright standing. Workspace restrictions of this sort put not only the worker, but also the ergonomist in a bind. The worker is affected by the limitations of the posture he or she must employ. The ergonomist may be deprived of favored techniques for reducing musculoskeletal disorder risk. For example, restricted space greatly limits the number and type of mechanical devices (cranes, hoists, forklifts, etc.) available to reduce the muscular demands on the worker. If mechanical assistance is to be provided, it frequently must be custom fabricated for the environment. Restrictions in workspace also limit opportunities to ease the strain arising from the worker's postural demands, often forcing the ergonomist to recommend working postures from a limited menu of unpalatable alternatives. In a vertical workspace of 125 cm, for instance, two working postures predominate (kneeling or stooping). Both postures are associated with increased musculoskeletal complaints, the former increases knee disorders while the latter is associated with increased low back pain. No matter which posture is recommended, the worker is likely to develop musculoskeletal symptoms, the choice boils down to which joints are to be conceded.

Restricted spaces can also result in more subtle effects. One is the tendency, as vertical space is reduced, to force workers into asymmetric motions. Lifting symmetrically (i.e., in the sagittal plane) is generally preferred in the standing posture, but becomes progressively more difficult if one is stooping in reduced vertical space. In fact, lifting capacity in asymmetric lifts tends to be higher than in symmetric tasks under low ceilings (Gallagher, 1991). This represents a change from the unrestricted standing position, where asymmetry reduces lifting capacity (Garg & Badger, 1986). Finally, as Drury (1985) points out, space limitations will tend to impose a single performance method on a worker. In unrestricted spaces, when a worker's preferred muscles fatigue, it is often possible for an individual to employ substitute motions which may shift part of the load off of fatigued muscles. For example, in unrestricted lifting people might intersperse stoop and squat lifting to relieve the load on back and leg muscles. In a 1 meter high coal mine, the worker will have to perform lifting tasks in a kneeling posture, without much opportunity to relieve the muscles that need to be used in this posture. The likely result is intensified fatigue, decrease performance, and increased risk of tissue injury in restricted postures.

The following sections detail research that has examined the influence of restricted postures on worker capabilities, and on the epidemiology of musculoskeletal disorders associated with restricted postures. A literature search was performed using the ISI Web of Science database (for years 1980-2004) using the following terms: Restricted Postures OR Stooping OR Kneeling OR Squatting. Articles retrieved from this search (a total of 488) were evaluated in terms of relevance to assessing physical capabilities of workers in these postures and/or the epidemiology associated with working in these postures. The resulting 26 articles were supplemented by relevant contract reports and journal articles from the author's library. As will be seen, the literature suggests that use of restricted postures during physical work results in significant costs in terms of both the capacity for work and in terms of injury experience. The final sections describe important research gaps regarding our current knowledge of the effects of working in restricted postures, and provide suggestions for future initiatives for productive research in the field.

3. PERFORMANCE LIMITATIONS IN RESTRICTED POSTURES

The past couple of decades have seen a number of studies that have examined the effects of working in unusual or restricted postures on a variety of performance measures. These measures have included psychophysical lifting capacity, muscular strength, metabolic cost, and trunk muscle activation patterns. The following sections provide information regarding some of the effects of restricted postures on these performance measures.

3.1 Effects of Posture on Lifting Capacity

3.1.1 Lifting Capacity for a Single Lift

A comprehensive analysis of single lift psychophysical lifting capabilities in non-traditional working posture was performed by researchers at Texas Tech University under a contract from the Air Force (Ayoub, Smith, Selan, & Fernandez, 1985; Ayoub et al., 1985; Gibbons, 1989). Under this contract, two lifting studies examined maximum psychophysical lifting capacities of both male and female subjects in standing, sitting, squatting, kneeling, and lying postures. The purpose was to simulate postures used during Air Force aircraft maintenance activities, which often involve use of unusual or restricted postures. Subjects were allowed to adjust the weight in lifting containers to the maximum they felt was acceptable for a single lift in each posture. It should be noted that the lifting tasks were standardized using percentages (35%, 60% and 85%) of the vertical reach height of the subject in each posture. Thus, a lift to 35% vertical reach height in the standing posture will have a greater vertical load excursion than a lift to 35% vertical reach height in a kneeling posture.

Figures 1 and 2 present data from male and female subjects, respectively, performing lifts in standing, kneeling (on one knee and on both knees), sitting and squatting postures. Inspection of these figures reveals several notable features. The first is that in all cases the standing posture resulted in the highest psychophysically acceptable loads compared to the restricted postures. One can also see from these figures that loads chosen in kneeling tasks result in the second highest estimates of lifting capacity (7-21% less than standing), and that one knee lifts did not differ from lifts on both knees in terms of load acceptability. The sitting posture resulted in acceptable lifting estimates just slightly below those achieved when kneeling (16-23% less than standing lifts), and squatting resulted in the lowest acceptable loads (20-33% less than standing). The squatting posture appears to be the least stable of the restricted postures, and it may be that the lower acceptable loads in this posture may be driven by the need to select a load that allows the subject to maintain his or her balance.

Figure 1. – Acceptable loads selected by males for single lifts in several postures. Bars represent means, error bars represent standard deviations (Gibbons, 1989).

