43

Working in Unusual or Restricted Postures

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43.1 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 is capable of performing equally well under all conditions. In fact, when faced with certain types of tasks or environmental demands, the body may have to adapt using methods that result in substantial performance limitations. Such a phenomenon is evident when workers must 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" designates postures that are forced upon workers due to restrictions in workspace.

The vast majority of ergonomics research has focused on establishing design criteria for work involving standing (e.g., Snook and Ciriello, 1991; Waters et al., 1993) or seated postures (e.g., Grandjean, 1988), and understandably so. However, it must be recognized that there are numerous jobs (e.g., underground miners, aircraft baggage handlers, plumbers, agricultural workers, mechanics, etc.) where workers must perform in less desirable postures such as kneeling, stooping, squatting, and lying down (Haselgrave et al., 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 a restricted posture is adopted (Gallagher and Hamrick, 1991). However, recent years have seen an increase in research examining the musculoskeletal risks and physical limitations associated with working in these postures. The purpose of this article is to summarize current knowledge in this area, and to establish principles for ergonomic design of jobs when working in unusual or restricted postures.

43.2 General Considerations

Workers typically enjoy the benefits of high strength capacity and mobility when they assume a normal standing position. This stance permits many powerful muscle groups to work in concert to accomplish occupational tasks. However, the muscular synergy present in the standing posture 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. This example illustrates two important aspects of work in unusual or restricted postures. First, the number of muscle groups available to generate forces to accomplish a task is often reduced compared to standing. Second, the reduced number of participating muscles may lead to increased demands on those that can be recruited. It should be evident that each unique postural configuration will result in its own set of strength limits. The number and identity of the muscles that can be effectively recruited for the job will largely determine these limits.

Task performance in unusual or restricted 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 may be dramatically reduced. Reduced mobility 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 he or she 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 energy efficient twisting motion, at the expense of experiencing 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 to maintain balance.

As mentioned previously, these awkward work postures are often the consequence of restrictions in workspace, either vertically or laterally. For example, underground miners and aircraft baggage handlers often operate in workspaces where the available vertical space does not allow upright standing. Workspace restrictions of this sort put not only the worker in a bind, but also the ergonomist. 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.

Restricted spaces may 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, psychophysical 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 and Badger, 1986). Finally, as Drury (1985) points out, space limitations 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. Unfortunately, the opportunity to employ substitute motion patterns decreases as workspace becomes more limited. The result is intensified fatigue and a decrease in performance capabilities in restricted postures.

43.3 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, studies that have investigated this relationship have tended to exhibit higher rates of musculoskeletal disorders in restricted as opposed to unrestricted postures.

Lawrence (1955) examined British coal miners to identify factors related to degenerative disc 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 et al. (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, compensation claims appear to be highest in seam heights of 0.9–1.8 m (where stooping is prevalent). Claims are slightly lower in seams less than 0.9 m (where kneeling and crawling predominate), and are lowest when the seam height is greater than 1.8 m.

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 (either mild or severe flexion) was strongly correlated with back disorders (OR 8.0, 95% CI 1.4–44) (OR, odds ratio; CI, confidence interval). In fact, this study disclosed a dose–response between the degree of torso flexion and the risk of low back disorder. Mild flexion was associated with an OR of 4.9 while severe flexion was associated with an OR of 5.7. 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 et al., 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 1 h 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 43.1). 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 43.1 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

	<1 h duration		1–4 h duration		>4 h 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)

Source: From Holmstrom, E.B., Lindell, J. and Moritz, U. *Spine*, 17(16):663–671, 1992. With permission.

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 and 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 4 ft 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 in relation to comparison occupational groups. Tanaka et al. (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 six 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 four times the body weight (Bhattacharya et al., 1985).

43.4 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 electromyography. The following sections provide information regarding some of the effects of restricted postures on these performance measures.

43.4.1 Effects of Posture on Lifting Capacity

43.4.1.1 Lifting Capacity for a Single Lift

A comprehensive analysis of single lift psychophysical lifting capabilities in nontraditional working posture was performed by researchers at Texas Tech University under a contract from the U.S. Air Force (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 were 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.

