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THE EFFECTS OF DIFFERENT LEVELS OF MUSCULAR STRENGTH
ON BODY POSTURING IN A MANUAL LIFTING TASK:
AN EXPLORATORY STUDY

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Gina Lynne Sharpe

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DEDICATION

To my parents, Larry and Sue Smith, who taught me the value of dreaming about the future and the discipline necessary to achieve my goals.

To my husband, Kenny, whose continuing support of my interests and goals I cherish.

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ABSTRACT

In back care programs the erect-torso squat lifting technique is sometimes recommended without concern for the strength of the person's trunk and leg musculature, which if insufficiently developed, may restrict the persons ability to lift in this manner when instructed to do so. The purpose of this study was to evaluate the effects of different levels of strength on body posturing during lifting. In this investigation forty two apparently healthy male university students underwent a battery of tests to determine their respective levels of strength. From this group six were identified as being of a high level of strength and six were identified as being of a low level of strength. These 12 subjects received instruction on how to perform a manual lifting task; the task was to displace a 90 kg box from the floor to the height of the umbilicus using the flexed-knee method of lifting. Cinematographic techniques were used to examine the (a) angular positioning of the knee and torso and (b) moment arm of the box lifted relative to the body's center of gravity. In addition, a lumbar monitor was used to record angular positioning of the low back. Differences were found between the high and low strength groups for posturing of the knee, torso, and lumbar spine. Throughout most of the duration of the lift the high strength subjects demonstrated more pronounced knee flexion and greater trunk

extension as is seen in the usually recommended squat method of lifting. The low strength subjects were more variable in their lifting postures; some lifted in a manner similar to the high strength subjects and others selected a more extended-knee, flexed-torso posturing. Based on the results of this study it was concluded that variations in the levels of strength may be accompanied by differences in body posturing during lifting.

TABLE OF CONTENTS

CHAPTER	PAGE
I. INTRODUCTION.	1
Purpose of the Study.	5
Scope of the Study.	5
Hypothesis.	6
II. REVIEW OF THE LITERATURE.	7
The Contribution of the Trunk and Leg Musculature to Minimizing Spinal Loads During Lifting.	7
Muscular Strength and Posture During Lifting. .	20
Summary	22
III. METHODOLOGY	23
Subject Selection	23
Experimental Protocol	27
Measurement Methods	29
Level of Strength Evaluation.	29
Joint Range-of-Motion Assessments	32
Assessment of Body Posturing in the Lift Task.	34
The lift task	34
Cinematographic measurements.	35
Potentiometer assessment of lumbar spinal posturing.	36
Data Analysis	42
IV. RESULTS AND DISCUSSION.	45
Knee Joint Angle.	46
Torso Angle	52
Lumbar Spinal Angular Positioning	58
Moment Arm of the Object Lifted	64
Summary	68
V. CONCLUSIONS, IMPLICATIONS, AND RECOMMENDATIONS. .	72
Implications.	73
Recommendations	74
REFERENCES.	75
APPENDIXES.	83

APPENDIX A.	CHARACTERISTICS OF THE HIGH AND LOW STRENGTH SUBJECTS.	84
APPENDIX B.	INFORMED CONSENT	85
APPENDIX C.	CONSENT FOR EXTERNAL USEAGE OF FILM. . .	87
APPENDIX D.	FORTRAN PROGRAM FOR DIGITIZING FILM. . .	88
VITA.		91

LIST OF TABLES

TABLE	PAGE
1. Subject Characteristics	25
2. Summary of t-tests for Range-of Motion Tests. . .	26
3. Protocol for First Testing Session.	28
4. Protocol for Second Testing Session	28
5. Protocol for Third Testing Session.	29
6. Summary of ANOVA for Posturing of the Knee. . . .	47
7. Summary of Univariate F-tests for Posturing of the Knee	50
8. Summary of ANOVA for Posturing of the Torso . . .	53
9. Summary of Univariate F-tests for Posturing of the Torso	56
10. Summary of ANOVA for Posturing of the Lumbar Spine	59
11. Summary of Univariate F-tests for Posturing of the Lumbar Spine.	62
12. Summary of ANOVA for the Moment Arm of the Box Lifted.	65
13. Summary of Univariate F-tests for the Moment Arm of the Box Lifted	69

LIST OF FIGURES

FIGURE	PAGE
1. Body Posturing Angles	37
2. The Ady-Hall Lumbar Monitor	38
3. Subject Wearing the Ady-Hall Lumbar Monitor . . .	40
4. The Lumbar Monitor with the Calibration Unit. . .	41
5. Posturing of the Knee During a Flexed-Knee Lift .	48
6. Variability in Posturing of the Knee.	51
7. Posturing of the Torso During a Flexed-Knee Lift.	54
8. Variability in Posturing of the Torso	57
9. Posturing of the Lumbar Spine During a Flexed-Knee Lift.	60
10. Variability in Posturing of the Lumbar Spine. . .	63
11. Moment Arm of the Box Lifted Relative to the Center of Gravity of the Body	67
12. Variability in the Moment Arm of the Box.	70

CHAPTER I

INTRODUCTION

In America and in other industrialized countries low back pain is a common complaint among employees; it furthermore (a) accounts for more absenteeism than other type of occupational injury and (b) is the most expensive health care problem in individuals within the age range of 30-50 years (Kelsey & White, 1985). In the United States 23% of all workers' compensation claims filled in 1984 involved back trouble; these cases accounted for 42% of all compensation (National Safety Council, 1985). Approximately 14 billion dollars are expended annually in the United States on the treatment of low back problems and compensation payments associated with this condition (Spengler, Bigos, Martin, Zeh, Fisher, & Nachemson, 1986).

Although there is some evidence of an increased risk of low back problems among persons who have had sedentary occupations for several years, there appears to be a higher incidence in those in jobs involving the handling of heavy materials (Frymoyer, Pope, Cotanza, Rosen, Goggin & Wilder, 1980; Kelsey & White, 1985). Heavy manual material handling tasks, particularly lifting, have been indicted as being potential causal factors in occupational-related low back pain and injury (Anderson, 1981; Chaffin & Park, 1973; Frymoyer et al., 1980). In a review of the literature

Kishino, Mayer, Gatchel, Anderson, Gustin, and Mooney (1985) noted that low-back injury rates related to lifting tasks constitute a large percentage of all compensable injuries in industry. The biomechanical model developed by Schultz and Andersson (1981) and the intradisc pressure transducer technique employed by Nachemson (1966) provide research evidence which suggests that typical lifting tasks can lead to excessive compressive forces on the lumbar discs, strains in the back muscles, and sprains in the surrounding connective tissue. Therefore, reduction of lift-related low-back pain and injury is of economic and humanitarian importance and underscores the need for a better understanding of how to prevent such pain incidents.

The strength of the trunk musculature is an important consideration in preventing lift-related back injuries. Poulsen and Jorgensen (1971) and Troup and Chapman (1969) believe that strong back extensor musculature is a crucial factor in reducing lift-related back injuries. Farfan (1975) and his colleagues have extolled the role of strong abdominal muscles in protecting the lumbar spine during lifting. In addition to strong trunk musculature, Davis, Troup, and Burnard (1965) contend that well developed quadriceps are needed to lift heavy loads from a squatting position (i.e., the classic recommended lifting method).

A substantial amount of research has been published on the role of strong trunk musculature in supporting the back. However, little attention has been given to how a person's level of strength affects his or her lifting posture despite the contention "that instructions as to lifting postures must reflect a concern for the person's strength and mobility ..." (National Institute for Occupational Safety and Health (NIOSH) Work Practice Guidelines for Manual Lifting, 1981).

Although the influence of strength on how people lift has not been scrutinized extensively, Davis et al. (1965) suggested that weak quadriceps might have accounted for the variations they noted in a study of body posturing during the course of lifting. Using cinematographic techniques they found that during the initial phase of lifting heavy objects with flexed-knees, their subjects tended to raise their hips faster than their shoulders; consequently their trunks assumed the more prone position seen in the straight-leg lifting posture. In contrast to this, however, they found that their subjects kept their trunks closer to the vertical when they lifted lighter loads. It is typically assumed that one of the major advantages of the flexed-knee lifting technique is that the trunk remains more vertical and is therefore subjected to compressive forces which would be presumably smaller than those associated with the straight-leg trunk-flexed lifting

technique. However, for the heavier loads, the body posturing exhibited by the subjects in the Davis et al. (1965) study would appear to offset the apparent advantage of this method of lifting. Although these investigators did not collect muscular strength data, they did suggest that one possible explanation for their finding was that the quadriceps femoris muscles were not strong enough to undertake the stress through the knee joint center; this caused the subjects to convert the flexed-knee lift into the straight-leg trunk-flexed lift in order to reduce the moment on the knees. In agreement with this contention, and based on observations of workers lifting heavy objects, it has been noted that often a person's quadriceps will be insufficiently developed to permit them to perform a flexed-knee lift when instructed to do so (NIOSH, 1981).

It is accepted that the stresses on the back during lifting are highly dependent upon postural configuration (Adams & Hutton, 1985; Andersson, Ortengren, & Nachemson, 1977). In considering the factors that influence posture it is generally agreed that it is to a certain extent dependent upon muscular strength. This would suggest that studies examining the effects of different levels of strength on body posturing during a lifting task would be warranted. Such studies could improve our knowledge of how people lift and hopefully bring us nearer to an

understanding of how to prevent lift-related low back injuries.

Purpose of the Study

The purpose of this exploratory study was to compare kinematic characteristics of the flexed-knee lift as performed by two groups of subjects; one group was selected as being of a high level of strength and the second group was identified as being of a low level of strength. Analysis was limited to (a) posturing of the knee, torso and lumbar spine and (b) the moment arm of the object lifted relative to the body's center of gravity.

Scope of the Study

The subjects were 42 male volunteers from physical education and engineering classes at the University of Tennessee. All subjects underwent an assessment of their level of strength and were subsequently identified as being of a high, average or low level of strength. Twelve of these volunteers were then designated for inclusion in the evaluation of the effects of different levels of strength on body posturing throughout the course of a lift task; six of these met the criteria for the high level of strength category and six met the criteria for the low level of strength category. Their evaluation was based on (a) cinematographic measurements of the angular positioning of the knee, angular positioning of the torso, and the moment

arm of the box lifted relative to the center of gravity of the body and (b) potentiometer measurements of posturing of the lumbar spine. These parameters were assessed throughout the duration of the lift and statistical comparisons of the performance of the high and low strength subjects were made at selected points in the lifting cycle.

Hypothesis

It was hypothesized that variations in the levels of strength of the subjects would be accompanied by differences in selected aspects of body posturing in a lifting task.

CHAPTER II

REVIEW OF THE LITERATURE

The high mechanical stress on the spine during lifting is known to be an aggravating factor in low back pain syndrome and may be a precipitating factor of this condition in susceptible individuals. Strong trunk and leg musculature are critical for safely lifting heavy loads. In this chapter two areas relative to lifting will be reviewed; these are the (a) functional roles of the trunk and leg musculature in protecting the lumbar spine from lift-related back injuries and (b) relationship between the strength of these muscle groups and body posturing during lifting.

The Contribution of the Trunk and Leg Musculature to Minimizing Spinal Loads During Lifting

Several different research methodologies have been employed to elucidate trunk and leg muscle actions during lifting; these include (a) electromyographic (EMG) techniques, (b) intervertebral disc pressure and intra-abdominal pressure (IAP) measurements, (c) cinematographic analyses of lifting postures, and (d) mathematical modeling of the back.

EMG analyses of the muscle groups relevant to lifting were first published more than 30 years ago by Floyd and

Silver (1955) and since then by several others. In general these studies yielded the following insights:

1. When flexing the trunk to pick up an object, initially there is considerable myoelectric activity in the erector spinae (ES) muscle group; however, this diminishes in the mid-range and ceases by the extreme flexed position (Floyd & Silver, 1955; Kippers & Parker, 1984; Morris, Lucas, & Bressler, 1961). When extending the trunk from the fully flexed position, ES activity, although it does not begin initially, commences again at least by mid-range and generally reaches magnitudes higher than that seen in trunk flexion (Floyd & Silver, 1955).

2. The magnitude of ES electrical activity increases as the weight and moment arm (relative to the back) of the load increases in both flexion and extension (Andersson, Ortengren, & Nachemson, 1976; Tichauer, 1971).

3. When lifting moderate loads minimal or no activity is seen in the rectus, oblique, and transversus abdominis; however, heavier loads elicit a greater response (Bartelink, 1957; Ekholm, Arborelius, & Nemeth, 1982; Morris et al, 1961; Zetterberg, Anderson, & Schultz, 1987).

4. Contraction of the leg musculature occurs before activation of the ES in trunk extension (Ekholm, Nissell, Arborelius, Hammerberg, & Nemeth, 1984; Nemeth, Ekholm, & Arborelius, 1984; Tanni & Masuda, 1985).

In addition to measurements of EMG activity of the muscles, several investigators have measured IAP during lifting. Comparatively few researchers have measured intervertebral disc pressures throughout the course of lifting. Most investigators agree that IAP increases with increasing forward flexion of the trunk and with increased weight of the load lifted (Andersson et al, 1976; Bartelink, 1957; Davis & Troup, 1964; Mairiaux, Davis, Stubbs, & Batty, 1984; Marras, Joynt, & King, 1985; Morris et al., 1961). There is also general agreement that IAP is maximum at the start of lifting when the inertia of the upper body and burden must be overcome and decreases as the trunk is raised (Anderson, et al., 1976; Davis & Troup, 1964). Similarly, forward bending postures can appreciably raise intradiscal pressures, particularly when weights are held (Andersson, et al. 1976; Andersson, Ortengren, & Nachemson, 1977; Nachemson, 1966)

Several investigators have conducted cinematographic analyses of body posturing during lifting; in general their studies have revealed the following:

1. Bending forward to pick up an object is initiated by lumbar flexion. In the mid-range the pelvis begins to rotate in tandem with flexion of the lumbar spine (Anderson, Chaffin, & Herrin, 1986; Kumar, 1974).

2. When returning to the upright position the lumbar/pelvic patterning is reversed; pelvic rotation

occurs first, then lumbar extension predominates. The delay in re-extension of the lumbar spine increases as the weight of the object lifted increases (Davis et al., 1965; Kumar, 1974).

The body posturing data have served as input data for several different biomechanical models of the lower back. These models are used to predict (a) trunk musculature contraction forces needed to lift moderate to heavy objects and (b) the corresponding compression and shear forces on the intervertebral discs. Most of the contemporary models of the torso are limited to static analyses over the range of movement. The static models that assume that the posterior muscles of the back alone balance the forward bending moment generally give predicted compression values that approach or even exceed the tolerance limits found in cadaver specimens. This is because the ES muscles have little leverage (i.e., a short moment arm relative to the center of reaction of the discs) and therefore create high compression on the discs.