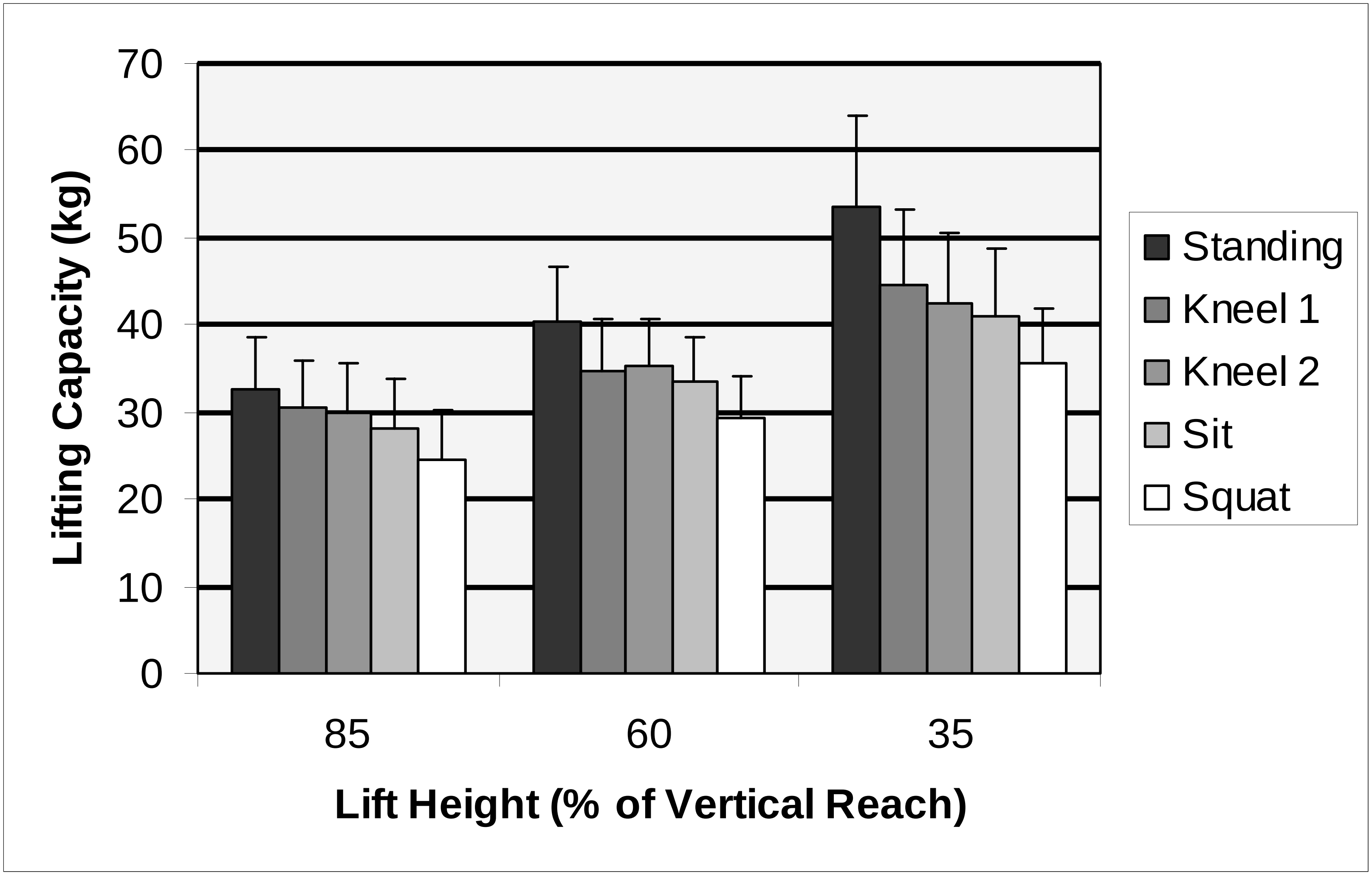
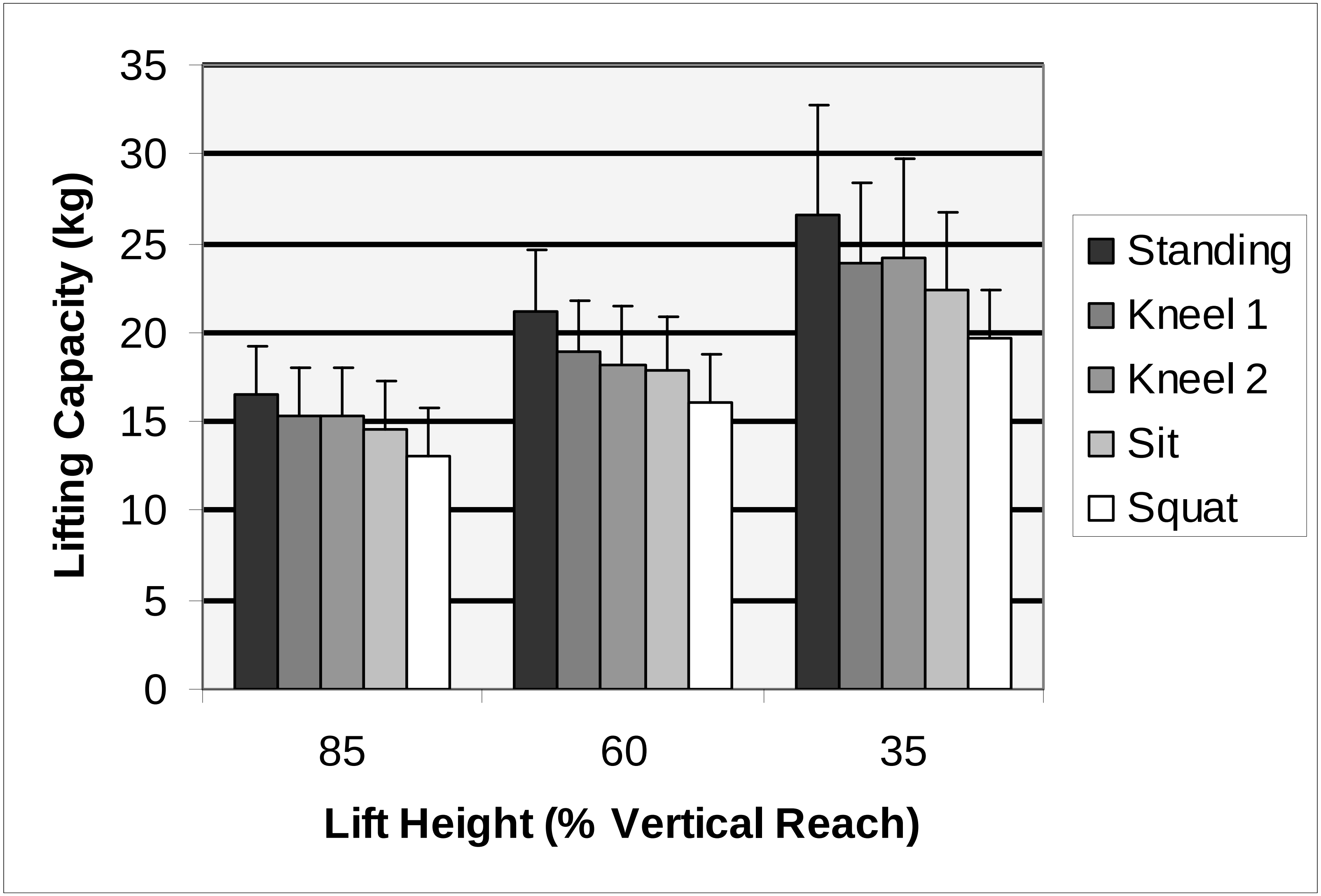


Figure 2. – Acceptable loads selected by females for single lifts in several postures. Bars represent means, error bars represent standard deviations (Gibbons, 1989).