Figure 43.1 and Figure 43.2 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 to 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 to 23% less than standing lifts), and squatting resulted in the lowest

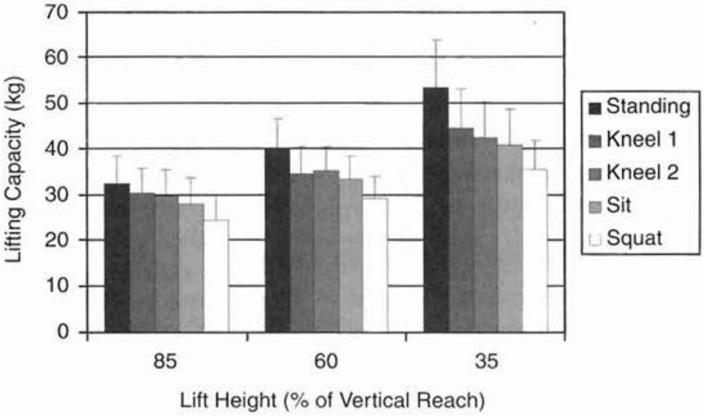

FIGURE 43.1 Acceptable loads selected by males for single lifts in several postures. Bars represent means, error bars represent standard deviations. (From Gibbons, L.E. Summary of Ergonomics Research for the Crew Chief Model Development: Interim Report for Period February 1984 to December 1989. Armstrong Aerospace Medical Research Laboratory Report No. AAMRL-TR-50-038. Wright-Patterson Air Force Bare, Dayton, OH, 1989. With permission.)

acceptable loads (20 to 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.

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 limitations in shoulder and arm strength, and are thus not as dependent on body posture per se. Finally, comparison of male strength (Figure 43.1) versus female strength (Figure 43.2) indicates that posture effects are similar for both genders; however, the strength exhibited by females averaged about 50 to 60% of that achieved by their male counterparts.

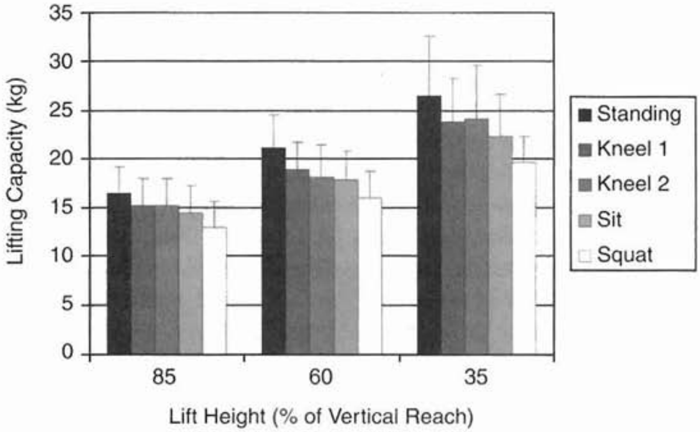

FIGURE 43.2 Acceptable loads selected by females for single lifts in several postures. Bars represent means, error bars represent standard deviations. (From Gibbons, L.E. Summary of Ergonomics Research for the Crew Chief Model Development: Interim Report for Period February 1984 to December 1989. Armstrong Aerospace Medical Research Laboratory Report No. AAMRL-TR-50-038. Wright-Patterson Air Force Bare, Dayton, OH, 1989. With permission.)

A separate study performed at Texas Tech looked at strength capacities in prone, supine, or side-lying positions (Gibbons, 1989). These postures exhibit drastic reductions in lifting capacity, with acceptable loads just 25 to 40% of standing values. The only exception was when the subject performed a two-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%. 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.

43.4.1.2 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 over more extended time frames (Gallagher et al., 1988; Gallagher and Unger, 1990; Gallagher, 1991; Gallagher and Hamrick, 1992). These studies also used the psychophysical approach, allowing subjects to adjust the weight in lifting boxes to acceptable loads during 20-min 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 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 and Hamrick, 1992), and kneeling was found to have a significantly reduced estimate of acceptable load compared to stooping (Gallagher et al., 1988; Gallagher and Unger, 1990; Gallagher, 1991). Kneeling and stooping postures 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 versus 0.9 m ceiling? Is lifting capacity when stooping different under a 1.5 versus 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 and 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 posture effects were no longer evident (Gallagher and Hamrick, 1992).