Schultz, Andersson, Ortengren, Haderspeck, and Nachemson (1982) calculated that holding two four-kg weights in outreached arms (i. e., parallel to the floor) while standing with the trunk flexed 30 degrees would place a 2,350 newton (N) compression force on the third lumbar disc. These investigators validated their static model of the spine by correlating the predicted ES muscle forces

required for a particular lift with measured ES EMG activities. Additionally, they correlated the predicted compression force on L3 with measured intra-abdominal and intradisc pressures. They found that the predicted ES forces correlated well with the EMG signal levels; furthermore, the predicted compression force on L3 and the measured L3 disc pressure were in agreement. The predicted compression force did not correlate as well with IAP; nevertheless, Schultz et al. (1982) concluded that their model provides relatively good estimates of spinal loads.

According to Ekholm et al. (1982) the mean compressive force on L5-S1 was 3,481 N when the subjects lifted a 12.8 kilogram load from the floor with the knees flexed and back erect; lifting with straight legs and a flexed trunk resulted in 4,390 N of compression. The Schultz model was used by Granhead, Jonson and Hansson (1987) to estimate the compressive force on L3 in eight elite power lifters during the performance of a dead lift at a competition. The weights lifted by these competitors ranged between 212 and 335 kg and the calculated compression on L3 ranged between 18,800 N to 36,400 N.

Static models of the trunk have been criticized because dynamic factors, such as the acceleration of the load, are not considered and compression may be underestimated. Taking into account dynamic effects, Leskinen, Stalhammer and, Kuorinka (1983) calculated mean

peak compression at L5-S1 to be 5,866 N when lifting 15 kilograms with the flexed-knee erect-torso method. The results of several other studies also support the contention that the predicted forces acting on the spine are higher with dynamic modelling (Anderson, Chaffin, Herrin, & Matthews, 1985; Bush-Joseph, Schipplein, Andersson, & Andriacchi, 1988; Freivalds, Chaffin, Garg, & Lee, 1984; Grieve, 1974; Hall, 1985; Troup, 1977).

The in vitro breaking point of the vertebral unit (i.e., vertebral body-disc-vertebral body) is considered to range between 2,500 and 12,000 N (White & Panjabi, 1978). Cadaver specimens from individuals under 40 years of age are typically much stronger than those from individuals over 60 years. In order to minimize the risk of back trouble, NIOSH (1981) recommends that disc compression loads above 3,425 N be avoided.

Models such as the aforementioned that suggest that damage to the spine may occur even if the burden lifted is of a moderate weight have been questioned. This puzzlement has led scientists to search for mechanisms that may reduce the tension in the trunk extensor musculature and thereby decrease lumbar compression to magnitudes below the failure point observed in vitro. It has been proposed that the activity of the abdominal muscles may relieve part of the load on the spine; however, controversy exists regarding the way in which these muscles contribute to stress

reduction. A widely held theory is that increased abdominal muscle tension contributes to an increase in IAP which presumably acts to reduce the load on the vertebral column during strenuous physical activities such as lifting. It has been hypothesized that the torque generated by IAP on the rear abdominal wall, by supplementing the extensor torque generated by the ES, reduces the amount of ES activity needed to lift heavy objects (Anderson et al., 1985; Bartelink, 1957; Morris, et al., 1961). Moreover, strong abdominal musculature is thought to increase the magnitude of load relief IAP can provide (Bartelink, 1957; Farfan, 1975; Nachemson, 1975).

Contrary to this, a team of investigators from Sweden concluded that there is no relationship between abdominal muscle strength and IAP during lifting (Hemborg, Moritz, Hamberg, Lowing, & Akesson, 1983; Hemborg & Moritz, 1985). These investigators subjected healthy individuals and low back pain patients to a progressive isometric abdominal muscle training program. The training regimen was similar for both groups except that the intensity was increased at a slower rate for some of the low back patients. Before and after the five week program the subjects underwent a trunk flexion strength test and performed a series of lifts. IAP and EMG activity of the ES and oblique abdominals muscles were recorded during the performance of the lifts. The training markedly increased trunk flexion

strength in both groups of subjects; however, it failed to affect ES activity and IAP during lifting. Moreover, the electrical activity of the obliques decreased after training. This finding implies that the subjects were able to perform the same task with fewer oblique abdominal motor units; it also suggests that the relationship between oblique activity and IAP may be nonlinear since the reduction in oblique activity did not cause a decrease in IAP. In a study by Marras et al. (1985), no significant correlations were found between IAP and electrical activity of the rectus abdominis, external oblique, or internal oblique musculature in a trunk extension task. However, a significant linear relationship was found between IAP and latissimus dorsi activity; it was concluded that both anterior and posterior trunk muscles may contribute to the development of IAP.

Gilbertson, Karg, and Pope (1983) studied the effectiveness of IAP in unloading the spine; in this study the subjects were asked to deliberately increase pressurization of their abdominal cavity (i.e., the Valsalva maneuver) while exerting trunk extension torques. It was hypothesized that the Valsalva maneuver should produce a decrease in the compressive load on the lumbar spine (i.e., a reduction in ES muscle activity). However, they found that this maneuver did not reduce the amount of ES activity needed to perform their trunk extension task.

In another study in which pressure transducers were inserted into the nucleus of the third lumbar intervertebral disc, Nachemson, Andersson, and Schultz (1986) found that the Valsalva maneuver did not appreciably reduce intradisc pressure during the performance of the lifting tasks examined. Since abdominal muscle exertions are necessary to increase IAP, it has been suggested that any potential extensor effect of increased IAP may be negated by the flexor moment generated by necessary contraction of the abdominals (Gilbertson et al., 1983; Nachemson et al., 1986).

After reviewing this issue one might conclude that the functional role of the IAP rise may be other than to modify compressive loads. It has been suggested that IAP may help stabilize the spine during the initial phase of heavy lifting in which the lifter must overcome the weight of the load (Gilbertson et al., 1983; Nachemson et al., 1986). In addition to the need for increased abdominal tension and IAP during the initial phase of lifting, Tanni and Masuda (1985) found that the activity of the abdominal muscles increased in back extension tasks when fatigue became a factor. This latter finding would give further support to the contention that strength and endurance of the abdominal musculature are important factors in decreasing lift-related back injuries.

The controversy concerning the importance of IAP as a spinal support mechanism has served as the impetus for the development of other explanations for the ability of some individuals to lift heavy loads without injuring their vertebral components. Dissections performed by Bogduk and Macintosh (1984) made it clear that the anatomical representation of the ES typically used in models of the trunk is inaccurate. The ES muscle group is generally represented by a single force vector with a 5 cm moment arm relative to the lumbar vertebral bodies. They found that it acts through a moment arm longer than 5 cm and contended that it should be represented by several force vectors (i.e., one for each muscle within the ES group). The anatomic considerations for modeling proposed by these investigators were recently incorporated in a dynamic model of the low back developed by McGill and Norman (1986). The estimates of L4-L5 disc compression derived from this model were lower than those predicted from traditional anatomic representations. However, these values were still close to the tolerance limits, particularly those for older individuals. This finding is consistent with the high incidence of lift-related back injuries.

Gracovetsky and Farfan (1986), in a study using mathematical modeling techniques, proposed that the posterior spinal ligamentous system (PLS), under the control of the hip extensor and abdominal musculature, is

important in the ability to lift heavy objects. In lifting, when lumbar lordosis is maintained the PLS remains slack, and as a result it does not contribute to generation of the extensor moment and therefore counterbalancing forces must be provided by the ES alone. Because the ES are closer to the center of reaction of the discs than the PLS, the ES have less leverage and create more compression on the discs than the ligaments for any given turning moment. Gracovetsky and Farfan (1986) have suggested that, due to increased compression upon the spinal column, the lordotic lifting technique may be inappropriate. Flattening the lordotic curve (i.e., tilting the pelvis backwards by contracting the gluteal, hamstring and abdominal musculature) increases the tension along the PLS. Tension in the PLS may also be increased by the IAP pushing dorsally. However, according to the Gracovetsky-Farfan model reduction of lordosis plays a greater role than IAP in enabling the PLS to assist in development of the extensor torque and concurrently contribute to reduction in lumbar disc compression.

In the development of their model the Gracovetsky-Farfan group originally proposed that contraction of the lateral trunk musculature, primarily the transversus abdominis, contributes significantly to the extensor moment by placing lateral tension on the PLS; this tension in turn can aid extension by bringing the spinous processes into

approximation (Gracovetsky, Farfan, and Helleur, 1985). However, Macintosh, Bogduck, and Gracovetsky (1987), in their detailed cadaver studies of the lines of actions of trunk muscles, found that only a limited portion of the transversus acts to exert lateral tension on the PLS. Therefore, they concluded that the contribution of the transversus abdominis to the PLS load relieving mechanism is minimal. It has been suggested that, in addition to kyphotic posturing, contraction of the latissimus dorsi may serve to stretch the PLS (Bogduk & Macintosh, 1984). Gracovetsky and Farfan (1986) contend that the ES alone are incapable of providing the extensor torque required for lifting heavy objects, and therefore must be aided by the anti-flexion moments generated by the PLS mechanisms.

In addition to the trunk musculature, the hip and knee extensors are prime movers in lifting tasks. In flexed-knee lifts the vastus medialis and lateralis are the first muscles to contract; in straight-leg lifts the hamstrings are first (Ekholm et al., 1982; Nemeth et al., 1984). The adductor magnus and gluteal muscles are also activated in the early phase of lifting prior to contraction of the ES. These muscles act to extend the hip; thus lifting is initiated by hip extension and then followed by extension in the lumbar spine. In an investigation of the sequencing of muscle contraction during trunk extension from a straight-leg position, myoelectric activity was

first detected in the semitendinosus and then in the ES. (Tanni & Masuda, 1985). The investigators suggested that, in addition to extending the hip, the semitendinosus helps stabilize the body while the ES are silent.

It is presumed that the flexed-knee erect-back lifting method enables the lifter to hold the load close to the torso, and therefore the forward turning moment and compression on the back will be minimized. In a study in which cinematographic techniques were used to analyze the flexed-knee lifting method, it was found that at the start of the lift most of the subjects positioned their center of gravity behind the center of motion of their knees (Ekholm et al., 1984). This posturing caused a large flexing moment at the knees which had to be counteracted by the knee extensor musculature. It has been contended that many people do not have the knee extensor strength necessary to lift heavy objects from this position (NIOSH, 1981). However, the effects of insufficient strength have not been studied specifically with reference to body posturing in flexed-knee lifting.

Muscular Strength and Posture During Lifting

Although the influence of strength on body posturing during lifting has not been scrutinized extensively, hypotheses concerning the effects of both (a) weak quadriceps on lifting posture and (b) weak trunk muscles on

lumbar spinal curvature have been proposed. It is generally agreed that the major advantage of the flexed-knee lifting technique is that the trunk remains more vertical and is therefore subjected to compressive forces which are smaller than those associated with the straight-leg trunk-flexed lifting posture. However, Davis et al., (1965), using photogrammetric techniques, noted that during the initial phase of lifting heavy objects with bent knees, the subjects tended to raise their hips faster than their shoulders, and thus their trunks were inclined toward the more prone position seen in the straight-leg lifting posture. The body posturing exhibited by these subjects would appear to offset the apparent advantage of this method of lifting. Although Davis et al. (1965) did not collect muscular strength data, they suggested that one possible explanation for this finding was that the quadriceps femoris muscles were not strong enough to undertake the stress through the knee joint causing the subjects to convert the bent-knee lift into the straight-knee and trunk-flexed lift in order to reduce the moment on the knees. In agreement with this hypothesis, and based on observations of workers lifting heavy objects, it has been contended that often a person's quadriceps muscles will be insufficiently developed to permit them to perform a flexed-leg lift when instructed to do so (NIOSH, 1981).

In addition to the previously proposed relationship between muscular strength and body posturing, it is widely held that the strength of the trunk muscles affects lumbar posturing. Specifically, weak abdominal and back musculature are thought to cause hyperlordosis (Assmussen & Heeboll-Nielsen, 1959). Isometric trunk flexor and extensor strength testing were employed in two studies designed to test this hypothesis (Flint, 1963; Suzuki & Endo, 1983); in the second of the aforementioned studies the subjects were also tested isokinetically at 30 degrees of trunk flexion and extension per second. In both studies, X-ray measurements of lumbar curvature in standing postures were not significantly correlated with trunk extension or trunk flexion strength. These findings suggest that the level of trunk muscle strength does not affect lumbar lordosis in standing. Additional studies are needed to determine its effects on lumbar posturing during more physically demanding dynamic activities such as lifting.

Although little attention has been given to the influence of strength on lumbar posturing in lifting, a few studies have focused on how different lumbar postures affect the loads imposed on the spine. As previously discussed, Gracovetsky and Farfan (1986), in a study using biomechanical modeling techniques, indicated that the kyphotic lifting posture (i.e., a backward pelvic tilt)

minimizes the compression on the lumbar discs by enabling the PLS to contribute to the development of the extensor moment. In contradistinction to this, Hart, Stobbe, and Jaraiedi (1987) contend the lordotic posture is safest for lifting. In a study using EMG techniques the latter investigators found minimal activity in the ES during the kyphotic lift and greater ES activity in the lordotic lift. Based on this observation these investigators contended that the lordotic posture was more appropriate for lifting because it facilitated rather than inhibited use of the prime trunk extensors.

Summary

The loads imposed on the lumbar spine during lifting are considered to be a significant factor in low back disorders. The strength of the trunk extensors is critical to the ability to safely lift heavy loads. The abdominal and leg muscles are important in lifting tasks as they contribute to the task. Although numerous studies have extolled the role of strong trunk and leg muscles in lifting, none have dealt specifically with the effects of low levels of strength on body posturing during lifting.

CHAPTER III

METHODOLOGY

In this study the effects of different levels of strength on body posturing in a lifting task were examined. Six strong and six less strong subjects provided data for the analysis. Evaluation was limited to (a) posturing of the knee, torso and lumbar spine and (b) the moment arm of the object lifted relative to the body's center of gravity. It was hypothesized that variations in strength would be accompanied by differences in the selected parameters. This chapter specifies the details concerning subject selection, experimental protocol, measurement methods, and data analysis.

Subject Selection

Male subjects were recruited from physical education and engineering classes at the University of Tennessee. When recruiting an attempt was made to control for age and anthropometric variability by limiting the subjects to volunteers who were (a) 20-35 years old and (b) within the fifth to ninety fifth percentile range for height (163.3 - 187.5 cm.) and weight (56.2 - 101.2 kg.) as promulgated by the Public Health Service (Stoudt, Damon, McFarland, & Roberts, 1965). In addition, participation was restricted to persons who (a) reported no signs or symptoms of acute

or chronic musculoskeletal and/or cardiovascular problems during the three months prior to the study and (b) had no marked standing postural deviation such as scoliosis or hyperlordosis. Individuals employed in jobs which require frequent lifting and competitive weight lifters were also excluded as subjects. These criteria for selection permitted the study of individuals who do not frequently practice a specific weight-lifting technique advocated by an employee training program or weight-lifting coach. However, prior to participation in this study some of the subjects had received instruction, from exercise leaders, pertaining to free weight lifting techniques. Furthermore, some of them regularly participated in exercise programs that included conventional free weight lifting activities.