It is also apparent that the effects of posture on lifting capacity are more pronounced with lifts of 35% of vertical reach, and that the effect becomes progressively diminished (though still apparent) when lifts to 60% and 85 % of vertical reach are performed. It may be that strength capbilities for lifts to higher heights may be controlled more by limitations in shoulder and arm strength, and are thus not as dependent on body posture. Finally, comparison of male strength (Figure 1) versus female strength (Figure 2) indicates that posture effects are similar for both genders; however, the strength exhibited by females averaged about 50-60% of that achieved by their male counterparts (note that the Y axis scale is different for Figures 1 and 2).

A separate study performed at Texas Tech looked at strength capacities in prone, supine, or side-lying positions (Ayoub et al., 1985; Gibbons, 1989). These postures exhibit drastic reductions in lifting capacity; with acceptable loads just 25-40% of standing values. The only exception was when the subject performed a 2-handed lift in a face-up (supine) position, similar to a weightlifter's bench press exertion. In this instance, the average acceptable load actually exceeded the standing value by 20 percent. It appears that control of the load, and a balanced exertion of forces by both arms, play important roles in determining lifting capacity in the supine position.

3.1.2 Lifting Capacity for Longer Duration Tasks

It should be emphasized that the data discussed in the previous section represent *one-repetition maximum values*, and assume that workers would perform such tasks only occasionally, not for extended periods. However, periods of extended lifting in restricted posture are common in some industries. Examples include underground coal miners unloading supply items in a low-seam coal mine, or an aircraft baggage handler loading suitcases and packages inside the baggage compartment of a commercial airliner. Several recent studies have examined the lifting capacity of underground coal miners adopting restricted postures involving repetitive lifting activities (Gallagher, Marras, & Bobick, 1988; Gallagher & Unger, 1990; Gallagher, 1991; Gallagher & Hamrick, 1992). These studies also used the psychophysical approach, allowing subjects to adjust the weight in lifting boxes to acceptable loads during 20-minute lifting periods. Most of these studies examined lifting capacities in kneeling and stooping postures, postures that predominate in underground coal mines having restricted vertical workspace.

In general, findings of these studies are quite congruent with limitations associated with these postures in the single lift studies described previously. Restricted postures (stooping and kneeling) were found to result in lower estimates of acceptable loads compared to the standing posture (Gallagher & Hamrick, 1992), and kneeling was found to have a significantly reduced estimate of acceptable load compared to stooping (Gallagher, Marras, & Bobick, 1988; Gallagher & Unger, 1990; Gallagher, 1991). Kneeling and stooping postures (approximately 60-70% of full standing posture) were examined under different vertical space constraints to see whether additional restrictions in space would further affect lifting capacity (i.e., is lifting capacity when kneeling different under a 1.2 vs. 0.9 m ceiling? Is lifting capacity when stooping different under a 1.5 vs. 1.2 m ceiling?). However, results indicated no additional decrements in lifting capacity were seen when comparing such conditions. The major determinant affecting lifting capacity in these studies was simply the posture adopted for the task (Gallagher & Unger, 1990). While posture was almost always an important determinant of lifting capacity in these studies, there were some factors, if present, that could reduce or eliminate the effect. In particular, it was found that if items had a poor hand-object coupling (no handholds), lifting capacity could be reduced to such an extent that effects due to posture were no longer an issue (Gallagher & Hamrick, 1992).

A surprising (and somewhat unsettling) finding from these studies is that psychophysical lifting capacity in a stooping posture (over a 20-minute time frame) is not much different from standing over the same time frame (Gallagher & Hamrick, 1992). In one respect, this is not too surprising because stooping is a posture where considerable strength is available to lift a load. In fact, most workers prefer this position when initiating a lift off of the floor, probably due to the ability to employ the powerful hip extensor muscles in overcoming the inertia of the load. In his critique of the psychophysical method, Snook (1985) states that psychophysical method of establishing acceptable loads does not appear to be sensitive to bending and twisting motions that are often associated with the onset of low back pain, and the results reported above seem to support this limitation. Recent studies have indicated that static or cyclic spine flexion for a 30 minute period may be associated with ligament creep and an attendant dysfunction of the back muscles for a period of up to 24 hours (Solomonow et al., 1999). Furthermore, it has been suggested that potentially damaging shear forces may be present when lifting in this posture (McGill, 1999), and more rapid fatigue failure of spinal tissues (Gallagher, 2003). Subjects may not get sufficient proprioceptive feedback on these matters; thus, they may not play into estimates of load acceptability. However, these and other biomechanical factors may be important in development of low back disorders. It seems clear that development of lifting standards for a stooping posture must not rely solely on estimates of psychophysical lifting capacity, but should take into account biomechanical and physiological factors that may influence development of low back disorders in this posture.

3.2 Biomechanics of Unusual or Restricted Postures

As significant changes in whole-body posture are adopted, one would anticipate changes in both the magnitude and distribution of biomechanical stresses amongst the joints of the body, and available evidence appears to support this notion. The following sections describe results of studies examining various aspects of the biomechanics of working in restricted postures.