A surprising (and somewhat unsettling) finding from these studies is that psychophysical lifting capacity in prolonged torso flexion (over a 20-min time frame) is not much different from unrestricted standing for the same lifting task (Gallagher and Hamrick, 1992). In one respect, this is not too surprising because the stooping posture is a position 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 prolonged stooping may be associated with ligament creep and an attendant reduction in the ability to recruit the back muscles (Bogduk, 1997; Solomonow et al., 1999). Furthermore, it has been suggested that potentially damaging shear forces may be present in this posture (McGill, 1999), and fatigue failure may occur more rapidly (Gallagher, 2003). Subjects may not get sufficient proprioceptive feedback regarding these matters; thus, they may not play into estimates of load acceptability. Nonetheless, 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.

43.4.2 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.

43.4.2.1 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 et al., 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.

An intriguing set of strength data comparing isometric strengths of coal miners working in restricted postures to a comparison population of industrial workers, presented by Ayoub et al. (1981), is shown in Figure 43.3. 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-seam 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

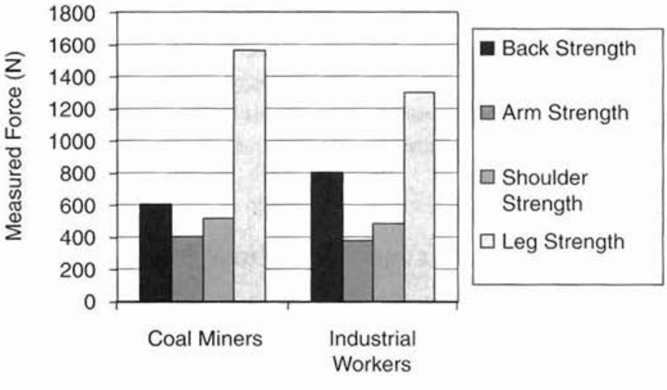

FIGURE 43.3 Comparison of strength measures for coal miners working in confined vertical space (Ayoub et al., 1981) to an industrial population (From Ayoub, M.M., Bethea, N.J., Deivanayagam, S., Asfour, S.S., Bakken, G.M., Liles, P., Mital, A., and Sherif, M. Determination and Modeling of Lighting Capacity, Final Report, Grant #5R010H-0054502, HEW, NIOSH. Texas Tech University, Lubbock TX, 1978. With permission.)

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 et al., 1988). The results of Ayoub et al. (1981) may reflect a relative deconditioning of back muscles when stooping (due to the flexion–relaxation phenomenon), perhaps the result of prolonged inhibition of muscular activity (e.g., Floyd and Silver, 1955) and damage associated with ligament creep (Solomonow et al., 2003). Furthermore, increased reliance on the leg and hip musculature may be necessary in situations where prolonged torso flexion is required (producing an increase in leg strength). Further research is needed to ascertain long-term adaptations in strength resulting from prolonged work in restricted postures.

43.4.2.2 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 43.4, recent evidence has shown that as vertical workspace is reduced, the moment experienced by the lumbar spine will be increased (Gallagher et al., 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. The lower the ceiling was the higher the moment experienced (no matter which posture was chosen). 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.

The point must be made, however, that though the spinal moments appear equivalent in these two postures, the same might not hold true for risk of experiencing a low back disorder. Biomechanical