At the initial testing all volunteers underwent an assessment of their level of strength. The upper and lower quartiles for "strength", found in a prior pilot testing of 48 male university students, were used to operationally define the strength level of the participant as high or low. (The procedures for designating the strength level of the subject are described in detail in the measurement methods section.) A participant whose strength score was in between these two extremes was classified as average. Forty two subjects were evaluated for strength; from this group six "high strength" and six "low strength"

participants were identified for inclusion in the comparative analysis of lifting postures.

Selected characteristics of the twelve subjects chosen for the evaluation of the effects of different levels of strength on lifting posture appear in Appendix A. No statistical differences ($p < .001$) were found in the age, height, and weight of the high and low strength subjects (Table 1).

Table 1. Subject Characteristics.

Parameter	High Strength (n=6)		Low Strength (n=6)		p
	X	SD	X	SD	
Age(yr.)	22.0	3.5	21.7	3.1	.86
Height (cm.)	179.6	4.9	176.3	4.8	.27
Weight (kg.)	79.6	5.7	74.2	14.6	.41

In addition to strength, trunk flexion, trunk extension, and hip flexion ROM were assessed. It was interesting to note that in the pilot study and the actual study no significant differences ($p < .001$) were found between the high and low strength groups with respect to trunk and hip ROM (Table 2). (The procedures used to assess ROM are included in the measurement methods

section.) The similarity of this finding in the independent samples provided justification for selecting only strength as the independent variable as opposed to examining the relationships between (a) all possible combinations of strength and ROM (i.e., strong-tight, less strong-tight, etc.) and (b) body posturing throughout the course of lifting. However, in spite of group homogeneity with respect to ROM and the selected demographic variables, it is recognized that it may be pretentious to attempt to isolate the influence of one parameter, in this case strength, on the complex variable, lifting posture.

Table 2. Summary of t-tests for Range-of-Motion Tests.

Parameter (degrees)	High Strength (n=6)		Low Strength (n=6)		p
	X	SD	X	SD	
Trunk Flexion	67.17	8.75	63.50	5.90	.88
Trunk Extension	25.33	3.01	26.17	10.33	.39
Hip Flexion	84.17	9.43	83.33	7.47	.87

Experimental Protocol

All 42 volunteers attended two testing sessions; the twelve subjects identified at the conclusion of the second sessions as being of a high or low level of strength subsequently came to third sessions. The sessions were held at the Comprehensive Back Center, Fort Sanders Regional Medical Center, Knoxville, Tennessee, and were scheduled within a two week time period. During the first session the subject (a) completed a letter of informed consent (Appendix B), (b) was familiarized with the experimental protocol and measurement methods, and (c) underwent a series of strength and flexibility tests. During the second session the 42 subjects' strength was reassessed so that repeatability estimates for each component of the strength test battery could be determined. The highest score on each strength test was used in the determination of the makeup of the respective strength groups. In the third testing session the lifting postures of the high and low strength subjects were recorded.

The sequence of events undertaken during each session are outlined in Tables 3-5; more detailed descriptions are provided in the measurement methods section of this chapter. All sessions began and ended with stationary bicycling and stretching exercises in order to reduce the risk of muscle soreness or injury. In addition, rest

Table 3. Protocol for the First Testing Session.

Subjects completed the following:

1. Letter of informed consent (Appendix B).
 2. Height and weight assessments using a physician's scale.
 3. Aerobic and stretching exercises. The subject (a) cycled 5 minutes at 60 rpm and 600kpm on a Cybex Fitron Cycle Ergometer and (b) performed stretching exercises demonstrated by the researcher.
 4. Strength assessment. The subject's level of strength was evaluated using the procedures outlined in the measurement methods section.
 5. Range-of-motion evaluations. The subject's trunk flexion, trunk extension, and hip flexion ranges-of-motion were evaluated using the protocols described in a latter section of this chapter.
 7. Stretching exercises. The subject repeated the stretching exercises performed at the beginning of the session.
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TABLE 4. Protocol for the Second Testing Session.

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1. Aerobic and stretching exercises.
 2. Repeat strength evaluations.
 4. Stretching exercises.
 5. Calculation of the subject's level of strength. The subject's who met the criteria for the high or low strength group were subsequently scheduled to participate in a third testing session.
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Table 5. Protocol for the Third Testing Session.

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1. Letter of consent for filming of lifting task (Appendix C)
 2. Aerobic and stretching exercises.
 3. Practice of the lift task described in the next section.
 4. Recording of the subjects's lifting posture using the procedures outlined in the following section.
 5. Stretching exercises.
-

periods were allotted between activities to avoid fatigue effects.

Measurement Methods

The measurement methods section includes descriptions of the instrumentation and protocols used in evaluating strength, joint ROM, and lifting posture. Some of the limitations associated with these assessments are also outlined.

Level of Strength Evaluation

The strength of each of the three muscle groups most involved in lifting (the trunk flexors, trunk extensors, and leg extensors) was assessed utilizing a one-repetition maximum (1 RM) procedure with Cybex Eagle Fitness System strength training machines. The machines used were the

abdominal, back extension, and leg press units. The procedures outlined by the manufacturer for positioning the subject within the apparatus were followed with certain modifications (Cybex, n.d.). Some alterations were aimed at minimizing the roles that extraneous muscle groups could play in the movements. On the abdominal machine the feet were not strapped to the foot support plate in order to minimize the contribution of the hip flexors to the movement. In pilot testing of 1 RM on the back extension machine the investigator observed that, in addition to utilizing the trunk extensors, the subject's tended to utilize their knee extensors (i.e., they appeared to be "pushing off" with their legs). To reduce this tendency the height of the foot plate and the positioning of the feet on the plate were adjusted to minimize the subject's ability to "push" with his legs. The sled on the leg press machine was adjusted so that the knee joint angle in the starting position was approximately 65 degrees.

Strength in the selected muscle groups was assessed using a 1 RM trial and error procedure; this involved selecting an amount of weight on the Cybex machine that, in the estimation of the tester, was the maximum load the subject could move through the designated ROM. Depending upon the subject's performance on the previous trial, the load was increased or decreased until the 1 RM was determined. During the first strength-testing session the

tester could usually determine the subject's 1 RM within seven trials. During the second testing session the number of trials was typically less. The three strength tests were administered in counterbalanced order. Just prior to measuring the 1 RM for a given muscle group, the subject performed three submaximal "warm-up" trials (the load was incremented on each of these trials). Rest periods included (a) twenty seconds between each warm-up and test trial and (b) approximately five minutes between the different evaluations. Throughout the evaluations consistent encouragement was given to facilitate maximum effort.

Since body weight has been found to be a useful adjustment factor for inter-individual comparisons of strength, each of the subject's three 1 RM values was divided by his weight. For purposes of this investigation each subject's rating for strength was the sum of these three 1 RM body weight ratios. The upper and lower quartiles for strength, found in pilot testing of 48 male university students, were used to operationally define the levels of the independent variable strength. Specifically, subjects with an overall strength score greater than the upper quartile (5.18) or less than the lower quartile (4.27) were identified as possessing a high or low level of strength, respectively. All subject's whose scores were in between the two extremes were classified as average. The

strength test scores for the six high strength and six low strength subjects in the present study are listed in Appendix A. Statistically significant differences ($p < .001$) were found between the high and low strength groups with respect to their mean scores for trunk flexion, trunk extension, leg extension, and overall strength.

The data from both the pilot ($n=48$) and actual ($n=42$) study were used to determine Pearson Reliability Coefficients for each one of the three strength tests. The intra-tester reliability coefficients for the abdominal, back extension, and leg press 1 RM's were .88, .79 and .80, respectively.

Joint Range-of-Motion Assessments

The subjects underwent trunk flexion, trunk extension and hip flexion ROM assessments. In the pilot study an attempt was made to also assess hip extension ROM. The Thomas Test was used for the measurement of the latter (Kendall, Kendall & Wadsworth, 1971); however, it was eventually dropped from the ROM test battery because the results demonstrated a low degree of reliability.

The inclinometer technique described by Mayer, Tencer, Kristoferson, and Mooney (1984) for evaluating lumbar ROM in flexion and extension was selected for this investigation because it has been found to be quite accurate compared with X-ray analysis and also highly

reliable (Keeley, Mayer, Cox, Gatchel, Smith, & Mooney, 1986; Mayer et al., 1984). The inclinometer technique is specifically a test of spinal ROM. In contrast, the more traditional means of assessing spinal ROM (e.g., the finger-tip-to-floor distance and the sit-and-reach) are dependent upon the mobility of multiple joints and are considered poor measures of low back flexibility (Jackson & Baker, 1986; Jackson & Langford, 1988; Kippers & Parker, 1987).

The inclinometer was also used to assess hip flexion ROM using the straight-leg raise procedure described by Mayer et al. (1984) and Keeley et al. (1986). Hip flexion ROM was reported as the average of the right and left limbs.

In a previous study conducted in our lab the reliability coefficients for the trunk and hip flexion ROM tests were .98 and .97, respectively (Sharpe, Liemohn, & Wasserman, 1989). The investigator did not determine the reliability coefficient for the trunk extension ROM test. Keeley et al. (1986) reported intra-rater reliabilities above .9 for all three inclinometer tests. ROM test scores for the six high strength and six low strength subjects in this study are listed in Appendix A.

Assessment of Body Posturing in the Lift Task

The lifting postures of the six high strength and six low strength subjects were examined to determine the effects of variations in the levels of strength on their body posturing. The methods used in this facet of the study included cinematographic and potentiometer measurements of body posturing as the subjects lifted a box. This section specifies the details concerning the (a) lift task and (b) cinematographic and potentiometer recordings of the task.

The Lift Task. The task was to use the flexed-knee lifting technique to displace a box from the floor to the height of the umbilicus. The investigator demonstrated the task by emphasizing (a) squatting with the legs straddling the load and (b) lifting to the height of the umbilicus; trunk positioning was not addressed. The flexed-knee technique was selected because it allows subjects to lift the box from between the legs; theoretically this minimizes the load moment arm and reduces the compressive forces on the intervertebral discs (Andersson et al., 1976; Ekholm et al., 1982; Grieve, 1975; Leskinen et al., 1983).

The box the subject lifted was 37.5 cm high, 33.0 cm deep and 33.0 cm wide; it had cut-out handles 33.0 cm above the floor and was laden with weight plates to reach a mass

of 40.5 kg. A relatively heavy load was selected because trial to trial and subject to subject variations in lifting posture have been shown to be greater for lighter loads (Davis et al., 1965; Kumar, 1974); this was of concern in this study since it could potentially mask group differences.

Cinematographic Measurements. The lifts were filmed with a Hycam 16mm camera at 100 frames/second; the camera was leveled and aligned with the optic axis 1.6 m above the floor and 9.0 m perpendicular to the sagittal plane of movement of the left side of the subject. Filming commenced as the subject bent down to perform the lift and ended when he returned to the upright position. Anatomic reference markers (i.e, black hemispheres placed on white adhesive pads) were placed on the skin over bony landmarks of interest on the left side of the body; the sites marked were the lateral malleolus, femoral condyle, greater trochanter, glenohumeral joint, lateral epicondyle of the wrist, and styloid process of the ulna.

The X-Y coordinates of the body landmarks were obtained by digitizing film images projected onto the surface of a Tektronix 4953 graphics tablet connected to a Tektronix 4115B graphics terminal that was interfaced with a VAX 11/780 mainframe computer. The computer program needed to record the positional data was written by the investigator (Appendix D). Digitizing commenced nine

frames prior to the frame of film in which the box ceased to be in contact with the ground. Thereafter, every ninth frame was digitized up to the frame when it was assumed that the upward displacement of the box had ended.

After the film segments had been digitized the data arrays containing the raw coordinates of the anatomical reference points were transferred from the VAX to an IBM microcomputer. The raw coordinates were then smoothed using a film data analysis system developed by Noble, Zollman & Yu (1988). The smoothed data sets were then used in other programs of the same data analysis system to calculate three of the four dependent variables; these included the (a) knee angle, formed by the upper and lower leg (Figure 1), (b) torso angle relative to the horizontal (Figure 1), and (c) horizontal distance between the geometric center of the box lifted and the center of gravity of the body. The method of assessing the fourth variable, angular positioning of the lower back, is described in the following section.

Potentiometer Assessment of Lumbar Spinal Posturing.

The Ady-Hall lumbar monitor (Hall, 1982) was used to electronically measure angular positioning of the lumbar spine throughout the course of lifting (Figure 2). Lumbar positioning (called alpha for this study) is defined as the angle between perpendiculars to the L1 and S1 tangents

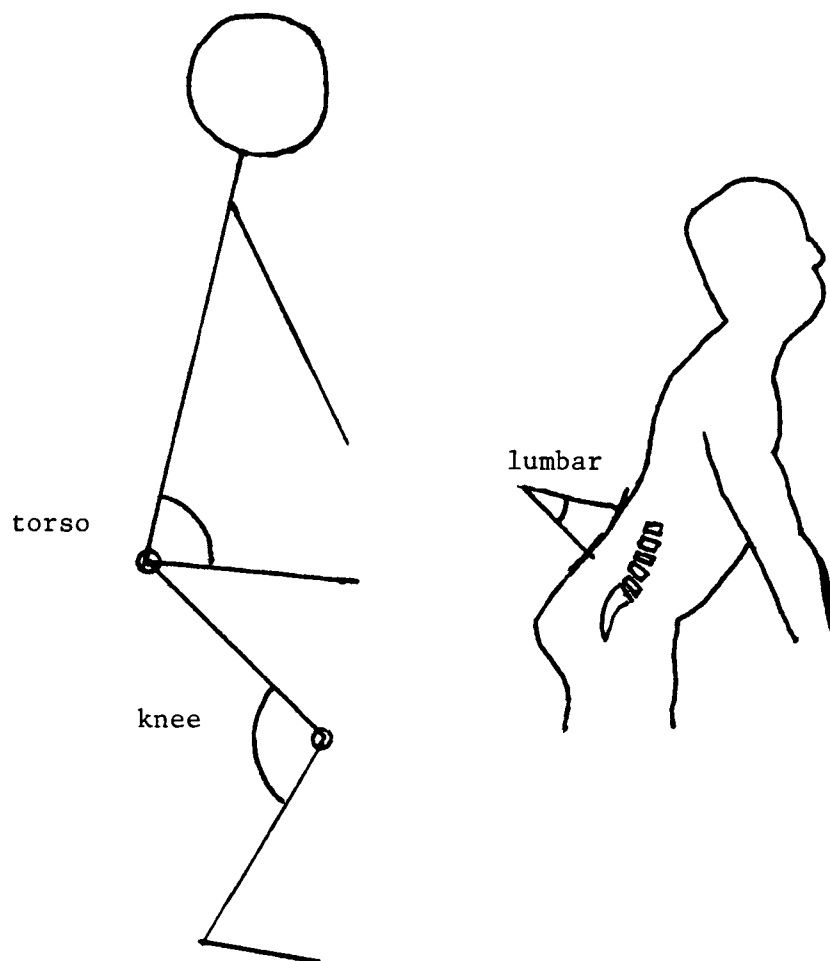


Figure 1. Body Posturing Angles.