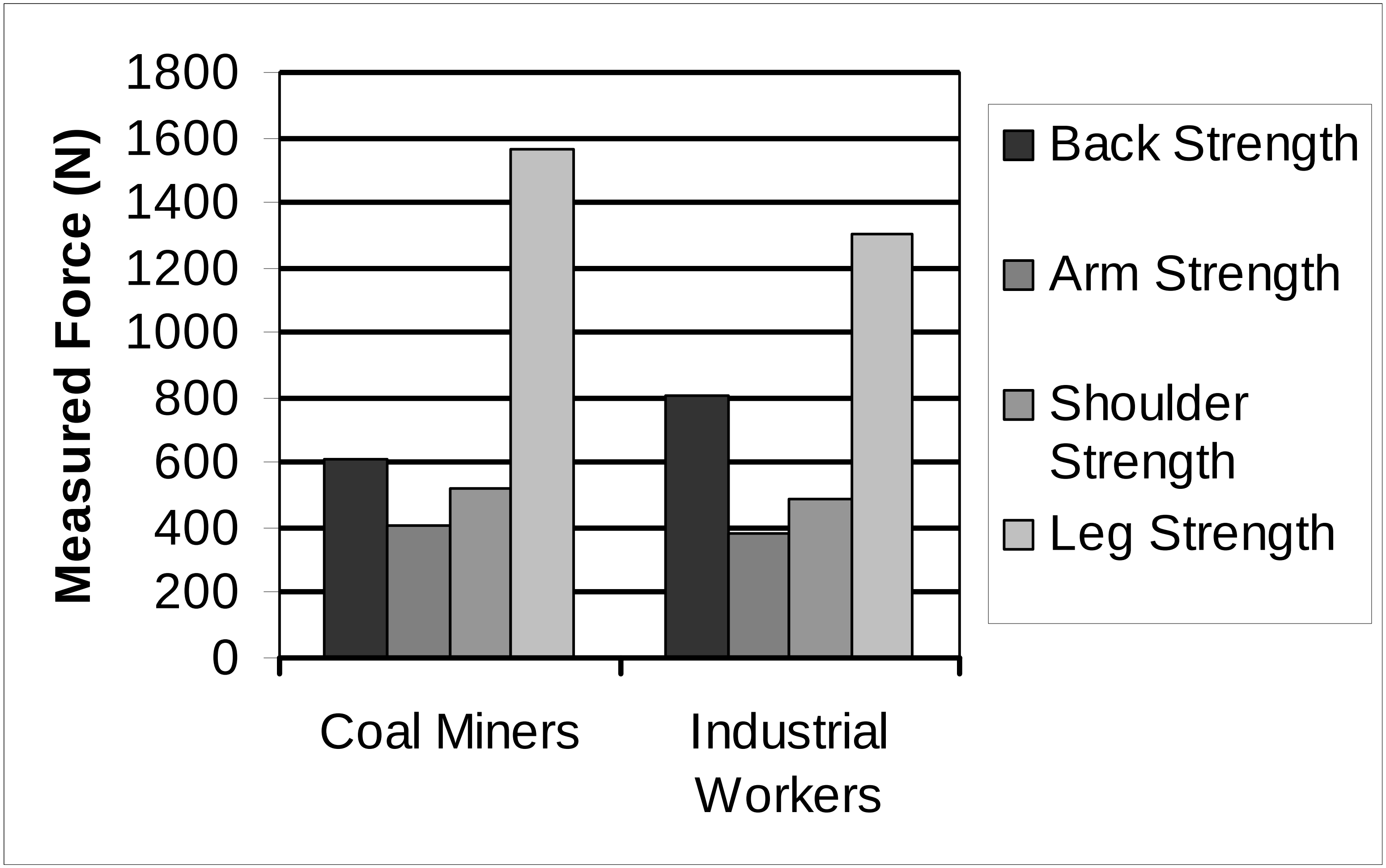
3.2.1. Effects of Restricted Postures on Strength

Studies examining static or dynamic strength capabilities in unusual or restricted postures are relatively rare. Isometric strength tests in kneeling versus standing postures have indicated that lateral exertions are weaker when kneeling; however, pushing forces are found to be equivalent or slightly higher when kneeling (Haselgrave, Tracy, & Corlett, 1997). Static pulling and lifting forces in the kneeling posture exceeded those in the standing position, by 25% and 44%. Pushing upwards against a handle at eye height results in similar values in all postures (Gallagher, 1989).

Gallagher (1997) investigated isometric and isokinetic trunk extension strength and muscle activity in standing and kneeling postures. Findings of this study showed that trunk extension strength is reduced by 16% in the kneeling posture in comparison with standing, similar to decreases observed in psychophysical lifting capacity when kneeling. However, trunk muscle activity was virtually the same between the two postures. This indicates that the reduction in trunk extension strength when kneeling may be the result of a reduced capability to perform a strong rotation of the pelvis when the kneeling posture is adopted, as opposed to a change in function of the spinal muscles.

Ayoub et al. (1981) presented an intriguing set of strength data comparing isometric strengths of coal miners working in restricted postures to a comparison population of industrial workers (Figure 3). Strength measures included back strength, shoulder strength, arm strength, sitting leg strength and standing leg strength. When compared with a sample of industrial workers (Ayoub et al., 1978), low-seam coal miners were found to have significantly lower back strength, but much higher leg strength. The authors ascribed the decrease in back strength to unspecified factors related to the postures imposed by the low-seam environment. Indeed, there is evidence to support this position. Low coal miners may be obliged to work in a stooping posture for extended periods. In this posture, the spine is largely supported by ligaments and other passive tissues, "sparing" the use of the back muscles. Studies of lifting in the stooping posture suggest that the gluteal muscles and hamstrings provide a large share of the forces in this position (Gallagher, Marras, and Bobick, 1988). The results of Ayoub et al. (1981) may reflect a relative de-conditioning of back muscles when stooping (due to the flexion-relaxation phenomenon), and an increased reliance on the leg and hip musculature to perform underground work tasks (producing an increase in leg strength). Further research is needed to ascertain long-term effects on strength resulting from prolonged work in restricted postures.