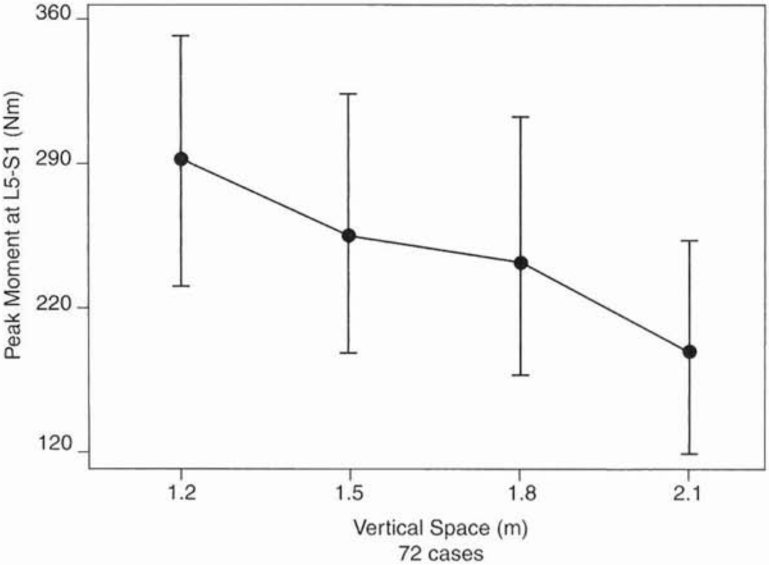

FIGURE 43.4 Lumbar moments, an indicator of strain experienced by the low back, are increased as vertical workspace becomes more confined (From Gallagher, S., Hamrick, C.A., Cornelian, K., and Redfern, M.S. *Occupational Ergonomics*, 2(4):201–213, 2001. With permission.)

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. 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).

43.4.2.3 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 and 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 et al., 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 and 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 disorder (Basmajian and DeLuca, 1985; Bogduk 1997; Solomonow et al., 2003).

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 et al., 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 load 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).

43.4.2.4 Intra-Abdominal Pressure

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 intra-abdominal pressure (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 to 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. Unfortunately, the assumption that IAP is a good indicator of spinal stress is still a contentious issue (McGill and Norman, 1987).

43.4.3 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 a restricted 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 et al. (1985). This study illustrated a progressive trend toward increasing metabolic cost as stooping becomes more severe (Table 43.2). Not only is the

TABLE 43.2 Physiological Cost of Erect Walking, Stoopwalking, and Crawling

Task	Sex	Heart Rate (beats/min)	Ventilation Volume (l/min)	Percent Work Capacity	Oxygen Uptake (ml kg^{-1} 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)	11.06 (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)

Note: Numbers in parentheses represent the standard deviation.

Source: From Morrissey, S.J., George, C.E., and Ayoub, M.M. *Applied Ergonomics*, 16, 99–102, 1985. With permission.

metabolic cost increased as stooping becomes more severe, the maximum speed attainable by subjects is reduced, particularly when stoopwalking at 60% normal stature and when crawling.

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 can be more costly than stooping when a lateral transfer of materials is done (Gallagher et al., 1988; Gallagher and Unger, 1990). However, other studies have illustrated that kneeling is more economical when the task requires increased vertical load displacement (Freivalds and Bise, 1991; Gallagher, 1991). A study of shoveling tasks found no difference in energy expenditure in standing, stooping and kneeling postures (Morrissey et al., 1983); however, only five subjects participated in this study and it may have suffered from a lack of sufficient statistical power to detect differences.

43.4.4 Recent Evidence on the Hazards of Torso Flexion

Torso flexion has long been considered on of the most hazardous positions in which to perform manual work. This belief has been reinforced by several recent studies that have uncovered some of the reasons why torso flexion may be so strongly related to the development of low back disorders. These studies have included an analysis of fatigue failure of the lumbar spine in flexed versus neutral postures (Gallagher, 2003), as well as studies that have investigated the neurological effects of creep of the posterior ligaments of the lumbar spine resulting from prolonged or repeated flexion (Solomonow et al., 2003). As will be seen, these studies suggest that deep torso flexion may be a significant pathway for the development of at least two different types of low back disorder.

Not only does deep flexion of the torso result in rapid fatigue failure of lumbar tissues when lifting, it also appears to be associated with neuromuscular dysfunction in the lumbar region. A series of studies summarized by Solomonow et al. (2003) using a cat model have shown that creep of lumbar ligaments can lead to a rapid and long lasting dysfunction in the lumbar musculature. In fact, these authors have shown that the creep developed in 20 min of static or cyclic flexion does not fully recover even after 7 h of rest (Solomonow et al., 2003). Flexion was also shown by these authors to elicit a large inflammatory response in the soft tissues of the lumbar spine, which may result from collagen micro-damage and which may explain the hyperexcitability observed in the multifidus muscle with ligament creep (Solomonow et al., 2003).