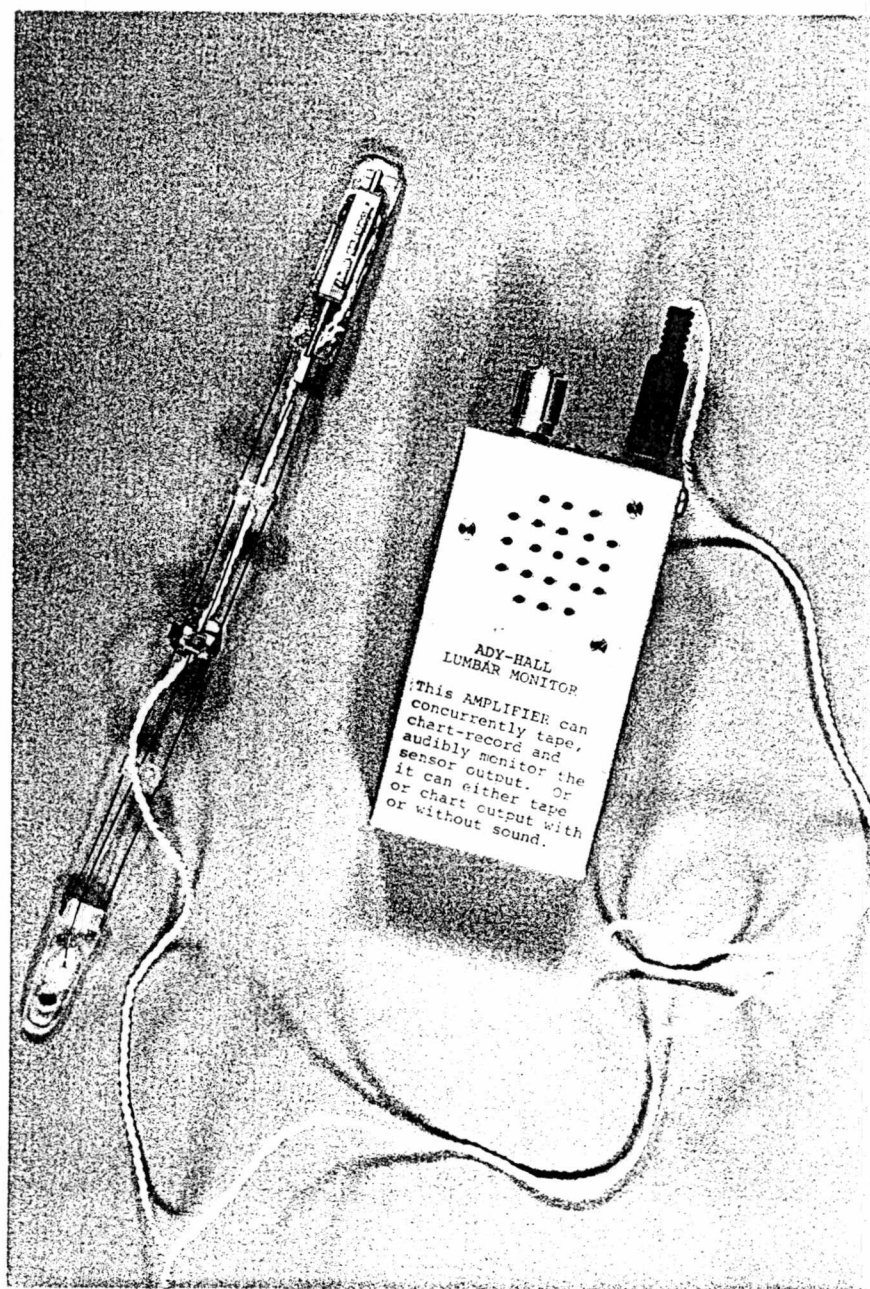


Figure 2. The Ady-Hall Lumbar Monitor.

on the device (Figure 1). The lumbar monitor was placed against the back; an adhesive pad was used to adhere it to the midpoint between the L1 and S1 spinous processes. The upper end of the Ady-Hall monitor was allowed to move freely within a cylindrical bridge that was secured to the back with an elastic wrap (Figure 3).

The Ady-Hall monitor is driven by a 9 volt battery and consists of three stiff wires; two of these rest against the surface of the back serving as references for lumbar posturing (Figure 3). The third wire is positioned above the skin and is connected to a linear slide potentiometer (10 kilo ohms). When the lumbar angular positioning changes the relative motion between the wires produces a resistance change which varies the reference voltage. This voltage change is about 0.253 millivolts/degree. The potentiometer signal was sampled at 333 points/second and recorded with the oscilloscope emulator in a computer program developed by Computational Systems, Incorporated (1988).

A scale relating voltage output to a known alpha was created by successively securing the L1 and S1 tangents on the monitor across the 110 degree range (-50 to 60 degrees) of the calibration template (Figure 4). This calibration scale was used to determine the regression line for which any lumbar monitor scribings could be quantified in terms of degrees.

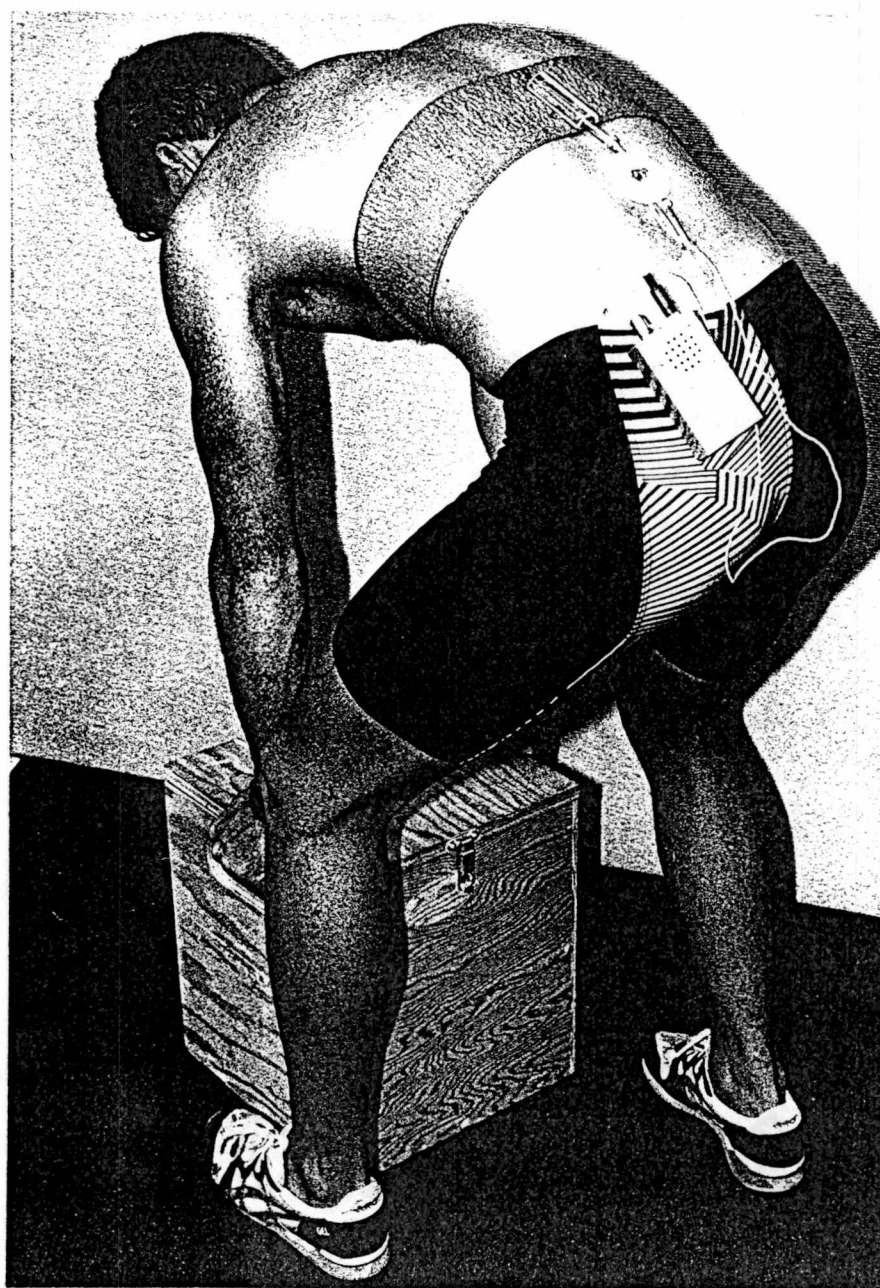


Figure 3. Subject Wearing the Ady-Hall Lumbar Monitor.

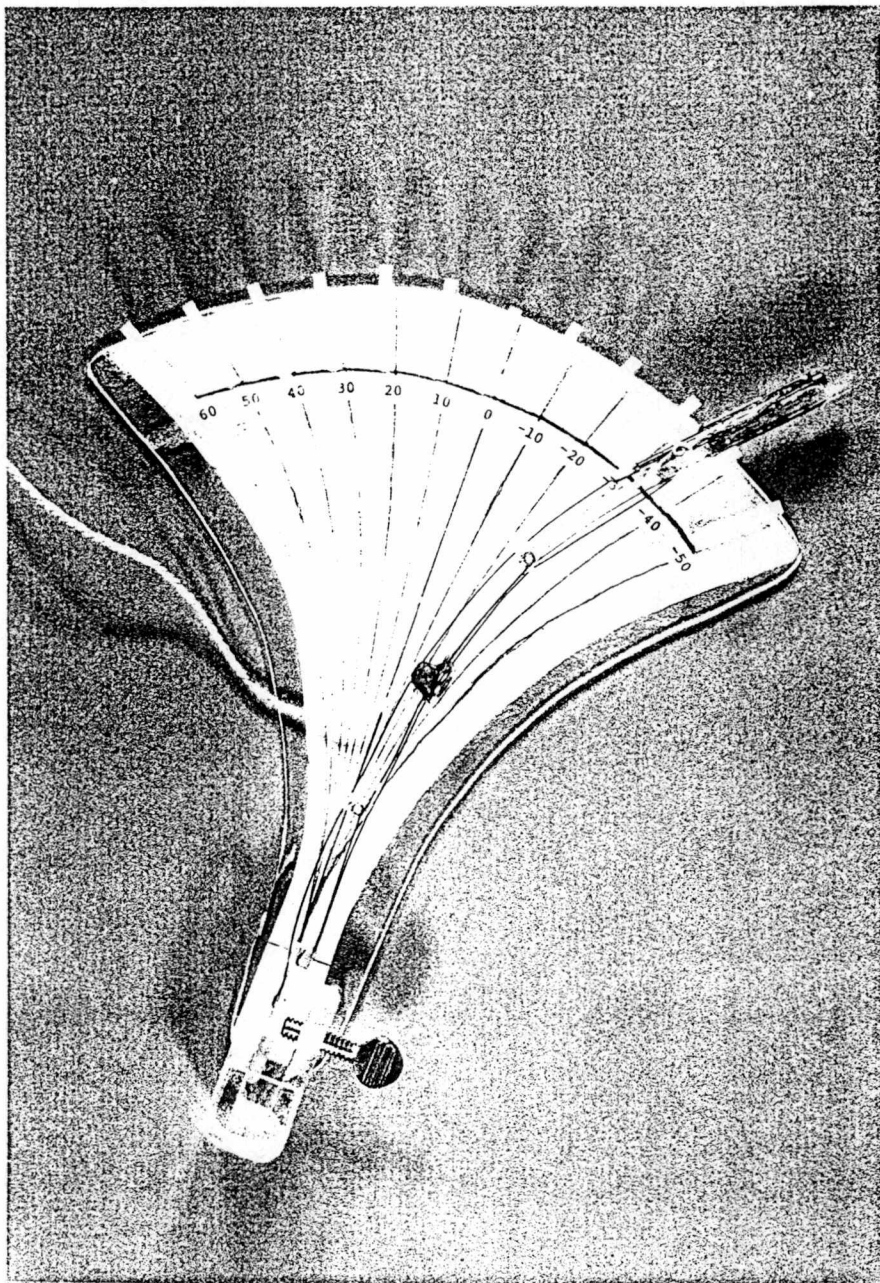


Figure 4. The Lumbar Monitor with the Calibration Unit.

It is recognized that the lumbar monitor has inherent errors. It can not be used to discern variants in curvature between adjacent lumbar spinous processes. Furthermore, since the monitor is a set length (19.05 cm) it can over or underestimate L1-S1 behavior in persons who are shorter or taller than the 50th percentile man (Hall, 1982). The error in precisely covering the L1-S1 span is a trade-off for the simplicity of a one length instrument. In previous testing in our lab lumbar angular positions measured with the Ady-Hall monitor closely approximated those measured with the inclinometer technique previously described and the flexible ruler technique described by (Israel, 1956); therefore, it is believed that this instrument was appropriate for use in this investigation.

Data Analysis

Comparisons were made at five different points in the lifting cycle of the (a) angular positioning of the knee, torso, and lumbar spine and (b) moment arm of the high and low strength subjects. These points were expressed as a percentage of the distance between the box and the ground at the completion of the lift; they were labeled 0, 25, 50, 75 and 100 percent of the maximum vertical displacement of the box. In most studies on lifting the data are normalized with respect to time rather than the height of the object lifted. The latter was chosen for this

investigation because the exact filming rate could not be determined due to the unavailability of an instrument that could be used to calibrate this parameter (e.g., a timing light system). However, it is believed that the actual filming rate was very close if not equivalent to the set speed of 100 frames/second since the equipment manufacturer had checked the camera calibration just prior to its use in this investigation.

Analysis of Variance (ANOVA) was used to determine whether significant differences in the selected kinematic variables existed between the high and low strength groups at the five points examined in the lifting cycle. Independent univariate F-tests were conducted to assess differences between group means and variances, respectively; a level of significance of .10 was selected for these tests. This less rigorous significance level was selected in order to decrease the probability of finding a factor "non-significant" that may actually be of importance. This has been deemed desirable for exploratory studies such as the present one since the elimination of potentially relevant factors could hinder future theory development (Franks & Huck, 1986).

F-max tests (i.e. Hartley's statistic) were also conducted to determine if there were differences in the variances within the respective strength groups. For these tests the significance level was .05, as opposed to

.10, because a table corresponding to the later was not available in the referenced statistical handbooks and text (Kirk, 1982; Pearson, 1976).

CHAPTER IV

RESULTS AND DISCUSSION

The purpose of this study was to determine whether variations in the level of strength were accompanied by differences in selected aspects of body posturing in a flexed-knee lifting task; the parameters examined were (a) angular positioning of the knee, torso, and lumbar spine and (b) the moment arm of the box lifted relative to the body's center of gravity. It was hypothesized that disparities in strength may explain variances in lifting posture.

In this chapter the kinematic data obtained from the subjects selected as being of a high level of strength and those of a low level of strength are presented graphically. The horizontal axis of the graphs shows vertical displacement of the box lifted expressed as a percentage of the distance between it and the ground. The displacement value 0% represents the initiation of the lift and 100% corresponds to the point at which the height of the box was maximum. This presentation of the results is divided into four sections; they are (a) knee joint angle, (b) torso angle, (c) lumbar spine angular positioning, and (d) moment arm of the object lifted.