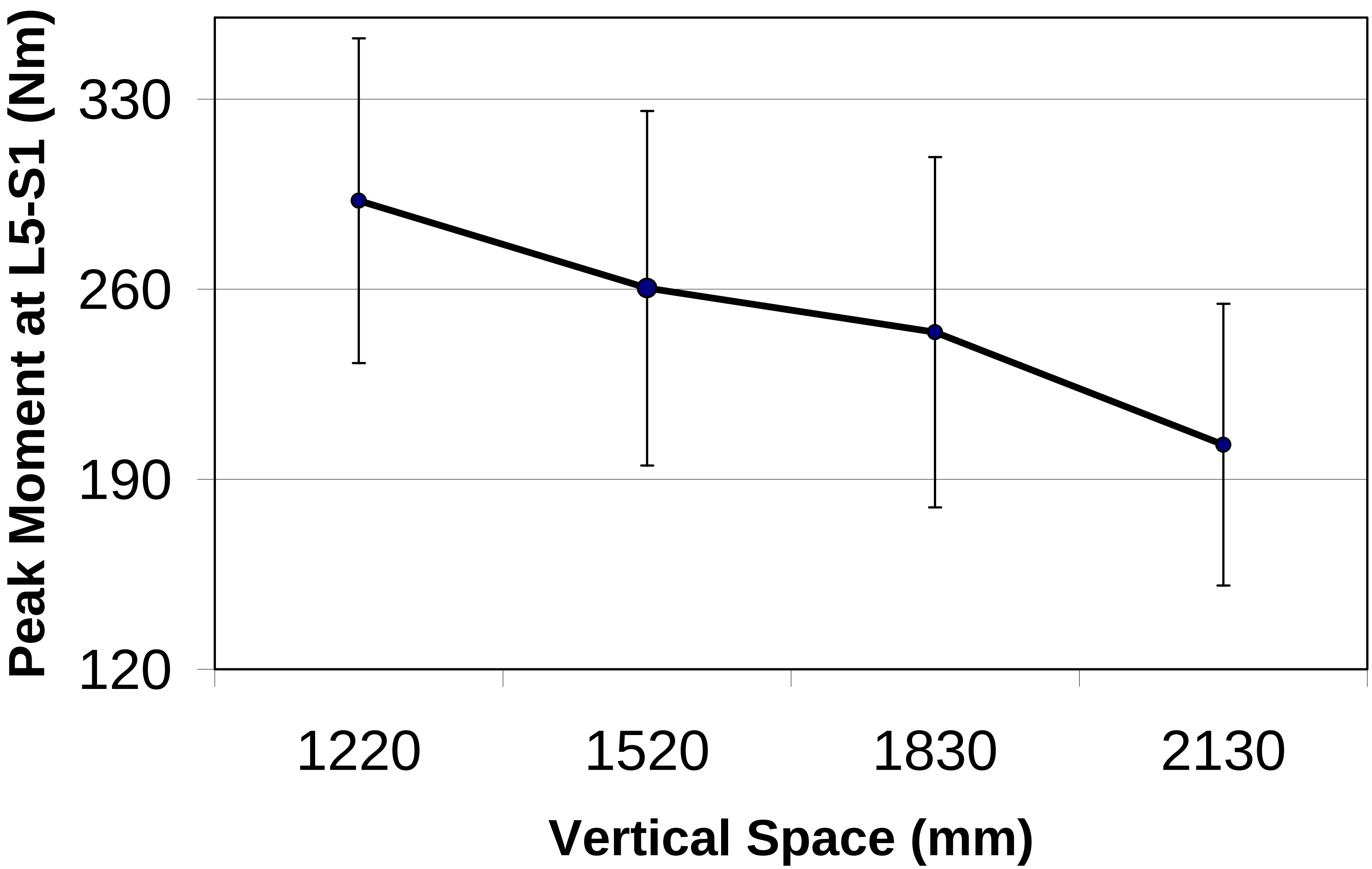
Figure 3. – Comparison of strength measures for coal miners working in confined vertical space (Ayoub et al. 1981) to an industrial population (Ayoub et al. 1978).



3.2.2 Lumbar Spine Loads in Restricted Workspaces

Studies have suggested that one of the best predictors for low-back pain is the external moment about the lumbar spine that results from the product of the force required to lift an object times the distance these force act away from the spine (Marras et al., 1993). As illustrated in figure 4, recent evidence has shown that as vertical workspace is restricted, the moment experienced by the lumbar spine is increased (Gallagher, Hamrick, Cornelius, & Redfern, 2001). Of course, such a response would be expected in the standing posture, where reduced ceiling heights would cause the trunk to bend forward increasing the moment on the lumbar spine. However, this study (which involved lifting heavy mining electrical cables) found no difference between stooping and kneeling postures in terms of the peak spinal moment experienced by the subject. The primary determinant of the lumbar moment was the ceiling height. Lower ceilings were associated with higher lumbar moments, and vice versa (no matter which posture was employed). The question raised by this study is why there was not a decreased moment when the kneeling posture is employed. Clearly, the trunk can maintain a more erect posture when kneeling. However, analysis of this position reveals that the knees create a barrier that prevents the worker from getting close to the load at the beginning (and most stressful part) of the lift. This creates a large horizontal distance between the spine and the load, resulting in a large moment, apparently offsetting the benefits of maintaining a more erect trunk position.

Figure 4. B Lumbar moments, an indicator of load imposed on the low back, are increased as vertical workspace becomes more confined (Gallagher et al. 2001). No differences in peak lumbar moments were observed between stooping and kneeling postures, thus the moments depicted are collapsed across these postures.



The point must be made, however, that though the spinal moments appear equivalent in these two postures, the same might not hold true for injury risk. Biomechanical analyses indicate that spinal shear forces are high when the spine is fully flexed. In addition, there are indications that the compression tolerance of the spine is decreased in this position (Adams & Hutton, 1982). These factors would tend to favor the kneeling posture. However, one must also bear in mind the lower lifting capacity when kneeling. If the stooping posture is necessary due to strength demands, care should be taken to avoid the end range of spinal motion when performing the lift (McGill, 1999).

3.2.3. Trunk muscle activity in restricted postures

Changes in posture necessarily influence the roles and activation patterns of the muscles of the body. Studies examining the influence of posture on trunk electromyography (muscle electrical activity) have illustrated that restricted postures often result in significant changes in the manner in which muscles are recruited. One of the first studies of the muscle activity of the erector spinae muscles showed that when the trunk is placed in extreme flexion, these muscles become electrically silent (Floyd & Silver, 1955). It appears that the spinal ligaments and fascia assume responsibility for supporting the spinal column when it is fully flexed (either in standing or sitting postures). Biomechanical models suggest that this change results in an increased shear load on the lumbar spine compared to when muscles maintain control (Potvin, McGill, & Norman, 1991). When lifting from a fully flexed posture, the back muscles remain silent during the initial stages of lifting weights of up to 28.5 kg (Floyd & Silver, 1955). Many authorities believe that the change from active muscle support to ligament support of the spine might entail increased risk of low back pain (Basmajian & DeLuca, 1985; Bogduk, 1997); however, neither the association nor the mechanism has yet been established.