Fatigue failure of lumbar motion segments subjected to loads associated with lifting an object in different torso flexion postures was recently investigated by Gallagher (2003). This author simulated the spinal

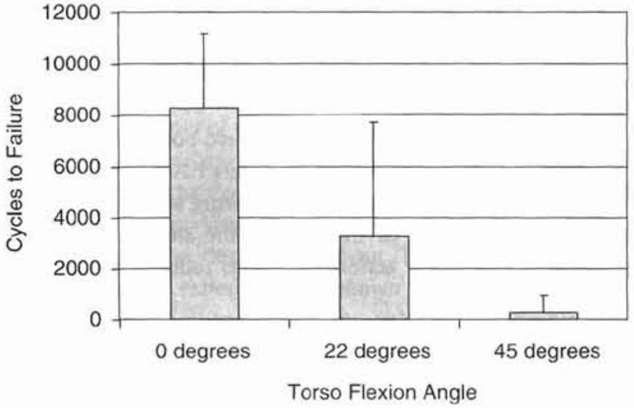

FIGURE 43.5 The number of cycles to failure for lumbar motion segments when exposed to spinal loads estimated when lifting a 9-kg box (From Gallagher, S., Ph.D. Dissertation, 2003).

loads associated with lifting a 9-kg weight in three torso flexion positions (neutral, partial, and full flexion), and subjected spinal motion segments to these loads repetitively until failure occurred. Results of this study are shown in Figure 43.5. As can be seen, the simulated loads associated with lifting 9 kg in the neutral posture could be tolerated for 8257 cycles on average; however, specimens in partial flexion lasted an average of 3257 cycles, while those at 45° lasted an average of only 263 cycles before failure. Results of this study suggest that lifting of loads in a flexed torso posture may result in rapid fatigue failure of tissues of the lumbar spine, and may be an important determinant in the development of low back disorders.

Epidemiologic studies have long revealed an association between torso flexion postures and low back disorders or pain. The etiology underlying the association has remained obscure, however. The recent studies described above suggest at least a couple of possible pathways by which low back disorders may develop during work in torso flexed postures. That is, the flexed trunk posture may lead to micro-damage of the ligaments of the spine, leading to a muscular dysfunction that, while recoverable, may affect the lumbar region for up to several days, or jobs such as lifting in trunk flexion may lead to more significant fatigue failure in motion segments of the lumbar spine, resulting in endplate fractures and disc degeneration which may lead to significant disability and pain, which may not be easily recoverable. It is hoped that continued research along these lines may further elucidate the etiology of low back disorders associated with torso flexion.

43.5 Intervention Principles for Unusual or 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 musculoskeletal disorders 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.

43.5.1 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 earlier, 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. 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 short time frame.

Evidence of the adverse effects associated with the flexed torso posture continues to mount, and several potential pathways to the development of low back disorders have been recently identified. Of all the restricted postures discussed in this paper, the stooping posture seems most likely to lead to short- or long-term low back disorders. Eliminating or minimizing the amount of torso flexion workers must perform on the job may be the best single action to take to reduce the risk of low back disorders in the occupational working environment.

43.5.2 Design Loads in Accordance with Posture-Specific Strength Capacity

As detailed previously, 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. Figure 43.6 shows an example of redesign of bags of rock dust, used to suppress coal dust in an underground mine. The traditional 50-lb (23 kg) bag is shown on the left. Based on a request from the mine, the manufacturer supplied rock dust in a 40-lb (18 kg) bag more acceptable to handle in the restricted postures workers used in the mine.