Knee Joint Angle

The ANOVA comparing knee joint angles of the high and low strength lifters resulted in significant differences between the groups (Table 6). At 0, 25 and 50% of the displacement of the box the mean angle of the knee was significantly closer to the vertical (i.e., 180 degrees) in the low strength lifters. In the graphic presentation of these data in Figure 5, it is noted that four of the six low strength subjects had knee posturing patterns that were more extended than those found for members of the high strength group. It was interesting that discrepancies in posturing of the knee were found at the beginning of the lift even though the investigator demonstrated the lifting task by emphasizing squatting down beside the load with the legs straddling it. The results would appear to lend some support the contention that some individuals' leg extensor muscles may be insufficiently developed to permit them to lift heavy objects using the flexed-knee technique when instructed to do so, and therefore they may choose a more extended knee position to reduce the resistive (i.e., anti-extension) moment about the knee (Davis et al., 1965; NIOSH, 1981). However, since two of the low strength subjects were able to initiate the lift with moderate to more pronounced knee flexion, the veracity of this hypothesis may be equivocal.

Table 6

Summary of ANOVA for Posturing of the Knee.

Displacement of the Box (% of total)	Knee Angle (degrees)				F	p*
	High Strength		Low Strength			
	(n=6)		(n=6)			
	$\bar{X}$	SD	$\bar{X}$	SD		
0	96.43	11.81	127.89	26.19	13.40	.001
25	122.15	11.80	153.22	27.35	13.01	.001
50	147.71	11.81	168.47	15.26	5.81	.022
75	170.55	7.60	176.55	6.00	0.49	.491
100	183.57	2.20	180.70	6.25	0.11	.741

* accepted level of significance = .10

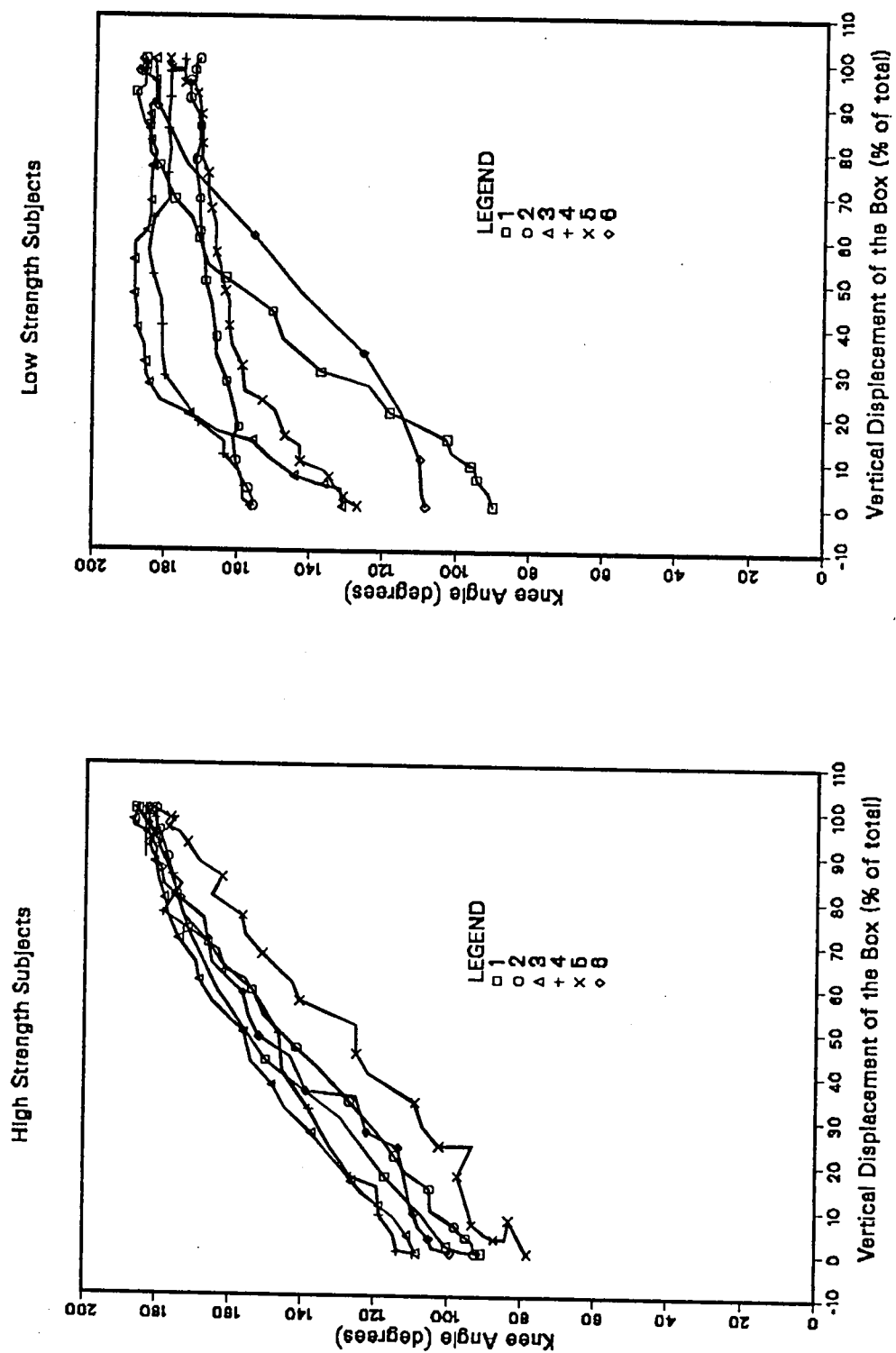


Figure 5. Posturing of the Knee During a Flexed-Knee Lift.

At the completion of the lift all of the high strength and four of the low strength subjects had knee angles greater than 180 degrees; the span of knee hyperextension demonstrated by these subjects was within the normal range of 6-9 degrees (Steindler, 1964). Ekholm et al. (1984) also found that in some subjects the joint was placed in this extreme position at the end of flexed-knee lifts; they contended that more pronounced knee flexion at the beginning of a lift, and hyperextension at the end as seen in most of the high strength subjects in the present study, may result in high patella-femoral and tibia-femoral compressive forces. Thus, it appears that the high strength subjects did not select a lifting pattern that minimizes the stress on the knee joint.

The F-tests indicated that the variability of the knee joint angle was significantly greater in the low strength group than the high strength group at 0, 25, and 100% of the vertical displacement of the box (Table 7). Furthermore, the F-max tests indicated that within the high strength group, and within the low strength group, the variability in posturing of the knee was significantly greater at the beginning of the lift (Figure 6). At this time, when the inertia of the object to be lifted and that of the upper body was being overcome, some of the lifters appeared to engage in ballistic or jerky motions. This type of movement may have accounted for the greater

Table 7

Summary of Univariate F-tests for Posturing of the Knee.

Displacement of the Box (% of total)	Knee Angle (degrees)				F	p*
	High Strength		Low Strength			
	(n=6)		(n=6)			
	$\bar{X}$	SD	$\bar{X}$	SD		
0	96.43	11.81	127.89	26.19	4.92	.05
25	122.15	11.80	153.22	27.35	5.37	.04
50	147.71	11.81	168.47	15.26	1.67	.29
75	170.55	7.60	176.55	6.00	1.60	.31
100	183.57	2.20	180.70	6.25	8.07	.02

* accepted level of significance = .10

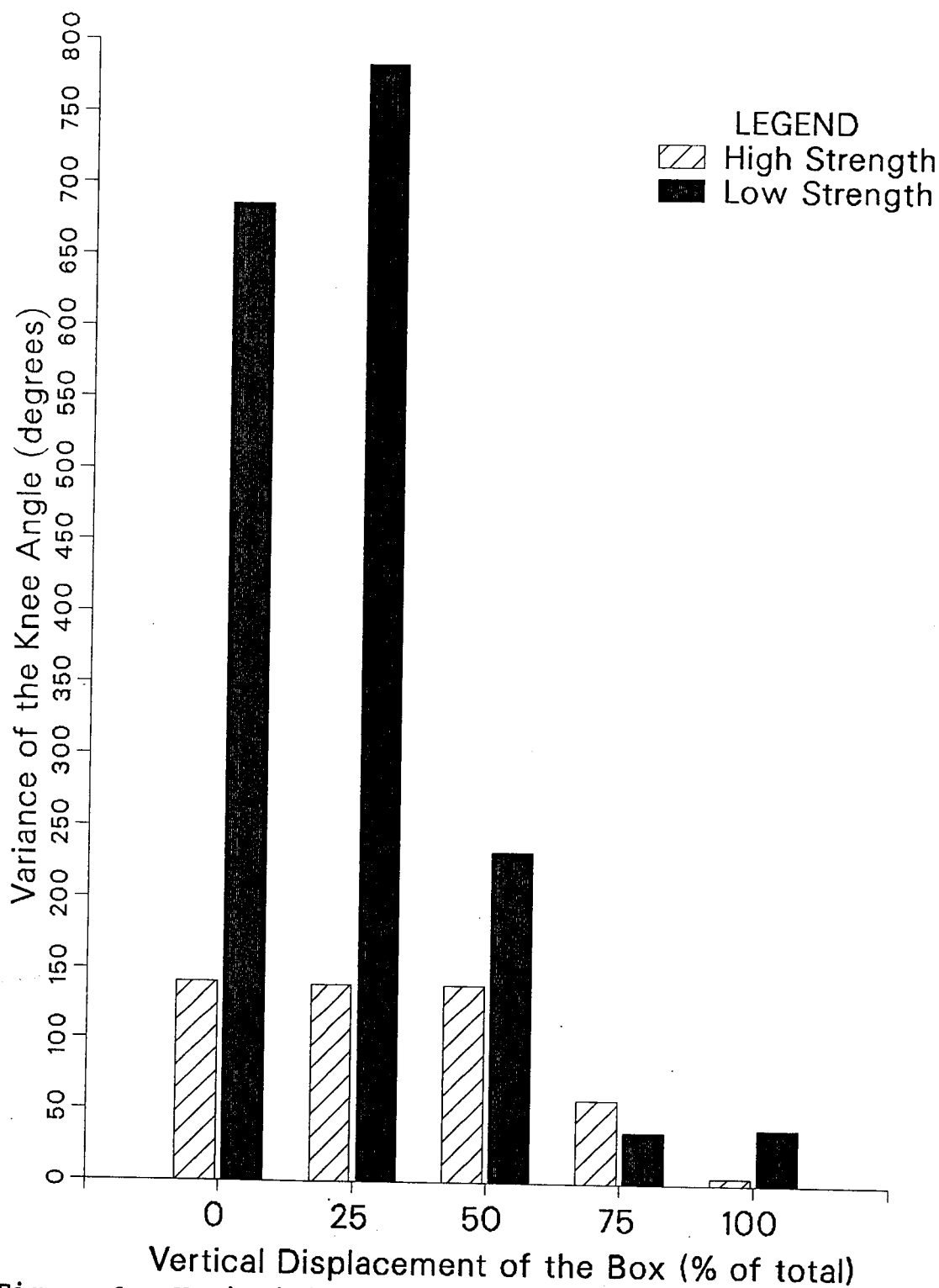


Figure 6. Variability in Posturing of the Knee. Significant differences were found for the variabilities within the respective strength groups. Between the two groups significant differences were found at 0, 25, and, 100% of the displacement of the box.

variability in Knee joint posturing in the early phase of the lift. The dissimilarities in variance between the two groups may be related to differences in strength and/or other factors such as previous lifting experience.

Torso Angle

Similar to the findings for the knee, comparisons of the torso angles of the high and low strength lifters resulted in significant differences at 0, 25, and 50% of the vertical displacement of the box (Table 8). At these points the torso was significantly closer to the vertical in the high strength subjects. Hence, the preferred style of the high strength subjects resembled the often recommended posture of flexed knees and erect torso. Two of the six low strength subjects, numbers 1 and 6, lifted in a manner similar to the six high strength subjects; however, the other low strength subjects approached an extended-knee, flexed-torso posture (Figures 5 and 7). The trunk flexion, trunk extension, leg extension, and sum strength scores for the two low strength subjects that lifted differently than their counterparts were (a) not the highest within their group and (b) lower than those reported for the other group (Appendix A). This finding precludes definitive acceptance of the hypothesis that the subject's level of strength was a major determinant of

Table 8

Summary of ANOVA for Posturing of the Torso.

Displacement of the Box (% of total)	Torso Angle (degrees)				F	p*
	High Strength		Low Strength			
	(n=6)		(n=6)			
	$\bar{X}$	SD	$\bar{X}$	SD		
0	44.09	6.80	27.35	21.05	8.64	.007
25	51.33	6.41	35.22	66.20	7.24	.012
50	58.40	7.74	44.13	8.34	4.00	.055
75	67.00	7.77	63.40	3.99	0.36	.553
100	83.17	4.92	82.35	6.88	0.01	.914

* accepted level of significance = .10

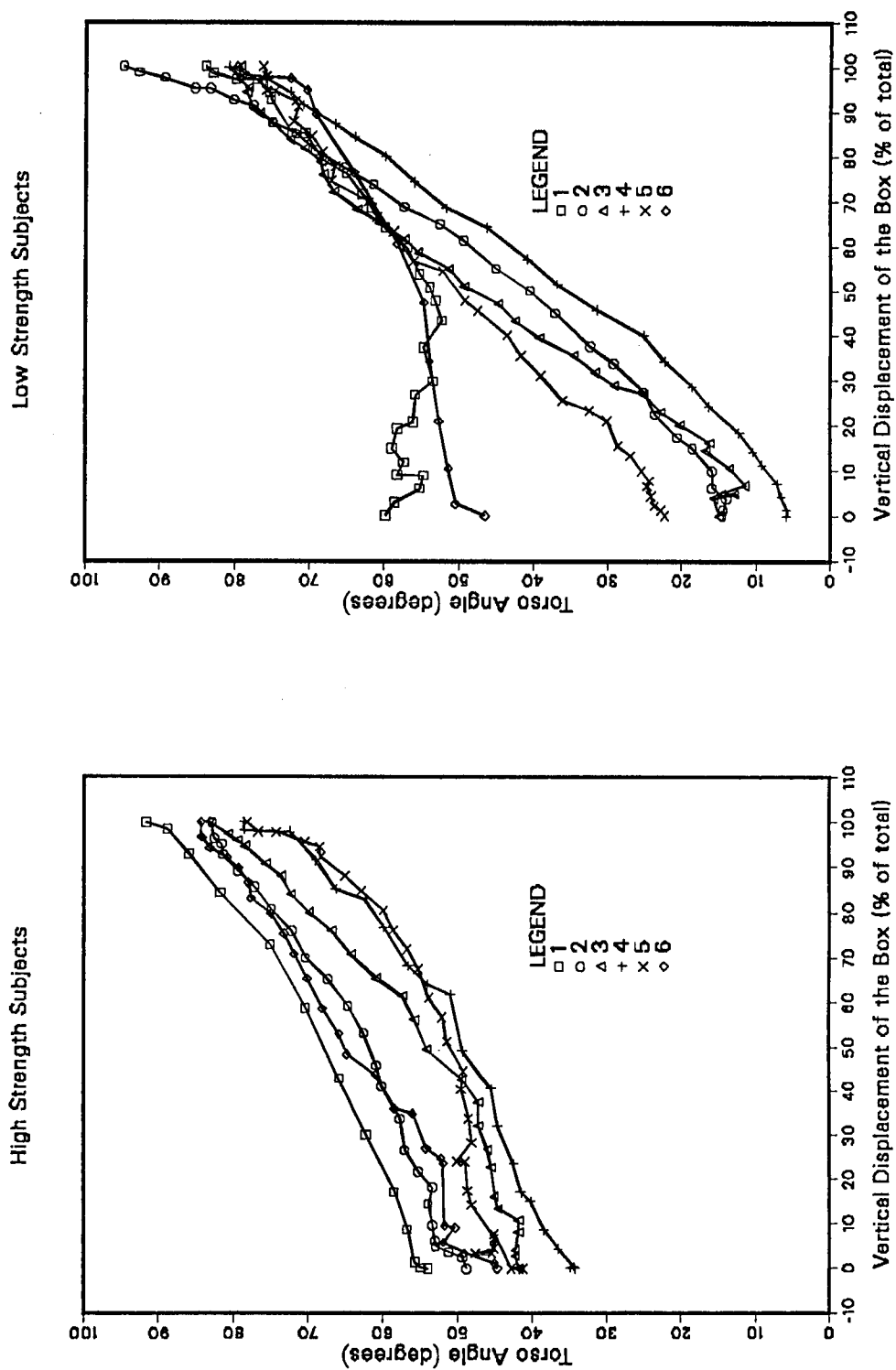


Figure 7. Posturing of the Torso During a Flexed-Knee Lift.

their knee/torso orientation in freestyle flexed-knee lifting.