A recent study examined the influence of posture and load on the electromyographic activity of ten trunk muscles during a heavy cable-lifting task (Gallagher, Marras, Davis, & Kovacs, 2002). Results of this study indicated that posture and load have quite different influences on trunk muscle recruitment (and thus loads experienced by the lumbar spine). No matter which posture was adopted, an increase in the load lifted resulted in increased muscle activity of all ten trunks muscles studied. However, changes in posture typically influenced the activity of trunk muscles in a more selective manner, usually involving only a small subset of the muscles (though the muscles affected by posture were often influential in terms of spine loading). Moreover, the effects of posture and load were found to be independent and additive (i.e. posture and load were found not to interact in terms of their influence on muscle activity).

3.2.4. Intra-abdominal pressure (IAP)

Increased pressure within the abdominal cavity has been used by some researchers as a measure of stress on the spine, and has been used to assess restricted postures (Ridd, 1985). Analysis of IAP responses in standing and stooping postures reveal an almost linear decrement with progressively lower vertical workspace up to 90% of stature, whereupon the decrement levels off. In stooping positions ranging from 66 - 90% of full stature, the decrease in lifting capacity was a consistent 60%, according to the IAP criterion. The kneeling posture was found to incur only an 8% decrease in lifting capacity where the space restriction was equivalent to 75% of stature. There is some indication that lifting asymmetrically is less stressful than sagittal plane activities in restricted postures. This result is in accord with psychophysical lifting capacity data described above. It is interesting to note that IAP is one of the few ergonomics measures which indicate increase stress in the stooping posture; however, the assumption that IAP is a good indicator of spinal stress is still a contentious issue (McGill & Norman, 1987).

3.3 Physiologic Costs of Work in Unusual or Restricted Postures

The posture adopted in the performance of a work task has a decided influence on the metabolic demands incurred by an individual. Nowhere is this more evident than in the evaluation of metabolic demands of working in restricted mining workspace. Several studies have indicated that restrictions in vertical space greatly increase the cost of locomotion. The most thorough experiment of the effects of stoop walking and crawling was reported by Morrissey, George, & Ayoub (1985). This study illustrated a progressive trend toward increasing metabolic cost as stooping becomes more severe (Table 1). Not only is the metabolic cost increased as stooping becomes more severe, the maximum speed attainable by subjects is reduced, particularly when stoopwalking at 60% stature and when crawling.

Table 1. Physiological cost of erect walking, stoopwalking, and crawling. Numbers in parentheses represent the standard deviation (Morrissey et al. 1985). The percentages for stoopwalking conditions refer to ceiling height restrictions based on each subject's full stature.

Task	Sex	Heart rate (beats/min)	Ventilation volume (L/min)	Percent Work Capacity	Oxygen uptake (ml$\cdot$ kg^{-1}$\cdot$min^{-1})
Normal Walk	Male	89.2 (5.4)	10.6 (0.4)	10.9 (0.9)	5.0 (0.9)
	Female	89.7 (3.6)	9.6 (0.7)	11.6(2.2)	4.4 (0.6)
90% Stoopwalk	Male	96.0 (9.3)	12.8 (0.9)	12.5 (2.0)	5.7 (1.4)
	Female	107.5 (6.8)	12.4 (1.8)	15.3 (2.9)	5.8 (0.4)
80% Stoopwalk	Male	86.8 (15.8)	13.9 (1.8)	14.7 (2.3)	6.8 (1.5)
	Female	92.0 (12.7)	12.0 (0.6)	15.2 (2.2)	5.8 (0.2)
70% Stoopwalk	Male	82.2 (7.2)	13.2 (1.7)	15.1 (4.1)	6.8 (1.5)
	Female	89.9 (11.1)	11.0 (1.2)	15.7 (3.5)	6.0 (1.0)
60% Stoopwalk	Male	88.5 (7.2)	17.0 (2.3)	18.1 (1.4)	8.3 (1.0)
	Female	100.5 (21.6)	16.2 (5.3)	21.3 (5.0)	8.1 (1.8)
Crawling	Male	81.3 (11.3)	12.5 (1.3)	15.5 (2.3)	7.0 (0.5)
	Female	87.4 (7.8)	10.3 (1.0)	14.8 (2.7)	5.7 (1.8)

The metabolic cost of manual materials handling in restricted postures (stooping and kneeling) has also been studied. These studies suggest that the metabolic cost of manual materials handling is influenced by an interaction between the posture adopted and the task being performed. For example, the kneeling posture is more costly than stooping when a lateral transfer of materials is done (Gallagher, Marras, & Bobick, 1988; Gallagher & Unger, 1990). However, other studies have illustrated that kneeling can be more economical when the task requires increased vertical load displacement (Freivalds & Bise, 1991; Gallagher, 1991). A study of shoveling tasks found no difference in energy expenditure in standing, stooping and kneeling postures (Morrissey, Bethea, & Ayoub, 1983); however, only five subjects participated in this study and it may suffer from a lack of sufficient power to detect differences.

4. EPIDEMIOLOGIC STUDIES OF RESTRICTED POSTURES AND MUSCULOSKELETAL DISORDERS

Unfortunately, the number of epidemiologic studies examining the association of restricted postures to the occurrence of musculoskeletal disorders remains sparse. However, as detailed below, studies that have investigated this relationship have indicated higher rates of musculoskeletal disorders in restricted as opposed to unrestricted postures. Lawrence (1955) examined British coal miners to identify factors related to degenerative disk changes, and found that injury, duration of heavy lifting, duration of stooping, and exposure to wet mine conditions were the factors most associated with spinal changes. Another study investigating spinal changes in miners was reported by MacDonald, Porter, Hibbert, & Hart (1984). These investigators used ultrasound to measure the spinal canal diameter of 204 coal miners and found that those with the greatest morbidity had significantly narrower spinal canals. The study by Lawrence (1955) and other evidence suggests that the seam height of the mine has a marked influence on the incidence of low back disorders. In general, low back compensation claims appear to be highest in seam heights of 0.9 - 1.8 meters (where stooping is prevalent). Low back claims are slightly lower in seams less than 0.9 meters (where kneeling and crawling predominate), and are substantially reduced when the seam height is greater than 1.8 meters.