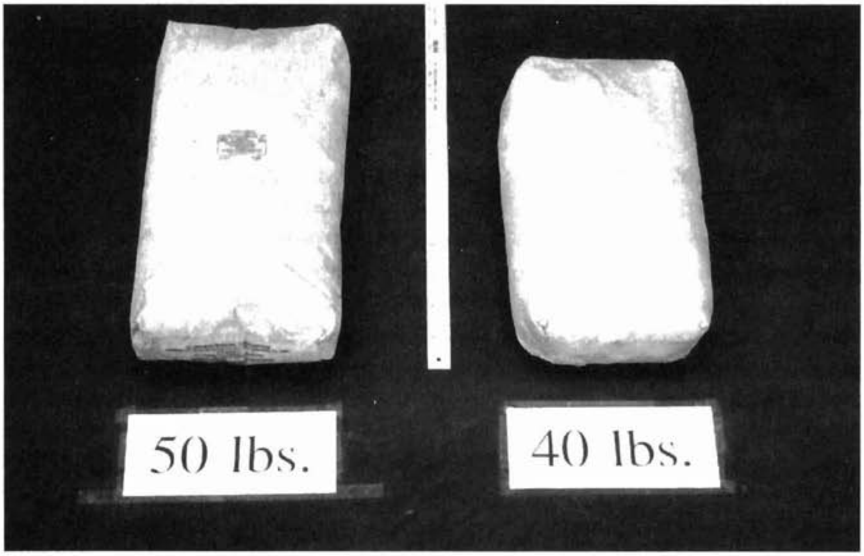

FIGURE 43.6 Redesign of a standard 50-lb (23 kg) bag to 40 lb (18 kg) was achieved by working with supplier, and creates a more acceptable load for workers operating in restricted postures.

43.5.3 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 fabricate specialized devices or tools that can reduce the risk of musculoskeletal disorders in restricted environments. An example from the coal mining industry is shown in Figure 43.7. This figure shows a specialized cart that rides on conveyor belt structure in a mine and can be used to move heavy supplies in restricted spaces. Various carts, jacks, and hoists can often be used quite effectively to assist with transport of materials in environments with restricted vertical space. Use of such equipment can significantly reduce the threat of musculoskeletal disorders when working in restricted space.

43.5.4 Rest Breaks/Job Rotation

As mentioned earlier in this chapter, 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 musculoskeletal disorders. 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.

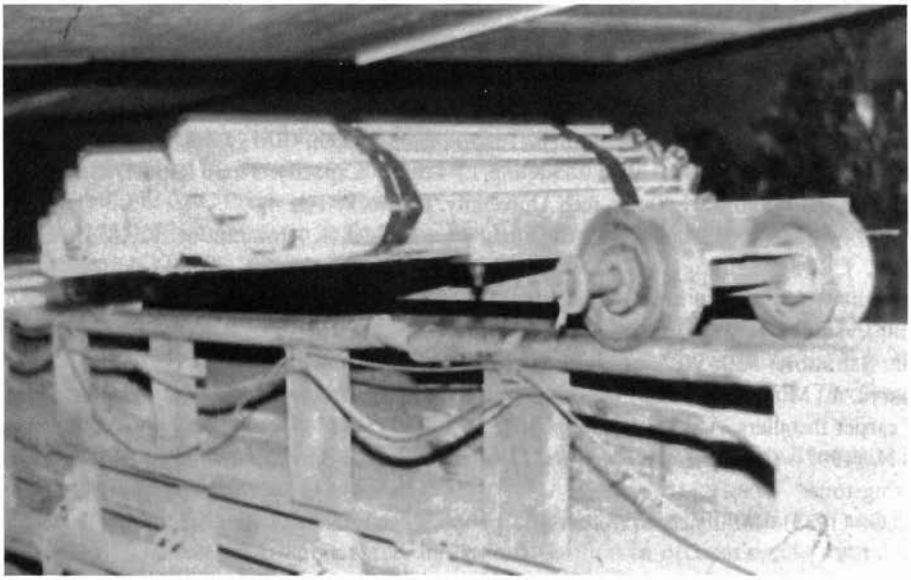

FIGURE 43.7 Example of a specialized cart to eliminate manual transfer of supplies in a restricted environment.

43.5.5 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.

43.6 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. Continued 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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