Within the low strength group there was a direct relationship between the degrees of knee extension and torso flexion; subjects with more extended knees leaned their torsos forward more in order to reach the box. This knee/torso relationship was not present in the high strength lifters. However, similar to the findings for the knee, during the first half of the lift the high strength lifters demonstrated less variability in posturing of the torso (Table 9). The smaller variance in knee and torso orientation in this group may be related to the fact that they had a greater capacity to resist the forward turning moment of the object lifted and the upper body. It is also possible that prior to participating in this experiment the high strength subjects had received more instruction on "proper" lifting techniques and that this instruction influenced their selection of the flexed-knee erect-torso posturing. Moreover, they may have had more experience in lifting and through practice developed the skill necessary to consistently execute this type of lift. Factors such as these may also help explain why the variabilities in torso angles within the high strength group were relatively homogeneous and those within the low strength group were heterogeneous (Figure 8).

Table 9

Summary of Univariate F-tests for Posturing of the Torso.

Displacement of the Box (% of total)	Torso Angle (degrees)				F	p*
	High Strength		Low Strength			
	(n=6)		(n=6)			
	$\bar{X}$	SD	$\bar{X}$	SD		
0	44.09	6.80	27.35	21.05	9.58	.01
25	51.33	6.41	35.22	66.20	6.39	.03
50	58.40	7.74	44.13	8.34	1.16	.43
75	67.00	7.77	63.40	3.99	3.79	.08
100	83.17	4.92	82.35	6.88	1.95	.24

* accepted level of significance = .10

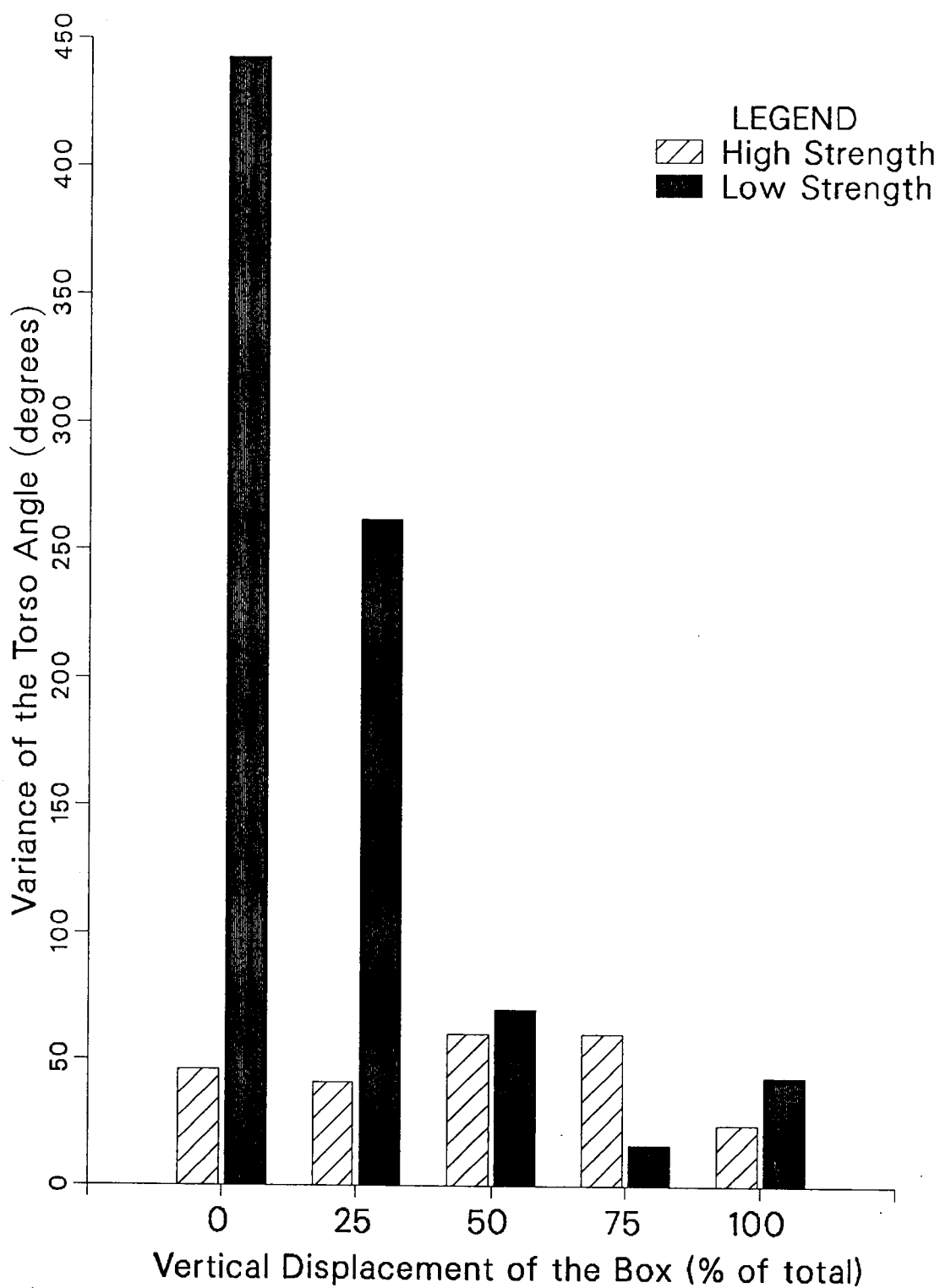


Figure 8. Variability in Posturing of the Torso. The variances for the high strength group were relatively homogeneous, those for the low strength group were heterogeneous. Between the groups differences were found at 0, 25, and, 75% of the displacement of the box.

Lumbar Spinal Angular Positioning

Lumbar spinal positioning was evaluated in terms of its angular deviation from the vertical. In the graphic representation of lumbar posturing, the vertical or straight lumbar spine is represented by zero degrees; positive values indicate that the lower back was in a flexed position relative to the vertical and negative values corresponded to extension relative to the vertical.

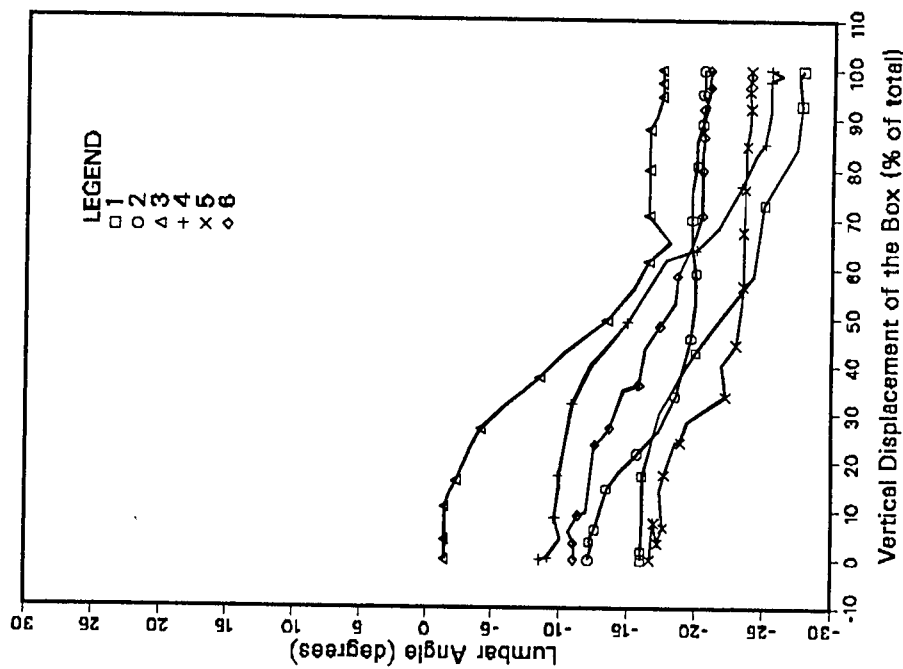
The low strength subjects tended to demonstrate a lesser amount of lumbar extension than the high strength subjects, who maintained extended postures throughout the lift (Table 10). At the initiation of the task, however, three of the six low strength subjects placed their lumbar spine in extension; the others were in flexion (Figure 9). Upon completion of the task all low strength lifters demonstrated lordosis except number four who had a nearly straight lower back. The less extended lumbar postures seen in the low strength group may have been caused by their presumably inferior ability to counteract the forward turning moment. On the other hand, it has been contended that straight or kyphotic lifting postures create smaller compression forces on the lumbar spine than do lordotic postures (Gracovetsky & Farfan, 1986; McGill & Norman, 1986); therefore it is possible that the less extended posture served as a protective mechanism for the spines of the low strength subjects. However, this conclusion is at

Table 10
Summary of ANOVA for Posturing of the Lumbar Spine

Displacement of the Box (% of total)	Lumbar Angle (degrees)				F	p*
	High Strength		Low Strength			
	(n=6)		(n=6)			
	$\bar{X}$	SD	$\bar{X}$	SD		
0	-10.95	5.57	3.56	13.42	7.67	.012
25	-13.40	5.59	-0.44	15.59	4.89	.039
50	-18.15	3.74	-8.09	15.76	3.20	.090
75	-21.75	3.87	-10.54	14.72	3.66	.071
100	-21.39	6.07	-14.30	8.97	0.71	.411

* accepted level of significance = .10

High Strength Subjects



Low Strength Subjects

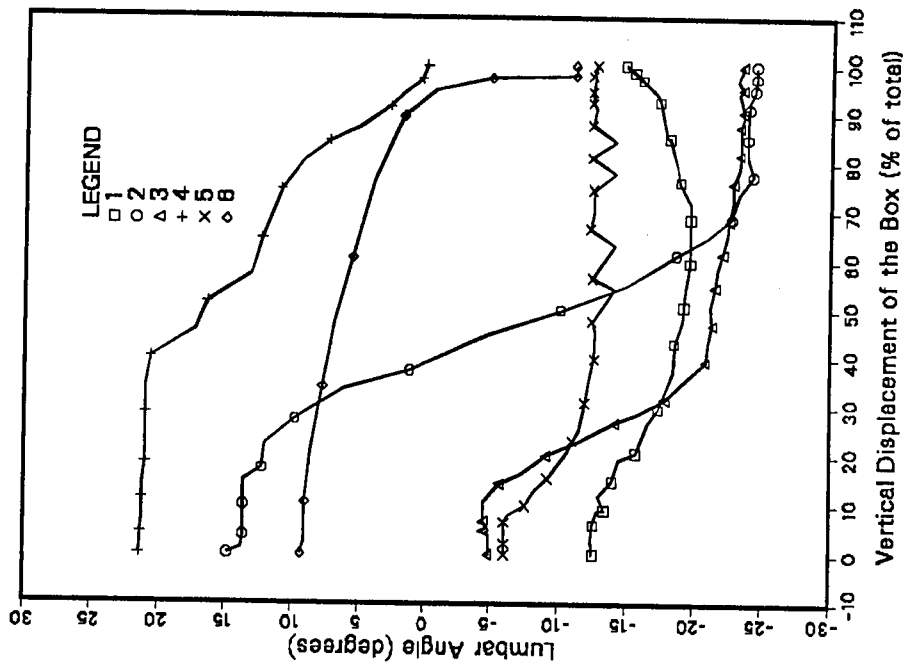


Figure 9. Posturing of the Lumbar Spine During a Flexed-Knee Lift. Zero, positive, and negative values correspond to straight, kyphotic, and lordotic posturing, respectively.

this time tenable since (a) the efficacies of these mechanisms are controversial and (b) there is little evidence that any one particular lumbar posturing is mechanically advantageous for all situation incurred in lifting.

For a short period at the beginning of the lift there was very little change in lumbar positioning and it often remained stationary (Figure 9). Thereafter, however, gradual continuous extension of the lower back occurred. This observation is in accordance with the findings of other investigators (Davis et al., 1965; Kumar, 1974). The approximate point during the lift at which continuous lumbar extension began ranged from 10 to 32% of the full height of box displacement.

There were no apparent differences in the delay in extension between high and low strength subjects. The low strength subjects demonstrated greater variability than the high strength subjects in their lumbar movement throughout the course of lifting (Table 11). This may be linked to their non-uniformity in posturing of the knees and torso. Although there were differences in the variabilities in the lumbar angle between the high and low strength groups, the within group variances were not significantly different (Figure 10).