The finding of increased low back claims in conditions where stooping predominates is congruent with other evidence relating non-neutral trunk postures to low back disorders. For example, a case-control study by Punnett et al. (1991) examined the relationship between non-neutral trunk postures and risk of low back disorders. After adjusting for covariates such as age, gender, length of employment and medical history, time spent in non-neutral trunk postures (mild or severe flexion and bending) was strongly associated with back disorders (OR 8.0, 95% CI 1.4-44). Although it was difficult in this study to find subjects that were not exposed to non-neutral postures, the strong increase in risk observed with both intensity and duration of exposure were notable.

A study of 1773 randomly selected construction workers also examined the effects of awkward working postures on the prevalence rates of low back pain (Holmstrom, Lindell, & Moritz, 1992). This study found that prevalence rate ratios for low back pain were increased for both stooping ($p < 0.01$) and kneeling ($p < 0.05$) when the duration of work in these postures were reported to be at least one hour per day. Furthermore, a dose-response relationship was observed whereby longer durations of stooping and kneeling were associated with increased prevalence rate ratios for severe low back pain (Table 2). Thus, workers who adopt stooping or kneeling postures for longer periods of time appear to be at increased risk of experiencing severe low back pain.

Table 2. Age-standardized Prevalence Rate Ratios with 95% Confidence Intervals for Low Back Pain and Severe Low Back Pain when Adopting Stooping and Kneeling Postures for Different Durations (from Holmstrom et al. 1992).

	< 1 hour duration		1-4 hours duration		> 4 hours duration	
	LBP	Severe LBP	LBP	Severe LBP	LBP	Severe LBP
Stooping	1.17 (1.1 – 1.3)	1.31 (0.9-1.8)	1.35 (1.2 – 1.5)	1.88 (1.4 - 2.6)	1.29 (1.1 – 1.4)	2.61 (1.7-3.8)
Kneeling	1.13 (1.0 – 1.3)	2.4 (1.7-3.3)	1.23 (1.1-1.4)	2.6 (1.9-3.5)	1.24 (1.1-1.4)	3.5 (2.4-4.9)

In addition to the effects on the back, working in certain unusual or restricted postures (particularly kneeling) has been shown to affect musculoskeletal disorders of the lower extremity (Lavender & Andersson, 1999). Sharrard (1963) reported on the results of examinations on 579 coal miners in a study examining the etiology of “beat knee”. Forty percent of the miners reportedly were symptomatic or had previously experienced symptoms, characterized as acute or simple chronic bursitis. Incidence rates were found to be higher in seam heights lower than four feet and in workers required to kneel for prolonged periods at the mine face. The incidence of “beat knee” was found to be higher in younger mineworkers; however, this finding was thought to be due to a “healthy worker” effect. Specifically, it was thought that older workers with “beat knee” may have left the mining profession.

Studies have also indicated that other occupations where frequent kneeling is required experience higher rates of knee problems than comparison occupational groups (Tanaka, Smith, Halperin, & Jensen, 1982; Myllymaki et al., 1993; Coggon et al., 2000; Jensen, Mikkelsen, Loft, & Eenberg, 2000; Sandmark, Hogstedt, & Vingard, 2000; Nahit et al. 2001; Manninen, Heliovarra, Riihimaki, & Suomalainen, 2002). Tanaka, Smith, Halperin, & Jensen (1982) found that occupational morbidity ratios for workers compensation claims involving knee-joint inflammation for carpet layers was over 13 times greater than that of carpenters, sheet metal workers and tinsmiths. Knee inflammation among tile setters and floor layers were over 6 times greater than the same comparison groups. Workers in these occupations have been shown more likely to exhibit fluid accumulation in the superficial infrapatellar bursa, subcutaneous thickening of this bursa, and increased thickness in the prepatellar region (Myllymaki et al., 1993). The much higher incidence associated with carpet layers is probably also related to their use of a knee-kicker, a device used to stretch carpet during its installation. Knee impact forces during the use of this device have been shown to be as high as 4 times body weight (Bhattacharya, Mueller, & Putz-Andersson, 1985).

5. STATUS OF KNOWLEDGE AND RESEARCH NEEDS

As noted earlier, a substantial number of workers may have to adopt unusual or restricted postures during the performance of their daily work. The research reviewed here has shown that these postures can cause significant reductions in performance capabilities and are also associated with an increase in musculoskeletal complaints. Performance limitations result from the combinations of increased biomechanical loads, higher physiological costs, reduced strength, decreased stability or balance, and by limiting the use of substitute motion patterns to relieve fatigued muscles. However, it must be recognized that in spite of the increased knowledge regarding the capabilities and risks associated with work restricted postures gained over the past couple of decades, many fundamental questions remain unanswered. The following list describes some of the most important unresolved research needs, in the author's mind, that should be addressed in this area:

5.1 Improved Exposure Assessment

Our current understanding of the risks associated with work in restricted postures is hampered by a lack of effective exposure assessment methods. Most exposure assessments are obtained via subjective reports of the amount of time spent in restricted postures. Development of methods or tools that provide more objective and quantifiable measures of exposure to these postures are necessary. Doing so may help identify more specifically the exposures that are related to the development of musculoskeletal disorders. For example, it may be that the time spent in deep knee flexion is the critical issue with respect to development of injuries to the menisci. Improved understanding of such relationships may be critical in the prevention and control of injuries resulting from work in restricted postures.

5.2 Understanding the Body's Adaptations to Work in Restricted Postures

The human body adapts to the physical demands placed upon it during activities of daily life. Some adaptations may accrue positive benefits (such as increased strength capacity), others may have detrimental effects (inflammatory processes). Our current understanding of the musculoskeletal adaptations made in response to work in restricted postures is not well developed. Among the many questions that should be addressed are: Do back muscles atrophy or experience dysfunction when subjected to frequent stooping, as suggested by the results of Ayoub et al. (1978, 1981)? How does work in restricted postures shift the muscular and biomechanical demands on the joints of the body? Is the body more subject to localized muscular fatigue in restricted postures? What impact might this have on injury experience? Are joint degenerative changes accelerated when working in restricted postures? Why? Answers to these and other questions regarding the adaptations made to work in restricted postures may lead to an improved ability to design jobs to reduce the risk of musculoskeletal disorders for workers who must employ such postures.