Table 11

Summary of Univariate F-tests for Posturing of the
Lumbar Spine

Displacement of the Box (% of total)	Lumbar Angle (degrees)				F	p*
	High Strength		Low Strength			
	(n=6)		(n=6)			
	$\bar{X}$	SD	$\bar{X}$	SD		
0	-10.95	5.57	3.56	13.42	5.80	.04
25	-13.40	5.59	-0.44	15.59	7.71	.02
50	-18.15	3.74	-8.09	15.76	17.20	.00
75	-21.75	3.87	-10.54	14.72	14.47	.00
100	-21.39	6.07	-14.30	8.97	2.18	.20

* accepted level of significance = .10

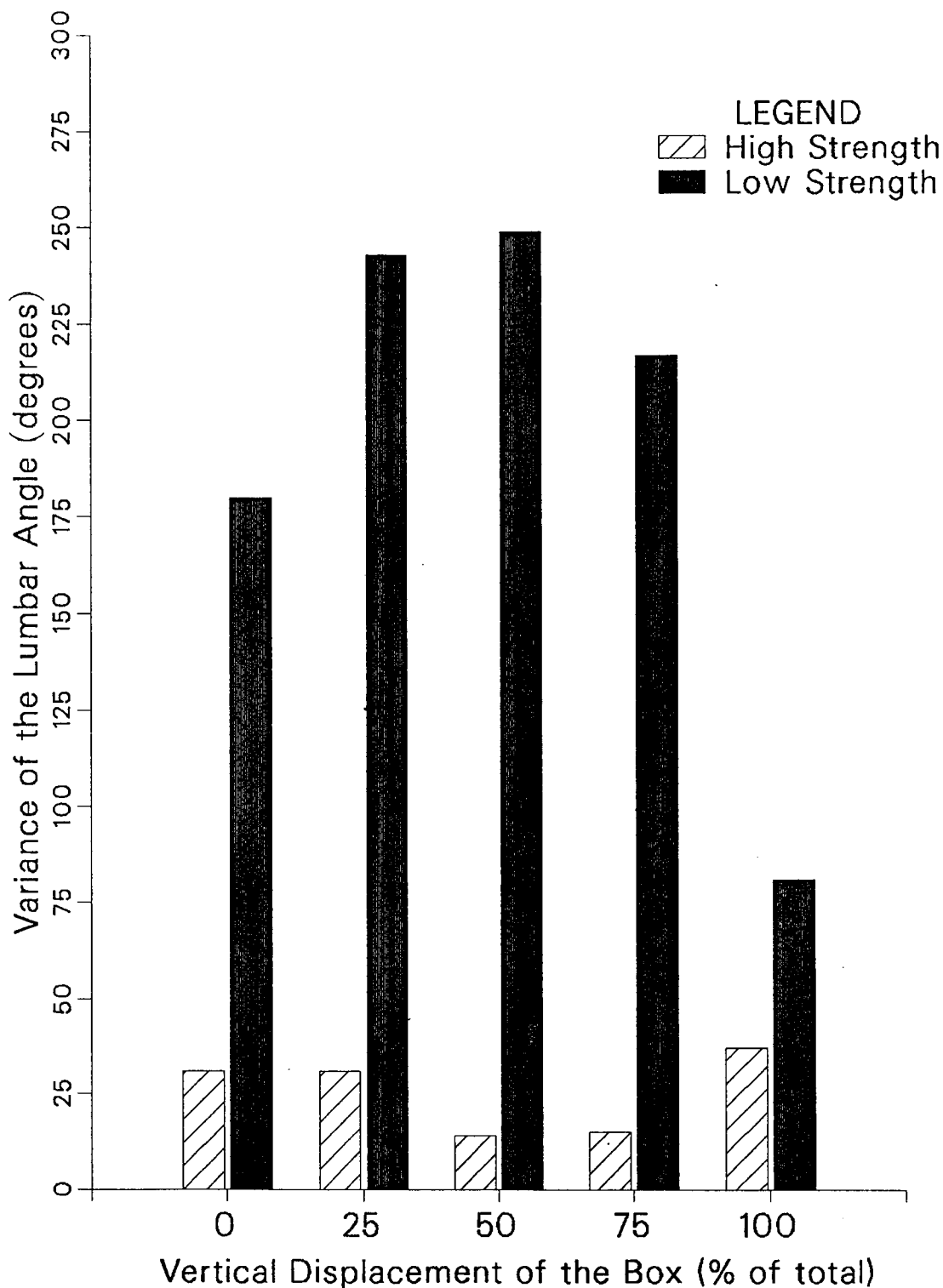


Figure 10. Variability in Posturing of the Lumbar Spine. The within group variances were not statistically different. Between the two groups significant differences were found at 0, 25, 50, and 75% of the displacement of the box.

Moment Arm of the Object Lifted

No significant differences in the mean moment arm at the points evaluated throughout the lift were found between the high and low strength groups (Table 12). At least at lift-off this finding might have been expected since the lifters were straddling the load. However, it was somewhat surprising to see this at 25 and 50% of the displacement since at these points in the lift differences were noted in body posturing. Based on repeated visual assessment of the film it seemed that most of the subjects attempted to minimize the moment arm; furthermore, their minimization strategies appeared to be dependent upon their knee/torso orientation. The subjects whose method of lifting approached the classic "squat lift" kept the box between their knees as long as the body did not interfere with its displacement. In contrast to this, those in the low strength group that employed the more "stooped-back" lifting technique leaned their torsos over the top of the box and thereby reduced the distance between the center of the box and the center of gravity of their bodies. In support of this observation, Park and Chaffin (1974) reported that the stooped lifting posture resulted in moment arms that were smaller than those seen in flexed knee lifts with the burden held in front of the knees (as opposed to between the legs).

Table 12

Summary Table of the ANOVA for the Moment Arm
of the Box Lifted

Displacement of the Box (% of total)	Moment Arm (cm)				F	p*
	High Strength		Low Strength			
	(n=6)		(n=6)			
	$\bar{X}$	SD	$\bar{X}$	SD		
0	15.60	6.18	19.60	4.17	2.66	.110
25	15.35	4.68	16.63	3.31	0.99	.330
50	17.28	3.73	15.53	2.33	0.91	.350
75	20.77	4.83	19.53	5.82	0.01	.940
100	25.95	3.55	25.88	7.07	0.22	.640

* accepted level of significance = .10

The range of the horizontal distance between the geometric center of the box and the body's center of gravity (i.e., the moment arm) was 7.5 to 36.2 centimeters. The moment arm tended to be shorter at lift-off than at the completion of the task (Figure 11). This probably was related to the fact that the subjects were instructed to straddle the box so that it could be lifted between their knees; theoretically, this would minimize the moment arm of the load about the back. The shortest moment arm recorded was associated with a member of the high strength group, number four; this individual lifted with his feet in a staggered position and placed his lead foot very close to the front edge of the box (i.e., the edge furthest from his body). The moment arms were longer at the end of the lift because the upper body limited the closeness of the box. The longest moment arm occurred in the third low strength subject who, at the completion of the lift, held the box above and more anterior to his umbilicus.

The fact that no differences were found between the levels of strength and the distances between the box and the body's center of gravity suggests that some people who do not have the strength necessary to perform a squatting type of lift, which theoretically minimizes the moment arm, may instead employ a stooped torso method to lessen the stresses on their low back. At the present, however, much more research is needed to test the validity of this

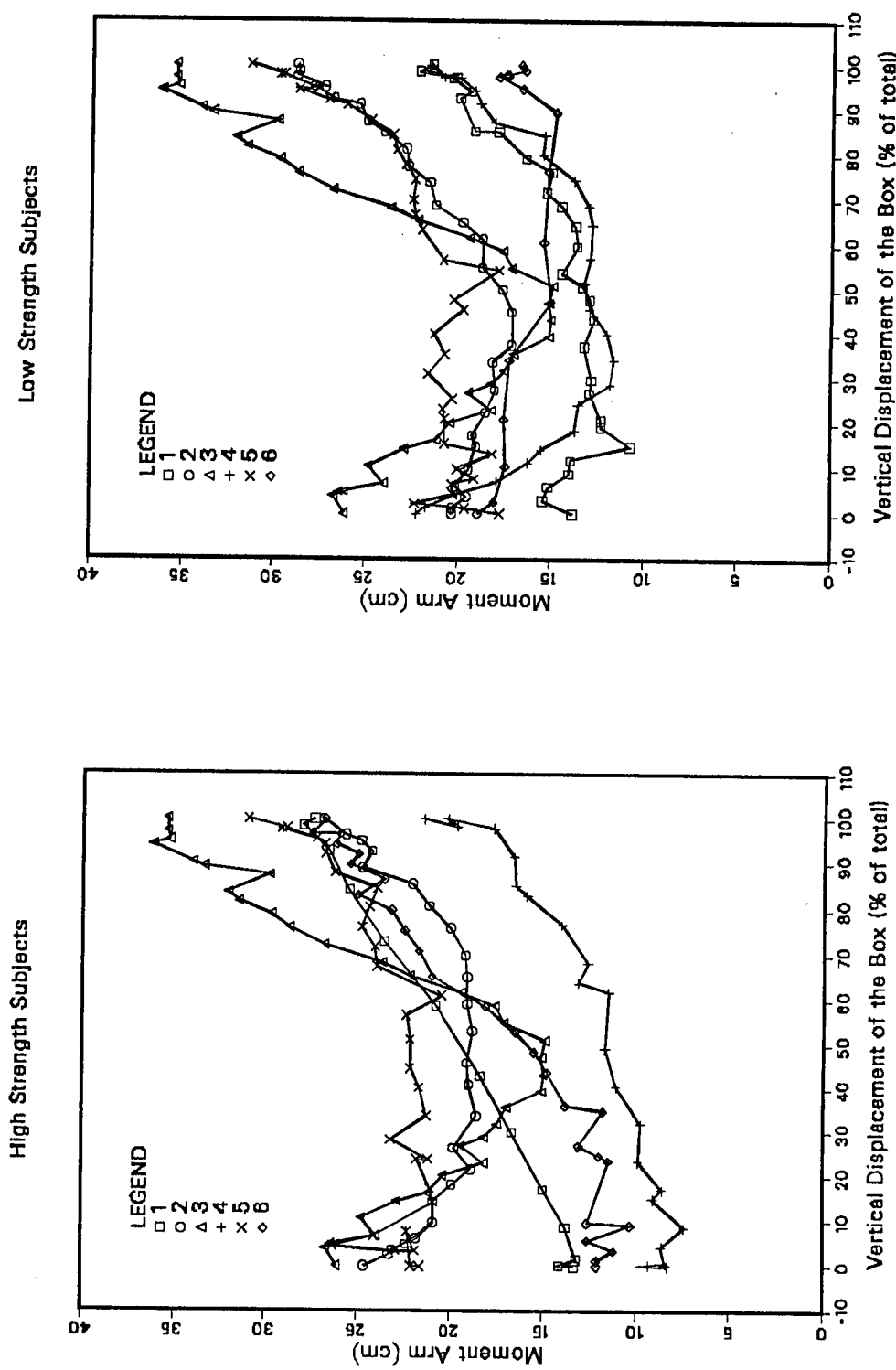


Figure 11. Moment Arm of the Box Lifted Relative to the Center of Gravity of the Body.

hypothesis. Furthermore, this observation should not be used as a basis for advocating that the stooped over technique be employed if using the squat lift fails for want of knee extensor strength. When lifting objects that are too large to pass between the knees, the stooped method may result in a shorter moment arm since the squat position requires that the oversized load be lifted in front of the knees (Park & Chaffin, 1974). However, the squatting leg lift, with the back nearly vertical, is often recommended for smaller loads because stooping far forward (i.e., hyperflexing the lumbar column) may be accompanied by high intra-disc pressure values and may increase the probability of muscle or ligamentous strain (Andersson et al., 1976; Anderson et al., 1985; Hart et al., 1987; Nachemson, 1966; Schultz et al., 1982).

The only significant difference found between the moment arm variances of the two groups occurred at the completion of the lift and was attributed to the previously mentioned subject who held the box further in the forward horizontal direction (Table 13). No differences were found in the variances of the moment arm within either group (Figure 12).

Summary

The purpose of this investigation was to evaluate the influence of strength on the performance of the lifters. A

Table 13

Summary Table of the Univariate F-test for the Moment Arm
of the Box Lifted

Displacement of the Box (% of total)	Moment Arm (cm)				F	p*
	High Strength		Low Strength			
	(n=6)		(n=6)			
	$\bar{X}$	SD	$\bar{X}$	SD		
0	15.60	6.18	19.60	4.17	2.20	.20
25	15.35	4.68	16.63	3.31	2.00	.23
50	17.28	3.73	15.53	2.33	2.56	.16
75	20.77	4.83	19.53	5.82	1.45	.35
100	25.95	3.55	25.88	7.07	3.97	.08

* accepted level of significance = .10

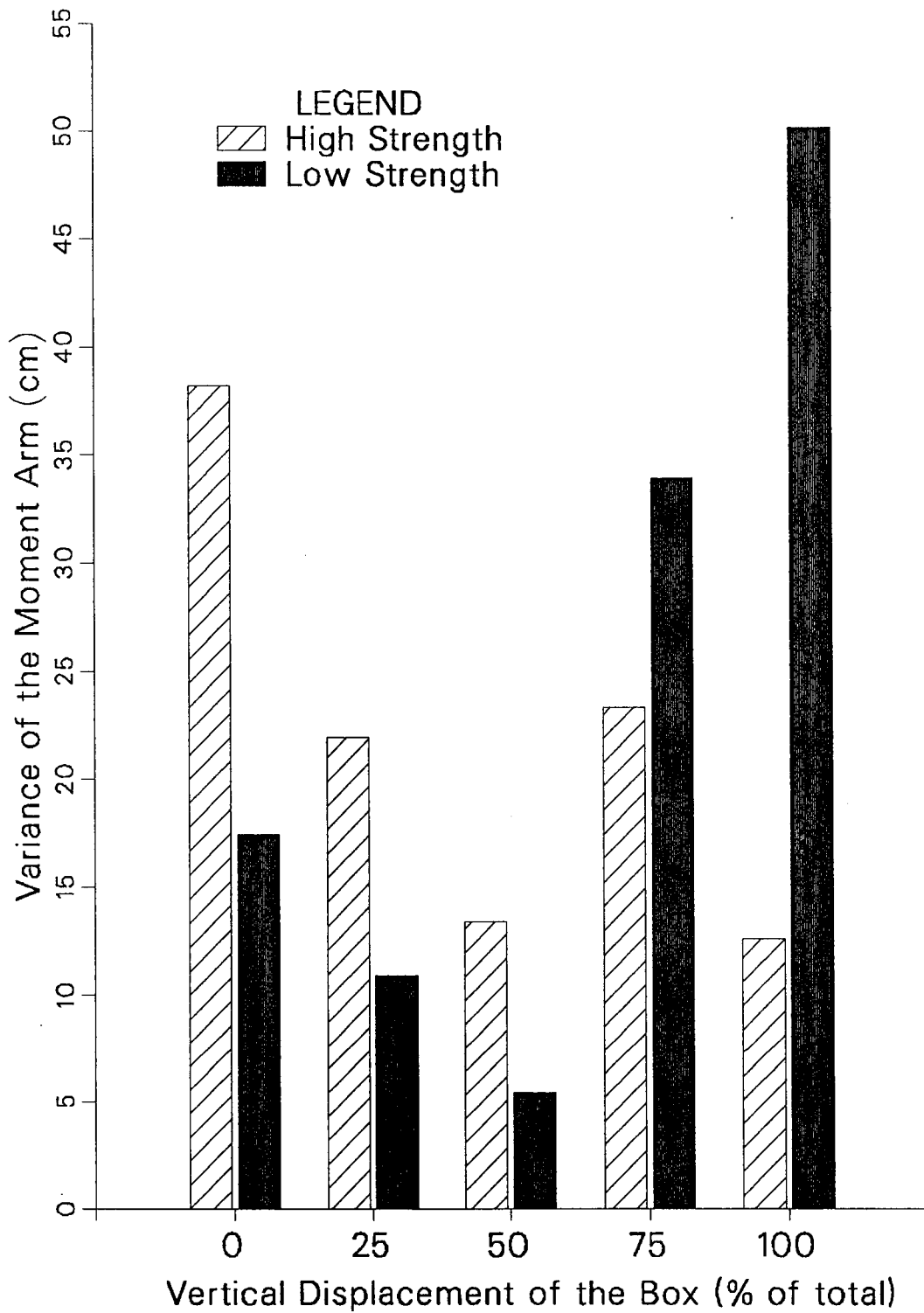


Figure 12. Variability in the Moment Arm of the Box. The within group variances were not statistically different. Between the two groups significant differences were found at 100% of the displacement of the box.

major limitation in this study is that body posturing during lifting is dictated not only by strength but also by several other variables such as body weight, joint ROM, and previous instruction on lifting. An effort was made to minimize these factors by selecting subjects who were similar in age, weight, stature, and joint range-of-motion. Furthermore, persons employed in jobs requiring frequent lifting and competitive weight lifters were excluded from the investigation.

Within the limitations of this study the following observations were made:

1. At the initiation of the lift the high strength subjects held their trunks in a more upright position and demonstrated greater flexion at the knees.

2. Throughout the lift both groups of subjects tended to hold their lumbar spines in extension; however, the degree of extension was generally less in the low strength group.

3. Even though differences were seen in body posturing, the high and low strength groups did not significantly differ in the magnitude of the moment arm of the box lifted.

4. Based upon posturing of the knees, torso, and lumbar spine, the low strength subjects demonstrated greater variability in their lifting patterns.

CHAPTER V

CONCLUSIONS, IMPLICATIONS, AND RECOMMENDATIONS

In the present study comparisons were made between the lifting postures of two groups of subjects. One of the groups was considered to have a high level of strength; the other group was considered to have a low level of strength. The findings showed that the lifting patterns demonstrated by the high strength subjects resembled the classic flexed-knee and erect-torso method of lifting which is usually recommended. The low strength subjects exhibited more variability in their lifting patterns; some lifted in a manner similar to the high strength subjects and others selected a more extended-knee and flexed-torso lifting posture. Based on the results of this study it was concluded that there were differences in the lifting postures demonstrated by the high and low strength subjects. However, because of the limitations of this study it is difficult to tell whether these differences were due primarily to variations in the level of strength or due to other factors that might have impacted upon strength and/or posture, such as previous participation in strenuous exercise activities and/or instruction on lifting.

Implications

Whereas the stooped method of lifting requires that only the torso be raised, the squat method of lifting requires both torso and knee extension. Thus, lifting from a squat position requires more mechanical work than lifting from the stooped position. This study suggests that in programs in which the squat lift is recommended, some of the individuals involved (particularly individuals identified as being of a low level of strength) may need resistance training for their knee and hip extensor musculature in order to provide the level of strength necessary to perform this lift. In addition, some individuals may require aerobic exercise training in order to execute the squat lift frequently without excessive fatigue.

Typically persons applying for jobs involving lifting are screened for prior back problems; however, their capacity for lifting is most often not assessed. As seen in this study, varying levels of strength, ranging from high to low, can be found within the population of people who do not have a history of back problems. Since strong trunk and leg musculature are required to lift heavy loads, NIOSH (1981) recommends that employee screening programs in manual labor industries include both medical history questionnaires and muscular strength testing.

Since a persons lifting posture is influenced to a certain extent by their level of muscular strength it is suggested that future research should attempt to define the strength levels which are needed for the safest postures for situations incurred in lifting.

Recommendations

The following recommendations are suggested for consideration in future investigations:

1. In addition to representing the lumbar angle in terms of its deviation from the vertical, it should be evaluated in terms of its deviation from the subject's standing posture. This information would enable the investigator to determine whether variations in the level of strength are accompanied by differences in the lumbar angle relative to the participants normal standing lordosis.
2. Kinetic analyses are needed to determine whether the high and low strength subjects differ in the magnitude of compression and shear loads imposed on the spine during the lift task.
3. It might also be desirable to examine the effects that trunk and leg muscle resistance training programs have on lifting postures.

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APPENDIXES

APPENDIX A

CHARACTERISTICS OF THE HIGH STRENGTH (HS) AND LOW STRENGTH (LS) SUBJECTS

SUBJECT	AGE (YR)	HEIGHT (CM)	WEIGHT (KG)	STRENGTH TEST SCORES (IRM: WEIGHT)				JOINT ROM TEST SCORES (DEGREES)			
				Trunk		Leg		Trunk		Hip	
				Flexion	Extension	Flexion	Extension	Flexion	Extension	Flexion	Extension
HS 1	22	187.50	80.72	0.85	1.94	2.92	5.71	53	21	74	
HS 2	20	172.50	74.00	1.08	1.84	2.90	5.82	76	28	102	
HS 3	20	181.25	88.88	1.08	1.80	2.53	5.41	57	23	82	
HS 4	21	177.50	80.00	0.96	1.76	2.94	5.66	65	29	84	
HS 5	20	178.75	73.13	0.84	2.19	3.08	6.11	62	26	80	
HS 6	29	180.00	80.72	0.77	2.50	2.72	5.99	72	25	83	
LS 1	20	175.00	68.40	0.70	1.00	2.07	3.77	60	27	82	
LS 2	20	172.50	73.00	0.77	1.45	1.85	4.07	72	33	97	
LS 3	20	172.50	62.00	0.80	0.99	2.36	4.15	67	28	86	
LS 4	27	175.00	62.30	0.75	1.20	1.76	3.71	62	25	80	
LS 5	24	185.25	101.20	0.53	1.20	1.28	3.01	55	23	76	
LS 6	19	177.50	78.00	0.67	1.26	1.81	3.74	65	26	79	

APPENDIX B

INFORMED CONSENT

The Effects of Different Levels of Muscular Strength On Lifting Postures

Purpose: Low back problems are responsible for a large percentage of all lost time in the work force in many employee work groups. Many of these problems relate to the manner in which objects are lifted. We believe the manner in which objects are lifted is related to the strength of certain muscle groups and flexibility at certain joints. We propose to research this area by (a) measuring strength and flexibility of the muscle groups most involved in lifting and (b) filming the individuals measured as they perform a lifting task (e. g., lifting a box weighing 90 pounds). The results of this research may be useful in helping to decrease the incidence of low back problems.

Methods. If you have been free of any acute or chronic musculoskeletal pain in the last three months and do not have a history of cardiovascular problems, you are eligible to be a subject in our research. All testing is being conducted at the Fort Sanders Regional Medical Center Comprehensive Back Clinic. Individuals participating in the testing will wear gym shorts and a low-cut gym-type shoe. All testing will be conducted outside of work hours and during two or three sessions; the sessions will take approximately 45 minutes to complete. The first session will be devoted to obtaining informed consent and familiarizing the subject with the testing protocols; the second to assessing the subject's strength and flexibility. Based on your performance on these evaluations you may be asked to attend a third session during which you will be filmed performing a lifting task. The following is a brief description of the testing procedures:

(1) Warm-up aerobic and flexibility exercises.

(2) Strength Tests. Strength of the leg extensors, trunk extensors, and trunk flexors will be assessed using Cybex Eagle machines and a one repetition maximum procedure.

(3) Flexibility Tests. An inclinometer will be used to assess trunk and hip range-of-motion. These tests are typically given by physical therapists when they work with individuals with athletic injuries and/or low back pain.

(4) Lifting Task. A box, weighing 90 pounds, will be lifted from the floor to the level of the umbilicus. To help analyze the posture you use in lifting, tape reference points will be placed on body landmarks (e.g. shoulder joint, hip joint). An Ady-Hall lumbar monitor will also be placed on your back so that a precision recording of movement in the low back can be made.

Proposed Risks and Precautions. The risks associated with participating in these testing procedures may include (a) muscle soreness within 48 hours after the session and (b) very rarely, abnormal blood pressure responses due to the Valsalva Maneuver. In order to minimize these risks all tests will be conducted either under clinical conditions and/or procedures established by the National Institute of Occupational Safety and Health; however, this does not entirely eliminate these risks.

I have read the above statement and understand my role in the research. I am furthermore aware:

(1) That the data collected on me will be used for research purposes and publications but that my identity will not be revealed.

(2) I am entitled to make further inquiries regarding the procedure: moreover I may request to be notified if the investigators believe that I might benefit from the finding of this research.

(3) I hereby release any and all liability from Fort Sanders Regional Medical Center for any injury or ailment incurred as a result of this program. I acknowledge that I have received no assurances with respect to the benefits to be realized or the consequence of the aforementioned study.

(4) I may withdraw my consent and discontinue participation at any time without penalty or prejudice toward me.

Participant:

Signature: _____ Date: _____

Witness:

Signature: _____ Date: _____

APPENDIX C

CONSENT FOR EXTERNAL USAGE OF FILM

I, _____, hereby authorize the investigators of this project titled "Lifting Posture and Low-back Pain Management" to film my activities during the testing session. Furthermore, I release Fort Sanders Medical Center and The University of Tennessee from any legal or other responsibilities for protecting my rights in the use of these films during scientific research/educational presentations.

Participant:

Date: _____ Signature: _____

Witness:

Date: _____ Signature: _____

APPENDIX D

FORTRAN PROGRAM FOR DIGITIZING FILM

```

C      FILENAME:  TABTCS.FOR
C      PROGRAM IS FOR DIGITIZING POINTS FROM A TABLET USING
C      TCS AND TABLET SOFTWARE.  POINTS ARE WRITTEN TO A
C      FILE CALLED FOR020.DAT.
C
      INTEGER H(18),X(18),Y(18),XRP,YRP,CSP,TI,CI,IFRAME
      INTEGER X1RL,Y1RL,X2RL,Y2RL
      REAL XRRP(18),YRRP(18),DRL,ARL,SCALE
      IFRAME=1
C
C      INPUT UP TO 1000 POINTS FROM THE TABLET.  FIRST C
C      ARGUMENT=0 (1023 X 780), FIRST ARGUMENT=1 (4096 X
C      3120).  SECOND ARGUMENT=0 (NO DISPLAY), SECOND
C      ARGUMENT=1 (LOCAL DISPLAY).  THIRD ARGUMENT=0 (PEN
C      MODE), THIRD ARGUMENT=1 (PRESENCE MODE).
C
C      MUST LINK TO BOTH TABLET AND TCS (IN THAT ORDER).
C      FOR EXAMPLE,
C      LINK TABTCS, TABLET/LIB, TCS/L
C
C      *****
C      INPUT INFORMATION FOR FIRST LINE OF DATA FILE (CSP TI
C      CI)
C      *****
C
      WRITE (6,102)
102  FORMAT (1X, 'INPUT CAMERA SPEED')
      READ (5,*)CSP
      WRITE (6,103)
103  FORMAT (1X, 'INPUT TIME INTERVAL')
      READ (5,*)TI
      WRITE (6,104)
104  FORMAT (1X, 'INPUT IMPLEMENT CODE')
      READ (5,*)CI
      OPEN
      (UNIT=20,FILE='FOR020.DAT',RECL=288,STATUS='NEW')
      WRITE (20,105)CSP,TI,CI
105  FORMAT(1X,I4,1X,I3,1X,I2)
      CLOSE (UNIT=20,STATUS='KEEP')
C      *****
C      INITIALIZE THE DIGITIZING TABLET
C      *****
      CALL INITT
      CALL TERM(3,4096)
      CALL TABINT(0,1,0)

```

```

C *****
C DIGITIZE TWO PTS THAT ARE A KNOWN DISTANCE APART.
C INPUT THE ACTUAL DISTANCE FOR THE TWO PTS
C CALCULATE MULTIPLIER USED TO FIGURE ACTUAL DISTANCE
C OF OTHER PTS
C *****
  CALL BELL
  CALL ANMODE
  WRITE (6,107)
107  FORMAT (1X, 'DIGITIZE ONE END OF REFERENCE LENGTH')
      CALL ONEPNT (X1RL, Y1RL)
      CALL BELL
      CALL ANMODE
      WRITE (6,109)
109  FORMAT (1X, 'DIGITIZE OTHER END OF REFERENCE LENGTH')
      CALL ONEPNT (X2RL,Y2RL)
      CALL ANMODE
      WRITE (6,111)
111  FORMAT (1X, 'ENTER THE ACTUAL DISTANCE OF THE
REFERENCE LENGTH')
      READ (5,*)ARL
      DRL=SQRT(FLOAT((X2RL-X1RL)**2 + (Y2RL-Y1RL)**2))
      SCALE=ARL/DRL
      CALL BELL
      DO WHILE (IFRAME .NE. 0)
C *****
C DIGITIZE REFERENCE POINT
C *****
      CALL BELL
      CALL ANMODE
      WRITE (6,113)
113  FORMAT (1X, 'DIGITIZE REFERENCE POINT')

      CALL ONEPNT(XRP,YRP)
C *****
C DIGITIZE SUBJECT POINTS
C *****
      CALL BELL
      CALL ANMODE
      WRITE (6,115)
115  FORMAT (1X, 'DIGITIZE SUBJECT POINTS AND
IMPLEMENT')
      CALL Mulpnt(18,N,H,X,Y)
      IF (N .NE. 18) THEN
        CALL ANMODE
        WRITE (6,117)
117  FORMAT (1X, 'DIGITIZING ERROR - REDO FRAME')
        GO TO 199
      ELSE
C

```

```

C *****
C CALCULATION TO TRANSPOSE DIGITIZED POINTS RELATIVE TO
C REFERENCE POINT AND TRANSFORM TO ACTUAL DISTANCES
C *****
      DO 1 I=1,18
        XRRP(I)=FLOAT(X(I)-XRP)*SCALE
        YRRP(I)=FLOAT(Y(I)-YRP)*SCALE
1      CONTINUE

OPEN(UNIT=20,FILE='FOR020.DAT',RECL=288,STATUS='OLD',
      3      ACCESS='APPEND')
      CALL ANMODE
      WRITE(20,189) ((XRRP(I),YRRP(I)),I=1,18)
189    FORMAT (36F8.2)
      CLOSE (UNIT=20,STATUS='KEEP')
      CALL ANMODE
199    WRITE (6,200)
200    FORMAT (1X, 'INPUT FRAME NUMBER OR 0 TO QUIT
DIGITIZING')
      READ (5,*)IFRAME
      END IF
      END DO
      CALL TINPUT(J)
      CALL FINITT(0,780)
      WRITE(6,201)
201    FORMAT(' END OF JOB')
      STOP
      END

```

VITA

Gina Lynne Sharpe was born in Salina, Kansas on November 21, 1960. She attended elementary schools in Rolla, Missouri and was graduated from West High School, Knoxville, Tennessee in June 1978. The following September she entered The University of Tennessee, Knoxville, and in June 1982 she received a Bachelor of Science degree in Physical Education.

In the fall of 1982 she accepted a graduate teaching assistantship at the University of Indiana, Bloomington and began study toward a Master's degree in Physical Education, with an emphasis in Biomechanics of Sport. She received the Master of Science degree in August 1983. In September 1984 she accepted a teaching assistantship at the University of Tennessee, Knoxville and began study toward a Doctor of Philosophy degree with a major in Education and an emphasis in Exercise Science. She received the Doctor of Philosophy degree in December, 1989.

Ms. Sharpe accepted an Assistant Professorship at Berry College, Rome, Georgia in August 1989. The author is a member of the American Alliance for Health, Physical Education, Recreation, and Dance.