5.3 Understanding Injury Pathways Resulting from Work in Restricted Postures

The epidemiological evidence described in this review clearly suggests that specific postures result in increased risk of injury to specific joints of the body. However, the injury pathways have not been clearly elucidated. Investigations should examine the role of joint forces, fatigue failure of musculoskeletal tissues, and inflammatory processes in the development of musculoskeletal disorders in the joints and tissues stressed in specific restricted postures.

5.4 Intervention Effectiveness

Several recommended practices for reducing injury risk are contained in the following section. While these are based on established ergonomics principles, it is not known the degree to which instituting such interventions will alleviate injury risk. Controlled intervention studies are needed to evaluate the effectiveness of job redesign, use of special personal protective equipment (e.g., knee pads), and administrative controls in protecting workers against the risks associated with working in restricted postures.

6. RECOMMENDATIONS FOR REDUCING MUSCULOSKELETAL DISORDER RISK IN RESTRICTED POSTURES

The findings of recent studies that have examined the capabilities, limitations, and tolerances of unusual or restricted postures can assist in forming a basis for intervention principles designed to reduce the risk of MSDs to workers who must adopt them. The following sections discuss methods that may be useful in reducing injury risk for those who must work in restricted postures.

6.1 Avoid full flexion of the torso

Perhaps the most important advice that can be given to reduce back injury risk is to avoid work in severe torso flexion. As discussed above, epidemiologic evidence indicates a clear association between flexion and low back disorders, and recent studies have highlighted several potential pathways associated with flexion that may lead to both short- or long-term low back disorders (Gallagher, 2003; Solomonow et al., 1999). If flexion cannot be avoided, it should be minimized, and frequent breaks should be allowed to assume a less stressful position on the back. Lifting in a flexed posture can lead to rapid fatigue failure of spinal tissues and should also be avoided entirely or, alternatively, minimized to the greatest extent possible. Any loads lifted in flexion should be as light as possible; however, it should be noted that even light loads may lead to fatigue failure over a relatively short-time frame (Gallagher, 2003).

6.2 Design Loads in Accordance with Posture-Specific Strength Capacity

As detailed above, many unusual or restricted postures are associated with a reduced strength capability. As a result, loads that are acceptable to lift in an upright standing posture may exceed those appropriate when workers adopt a restricted posture. In general, lifting capacity in the kneeling and sitting postures is reduced by up to 20% compared to standing; whereas, squatting lifting capabilities may be reduced by up to 33% of the standing value. Lifting capacity in lying postures is generally much lower, with acceptable loads just 25-40% those considered acceptable when standing. It should be apparent that if workers must adopt one of the postures listed above for lifting activities, loads need to be adjusted downward to reflect the reduced strength capabilities associated with specific postures. This may require working closely with suppliers or manufacturers of items that must be manually handled in specific work postures.

6.3 Use of Mechanical-Assist Devices and Tools

Use of mechanical-assist devices and application-specific tools can often reduce the need to adopt awkward or restricted postures, or may reduce the stresses associated with operating in such postures. In unrestricted environments, examples of devices that can reduce the need to adopt awkward postures include lift tables and bin tilters. These devices may reduce the need for the worker to flex the trunk as would be needed to lift items off of the floor or to retrieve items from a large bin.

Often, it may be necessary to develop specialized devices or tools to reduce postural stress in restricted environments. While restrictions in workspace may limit the degree to which certain types of mechanical-assist devices can be employed, experience has shown that it is often possible to develop and/or fabricate specialized devices or tools that can reduce the risk of MSDs in restricted environments.

6.4 Rest breaks/Job rotation

As mentioned earlier in this paper, restricted spaces tend to force workers into situations where the burden or work will be borne by specific muscle groups, with a limited ability to employ substitute motion patterns as these muscles fatigue. As a result, localized muscle fatigue is likely to develop more quickly in the stressed muscle groups, with an attendant reduction in strength capacity and an increase in the risk of cumulative soft tissue damage and the development of MSDs. As a result, it is important to provide workers with more frequent rest breaks or opportunities to perform alternative tasks that relieve the strain experienced by affected muscle groups. However, while rest breaks and job rotation may be an effective method for reducing fatigue and strain associated with work involving restricted space, use of these methods also serves as an indicator that redesign of the job should be considered.

6.5 Personal protective equipment

If workers are required to perform tasks in a kneeling posture for any significant period of time, a good pair of kneepads should be provided and worn by the worker so that the risk of inflammation and bursitis can be reduced. Kneepads should provide cushioning foam or gel to reduce contact stresses on the knee joint, especially the patella and the patellar ligament. Often, kneepads are designed with a stiff exterior of plastic or rubber to protect the knee against puncture wounds from sharp objects as might be encountered when kneeling in a rocky or debris-covered surface. Some kneepads are articulated so that they bend with the knee as workers adopt standing and kneeling postures.

7. SUMMARY

Many workers adopt unusual or restricted postures during performance of their daily work. Recent research has shown that these postures can cause significant reductions in performance capabilities and are associated with an increase in musculoskeletal complaints. Performance limitations result from the combinations of increased biomechanical loads, higher physiological costs, reduced strength, decreased stability or balance, and by limiting the use of substitute motion patterns to relieve fatigued muscles. Special care needs to be taken in the design of jobs requiring the use of such positions, in order that reduced capabilities can be accommodated. Recommendations based on studies of lifting capabilities in the standing posture may far exceed what should be lifted in restricted postures. The data presented in this review article may provide a starting point for the development of ergonomics recommendations that apply to workers who must cope with work in restricted postures. Mechanical aids can reduce the risk of overexertion, but may need to be custom fabricated when restricted workspaces are present. In many cases, it may be possible to reduce object weights or strength requirements of a task, and increasing the frequency of rest breaks is advisable when awkward postures are used. Job rotation may be an effective strategy if the job to which the worker is rotated allows relief of the muscular fatigue or stress experienced in an unusual or restricted posture.

Though we have learned a substantial amount regarding such working postures in recent years, they remain a challenge to the ergonomics community. A particular need is to expand the applicability of ergonomics models and evaluation tools that currently do not address many of the unique demands associated with work in these postures. Development of models robust to changes in whole-body posture should do much to increase our insight into the structure and function of the musculoskeletal system.

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